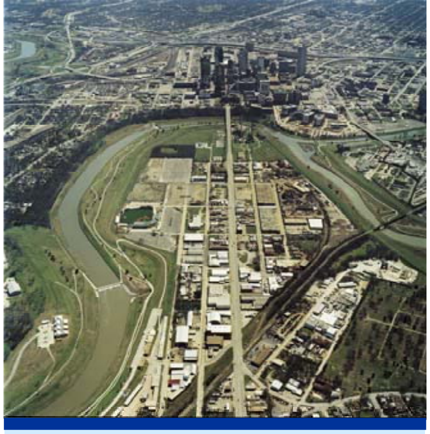
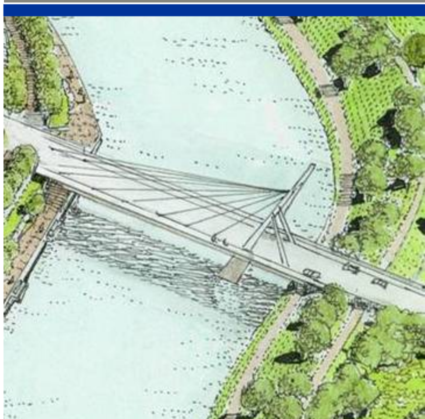


Fort Worth Central City Preliminary Design

Civil/Structural Preliminary Design

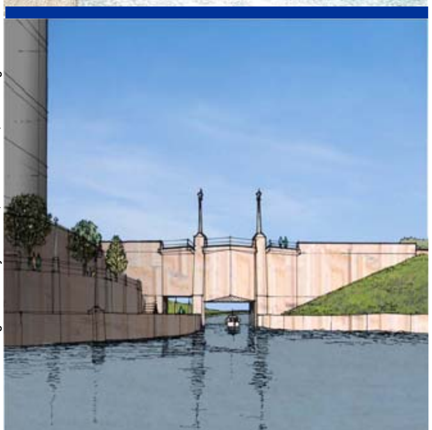


Draft Environmental Impact Statement

Appendix C

May 2005

Volume IV – Stability Analysis Samuels Avenue Dam



Contents: Stability Analysis Samuels Avenue Dam

Volume IV

Section 1
Common Geometry

Common Geometry:

Geometry:

$E_{head} := 525 \cdot ft$

$E_{tail} := 495 \cdot ft$

$t_c := 6 \cdot ft$

$E_{ramp} := 503.5 \cdot ft$

$E_{ukey} := E_{ramp} - t_c - 9.5ft$ $\qquad E_{ukey} = 488.00\,ft$

$E_{dkey} := E_{ramp} - t_c - \frac{25 \cdot ft}{2} - 14.0 \cdot ft$ $\qquad E_{dkey} = 471.00\,ft$

$E_{sill} := 495 \cdot ft$

$s_{tw\_redux} := 0.6$ (lower bound of specific gravity of tailwater for lateral and gravity loads)

$E_{tail\_redux} := E_{tail} - (1 - s_{tw\_redux}) \cdot (E_{tail} - E_{sill})$ $\qquad E_{tail\_redux} = 495.0\,ft$

$E_{crest} := 507 \cdot ft$

$E_{gate} := 526 \cdot ft$

$E_{basin} := 491 \cdot ft$

$E_{pier} := 530 \cdot ft$

$E_{approach} := 500 \cdot ft$

$s_{pier} := 56 \cdot ft$ (c/c spacing of piers)

$w_{pier} := 8 \cdot ft$ (width of pier)

$slope_{basin} := 2$ (run per unit rise)

$L_{basin} := 55 \cdot ft$

$t_{basin} := 6 \cdot ft$

$FS_{sliding\_reqd} := 2.0$

$L_{ukey} := 6 \cdot ft$

$L_{dkey} := 6 \cdot ft$

Drain Information:

$eff_{drain} := 50\%$ (efficiency of drain)

$x_{drain} := 55 \cdot ft$ (position of drain with respect to toe)

Constants:

$\gamma_c := 150 \cdot pcf$

$\gamma_{RCC} := 130 \cdot pcf$

$\gamma_w := 62.5 \cdot pcf$

$\gamma_{Su} := 60 \cdot pcf$ (submerged unti weight of alluvium)

$k_{Su} := 0.5$ (coefficient of lateral earth pressure at rest for alluvium)

$\gamma_{Sd} := 60 \cdot pcf$ (submerged unti weight of alluvium)

$k_{Sd} := 0.5$ (coefficient of lateral earth pressure at rest for alluvium)

$\gamma_{rock} := 130 \cdot pcf$ (unit weight of rock below dam)

$\phi_{limestone} := 40 \cdot deg$

$\phi_{ls\_inc} := 50 \cdot deg$ (for a inclined failure planes only)

$\phi_{shale} := 20 \cdot deg$ (for horizontal failure planes only)

$\phi_{RCC\_Rock} := 25 \cdot deg$

$\phi_{conc\_rock} := 20 \cdot deg$ (consider possibility of shale layers)

$\sigma_{rock\_pass\_lat} := 3000 \cdot psf$

$k\gamma_{rock\_pass\_lat} := 642 \cdot pcf$

$FS_{lateral\_brg\_reqd} := 3.0$

$FS_{sliding\_reqd} := 2.0$

Wall load soil values:

$\gamma_{fill\_eff} := 65 \cdot pcf$

$\gamma_{fill} := 130 \cdot pcf$

$\gamma_{sat} := \gamma_{fill\_eff} + \gamma_w$ $\qquad \gamma_{sat} = 127.5\,pcf$

$k_{0\_fill} := 0.5$

$\phi_{fill} := 32 \cdot deg$

$c_{fill} := 0 \cdot psf$

Pre-Definitions:

$kip \equiv 1000 \cdot lbf$ $\qquad ksi \equiv 1000 \cdot psi$ $\qquad ok \equiv$ "Ok"

$psf \equiv \frac{lbf}{ft^2}$ $\qquad plf \equiv \frac{lbf}{ft}$ $\qquad ORIGIN = 1.0$

$pcf \equiv \frac{lbf}{ft^3}$ $\qquad klf \equiv 1000 \cdot plf$ $\qquad ksf := \frac{1000 \cdot lbf}{ft^2}$

Section 2
Downstream Retaining Walls

Downstream Training Wall at Right: (Grade = 507.0')

Reference:T:\ST\CALCS\Common geometry.mcd(R)

Geometry:

$E_{wall} := 510 \cdot ft$

$E_{ftg} := E_{sill}$ $\qquad E_{ftg} = 495.0\,ft$

$t_{base} := 6 \cdot ft$

$E_{bftg} := E_{ftg} - t_{base}$ $\qquad E_{bftg} = 489.0\,ft$

$E_{grade} := 507 \cdot ft$

$n := 5$

$i := 1..n$

$\Delta_w := 10 \cdot ft$ (maximum height of retained water above water in basin)

$$E_{wheel_i} := E_{grade} - \frac{\left[E_{grade} - \left(E_{ftg} + \frac{\Delta_w}{2}\right)\right]}{n-1} \cdot (i-1) \qquad E_{wheel} = \begin{pmatrix} 507.0 \\ 505.3 \\ 503.5 \\ 501.8 \\ 500.0 \end{pmatrix} ft$$

$$E_{wtoe_i} := \max\left(\begin{pmatrix} E_{wheel_i} - \Delta_w \\ E_{ftg} \end{pmatrix}\right) \qquad E_{wtoe} = \begin{pmatrix} 497.0 \\ 495.3 \\ 495.0 \\ 495.0 \\ 495.0 \end{pmatrix} ft$$

$$h := \min\left[\begin{bmatrix} \left[\frac{1.0}{1.5} \cdot 2 \cdot (E_{grade} - E_{ftg})\right] + E_{grade} \\ 527 \cdot ft - E_{ftg} \end{bmatrix}\right] \qquad h = 32.0\,ft$$

$$\beta := \operatorname{atan}\left(\frac{1.0}{1.5}\right) \qquad \beta = 33.7\,deg$$

$h_\beta := 527 \cdot ft - E_{grade}$ $\qquad h_\beta = 20.0\,ft$

$t_{w\_top} := 1.5 \cdot ft$

$$t_{w\_bot} := t_{w\_top} + \frac{(E_{wall} - E_{ftg})}{8} \qquad t_{w\_bot} = 3.38\,ft$$

$L_{toe} = 10.0\,ft$

$L_{heel} = 19.0\,ft$

$L_{ftg} := L_{toe} + L_{heel}$ $\quad L_{ftg} = 29.0\,ft$

$h_{wall} := E_{wall} - E_{ftg}$ $\quad h_{wall} = 15.0\,ft$

$h_{key} = 5.0\,ft$

$L_{key} := 3 \cdot ft$ $\quad L_{key} = 3.0\,ft$

$x_{key} := L_{toe} + t_{w\_bot} - \frac{L_{key}}{2}$ $\quad x_{key} = 11.9\,ft$

Constants:

$\gamma_w = 62.5\,pcf$

Soil parameters:

$\gamma_{fill\_eff} = 65.0\,pcf$ $\quad \gamma_{sat} = 127.5\,pcf$

$\gamma_{fill} = 130.0\,pcf$

$k_{0\_fill} = 0.5$

$\phi_{fill} = 32.0\,deg$

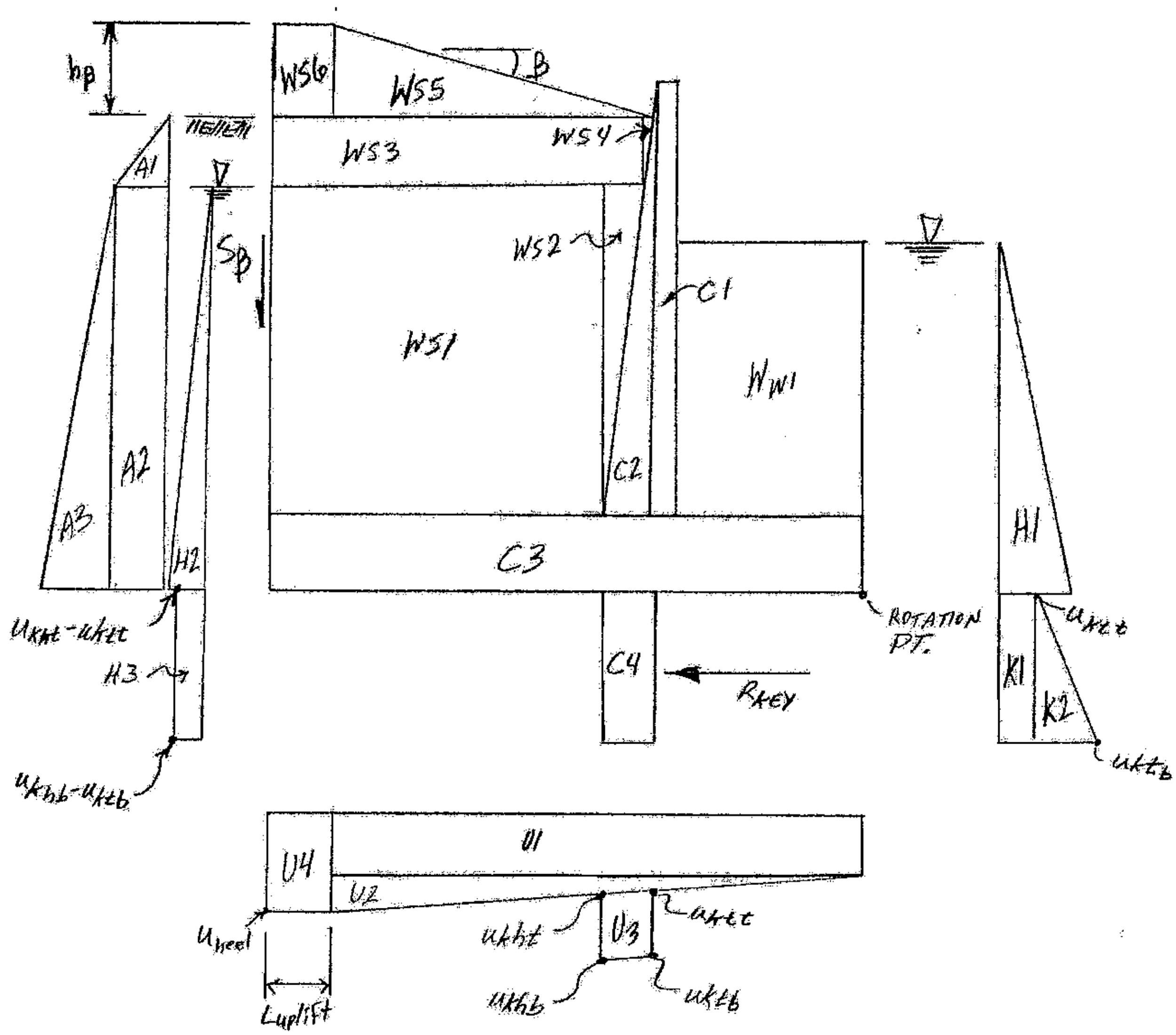
$k_{0\beta} := k_{0\_fill} \cdot (1 + \sin(\beta))$ $\quad k_{0\beta} = 0.777$ (USACE EM 1110-2-2502, Eq. 3-5)

Pre-Definitions:

$kip \equiv 1000 \cdot lbf$ $\quad ksi \equiv 1000 \cdot psi$ $\quad ok \equiv$ "Ok" $\quad klf \equiv 1000 \cdot \frac{lbf}{ft}$

$psf \equiv \frac{lbf}{ft^2}$ $\quad plf \equiv \frac{lbf}{ft}$ $\quad pcf \equiv \frac{lbf}{ft^3}$

ORIGIN = 1.0 (must equal to 1)


hp
β
WS6
WS5
WS4
WS3
WS2
WS1
C1
C2
C3
C4
Ww1
A1
A2
A3
H1
H2
H3
K1
K2
Sp
ROTATION PT.
RKEY
U1
U2
U3
U4
Uheel
Luplift
ukht
ukhb
uktt
uktb

Analysis:

Gravity Loads:

$h_{C_1} := h_{wall}$ $h_{C_1} = 15.0\,ft$

$L_{C_1} := t_{w\_top}$ $L_{C_1} = 1.5\,ft$

$x_{C_1} := L_{toe} + \frac{L_{C_1}}{2}$ $x_{C_1} = 10.8\,ft$

$W_{C_1} := \gamma_c \cdot h_{C_1} \cdot L_{C_1}$ $W_{C_1} = 3.4\,klf$

$h_{C_2} := h_{C_1}$ $h_{C_2} = 15.0\,ft$

$L_{C_2} := t_{w\_bot} - t_{w\_top}$ $L_{C_2} = 1.9\,ft$

$x_{C_2} := L_{toe} + L_{C_1} + \frac{L_{C_2}}{3}$ $x_{C_2} = 12.1\,ft$

$W_{C_2} := \gamma_c \cdot \frac{h_{C_2} \cdot L_{C_2}}{2}$ $W_{C_2} = 2.1\,klf$

$h_{C_3} := t_{base}$ $h_{C_3} = 6.0\,ft$

$L_{C_3} := L_{ftg}$ $L_{C_3} = 29.0\,ft$

$x_{C_3} := \frac{L_{C_3}}{2}$ $x_{C_3} = 14.5\,ft$

$W_{C_3} := \gamma_c \cdot h_{C_3} \cdot L_{C_3}$ $W_{C_3} = 26.1\,klf$

$h_{C_4} := h_{key}$ $h_{C_4} = 5.0\,ft$

$L_{C_4} := L_{key}$ $L_{C_4} = 3.0\,ft$

$x_{C_4} := x_{key}$ $x_{C_4} = 11.9\,ft$

$W_{C_4} := \gamma_c \cdot h_{C_4} \cdot L_{C_4}$ $W_{C_4} = 2.3\,klf$

Weight of water at toe:

$h_{W1_i} := E_{wtoe_i} - E_{ftg}$ $h_{W1} = \begin{pmatrix} 2.00 \\ 0.25 \\ 0.00 \\ 0.00 \\ 0.00 \end{pmatrix} ft$

$L_{W1} := L_{toe}$ $L_{W1} = 10.0\,ft$

$x_{W1} := \dfrac{L_{toe}}{2}$ $x_{W1} = 5.0\,ft$

$W_{W1_i} := \gamma_w \cdot h_{W1_i} \cdot L_{W1}$ $W_{W1} = \begin{pmatrix} 1.3 \\ 0.2 \\ 0.0 \\ 0.0 \\ 0.0 \end{pmatrix} klf$

Weight of water/soil at heel:

$h_{WS1_i} := E_{wheel_i} - E_{ftg}$ $h_{WS1} = \begin{pmatrix} 12.00 \\ 10.25 \\ 8.50 \\ 6.75 \\ 5.00 \end{pmatrix} ft$

$L_{WS1} := L_{heel} - t_{w\_bot}$ $L_{WS1} = 15.6\,ft$

$x_{WS1} := L_{toe} + t_{w\_bot} + \dfrac{L_{WS1}}{2}$ $x_{WS1} = 21.2\,ft$

$W_{WS1_i} := (\gamma_{sat}) \cdot h_{WS1_i} \cdot L_{WS1}$ $W_{WS1} = \begin{pmatrix} 23.9 \\ 20.4 \\ 16.9 \\ 13.4 \\ 10.0 \end{pmatrix} klf$

$h_{WS2_i} := h_{WS1_i}$

$L_{WS2_i} := \dfrac{t_{w\_bot} - t_{w\_top}}{h_{wall}} \cdot h_{WS2_i}$ $L_{WS2} = \begin{pmatrix} 1.50 \\ 1.28 \\ 1.06 \\ 0.84 \\ 0.63 \end{pmatrix} ft$

$x_{WS2_i} := L_{toe} + t_{w\_bot} - \dfrac{L_{WS2_i}}{3}$ $x_{WS2} = \begin{pmatrix} 12.9 \\ 12.9 \\ 13.0 \\ 13.1 \\ 13.2 \end{pmatrix} ft$

$W_{WS2_i} := (\gamma_{sat}) \cdot \frac{h_{WS2_i} \cdot L_{WS2_i}}{2}$

$h_{WS3_i} := E_{grade} - E_{wheel_i}$

$L_{WS3_i} := L_{WS1} + L_{WS2_i}$

$x_{WS3_i} := L_{ftg} - \frac{L_{WS3_i}}{2}$

$W_{WS3_i} := \gamma_{fill} \cdot h_{WS3_i} \cdot L_{WS3_i}$

W_{WS2_i} (klf)	h_{WS3_i} (ft)	L_{WS3_i} (ft)	x_{WS3_i} (ft)	W_{WS3_i} (klf)
1.1	0.0	17.1	20.4	0.0
0.8	1.8	16.9	20.5	3.8
0.6	3.5	16.7	20.7	7.6
0.4	5.3	16.5	20.8	11.2
0.2	7.0	16.3	20.9	14.8

$h_{WS4_i} := h_{WS3_i}$

$L_{WS4_i} := \frac{t_{w\_bot} - t_{w\_top}}{h_{wall}} \cdot h_{WS4_i}$

$x_{WS4_i} := L_{ftg} - L_{WS3_i} - \frac{L_{WS4_i}}{3}$

$W_{WS4_i} := \gamma_{fill} \cdot \frac{h_{WS4_i} \cdot L_{WS4_i}}{2}$

L_{WS4_i} (ft)	x_{WS4_i} (ft)	W_{WS4_i} (klf)
0.0	11.9	0.0
0.2	12.0	0.0
0.4	12.2	0.1
0.7	12.3	0.2
0.9	12.5	0.4

$L_{WS5} := \min\left(\begin{bmatrix} \frac{t_{w\_bot} - t_{w\_top}}{h_{wall}} (E_{grade} - E_{ftg}) + L_{WS1} \\ \frac{h_\beta}{\tan(\beta)} \end{bmatrix}\right)$ $\quad L_{WS5} = 17.13\,ft$

$h_{WS5} := L_{WS5} \cdot \tan(\beta)$ $\quad h_{WS5} = 11.42\,ft$

$x_{WS5} := \frac{2}{3} \cdot L_{WS5} + L_{toe} + t_{w\_top} + \frac{(E_{wall} - E_{grade})}{E_{wall} - E_{ftg}} \cdot (t_{w\_bot} - t_{w\_top})$ $\quad x_{WS5} = 23.29\,ft$

$W_{WS5} := \gamma_{fill} \cdot \frac{h_{WS5} \cdot L_{WS5}}{2}$ $\quad W_{WS5} = 12.7\,klf$

$L_{WS6} := \frac{E_{grade} - E_{ftg}}{h_{wall}} \cdot (t_{w\_bot} - t_{w\_top}) + L_{WS1} - L_{WS5}$ $\quad L_{WS6} = 0.0\,ft$

$h_{WS6} := h_{WS5}$ $\quad h_{WS6} = 11.4\,ft$

$x_{WS6} := L_{ftg} - \frac{L_{WS6}}{2}$ $\quad x_{WS6} = 29.0\,ft$

$W_{WS6} := \gamma_{fill} \cdot (h_{WS6} \cdot L_{WS6})$ $\quad W_{WS6} = 0.0\,klf$

Uplift:

$u_{toe_i} := \gamma_w \cdot (E_{wtoe_i} - E_{bftg})$

$u_{heel_i} := \gamma_w \cdot (E_{wheel_i} - E_{bftg})$

$\delta_{seep_i} := \dfrac{u_{heel_i} - u_{toe_i}}{L_{ftg} - L_{uplift_i}}$

$u_{ktt_i} := u_{heel_i} + \left(x_{key} - \dfrac{L_{key}}{2}\right) \cdot \delta_{seep_i}$

$u_{kht_i} := u_{ktt_i} + L_{key} \cdot \delta_{seep_i}$

$u_{ktb_i} := u_{ktt_i} + \gamma_w \cdot h_{key}$

$u_{khb_i} := u_{ktb_i} + L_{key} \cdot \delta_{seep_i}$

$x_{U1} := \dfrac{L_{ftg} - L_{uplift}}{2}$

$U1_i := u_{toe_i} \cdot L_{ftg}$

$x_{U2_i} := \dfrac{2}{3} \cdot (L_{ftg} - L_{uplift_i})$

$U2_i := (u_{heel_i} - u_{toe_i}) \cdot \dfrac{L_{ftg}}{2}$

$x_{U3} := x_{key}$

$U3_i := (u_{ktb_i} - u_{ktt_i}) \cdot L_{key}$

$x_{U4_i} := L_{ftg} - \dfrac{L_{uplift_i}}{2}$

$L_{U4_i} := L_{uplift_i}$

$U4_i := u_{heel_i} \cdot L_{U4_i}$

u_{toe_i} (ksf)	u_{heel_i} (ksf)	δ_{seep_i} (psf/ft)	u_{ktt_i} (ksf)	u_{kht_i} (ksf)
0.500	1.125	21.552	1.349	1.413
0.391	1.016	21.552	1.239	1.304
0.375	0.906	18.319	1.096	1.151
0.375	0.797	14.547	0.948	0.991
0.375	0.688	10.776	0.799	0.832

u_{ktb_i} (ksf)	u_{khb_i} (ksf)	x_{U1_i} (ft)	$U1_i$ (klf)	x_{U2_i} (ft)	$U2_i$ (klf)
1.661	1.726	14.5	14.5	19.33	9.1
1.552	1.616	14.5	11.3	19.33	9.1
1.409	1.464	14.5	10.9	19.33	7.7
1.260	1.304	14.5	10.9	19.33	6.1
1.112	1.144	14.5	10.9	19.33	4.5

$x_{U3} = 11.9\,ft$

$U3 = \begin{pmatrix} 0.9 \\ 0.9 \\ 0.9 \\ 0.9 \\ 0.9 \end{pmatrix} klf$

$xU4_i =$ (ft)	$U4_i =$ (klf)
29.0	0.0
29.0	0.0
29.0	0.0
29.0	0.0
29.0	0.0

Lateral load due to water at toe:

$h_{H1_i} := E_{wtoe_i} - E_{bftg}$

$y_{H1_i} := \frac{h_{H1_i}}{3}$

$H1_i := \gamma_w \cdot \frac{\left(h_{H1_i}\right)^2}{2}$

$h_{H2_i} := E_{wheel_i} - E_{bftg}$

$y_{H2_i} := \frac{h_{H2_i}}{3}$

$H2_i := \gamma_w \cdot \frac{\left(h_{H2_i}\right)^2}{2}$

$h_{H1_i} =$ (ft)	$y_{H1_i} =$ (ft)	$H1_i =$ (klf)	$h_{H2_i} =$ (ft)	$H2_i =$ (klf)
8.00	2.67	2.0	18.00	10.1
6.25	2.08	1.2	16.25	8.3
6.00	2.00	1.1	14.50	6.6
6.00	2.00	1.1	12.75	5.1
6.00	2.00	1.1	11.00	3.8

$h_{H3} := h_{key}$ $\quad h_{H3} = 5.0\,\text{ft}$

$y_{H3} := \frac{-h_{key}}{2}$ $\quad y_{H3} = -2.5\,\text{ft}$

$H3_i := \left(u_{khb_i} - u_{ktb_i}\right) \cdot h_{H3}$

$h_{K1} := h_{key}$ $\quad h_{K1} = 5.0\,\text{ft}$

$K1_i := u_{ktt_i} \cdot h_{K1}$

$h_{K2} := h_{key}$ $\quad h_{K2} = 5.0\,\text{ft}$

$K2_i := \left(u_{ktb_i} - u_{ktt_i}\right) \cdot \frac{h_{K2}}{2}$

$y_{K1} := \frac{-h_{key}}{2}$ $\quad y_{K1} = -2.5\,\text{ft}$

$y_{K2} := \frac{-2}{3} \cdot h_{key}$ $\quad y_{K2} = -3.3\,\text{ft}$

$y_{H2_i} =$ (ft)	$H3_i =$ (klf)	$K1_i =$ (klf)	$K2_i =$ (klf)
6.0	0.32	6.7	0.8
5.4	0.32	6.2	0.8
4.8	0.27	5.5	0.8
4.3	0.22	4.7	0.8
3.7	0.16	4.0	0.8

Lateral load due to retained soil/water:

$h_{A1_i} := E_{grade} - E_{wheel_i}$

$y_{A1_i} := E_{grade} - E_{bftg} - \frac{2}{3} \cdot h_{A1_i}$

$A1_i := k_{0\beta} \cdot \gamma_{fill} \cdot \frac{(h_{A1_i})^2}{2}$

h_{A1_i} = (ft)	y_{A1_i} = (ft)	$A1_i$ = (klf)
0.00	18.00	0.0
1.75	16.83	0.2
3.50	15.67	0.6
5.25	14.50	1.4
7.00	13.33	2.5

$h_{A2_i} := E_{wheel_i} - E_{bftg}$

$y_{A2_i} := \frac{h_{A2_i}}{2}$

$A2_i := k_{0\beta} \cdot \gamma_{fill} \cdot h_{A1_i} \cdot h_{A2_i}$

h_{A2_i} = (ft)	y_{A2_i} = (ft)	$A2_i$ = (klf)
18.00	9.00	0.0
16.25	8.13	2.9
14.50	7.25	5.1
12.75	6.38	6.8
11.00	5.50	7.8

$h_{A3_i} := h_{A2_i}$

$y_{A3_i} := \frac{h_{A3_i}}{3}$

$A3_i := k_{0\beta} \cdot \gamma_{fill\_eff} \cdot \frac{(h_{A3_i})^2}{2}$

h_{A3_i} = (ft)	y_{A3_i} = (ft)	$A3_i$ = (klf)
18.00	6.00	8.2
16.25	5.42	6.7
14.50	4.83	5.3
12.75	4.25	4.1
11.00	3.67	3.1

Shear force due to sloped backfill: (EM 1110-2-2502, Fig. 4-7)

$h_2 := E_{grade} - E_{ftg}$ $\qquad h_2 = 12.0\,ft$

$h_1 := h_2 + \tan(\beta) \cdot L_{WS5}$ $\qquad h_1 = 23.4\,ft$

$$P_i := k_{0\beta} \cdot \gamma_{fill} \cdot h_{A1_i} \cdot (h_{A2_i} - t_{base}) + k_{0\beta} \cdot \gamma_{fill\_eff} \cdot \frac{(h_{A3_i} - t_{base})^2}{2}$$

$$S_{\beta_i} := \text{if}\left[h_1 > h_2, \left[\frac{P_i \cdot (h_1 - h_2)}{3 \cdot L_{WS5}}\right], 0 \cdot klf\right]$$

$x_{S\beta} := L_{ftg}$ $\qquad x_{S\beta} = 29.0\,ft$

Sum forces:

$$\Sigma V_i := \sum_{i=1}^{4} W_{C_i} + W_{W1_i} + W_{WS1_i} + W_{WS2_i} + W_{WS3_i} + W_{WS4_i} + W_{WS5} + W_{WS6} + S_{\beta_i} - \left(U1_i + U2_i + U3_i + U4_i\right)$$

$$\Sigma M_{grav_i} := \left(\sum_{i=1}^{4} W_{C_i} \cdot x_{C_i} + W_{W1_i} \cdot x_{W1} + W_{WS1_i} \cdot x_{WS1} + W_{WS2_i} \cdot x_{WS2_i} + W_{WS3_i} \cdot x_{WS3_i} + W_{WS4_i} \cdot x_{WS4_i}\right) \dots$$
$$+ W_{WS5} \cdot x_{WS5} + W_{WS6} \cdot x_{WS6} + S_{\beta_i} \cdot x_{S\beta} - \left(U1_i \cdot x_{U1_i} + U2_i \cdot x_{U2_i} + U3_i \cdot x_{U3} + U4_i \cdot x_{U4_i}\right)$$

$$R_{key_i} := -H1_i - K1_i - K2_i + H2_i + H3_i + A1_i + A2_i + A3_i$$

$$y_{Rkey} := \frac{-h_{key}}{2} \qquad y_{Rkey} = -2.5\,\text{ft}$$

$$\Sigma H_i := -H1_i - K1_i - K2_i + H2_i + H3_i + A1_i + A2_i + A3_i - R_{key_i}$$

$$\Sigma M_{lat_i} := -H1_i \cdot y_{H1_i} - K1_i \cdot y_{K1} - K2_i \cdot y_{K2} + H2_i \cdot y_{H2_i} + H3_i \cdot y_{H3} \dots$$
$$+ A1_i \cdot y_{A1_i} + A2_i \cdot y_{A2_i} + A3_i \cdot y_{A3_i} - R_{key_i} \cdot y_{Rkey}$$

$$\Sigma M_i := \Sigma M_{grav_i} - \Sigma M_{lat_i}$$

$$x_{R_i} := \frac{\Sigma M_i}{\Sigma V_i}$$

$$L_{brg_i} := \max\left[\min\left(\begin{pmatrix} 3 \cdot x_{R_i} \\ L_{ftg} \end{pmatrix}\right), 0 \cdot \text{ft}\right]$$

P_i = (klf)	S_{β_i} = (klf)	R_{key_i} = (klf)
3.6	0.8	9.1
4.5	1.0	10.1
4.8	1.1	10.5
4.7	1.1	10.9
4.2	0.9	11.4

ΣV_i = (klf)	ΣM_{grav_i} = (kip)	ΣM_{lat_i} = (kip)	ΣM_i = (kip)	ΣH_i = (klf)	R_{key_i} = (klf)	x_{R_i} = (ft)	L_{brg_i} = (ft)
49.2	917	146	771	0.0	9.1	15.69	29.000
51.5	965	147	818	0.0	10.1	15.89	29.000
53.3	1001	144	857	0.0	10.5	16.07	29.000
54.9	1032	141	891	0.0	10.9	16.22	29.000
56.5	1061	139	922	0.0	11.4	16.32	29.000

Bearing Capacity: (per EM 1110-1-1905)

$c := c_{fill}$ $c = 0.0\,psf$

$\phi := \phi_{fill}$ $\phi = 32.0\,deg$

$\gamma_{eff} := \gamma_{fill\_eff}$ $\gamma_{eff} = 65.0\,pcf$

$\gamma_{H\_eff} := \gamma_{eff}$ $\gamma_{H\_eff} = 65.0\,pcf$

$B_{eff_i} := L_{ftg} - 2 \cdot \left| \frac{L_{brg_i}}{2} - x_{R_i} \right|$ $B_{eff} = \begin{pmatrix} 26.6 \\ 26.2 \\ 25.9 \\ 25.6 \\ 25.4 \end{pmatrix} ft$

Table 4-3:

$N_\phi := \tan\left(45 \cdot deg + \frac{\phi}{2}\right)^2$ $N_\phi = 3.255$

$N_q := if\left(\phi = 0, 1.0, N_\phi \cdot e^{\pi \tan(\phi)}\right)$ $N_q = 23.2$

$N_c := if\left[\phi = 0, 5.14, (N_q - 1) \cdot \cot(\phi)\right]$ $N_c = 35.5$

$N_\gamma := if\left[\phi = 0, 0.00, (N_q - 1) \cdot \tan(1.4 \cdot \phi)\right]$ $N_\gamma = 22.0$

Inclined loading correction:

$\theta_i := atan\left(\frac{R_{key_i} + K1_i + K2_i}{\Sigma V_i}\right)$ $\theta = \begin{pmatrix} 18.70 \\ 18.33 \\ 17.47 \\ 16.66 \\ 15.94 \end{pmatrix} deg$

$\xi_{ci_i} := if\left[\phi = 0, \left(1 - \frac{\theta_i}{90 \cdot deg}\right), \left(1 - \frac{\theta_i}{90 \cdot deg}\right)^2\right]$ $\xi_{ci} = \begin{pmatrix} 0.628 \\ 0.634 \\ 0.649 \\ 0.664 \\ 0.677 \end{pmatrix}$

$\xi_{\gamma i_i} := if\left[\phi = 0, 1.0, if\left[\theta_i \le \phi, \left(1 - \frac{\theta_i}{\phi}\right)^2, 0.0\right]\right]$ $\xi_{\gamma i} = \begin{pmatrix} 0.173 \\ 0.183 \\ 0.206 \\ 0.230 \\ 0.252 \end{pmatrix}$

$\xi_{qi_i} := if\left[\phi = 0, \left(1 - \frac{\theta_i}{90 \cdot deg}\right), \left(1 - \frac{\theta_i}{90 \cdot deg}\right)^2\right]$ $\xi_{qi} = \begin{pmatrix} 0.628 \\ 0.634 \\ 0.649 \\ 0.664 \\ 0.677 \end{pmatrix}$

$B_i := L_{brg_i}$ $B = \begin{pmatrix} 29.0 \\ 29.0 \\ 29.0 \\ 29.0 \\ 29.0 \end{pmatrix} ft$

$W := 100 \cdot ft$

Foundation depth correction: (at toe)

$D := t_{base}$ $\qquad D = 6.0\,\text{ft}$

$\sigma_{D\_eff} := \gamma_{eff} \cdot D$ $\qquad \sigma_{D\_eff} = 390.0\,\text{psf}$

$\xi_{cd_i} := 1 + 0.2 \cdot (N_\phi)^{\frac{1}{2}} \cdot \frac{D}{B_i}$ $\qquad \xi_{cd} = \begin{pmatrix} 1.075 \\ 1.075 \\ 1.075 \\ 1.075 \\ 1.075 \end{pmatrix}$

$\xi_{\gamma d\_10_i} := 1 + 0.1 \cdot \left(\tan\left(45 \cdot \text{deg} + \frac{10 \cdot \text{deg}}{2}\right)^2\right)^{\frac{1}{2}} \cdot \frac{D}{B_i}$ $\qquad \xi_{\gamma d\_10} = \begin{pmatrix} 1.025 \\ 1.025 \\ 1.025 \\ 1.025 \\ 1.025 \end{pmatrix}$

$\xi_{\gamma d_i} := \text{if}\left[\phi \le 10 \cdot \text{deg}, \xi_{\gamma d\_0} + \frac{\phi}{10 \cdot \text{deg}} \cdot \left(\xi_{\gamma d\_10_i} - \xi_{\gamma d\_0}\right), 1 + 0.1 \cdot (N_\phi)^{\frac{1}{2}} \cdot \frac{D}{B_i}\right]$ $\qquad \xi_{\gamma d} = \begin{pmatrix} 1.037 \\ 1.037 \\ 1.037 \\ 1.037 \\ 1.037 \end{pmatrix}$

$\xi_{qd_i} := \xi_{\gamma d_i}$ $\qquad \xi_{qd} = \begin{pmatrix} 1.037 \\ 1.037 \\ 1.037 \\ 1.\text{[illegible]} \\ 1.\text{[illegible]} \end{pmatrix}$

USACE EM 1110-1-1905, Eq. 4-16:

$q_{u\_toe_i} := c \cdot N_c \cdot \xi_{cd} \cdot \xi_{ci} + \frac{1}{2} \cdot B_{eff_i} \cdot \gamma_{H\_eff} \cdot N_\gamma \cdot \xi_{\gamma d} \cdot \xi_{\gamma i} + \sigma_{D\_eff} \cdot N_q \cdot \xi_{qd} \cdot \xi_{qi}$ $\qquad q_{u\_toe} = \begin{pmatrix} 51.108 \\ 50.809 \\ 50.520 \\ 50.298 \\ 50.140 \end{pmatrix} \text{ksf}$

Foundation depth correction: (at heel)

$D := E_{grade} - E_{ftg} + t_{base} + h_\beta$ $\qquad D = 38.0\,\text{ft}$

$\sigma_{D\_eff\_heel} := \gamma_{eff} \cdot D$ $\qquad \sigma_{D\_eff} = 0.390\,\text{ksf}$

$\xi_{cd_i} := 1 + 0.2 \cdot (N_\phi)^{\frac{1}{2}} \cdot \frac{D}{\text{[illegible]}}$ $\qquad \xi_{cd} = \begin{pmatrix} 1.473 \\ 1.473 \\ 1.473 \\ 1.473 \\ 1.473 \end{pmatrix}$

$\xi_{\gamma d\_10_i} := 1 + 0.1 \cdot \left(\tan\left(45 \cdot \text{deg} + \frac{10 \cdot \text{deg}}{2}\right)^2\right)^{\frac{1}{2}} \cdot \frac{D}{B_i}$ $\qquad \xi_{\gamma d\_10} = \begin{pmatrix} 1.156 \\ 1.156 \\ 1.156 \\ 1.156 \\ 1.156 \end{pmatrix}$

$\xi_{\gamma d_i} := \text{if}\left[\phi \le 10 \cdot \text{deg}, \xi_{\gamma d\_0} + \frac{\phi}{10 \cdot \text{deg}} \cdot \left(\xi_{\gamma d\_10_i} - \xi_{\gamma d\_0}\right), 1 + 0.1 \cdot (N_\phi)^{\frac{1}{2}} \cdot \frac{D}{B_i}\right]$ $\qquad \xi_{\gamma d} = \begin{pmatrix} 1.236 \\ 1.236 \\ 1.236 \\ 1.236 \\ 1.236 \end{pmatrix}$

$\xi_{qd_i} := \xi_{\gamma d_i}$ $\qquad \xi_{qd} = \begin{pmatrix} 1.236 \\ 1.236 \\ 1.236 \\ 1.\text{[illegible]} \\ 1\text{[illegible]} \end{pmatrix}$

USACE EM 1110-1-1905, Eq. 4-16:

$q_{u\_heel_i} := c \cdot N_c \cdot \xi_{cd} \cdot \xi_{ci} + \frac{1}{2} \cdot B_{eff_i} \cdot \gamma_{H\_eff} \cdot N_\gamma \cdot \xi_{\gamma d} \cdot \xi_{\gamma i} + \sigma_{D\_eff} \cdot N_q \cdot \xi_{qd} \cdot \xi_{qi}$ $\qquad q_{u\_heel} = \begin{pmatrix} 60.916 \\ 60.559 \\ 60.215 \\ 59.950 \\ 59.762 \end{pmatrix} \text{ksf}$

$check\_uplift_i := L_{ftg} - L_{brg_i} - L_{uplift_i}$

$check\_uplift_i =$

0.0000 ft
0.0000
0.0000
0.0000
0.0000

ok := if(max(|check_uplift|) < 0.001 · ft, ok, "Uplift assumptions do not match bearing area.")

ok = "Ok"

$$e_{brg_i} := \frac{L_{brg_i}}{2} - x_{R_i}$$

$$\sigma_{brg\_toe_i} := \frac{\Sigma V_i}{L_{brg_j}} + \frac{\Sigma V_i \cdot e_{brg_i}}{\frac{(L_{brg_j})^2}{6}}$$

$$\sigma_{brg\_heel_i} := \frac{\Sigma V_i}{L_{brg_i}} - \frac{\Sigma V_i \cdot e_{brg_i}}{\frac{(L_{brg_i})^2}{6}}$$

$$FS_{brg_i} := \min\left(\frac{q_{u\_toe_i}}{\sigma_{brg\_toe_i}}, \frac{q_{u\_heel_i}}{\sigma_{brg\_heel_i}}\right)$$

$$\%_{brg_i} := \frac{L_{brg_i}}{L_{ftg}}$$

$$\%_{brg_i} = \begin{pmatrix} 100.0 \\ 100.0 \\ 100.0 \\ 100.0 \\ 100.0 \end{pmatrix} \%$$

ok := if($\%_{brg_1} \geq 75 \cdot \%$, ok, "OT instability: LC#1")

$L_{ftg} = 29.0\ ft$

ok := if($\%_{brg_n} \geq 100\%$, ok, "OT instability: LC#n")

$t_{w\_bot} = 3.4\ ft$

$\frac{L_{ftg}}{4} = 7.250\ ft$

e_{brg_i} = (ft)	$\sigma_{brg\_toe_i}$ = (ksf)	$\sigma_{brg\_heel_i}$ = (ksf)	FS_{brg_i} =	$L_{ftg} - L_{brg_i}$ = (ft)
-1.19	1.276	2.114	28.82	0.000
-1.39	1.266	2.285	26 50	0.000
-1.57	1.240	2.436	24 71	0.000
-1.72	1.221	2.567	23.35	0.000
-1.82	1.214	2.680	22 30	0.000

$$L_{uplift} \equiv \begin{pmatrix} 0 \\ 0 \\ 0 \\ 0 \\ 0 \end{pmatrix} \cdot ft$$

ok := if[max[|$L_{brg} - (L_{ftg} - L_{uplift})$|] < 0.001 · ft, ok, "Uplift area does not match

ok := if($FS_{brg_1} < 2$, "Bearing problem LC#1", ok)

$L_{ftg} = 29.0\ ft$

ok := if($FS_{brg_n} < 3$, "Bearing problem LC#n", ok)

ok = "Ok"

Base Pressures:

$$e_{ftg_i} := \frac{L_{ftg}}{2} - x_{R_i}$$ (eccentricity with respect to the footing centroid)

$\Sigma H_i + R_{key_i} =$ (klf)	$\Sigma V_i =$ (klf)	$e_{ftg_i} =$ (ft)	$x_{R_i} =$ (ft)	$\sigma_{brg\_heel_i} =$ (ksf)	$\sigma_{brg\_toe_i} =$ (ksf)
9.1	49.2	-1.19	15.69	2.114	1.276
10.1	51.5	-1.39	15.89	2.285	1.266
10.5	53.3	-1.57	16.07	2.436	1.240
10.9	54.9	-1.72	16.22	2.567	1.221
11.4	56.5	-1.82	16.32	2.680	1.214

$L_{brg_1} = 29.00\,ft$

$$\frac{L_{brg}}{L_{ftg}} = \begin{pmatrix} 100.0 \\ 100.0 \\ 100.0 \\ 100.0 \\ 100.0 \end{pmatrix} \%$$

Sliding Analysis:

Function Definitions:

$$c_1(\phi_d) := 2 \cdot \tan(\phi_d)$$

$$c_2(\phi_d, \beta) := 1 - \tan(\phi_d) \cdot \tan(\beta) - \left(\frac{\tan(\beta)}{\tan(\phi_d)}\right)$$

$$\alpha_{driving}(\phi_d, \beta) := -\operatorname{atan}\left(\frac{c_1(\phi_d) + \sqrt{c_1(\phi_d)^2 + 4 \cdot c_2(\phi_d, \beta)}}{2}\right)$$

$$L_\beta := \max\left(\begin{pmatrix} \frac{h_\beta}{\tan(\beta)} - L_{WS5} - L_{WS6} \\ 0 \cdot ft \end{pmatrix}\right) \qquad L_\beta = 12.9\ ft$$

Sliding Analysis #1:

$$\beta_w := \beta \qquad \beta_w = 33.7\ deg$$

$$\phi_i := \phi_{fill} \qquad \phi = \begin{pmatrix} 32.0 \\ 32.0 \\ 32.0 \\ 32.0 \\ 32.0 \end{pmatrix} deg$$

$$c := 0\ \ ksf$$

$$\phi_{d_i} := \operatorname{atan}\left(\frac{\tan(\phi_i)}{FS_{1_i}}\right) \qquad \phi_{d_i} = \begin{pmatrix} 23.2 \\ 22.3 \\ 21.5 \\ 20.5 \\ 19.8 \end{pmatrix} deg$$

$$\operatorname{atan}\left(\tan(\beta) \cdot FS_{1_i}\right) = \begin{pmatrix} 44.2 \\ 45.4 \\ 46.7 \\ 48.1 \\ 49.2 \end{pmatrix} deg$$

(back solve for minimum ϕ value for stable slope β, EM 1110–2–2502, pg. 3-31)

$$\phi_i := \text{if}\left[\left(c_1(\phi_{d_i})^2 + 4 \cdot c_2(\phi_{d_i}, \beta_w) < 0\right), \operatorname{atan}\left(\tan(\beta_w) \cdot FS_{1_i}\right), \phi_i\right] \qquad \phi = \begin{pmatrix} 44.2 \\ 45.4 \\ 46.7 \\ 48.1 \\ 49.2 \end{pmatrix} deg$$

(substitue minimum ϕ if slope is unstable)

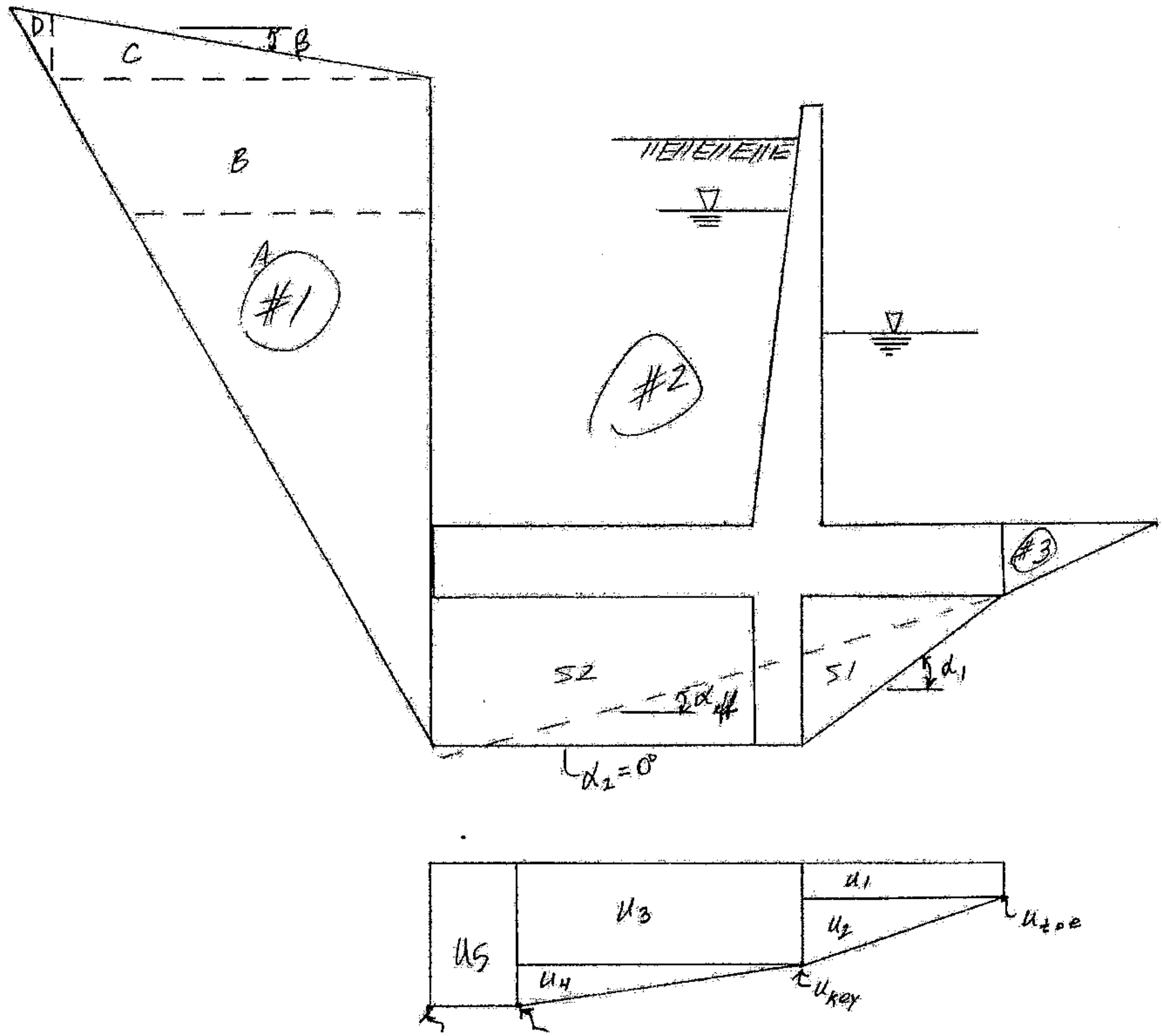
$$\phi_{d\_1b_i} := \operatorname{atan}\left(\frac{\tan(\phi_i)}{FS_{1_i}}\right) \qquad \phi_{d\_1b_i} = \begin{pmatrix} 33.7 \\ 33.7 \\ 33.7 \\ 33.7 \\ 33.7 \end{pmatrix} deg$$

$$\alpha_{1b_i} := \alpha_{driving}(\phi_{d\_1b_i}, \beta_w)$$

$$h_{1b} := \left(E_{grade} + L_{WS5} \cdot \tan(\beta_w)\right) - \left(E_{bftg} - h_{key}\right) \qquad h_{1b} = 34.4\ ft$$

$$L_{max_i} := \text{if}\left[-\alpha_{1b_i} = \phi_{d\_1b_i}, 1000 \cdot ft, \frac{\frac{h_{1b}}{\cos(-\alpha_{1b_i})\left(\tan(-\alpha_{1b_i}) - \tan(\beta_w)\right)}}{\cos(-\alpha_{1b_i})}\right] \qquad \alpha_{1b} = \begin{pmatrix} -33.7 \\ -33.7 \\ -33.7 \\ -33.7 \\ -33.7 \end{pmatrix} deg \qquad L_{max} = \begin{pmatrix} 1000.0 \\ 1000.0 \\ 1000.0 \\ 1000.0 \\ 1000.0 \end{pmatrix} ft$$

$$h_{1a_i} := \text{if}\left[L_\beta < L_{max_i}, h_{1b} + L_\beta \cdot \left(\tan(\beta) - \tan(-\alpha_{1b_i})\right), 0 \cdot ft\right]$$



Sliding Analysis #1

Driving Wedge (#1a):

$\beta_w := 0 \cdot deg$ $\beta_w = 0.0\,deg$

$\phi := \phi_{fill}$ $\phi = 32.0\,deg$

$c := 0 \cdot ksf$

$\phi_{d_i} := atan\left(\frac{\tan(\phi)}{FS_{1_i}}\right)$ $\phi_d = \begin{pmatrix} 23.2 \\ 22.3 \\ 21.5 \\ 20.5 \\ 19.8 \end{pmatrix} deg$

$\alpha_i := \alpha_{driving}\left(\phi_{d_i}, \beta_w\right)$ $\alpha = \begin{pmatrix} -56.6 \\ -56.2 \\ -55.7 \\ -55.3 \\ -54.9 \end{pmatrix} deg$

$h_{1a} = \begin{pmatrix} 34.4 \\ 34.4 \\ 34.4 \\ 34.4 \\ 34.4 \end{pmatrix} ft$

$h_i := h_{1a_i}$ $h = \begin{pmatrix} 34.4 \\ 34.4 \\ 34.4 \\ 34.4 \\ 34.4 \end{pmatrix} ft$

$L_i := \frac{h_i}{\cos(-\alpha_i) \cdot (\tan(-\alpha_i) - \tan(\beta_w))}$ $L = \begin{pmatrix} 41.2 \\ 41.4 \\ 41.6 \\ 41.9 \\ 42.1 \end{pmatrix} ft$

$h_{sat_i} := max\left[\left[\begin{matrix} E_{wheel_i} - (E_{ftg} - t_{base} - h_{key}) - L_\beta \cdot \tan(-\alpha_{1b_i}) \\ 0 \cdot ft \end{matrix}\right]\right]$ $h_{sat} = \begin{pmatrix} 14.4 \\ 12.7 \\ 10.9 \\ 9.2 \\ 7.4 \end{pmatrix} ft$

$L_{h_i} := \frac{h_i}{\tan(-\alpha_i)}$ $L_h = \begin{pmatrix} 22.7 \\ 23.1 \\ 23.5 \\ 23.9 \\ 24.2 \end{pmatrix} ft$

$L_{sat_i} := \frac{h_{sat_i}}{\tan(-\alpha_i)}$ $L_{sat} = \begin{pmatrix} 9.5 \\ 8.5 \\ 7.4 \\ 6.4 \\ 5.2 \end{pmatrix} ft$

$h_{left} := 0 \cdot ft$

$h_{right_i} := h_{1a_i}$

$W_i := \gamma_{fill} \cdot \left(L_{h_i} \cdot \frac{h_{left} + h_{right_i}}{2}\right) + (\gamma_{sat} - \gamma_{fill}) \cdot \frac{L_{sat_i} \cdot h_{sat_i}}{2}$

$W_i =$

50.6
51.5
52.4
53.3
54.1

klf

$V := 0 \cdot klf$

$H_L := 0 \cdot klf$

$H_R := 0 \cdot klf$

$U_i := \gamma_w \cdot \left(\frac{h_{sat_i}}{2}\right) \cdot \sqrt{(h_{sat_i})^2 + (L_{sat_i})^2}$ $U = \begin{pmatrix} 7.8 \\ 6.0 \\ 4.5 \\ 3.2 \\ 2.1 \end{pmatrix} klf$

$$\Delta P_{1a_i} := \frac{\left[\left(W_i + V\right)\cdot\left(\tan\left(\phi_{d_i}\right)\cdot\cos\left(\alpha_i\right) + \sin\left(\alpha_i\right)\right) - U_i\cdot\tan\left(\phi_{d_i}\right) + \left(H_L - H_R\right)\cdot\left(\tan\left(\phi_{d_i}\right)\cdot\sin\left(\alpha_i\right) - \cos\left(\alpha_i\right)\right) + \frac{c}{FS_{1_i}}\cdot L_i\right]}{\left(\cos\left(\alpha_i\right) - \tan\left(\phi_{d_i}\right)\cdot\sin\left(\alpha_i\right)\right)}$$

Driving Wedge (#1b):

$\beta_w := \beta$ $\qquad \beta_w = 33.7\,deg$

$\alpha := \alpha_{1b}$ $\qquad \alpha = \begin{pmatrix} -33.7 \\ -33.7 \\ -33.7 \\ -33.7 \\ -33.7 \end{pmatrix} deg$

$\phi_d := \phi_{d\_1b}$ $\qquad \phi_d = \begin{pmatrix} 33.7 \\ 33.7 \\ 33.7 \\ 33.7 \\ 33.7 \end{pmatrix} deg$

$h = \begin{pmatrix} 34.4 \\ 34.4 \\ 34.4 \\ 34.4 \\ 34.4 \end{pmatrix} ft$

$L_h := L_\beta$ $\qquad L_h = 12.9\,ft$

$L_i := \dfrac{L_\beta}{\cos\left(\alpha_i\right)}$ $\qquad L = \begin{pmatrix} 15.5 \\ 15.5 \\ 15.5 \\ 15.5 \\ 15.5 \end{pmatrix} ft$

$h_{satr_i} := \max\left[\begin{bmatrix} E_{wheel_i} - \left(E_{ftg} - t_{base} - h_{key}\right) \\ 0\cdot ft \end{bmatrix}\right]$ $\qquad h_{satr} = \begin{pmatrix} 23.0 \\ 21.3 \\ 19.5 \\ 17.8 \\ 16.0 \end{pmatrix} ft$

$h_{satl_i} := \max\left[\begin{bmatrix} E_{wheel_i} - \left(E_{ftg} - t_{base} - h_{key}\right) - \dfrac{L_\beta}{\cos\left(\alpha_i\right)} \\ 0\cdot ft \end{bmatrix}\right]$ $\qquad h_{satl} = \begin{pmatrix} 7.5 \\ 5.8 \\ 4.0 \\ 2.3 \\ 0.5 \end{pmatrix} ft$

$L_{sat_i} := \min\left[\begin{bmatrix} L_\beta \\ \dfrac{h_{satr_i}}{\tan\left[\left(-\alpha\right)_i\right]} \end{bmatrix}\right]$ $\qquad L_{sat} = \begin{pmatrix} 12.9 \\ 12.9 \\ 12.9 \\ 12.9 \\ 12.9 \end{pmatrix} ft$

$h_{left_i} := h_{1a_i}$ $\qquad h_{left} = \begin{pmatrix} 34.4 \\ 34.4 \\ 34.4 \\ 34.4 \\ 34.4 \end{pmatrix} ft$

$h_{right} := h_{1b}$

$$W_i := \gamma_{fill} \cdot \left(L_h \cdot \frac{h_{left_i} + h_{right}}{2}\right) + (\gamma_{sat} - \gamma_{fill}) \cdot L_{sat_i} \cdot \left(\frac{h_{satr_i} + h_{satl_i}}{2}\right)$$

$W_i =$

57.1
57.2
57.2
57.3
57.3

klf

$V := 0 \cdot klf$

$H_L := 0 \cdot klf$

$H_R := 0 \cdot klf$

$$U_i := \gamma_w \cdot \left(\frac{h_{satr_i} + h_{satl_i}}{2}\right) \cdot \sqrt{\left(h_{satr_i} - h_{satl_i}\right)^2 + (L_h)^2}$$

$$\Delta P_{1b_i} := \frac{\left[(W_i + V) \cdot \left(\tan(\phi_{d_i}) \cdot \cos(\alpha_i) + \sin(\alpha_i)\right) - U_i \cdot \tan(\phi_{d_i}) + (H_L - H_R) \cdot \left(\tan(\phi_{d_i}) \cdot \sin(\alpha_i) - \cos(\alpha_i)\right) + \frac{c}{FS_{1_i}} \cdot L_i\right]}{\left(\cos(\alpha_i) - \tan(\phi_{d_i}) \cdot \sin(\alpha_i)\right)}$$

Structure Wedge (#2):

$U_i =$

19.203
17.001
14.799
12.598
10.396

klf

$\beta_w := 0 \ deg$

$\phi := \phi_{fill}$ $\qquad \phi = 32.0\,deg$

$c := 0 \cdot ksf$

$$\phi_{d_i} := \operatorname{atan}\left(\frac{\tan(\phi)}{FS_{1_i}}\right)$$

$$\phi_{d_i} = \begin{pmatrix} 23.2 \\ 22.3 \\ 21.5 \\ 20.5 \\ 19.8 \end{pmatrix} deg$$

$$\alpha_1 := \operatorname{atan}\left(\frac{h_{key}}{x_{key} - \frac{L_{key}}{2}}\right)$$

$\alpha_1 = 25.7\,deg$ (angle of shear plane between toe and key)

$\alpha_2 := 0 \ deg$ (angle of shear plane between key and heel)

$$\alpha := \alpha_1 \cdot \left(\frac{x_{key}}{L_{ftg}}\right) + \alpha_2 \cdot \left(\frac{L_{ftg} - x_{key}}{L_{ftg}}\right)$$

$\alpha = 10.5\,deg$ (average angle of shear plane for structural wedge)

$L := \frac{L_{ftg}}{\cos(\alpha)}$ $\qquad L = 29.5\,ft$

$h_{S1} := h_{key}$ $\qquad h_{S1} = 5.0\,ft$

$L_{S1} := x_{key} - \frac{L_{key}}{2}$ $\qquad L_{S1} = 10.4\,ft$

$x_{S1} := \frac{2}{3} \cdot L_{S1}$ $\qquad x_{S1} = 6.9\,ft$

$S1 := \gamma_{sat} \cdot \frac{h_{S1} \cdot L_{S1}}{2}$ $\qquad S1 = 3.3\,klf$

$h_{S2} := h_{key}$ $\qquad h_{S2} = 5.0\,ft$

$L_{S2} := L_{ftg} - x_{key} - \frac{L_{key}}{2}$ $\qquad L_{S2} = 15.6\,ft$

$x_{S2} := L_{ftg} - \frac{L_{S2}}{2}$ $\qquad x_{S2} = 21.2\,ft$

$S2 := \gamma_{sat} \cdot h_{S2} \cdot L_{S2}$ $\qquad S2 = 10.0\,klf$

$$W_i := \sum_{i=1}^{4} W_{C_i} + W_{W1_i} + W_{WS1_i} + W_{WS2_i} + W_{WS3_i} + W_{WS4_i} + W_{WS5} + W_{WS6} + S1 + S2 + S_{\beta_i}$$

Uplift below structural wedge:

$u_{toe_i} := \gamma_w \cdot \left(E_{wtoe_i} - E_{bftg}\right)$

$u_{heel_i} := \gamma_w \cdot \left[E_{wheel_i} - \left(E_{bftg} - h_{key}\right)\right]$

$$\delta_{u_i} := \frac{\gamma_w \cdot \left(E_{wheel_i} - E_{wtoe_i}\right)}{L_{ftg} - L_{t1_i}}$$

$u_{key_i} := u_{toe_i} + \delta_{u_i} \cdot \left(x_{key} - \frac{L_{key}}{2}\right) + \gamma_w \cdot h_{key}$

$ok := if\left[\left[u_{key_1} + \delta_{u_1} \cdot \left(L_{ftg} - x_{key} + \frac{L_{key}}{2} - L_{t1_1}\right) = u_{heel_1}\right], ok, \text{"Uplift pressures do not close."}\right]$

ok = "Ok"

$u_{1_i} := u_{toe_i} \cdot \left(x_{key} - \frac{L_{key}}{2}\right)$

$$x_{u1} := \frac{x_{key} - \frac{L_{key}}{2}}{2}$$ $\qquad x_{u1} = 5.2\,ft$

$$u_{2_i} := \left(u_{key_i} - u_{toe_i}\right) \cdot \frac{\left(x_{key} - \frac{L_{key}}{2}\right)}{2}$$

$$x_{u2} := \frac{2}{3}\cdot\left(x_{key} - \frac{L_{key}}{2}\right) \qquad x_{u2} = 6.9\,\text{ft}$$

$$u3_i := u_{key_i}\cdot\left(L_{ftg} - L_{t1_i} - x_{key} + \frac{L_{key}}{2}\right)$$

$$x_{u3_i} := x_{key} - \frac{L_{key}}{2} + \frac{1}{2}\cdot\left[L_{ftg} - L_{t1_i} - \left(x_{key} - \frac{L_{key}}{2}\right)\right]$$

$$u4_i := \left(u_{heel_i} - u_{key_i}\right)\cdot\frac{\left(L_{ftg} - L_{t1_i} - x_{key} + \frac{L_{key}}{2}\right)}{2}$$

$$x_{u4_i} := x_{key} - \frac{L_{key}}{2} + \frac{2}{3}\cdot\left[L_{ftg} - L_{t1_i} - \left(x_{key} - \frac{L_{key}}{2}\right)\right]$$

$$u5_i := u_{heel_i}\cdot L_{t1_i}$$

$$x_{u5_i} := L_{ftg} - \frac{L_{t1_i}}{2}$$

$$U_i := u1_i + u2_i + u3_i + u4_i + u5_i$$

$$x_{U_i} := \frac{u1_i\cdot x_{u1} + u2_i\cdot x_{u2} + u3_i\cdot x_{u3_i} + u4_i\cdot x_{u4_i} + u5_i\cdot x_{u5_i}}{U_i}$$

$$\Sigma M_{grav_i} := \left(\sum_{i=1}^{4} W_{C_i}\cdot x_{C_i} + W_{W1_i}\cdot x_{W1} + W_{WS1_i}\cdot x_{WS1} + W_{WS2_i}\cdot x_{WS2_i} + W_{WS3_i}\cdot x_{WS3_i}\right)\ldots$$
$$+ W_{WS4_i}\cdot x_{WS4_i} + W_{WS5}\cdot x_{WS5} + W_{WS6}\cdot x_{WS6} + S1\cdot x_{S1} + S2\cdot x_{S2} + S_{\beta_i}\cdot x_{S\beta} - \left(U_i\cdot x_{U_i}\right)$$

$h_{A2_i} := E_{wheel_i} - E_{bftg} + h_{key}$

$y_{A2_i} := \frac{h_{A2_i}}{2} - h_{key}$

$A2_i := k_{0\beta} \cdot \gamma_{fill} \; h_{A1_i} \; h_{A2_i}$

$h_{A3_i} := h_{A2_i}$

$y_{A3_i} := \frac{h_{A3_i}}{3} - h_{key}$

$A3_i := k_{0\beta} \cdot \gamma_{fill\_eff} \cdot \frac{(h_{A3_i})^2}{2}$

$H3_i := 0 \cdot klf$

$h_{H2_i} := E_{wheel_i} - E_{bftg} + h_{key}$

$y_{H2_i} := \frac{h_{H2_i}}{3} - h_{key}$

$h_{A2_i} =$ (ft)

23.00
21.25
19.50
17.75
16.00

$y_{A2_i} =$ (ft)

6.50
5.63
4.75
3.88
3.00

$A2_i =$ (klf)

0.0
3.8
6.9
9.4
11.3

$h_{A3_i} =$ (ft)

23.00
21.25
19.50
17.75
16.00

$y_{A3_i} =$ (ft)

2.67
2.08
1.50
0.92
0.33

$A3_i =$ (klf)

13.4
11.4
9.6
8.0
6.5

$H2_i := \gamma_w \cdot \frac{(h_{H2_i})^2}{2}$

$\Sigma M_{lat_i} := -H1_i \cdot (y_{H1_i}) - K1_i \cdot (y_{K1}) - K2_i \; (y_{K2}) + H2_i \cdot (y_{H2_i}) + H3_i \cdot (y_{H3}) \ldots$
$+ A1_i \cdot (y_{A1_i}) + A2_i \cdot (y_{A2_i}) + A3_i \cdot (y_{A3_i}) - R_{key_i} \cdot (y_{Rkey})$

$x_{R_i} := \frac{\Sigma M_{grav_i} - \Sigma M_{lat_i}}{W_i - U_i}$ $\qquad L_{brg_i} := \min(3 \; x_{R_i}, L_{ftg})$

$ok_{u_i} := \text{if}\left[\left|L_{brg_i} - (L_{ftg} - L_{t1_i})\right| > 0.001 \cdot ft, \text{"Uplift assumptions wrong in sliding analysis."}, \text{"Matched."}\right]$

$W_i =$ (klf)	$u_{toe_i} =$ (ksf)	$u_{heel_i} =$ (ksf)	$\delta u_i =$ (psf/ft)	$u_{key_i} =$ (ksf)	$u1_i =$ (klf)	$u2_i =$ (klf)	$u3_i =$ (klf)
86.9	0.500	1.438	21.6	1.036	5.188	2.781	19.297
86.1	0.391	1.328	21.6	0.927	4.053	2.781	17.260
86.1	0.375	1.219	18.3	0.878	3.891	2.607	16.345
86.1	0.375	1.109	14.5	0.838	3.891	2.404	15.616
86.1	0.375	1.000	10.8	0.799	3.891	2.201	14.887

$u4_i$ =		$u5_i$ =		x_{u3_i} =		x_{u4_i} =		x_{u5_i} =		h_{H2_i} =		y_{H2_i} =		$H2_i$ =	
3.738	klf	0.0	klf	19.7	ft	22.8	ft	29.0	ft	23.0	ft	2.7	ft	16.5	klf
3.738		0.0		19.7		22.8		29.0		21.3		2.1		14.1	
3.177		0.0		19.7		22.8		29.0		19.5		1.5		11.9	
2.523		0.0		19.7		22.8		29.0		17.8		0.9		9.8	
1.869		0.0		19.7		22.8		29.0		16.0		0.3		8.0	

U_i =		x_{U_i} =		ΣM_{grav_i} =		ΣM_{lat_i} =		x_{R_i} =		L_{brg_i} =	
31.0	klf	16.5	ft	1037	kip	117	kip	16.5	ft	29.0	ft
27.8		16.7		1084		118		16.6		29.0	
26.0		16.6		1120		115		16.7		29.0	
24.4		16.4		1152		113		16.8		29.0	
22.8		16.2		1180		111		16.9		29.0	

$$H_{L_i} := 0 \cdot \text{klf}$$

$$H_{R_i} := \gamma_w \cdot \frac{\left(E_{wtoe_i} - E_{ftg}\right)^2}{2}$$

$$\Delta P_{2_i} := \frac{\left[(W_i + V)\cdot(\tan(\phi_{d_i})\cdot\cos(\alpha)+\sin(\alpha)) - U_i\cdot\tan(\phi_{d_i}) + (H_{L_i} - H_{R_i})\cdot(\tan(\phi_{d_i})\cdot\sin(\alpha)-\cos(\alpha)) + \frac{c}{FS_{1_i}}\cdot L\right]}{(\cos(\alpha) - \tan(\phi_{d_i})\cdot\sin(\alpha))}$$

$H_{L_i} =$		$H_{R_i} =$	
0.0	klf	0.1	klf
0.0		0.0	
0.0		0.0	
0.0		0.0	
0.0		0.0	

$$ok_{u_i} = \begin{pmatrix} \text{"Matched."} \\ \text{"Matched."} \\ \text{"Matched."} \\ \text{"Matched."} \\ \text{"Matched."} \end{pmatrix}$$

$L_{ftg} - L_{brg_i} =$	
0.000	ft
0.000	
0.000	
0.000	
0.000	

$$L_{t1} \equiv \begin{pmatrix} 0 \\ 0 \\ 0 \\ 0 \\ 0 \end{pmatrix}\cdot ft$$

$$ok := if\left[\max\left[\left|L_{brg} - (L_{ftg} - L_{t1})\right|\right] < 0.001\ ft, ok, \text{"Uplift area does not match."}\right]$$

$$ok := if\left(\min(L_{brg}) < x_{key} + \frac{L_{key}}{2}, \text{"Uplift assumptions incorrect."}, ok\right) \qquad ok = \text{"Ok"}$$

Resisting Wedge (#3):

$\beta_w := 0 \cdot deg$

$\phi := \phi_{fill}$ $\phi = 32.0\ deg$

$c := 0 \cdot ksf$

$\phi_{d_i} := atan\left(\frac{tan(\phi)}{FS1_i}\right)$ $\phi_{d_i} = \begin{pmatrix} 23.2 \\ 22.3 \\ 21.5 \\ 20.5 \\ 19.8 \end{pmatrix} deg$

$\alpha_i := 45 \cdot deg - \frac{\phi_{d_i}}{2}$ $\alpha_i = \begin{pmatrix} 33.4 \\ 33.8 \\ 34.3 \\ 34.7 \\ 35.1 \end{pmatrix} deg$

$L_i := \frac{t_{base}}{sin(\alpha_i)}$ $L = \begin{pmatrix} 10.895 \\ 10.778 \\ 10.655 \\ 10.528 \\ 10.429 \end{pmatrix} ft$

$W_i := \gamma_{sat} \cdot \frac{L_i \cdot cos(\alpha_i) \cdot t_{base}}{2} + \gamma_w \cdot (E_{wtoe_i} - E_{ftg}) \cdot L_i \cdot cos(\alpha_i)$

$U_i := \gamma_w \cdot \left(E_{wtoe_i} - E_{ftg} + \frac{t_{base}}{2}\right) \cdot L_i$

$H_L := 0 \cdot klf$

$H_R := 0 \cdot klf$

$V := 0 \cdot klf$

$$\Delta P_{3_i} := \frac{\left[(W_i + V)\cdot\left(tan(\phi_{d_i})\cdot cos(\alpha_i) + sin(\alpha_i)\right) - U_i \cdot tan(\phi_{d_i}) + (H_L - H_R)\cdot\left(tan(\phi_{d_i})\cdot sin(\alpha_i) - cos(\alpha_i)\right) + \frac{c}{FS1_i}\cdot L_i\right]}{\left(cos(\alpha_i) - tan(\phi_{d_i})\cdot sin(\alpha_i)\right)}$$

$\Sigma P_i := \Delta P_{1a_i} + \Delta P_{1b_i} + \Delta P_{2_i} + \Delta P_{3_i}$

W_i = (klf)	U_i = (klf)	ΔP_{1a_i} = (klf)	ΔP_{1b_i} = (klf)	ΔP_{2_i} = (klf)	ΔP_{3_i} = (klf)	ΣP_i = (klf)
4.6	3.4	-37.1	-10.7	43.4	4.6	0.3
3.6	2.2	-37.2	-9.4	43.1	3.8	0.2
3.4	2.0	-37.7	-8.2	42.6	3.6	0.3
3.3	2.0	-38.3	-7.0	41.9	3.6	0.1
3.3	2.0	-38.9	-5.8	41.3	3.5	0.1

$FS_1 = \begin{pmatrix} 1.46 \\ 1.52 \\ 1.59 \\ 1.67 \\ 1.74 \end{pmatrix}$

ok := if($FS1_1 \geq 1.33$, ok, "Sliding instability: LC#1")

ok := if($FS1_n \geq 1.50$, ok, "Sliding instability: LC#n")

ok = "Ok"

Sliding Analysis #2:

$L_\beta = 12.88\,ft$

$\phi_i := \phi_{fill}$ $\beta_w := \beta$ $\beta_w = 33.7\,deg$

$$\phi = \begin{pmatrix}32.0\\32.0\\32.0\\32.0\\32.0\end{pmatrix} deg$$

$c := 0 \cdot ksf$

$$\phi_{d_i} := atan\left(\frac{tan(\phi_i)}{FS2_i}\right) \qquad \phi_{d_i} = \begin{pmatrix}26.9\\26.4\\25.5\\24.7\\23.9\end{pmatrix} deg$$

$$atan\left(tan(\beta) \cdot FS2_i\right) = \begin{pmatrix}39.4\\40.0\\41.1\\42.2\\43.2\end{pmatrix} deg$$

(back solve for minimum ϕ value for stable slope β, EM 1110–2–2502, pg. 3-31)

$$\phi_i := if\left[\left(c_1(\phi_{d_i})^2 + 4 \cdot c_2(\phi_{d_i}, \beta_w) < 0\right), atan\left(tan(\beta_w) \cdot FS2_i\right), \phi_i\right] \qquad \phi = \begin{pmatrix}39.4\\40.0\\41.1\\42.2\\43.2\end{pmatrix} deg$$

(substitute minimum ϕ if slope is unstable)

$$\phi_{d\_1b_i} := atan\left(\frac{tan(\phi_i)}{FS2_i}\right) \qquad \phi_{d\_1b_j} = \begin{pmatrix}33.7\\33.7\\33.7\\33.7\\33.7\end{pmatrix} deg$$

$$\beta_{max_i} := atan\left[\frac{\frac{\left(2 \cdot tan(\phi_{d_i})\right)^2}{4} - 1}{-tan(\phi_{d_i}) - \frac{1}{tan(\phi_{d_i})}}\right] - 0.000000001 \cdot deg \qquad \beta_{max_i} = \begin{pmatrix}26.9\\26.4\\25.5\\24.7\\23.9\end{pmatrix} deg$$

(compute maximum stable slope)

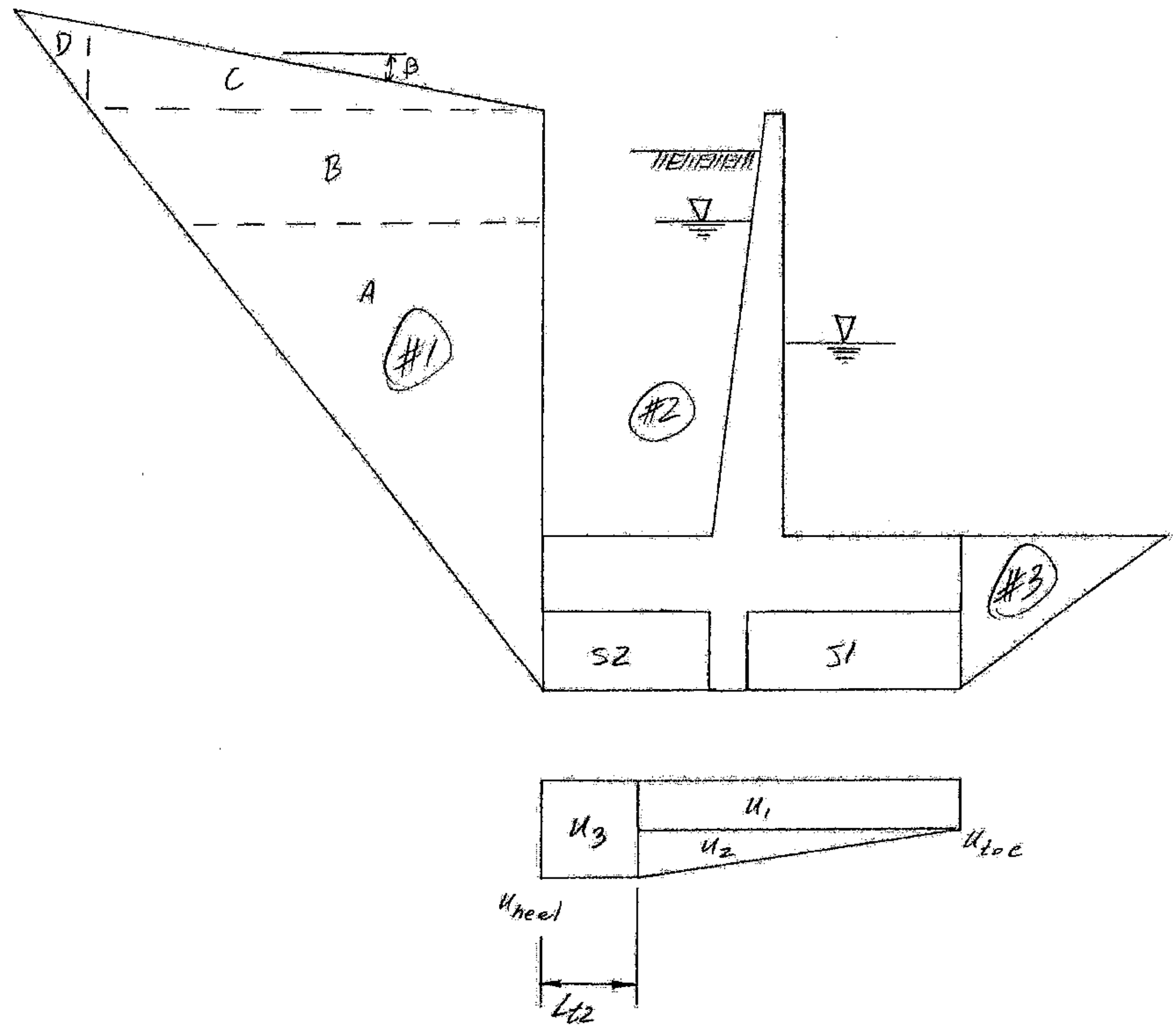
$$\beta_{eff_i} := if\left(\beta_w > \beta_{max_i}, \beta_{max_i}, \beta_w\right) \qquad \beta_{eff} = \begin{pmatrix}26.4\\25.5\\24.7\\23.9\end{pmatrix} deg$$

$$\alpha_{1b_i} := \alpha_{driving}\left(\phi_{d_i}, 0 \cdot deg\right) \qquad \alpha_{1b} = \begin{pmatrix}-58.5\\-58.2\\-57.8\\-57.3\\-57.0\end{pmatrix} deg$$

$$h_{1b} := \left(E_{grade} + L_{WS5} \cdot tan(\beta_w)\right) - \left(E_{bftg} - h_{key}\right) \qquad h_{1b} = 34.4\,ft$$

$$L_{max_i} := if\left[-\alpha_{1b_i} = \phi_{d\_1b_i}, 1000 \cdot ft, \frac{\frac{h_{1b}}{cos(-\alpha_{1b_i}) \cdot \left(tan(-\alpha_{1b_i}) - tan(\beta_w)\right)}}{cos(-\alpha_{1b_i})}\right] \qquad L_{max} = \begin{pmatrix}1000.0\\1000.0\\1000.0\\1000.0\\1000.0\end{pmatrix} ft$$

$$h_{1a_i} := if\left[L_\beta < L_{max_i}, h_{1b} + L_\beta \cdot \left(tan(\beta) - tan(-\alpha_{1b_i})\right), 0 \cdot ft\right] \qquad h_{1a} = \begin{pmatrix}22.0\\22.2\\22.6\\22.9\\23.2\end{pmatrix} ft$$



Sliding Analysis #2

Driving Wedge (#1a):

$\beta_w := 0 \cdot deg$ $\beta_w = 0.0\,deg$

$\phi := \phi_{fill}$ $\phi = 32.0\,deg$

$c := 0 \;\; ksf$

$\phi_{d_i} := atan\left(\frac{tan(\phi)}{FS2_i}\right)$ $\phi_d = \begin{pmatrix} 26.9 \\ 26.4 \\ 25.5 \\ 24.7 \\ 23.9 \end{pmatrix} deg$

$\alpha_i := \alpha_{driving}\left(\phi_{d_i}, \beta_w\right)$ $\alpha = \begin{pmatrix} -58.47 \\ -58.19 \\ -57.75 \\ -57.34 \\ -56.95 \end{pmatrix} deg$

$h_i := h_{1a_i}$

$h_i := h_{1a_i}$ $h = \begin{pmatrix} 22.0 \\ 22.2 \\ 22.6 \\ 22.9 \\ 23.2 \end{pmatrix} ft$

$L_i := \frac{h_i}{cos(-\alpha_i)\,\left(tan(-\alpha_i) - tan(\beta_w)\right)}$ $= \begin{pmatrix} 25.83 \\ 26.18 \\ 26.72 \\ 27.22 \\ 27.69 \end{pmatrix} ft$

$h_{sat_i} := max\left[\begin{bmatrix} E_{wheel_i} - \left(E_{ftg} - t_{base} - h_{key}\right) - L_\beta \cdot tan\left(-\alpha_{1b_i}\right) \\ 0 \cdot ft \end{bmatrix}\right]$ $h_{sat} = \begin{pmatrix} 2.0 \\ 0.5 \\ 0.0 \\ 0.0 \\ 0.0 \end{pmatrix} ft$

$L_{h_i} := \frac{h_i}{tan(-\alpha_i)}$ $L_h = \begin{pmatrix} 13.511 \\ 13.798 \\ 14.255 \\ 14.690 \\ 15.102 \end{pmatrix} ft$

$L_{sat_i} := \frac{h_{sat_i}}{tan(-\alpha_i)}$ $L_{sat} = \begin{pmatrix} 1.24 \\ 0.31 \\ 0.00 \\ 0.00 \\ 0.00 \end{pmatrix} ft$

$h_{left} := 0 \cdot ft$

$h_{right_i} := h_{1a_i}$

$W_i := \gamma_{fill} \cdot \left(L_{h_i} \cdot \frac{h_{left} + h_{right_i}}{2}\right) + \left(\gamma_{sat} - \gamma_{fill}\right) \cdot \frac{L_{sat_i} \cdot h_{sat_i}}{2}$

$W_i =$

19.333
19.949
20.936
21.880
22.785

klf

$V := 0 \;\; klf$

$H_L := 0 \cdot klf$

$H_R := 0 \cdot klf$

$U_i := \gamma_w \cdot \left(\frac{h_{sat_i}}{2}\right) \cdot \sqrt{\left(h_{sat_i}\right)^2 + \left(L_{sat_i}\right)^2}$

$U = \begin{pmatrix} 0.149 \\ 0.009 \\ 0.000 \\ 0.000 \\ 0.000 \end{pmatrix} \text{klf}$

$$\Delta P_{1a_i} := \frac{\left[\left(W_i + V\right) \cdot \left(\tan\left(\phi_{d_i}\right) \cdot \cos\left(\alpha_i\right) + \sin\left(\alpha_i\right)\right) - U_i \tan\left(\phi_{d_i}\right) + \left(H_L - H_R\right) \cdot \left(\tan\left(\phi_{d_i}\right) \sin\left(\alpha_i\right) - \cos\left(\alpha_i\right)\right) + \frac{c}{FS_{2_i}} \cdot L_i\right]}{\left(\cos\left(\alpha_i\right) - \tan\left(\phi_{d_i}\right) \cdot \sin\left(\alpha_i\right)\right)}$$

Driving Wedge (#1b): $L_\beta = 12.9\,\text{ft}$

$\beta_w := \beta$ $\beta_w = 33.7\,\text{deg}$

$\alpha := \alpha_{1b}$ $\alpha = \begin{pmatrix} -58.5 \\ -58.2 \\ -57.8 \\ -57.3 \\ -57.0 \end{pmatrix} \text{deg}$

$\phi_d := \phi_{d\_1b}$ $\phi_d = \begin{pmatrix} 33.7 \\ 33.7 \\ 33.7 \\ 33.7 \\ 33.7 \end{pmatrix} \text{deg}$

$L_h := L_\beta$ $L_h = 12.9\,\text{ft}$

$h = \begin{pmatrix} 22.0 \\ 22.2 \\ 22.6 \\ 22.9 \\ 23.2 \end{pmatrix} \text{ft}$

$L_i := \frac{L_\beta}{\cos\left(\alpha_i\right)}$ $L = \begin{pmatrix} 24.6 \\ 24.4 \\ 24.1 \\ 23.9 \\ 23.6 \end{pmatrix} \text{ft}$

$h_{satr_i} := \max\left[\begin{bmatrix} E_{wheel_i} - \left(E_{ftg} - t_{base} - h_{key}\right) \\ 0 \cdot \text{ft} \end{bmatrix}\right]$ $h_{satr} = \begin{pmatrix} 23.0 \\ 21.3 \\ 19.5 \\ 17.8 \\ 16.0 \end{pmatrix} \text{ft}$

$h_{satl_i} := \max\left[\begin{bmatrix} E_{wheel_i} - \left(E_{ftg} - t_{base} - h_{key}\right) - \frac{L_\beta}{\cos\left(\alpha_i\right)} \\ 0 \cdot \text{ft} \end{bmatrix}\right]$ $h_{satl} = \begin{pmatrix} 0.0 \\ 0.0 \\ 0.0 \\ 0.0 \\ 0.0 \end{pmatrix} \text{ft}$

$L_{sat_i} := \min\left[\begin{bmatrix} L_\beta \\ \frac{h_{satr_i}}{\tan\left[\left(-\alpha\right)_i\right]} \end{bmatrix}\right]$ $L_{sat} = \begin{pmatrix} 12.9 \\ 12.9 \\ 12.3 \\ 11.4 \\ 10.4 \end{pmatrix} \text{ft}$

$h_{left_i} := h_{1a_i}$ $h_{left} = \begin{pmatrix} 22.0 \\ 22.2 \\ 22.6 \\ 22.9 \\ 23.2 \end{pmatrix} \text{ft}$

$h_{right} := h_{1b}$ $h_{right} = 34.4\,\text{ft}$

$$W_i := \gamma_{fill} \cdot \left(L_h \cdot \frac{h_{left_i} + h_{right}}{2}\right) + \left(\gamma_{sat} - \gamma_{fill}\right) \cdot L_{sat_i} \left(\frac{h_{satr_i} + h_{satl_i}}{2}\right)$$

$V := 0 \cdot klf$

$H_L := 0 \cdot klf$

$H_R := 0 \cdot klf$

$$U_i := \gamma_w \cdot \left(\frac{h_{satr_i} + h_{satl_i}}{2}\right) \cdot \sqrt{\left(h_{satr_i} - h_{satl_i}\right)^2 + \left(L_h\right)^2}$$

$$\Delta P_{1b_i} := \frac{\left[\left(W_i + V\right) \cdot \left(\tan\left(\phi_{d_i}\right) \cdot \cos\left(\alpha_i\right) + \sin\left(\alpha_i\right)\right) - U_i \cdot \tan\left(\phi_{d_i}\right) + \left(H_L - H_R\right) \cdot \left(\tan\left(\phi_{d_i}\right) \cdot \sin\left(\alpha_i\right) - \cos\left(\alpha_i\right)\right) + \frac{c}{FS2_i} \cdot L_i\right]}{\left(\cos\left(\alpha_i\right) - \tan\left(\phi_{d_i}\right) \cdot \sin\left(\alpha_i\right)\right)}$$

$W_i =$

46.9
47.1
47.4
47.7
48.0

klf

Structure Wedge (#2):

$U_i =$

18.9
16.5
14.2
12.2
10.3

klf

$\beta_w := 0 \cdot deg$

$\phi := \phi_{fill}$ $\qquad \phi = 32.0\,deg$

$c := 0 \cdot ksf$

$$\phi_{d_i} := \operatorname{atan}\left(\frac{\tan(\phi)}{FS2_i}\right) \qquad \phi_{d_i} = \begin{pmatrix} 26.9 \\ 26.4 \\ 25.5 \\ 24.7 \\ 23.9 \end{pmatrix} deg$$

$\alpha := 0 \cdot deg$ $\qquad \alpha = 0.0\,deg$

$$L := \frac{L_{ftg}}{\cos(\alpha)} \qquad L = 29.0\,ft$$

$h_{S1} := h_{key}$ $\qquad h_{S1} = 5.0\,ft$

$$L_{S1} := x_{key} - \frac{L_{key}}{2} \qquad L_{S1} = 10.4\,ft$$

$$x_{S1} := \frac{1}{2} \cdot L_{S1} \qquad x_{S1} = 5.2\,ft$$

$S1 := \gamma_{sat} \cdot h_{S1} \cdot L_{S1}$ $\qquad S1 = 6.6\,klf$

$h_{S2} := h_{key}$ $\quad h_{S2} = 5.0\,ft$

$L_{S2} := L_{ftg} - x_{key} - \frac{L_{key}}{2}$ $\quad L_{S2} = 15.6\,ft$

$x_{S2} := L_{ftg} - \frac{L_{S2}}{2}$ $\quad x_{S2} = 21.2\,ft$

$S2 := \gamma_{sat} \cdot h_{S2} \cdot L_{S2}$ $\quad S2 = 10.0\,klf$

$$W_i := \sum_{i=1}^{4} W_{C_i} + W_{W1_i} + W_{WS1_i} + W_{WS2_i} + W_{WS3_i} + W_{WS4_i} + W_{WS5} + W_{WS6} + S1 + S2 + S_{\beta_i}$$

Uplift below structural wedge:

$$u_{toe_i} := \gamma_w \cdot \left\lfloor E_{wtoe_i} - \left(E_{bftg} - h_{key}\right)\right\rfloor$$

$$u_{heel_i} := \gamma_w \cdot \left\lfloor E_{wheel_i} - \left(E_{bftg} - h_{key}\right)\right\rfloor$$

$$\delta_{u_i} := \frac{\gamma_w \cdot \left(E_{wheel_i} - E_{wtoe_i}\right)}{L_{ftg} - L_{t2_i}}$$

$$u_{1_i} := u_{toe_i} \cdot \left(L_{ftg} - L_{t2_i}\right)$$

$$x_{u1_i} := \frac{L_{ftg} - L_{t2_i}}{2} \qquad x_{u1} = \begin{pmatrix} 14.5 \\ 14.5 \\ 14.5 \\ 14.5 \\ 14.5 \end{pmatrix} ft$$

$$u_{2_i} := \left(u_{heel_i} - u_{toe_i}\right) \cdot \frac{\left(L_{ftg} - L_{t2_i}\right)}{2}$$

$$x_{u2_i} := \frac{2}{3} \cdot \left(L_{ftg} - L_{t2_i}\right) \qquad x_{u2} = \begin{pmatrix} 19.3 \\ 19.3 \\ 19.3 \\ 19.3 \\ 19.3 \end{pmatrix} ft$$

$$u_{3_i} := u_{heel_i} \cdot \left(L_{t2_i}\right)$$

$$x_{u3_i} := L_{ftg} - \frac{L_{t2_i}}{2}$$

$$U_i := u_{1_i} + u_{2_i} + u_{3_i}$$

$$x_{U_i} := \frac{u_{1_i} \cdot x_{u1_i} + u_{2_i} \cdot x_{u2_i} + u_{3_i} \cdot x_{u3_i}}{U_i} \qquad x_U = \begin{pmatrix} 15.8 \\ 16.0 \\ 15.8 \\ 15.6 \\ 15.4 \end{pmatrix} ft$$

$$\Sigma M_{grav_i} := \left(\sum_{i=1}^{4} W_{C_i} \cdot x_{C_i} + W_{W1_i} \cdot x_{W1} + W_{WS1_i} \cdot x_{WS1} + W_{WS2_i} \cdot x_{WS2_i} + W_{WS3_i} \cdot x_{WS3_i}\right) \cdots + W_{WS4_i} \cdot x_{WS4_i} + W_{WS5} \cdot x_{WS5} + W_{WS6} \cdot x_{WS6} + S1 \cdot x_{S1} + S2 \cdot x_{S2} + S_{\beta_i} \cdot x_{S\beta} - \left(U_i \cdot x_{U_i}\right)$$

$$h_{H1_i} := E_{wtoe_i} - \left(E_{bftg} - h_{key}\right)$$

$$y_{H1_i} := \frac{h_{H1_i}}{3} - h_{key}$$

$$H1_i := \gamma_w \cdot \frac{\left(h_{H1_i}\right)^2}{2}$$

$h_{H1_i} =$ (ft)	$y_{H1_i} =$ (ft)	$H1_i =$ (klf)
13.00	-0.67	5.3
11.25	-1.25	4.0
11.00	-1.33	3.8
11.00	-1.33	3.8
11.00	-1.33	3.8

$$K1_i := 0 \cdot klf$$

$$K2_i := 0 \cdot klf$$

$$\Sigma M_{lat_i} := -H1_i \cdot \left(y_{H1_i}\right) - K1_i \cdot \left(y_{K1}\right) - K2_i \cdot \left(y_{K2}\right) + H2_i \cdot \left(y_{H2_i}\right) + H3_i \cdot \left(y_{H3}\right) \cdots + A1_i \cdot \left(y_{A1_i}\right) + A2_i \cdot \left(y_{A2_i}\right) + A3_i \cdot \left(y_{A3_i}\right) - R_{key_i} \cdot \left(y_{Rkey}\right)$$

$$x_{R_i} := \frac{\Sigma M_{grav_i} - \Sigma M_{lat_i}}{W_i - U_i} \qquad L_{brg_i} := \min\left(3 \cdot x_{R_i}, L_{ftg}\right)$$

$$ok_{u_i} := \text{if}\left[\left|L_{brg_i} - \left(L_{ftg} - L_{t2_i}\right)\right| > 0.001 \cdot ft, \text{"Uplift assumptions wrong in sliding analysis."}, \text{"Matched."}\right]$$

$W_i =$ (klf)	$u_{toe_i} =$ (ksf)	$u_{heel_i} =$ (ksf)	$\delta_{u_i} =$ (psf/ft)	$u_{1_i} =$ (klf)	$u_{2_i} =$ (klf)	$u_{3_i} =$ (klf)
90.2	0.813	1.438	21.6	23.562	9.063	0.000
89.4	0.703	1.328	21.6	20.391	9.063	0.000
89.4	0.688	1.219	18.3	19.938	7.703	0.000
89.4	0.688	1.109	14.5	19.938	6.117	0.000
89.4	0.688	1.000	10.8	19.938	4.531	0.000

$x_{u3_i} =$ (ft)	$h_{H2_i} =$ (ft)	$y_{H2_i} =$ (ft)	$H2_i =$ (klf)
29.0	23.0	2.7	16.5
29.0	21.3	2.1	14.1
29.0	19.5	1.5	11.9
29.0	17.8	0.9	9.8
29.0	16.0	0.3	8.0

$U_i =$ (klf)	$x_{U_i} =$ (ft)	$\Sigma M_{grav_i} =$ (kip)	$\Sigma M_{lat_i} =$ (kip)	$x_{R_i} =$ (ft)	$L_{brg_i} =$ (ft)
32.6	15.8	1042	106	16.3	29.0
29.5	16.0	1090	107	16.4	29.0
27.6	15.8	1126	106	16.5	29.0
26.1	15.6	1157	105	16.6	29.0
24.5	15.4	1186	105	16.6	29.0

$H_{L_i} := 0 \text{ klf}$

$$H_{R_i} := \gamma_w \cdot \frac{\left(E_{wtoe_i} - E_{ftg}\right)^2}{2}$$

$$\Delta P_{2_j} := \frac{\left[\left(W_i + V\right)\cdot\left(\tan\left(\phi_{d_j}\right)\cdot\cos(\alpha) + \sin(\alpha)\right) - U_i \cdot \tan\left(\phi_{d_i}\right) + \left(H_{L_i} - H_{R_i}\right)\cdot\left(\tan\left(\phi_{d_i}\right)\cdot\sin(\alpha) - \cos(\alpha)\right) + \frac{c}{FS_{2_i}}\cdot L\right]}{\left(\cos(\alpha) - \tan\left(\phi_{d_i}\right)\cdot\sin(\alpha)\right)}$$

$H_{L_i} =$ (klf)	$H_{R_i} =$ (klf)	$ok_{u_i} =$	$L_{ftg} - L_{brg_i} =$ (ft)
0.0	0.1	"Matched."	0.000
0.0	0.0	"Matched."	0.000
0.0	0.0	"Matched."	0.000
0.0	0.0	"Matched."	0.000
0.0	0.0	"Matched."	0.000

$$L_{t2} \equiv \begin{pmatrix} 0 \\ 0 \\ 0 \\ 0 \\ 0 \end{pmatrix} \cdot \text{ft}$$

$ok := \text{if}\left[\max\left(\left|L_{brg} - \left(L_{ftg} - L_{t2}\right)\right|\right) < 0.001 \cdot \text{ft}, ok, \text{"Uplift area does not match."}\right]$

$ok := \text{if}\left(\min\left(L_{brg}\right) < x_{key} + \frac{L_{key}}{2}, \text{"Uplift assumptions incorrect."}, ok\right)$ $\quad ok = \text{"Ok"}$

Resisting Wedge (#3):

$\beta_w := 0 \cdot deg$

$\phi := \phi_{fill}$ $\phi = 32.0\,deg$

$c := 0 \cdot ksf$

$\phi_{d_i} := atan\left(\frac{tan(\phi)}{FS_{2_i}}\right)$ $\phi_{d_i} = \begin{pmatrix}26.9\\26.4\\25.5\\24.7\\23.9\end{pmatrix} deg$

$\alpha_i := 45 \cdot deg - \frac{\phi_{d_i}}{2}$ $\alpha_i = \begin{pmatrix}31.5\\31.8\\32.2\\32.7\\33.0\end{pmatrix} deg$

$L_i := \frac{t_{base} + h_{key}}{sin(\alpha_i)}$ $L = \begin{pmatrix}21.032\\20.868\\20.614\\20.383\\20.170\end{pmatrix} ft$

$W_i := \gamma_{sat} \cdot \frac{L_i \cdot cos(\alpha_i) \cdot (t_{base} + h_{key})}{2} + \gamma_w \cdot (E_{wtoe_i} - E_{ftg}) \cdot L_i \cdot cos(\alpha_i)$

$U_i := \gamma_w \cdot \left(E_{wtoe_i} - E_{ftg} + \frac{t_{base} + h_{key}}{2}\right) \cdot L_i$

$H_L := 0 \cdot klf$

$H_R := 0 \cdot klf$

$V := 0 \cdot klf$

$$\Delta P_{3_i} := \frac{\left[(W_i + V) \cdot (tan(\phi_{d_i}) \cdot cos(\alpha_i) + sin(\alpha_i)) - U_i \cdot tan(\phi_{d_i}) + (H_L - H_R) \cdot (tan(\phi_{d_i}) \cdot sin(\alpha_i) - cos(\alpha_i)) + \frac{c}{FS_{2_i}} \cdot L_i\right]}{(cos(\alpha_i) - tan(\phi_{d_i}) \cdot sin(\alpha_i))}$$

$\Sigma P_i := \Delta P_{1a_i} + \Delta P_{1b_i} + \Delta P_{2_i} + \Delta P_{3_i}$

$FS_2 \equiv \begin{pmatrix}1.23\\1.26\\1.31\\1.36\\1.41\end{pmatrix}$

W_i = (klf)	U_i = (klf)	ΔP_{1a_i} = (klf)	ΔP_{1b_i} = (klf)	ΔP_{2_i} = (klf)	ΔP_{3_i} = (klf)	ΣP_i = (klf)
14.8	9.9	-11.9	-33.2	29.4	15.6	-0.2
12.7	7.5	-12.4	-31.5	29.7	14.2	0.0
12.2	7.1	-13.2	-29.8	29.5	13.7	0.1
12.0	7.0	-14.0	-28.3	29.1	13.4	0.2
11.9	6.9	-14.8	-26.8	28.8	13.1	0.2

$L_{heel} \equiv 19 \cdot ft$

$h_{key} \equiv 5 \cdot ft$

$L_{ftg} = 29.0\,ft$

ok := if($FS_{2_1} \geq 1.33$, ok, "Sliding instability: LC#1")

ok := if($FS_{2_n} \geq 1.50$, ok, "Sliding instability: LC#n")

$L_{ftg} - x_{key} - \frac{L_{key}}{2} = 15.6\,ft$ $L_{toe} \equiv 10 \cdot ft$

ok = "Sliding instability: LC#n"

Downstream Training Wall at Right: (Grade = 517.0')

Reference:T:\ST\CALCS\Common geometry.mcd(R)

Geometry:

$E_{wall} := 520 \ ft$

$E_{ftg} := E_{sill}$ $\quad E_{ftg} = 495.0\,ft$

$t_{base} := 6 \cdot ft$

$E_{bftg} := E_{ftg} - t_{base}$ $\quad E_{bftg} = 489.0\,ft$

$E_{grade} := 517 \ ft$

$n := 5$

$i := 1 .. n$

$\Delta_w := 10 \cdot ft$ (maximum height of retained water above water in basin)

$$E_{wheel_i} := E_{grade} - \frac{\left[E_{grade} - \left(E_{ftg} + \frac{\Delta_w}{2}\right)\right]}{n-1} \cdot (i-1) \qquad E_{wheel} = \begin{pmatrix} 517.0 \\ 512.8 \\ 508.5 \\ 504.3 \\ 500.0 \end{pmatrix} ft$$

$$E_{wtoe_i} := \max\left(\begin{pmatrix} E_{wheel_i} - \Delta_w \\ E_{ftg} \end{pmatrix}\right) \qquad E_{wtoe} = \begin{pmatrix} 507.0 \\ 502.8 \\ 498.5 \\ 495.0 \\ 495.0 \end{pmatrix} ft$$

$$h := \min\left[\begin{bmatrix} \left[\frac{1.0}{1.5} \cdot 2 \cdot \left(E_{grade} - E_{ftg}\right)\right] + E_{grade} \\ 527 \cdot ft - E_{ftg} \end{bmatrix}\right] \qquad h = 32.0\,ft$$

$$\beta := \operatorname{atan}\left(\frac{1.0}{1.5}\right) \qquad \beta = 33.7\,deg$$

$h_\beta := 527 \cdot ft - E_{grade}$ $\quad h_\beta = 10.0\,ft$

$t_{w\_top} := 1.5 \cdot ft$

$$t_{w\_bot} := t_{w\_top} + \frac{\left(E_{wall} - E_{ftg}\right)}{8} \qquad t_{w\_bot} = 4.63\,ft$$

$L_{toe} = 10.0\,ft$

$L_{heel} = 22.5\,ft$

$L_{ftg} := L_{toe} + L_{heel}$ $\quad$ $L_{ftg} = 32.5\,ft$

$h_{wall} := E_{wall} - E_{ftg}$ $\quad$ $h_{wall} = 25.0\,ft$

$h_{key} = 7.0\,ft$

$L_{key} := 4 \cdot ft$ $\quad$ $L_{key} = 4.0\,ft$

$x_{key} := L_{toe} + t_{w\_bot} - \dfrac{L_{key}}{2}$ $\quad$ $x_{key} = 12.6\,ft$

Constants:

$\gamma_w = 62.5\,pcf$

Soil parameters:

$\gamma_{fill\_eff} = 65.0\,pcf$ $\quad$ $\gamma_{sat} = 127.5\,pcf$

$\gamma_{fill} = 130.0\,pcf$

$k_{0\_fill} = 0.5$

$\phi_{fill} = 32.0\,deg$

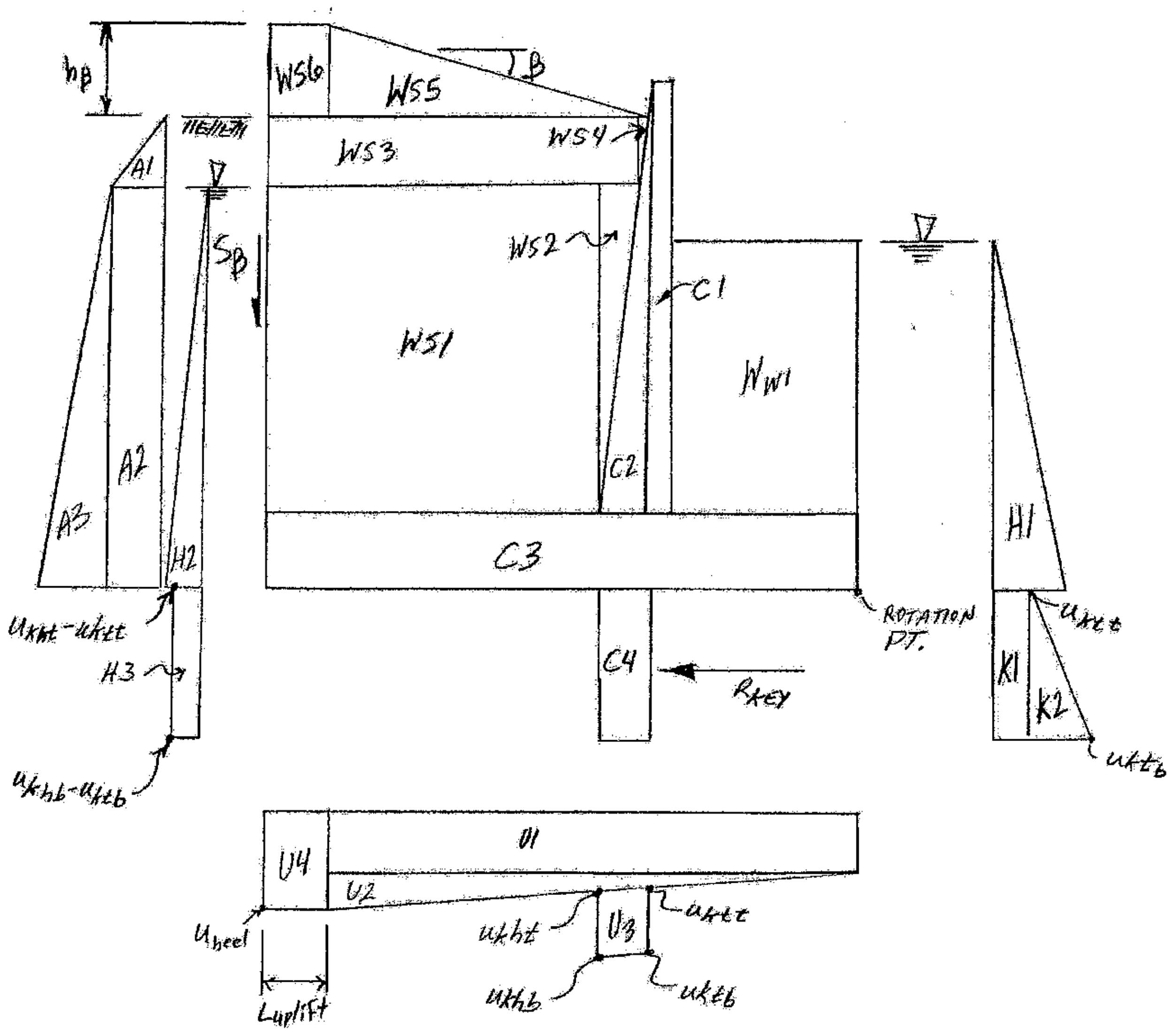
$k_{0\beta} := k_{0\_fill} \cdot (1 + \sin(\beta))$ $\quad$ $k_{0\beta} = 0.777$ $\quad$ (USACE EM 1110-2-2502, Eq. 3-5)

Pre-Definitions:

$kip \equiv 1000 \cdot lbf$ $\quad$ $ksi \equiv 1000 \cdot psi$ $\quad$ $ok \equiv \text{"Ok"}$ $\quad$ $klf \equiv 1000 \cdot \dfrac{lbf}{ft}$

$psf \equiv \dfrac{lbf}{ft^2}$ $\quad$ $plf \equiv \dfrac{lbf}{ft}$ $\quad$ $pcf \equiv \dfrac{lbf}{ft^3}$

$ORIGIN = 1.0$ $\quad$ (must equal to 1)


hβ
β
WS6
WS5
WS3
WS4
A1
Sβ
WS2
C1
WS1
Ww1
A2
A3
C2
H2
H1
C3
ROTATION PT.
ukht-uktt
H3
C4
RKEY
K1
K2
uktt
ukhb-uktb
uktb
U1
U4
U2
Uheel
ukht
U3
uktt
ukhb
uktb
Luplift

Analysis:

Gravity Loads:

$h_{C_1} := h_{wall}$ $h_{C_1} = 25.0\,ft$

$L_{C_1} := t_{w\_top}$ $L_{C_1} = 1.5\,ft$

$x_{C_1} := L_{toe} + \frac{L_{C_1}}{2}$ $x_{C_1} = 10.8\,ft$

$W_{C_1} := \gamma_c \cdot h_{C_1} \cdot L_{C_1}$ $W_{C_1} = 5.6\,klf$

$h_{C_2} := h_{C_1}$ $h_{C_2} = 25.0\,ft$

$L_{C_2} := t_{w\_bot} - t_{w\_top}$ $L_{C_2} = 3.1\,ft$

$x_{C_2} := L_{toe} + L_{C_1} + \frac{L_{C_2}}{3}$ $x_{C_2} = 12.5\,ft$

$W_{C_2} := \gamma_c \cdot \frac{h_{C_2} \cdot L_{C_2}}{2}$ $W_{C_2} = 5.9\,klf$

$h_{C_3} := t_{base}$ $h_{C_3} = 6.0\,ft$

$L_{C_3} := L_{ftg}$ $L_{C_3} = 32.5\,ft$

$x_{C_3} := \frac{L_{C_3}}{2}$ $x_{C_3} = 16.3\,ft$

$W_{C_3} := \gamma_c \cdot h_{C_3} \cdot L_{C_3}$ $W_{C_3} = 29.2\,klf$

$h_{C_4} := h_{key}$ $h_{C_4} = 7.0\,ft$

$L_{C_4} := L_{key}$ $L_{C_4} = 4.0\,ft$

$x_{C_4} := x_{key}$ $x_{C_4} = 12.6\,ft$

$W_{C_4} := \gamma_c \cdot h_{C_4} \cdot L_{C_4}$ $\qquad W_{C_4} = 4.2\,\text{klf}$

Weight of water at toe:

$h_{W1_i} := E_{wtoe_i} - E_{ftg}$ $\qquad h_{W1} = \begin{pmatrix} 12.00 \\ 7.75 \\ 3.50 \\ 0.00 \\ 0.00 \end{pmatrix} \text{ft}$

$L_{W1} := L_{toe}$ $\qquad L_{W1} = 10.0\,\text{ft}$

$x_{W1} := \frac{L_{toe}}{2}$ $\qquad x_{W1} = 5.0\,\text{ft}$

$W_{W1_i} := \gamma_w \cdot h_{W1_i} \cdot L_{W1}$ $\qquad W_{W1} = \begin{pmatrix} 7.5 \\ 4.8 \\ 2.2 \\ 0.0 \\ 0.0 \end{pmatrix} \text{klf}$

Weight of water/soil at heel:

$h_{WS1_i} := E_{wheel_i} - E_{ftg}$ $\qquad h_{WS1} = \begin{pmatrix} 22.00 \\ 17.75 \\ 13.50 \\ 9.25 \\ 5.00 \end{pmatrix} \text{ft}$

$L_{WS1} := L_{heel} - t_{w\_bot}$ $\qquad L_{WS1} = 17.9\,\text{ft}$

$x_{WS1} := L_{toe} + t_{w\_bot} + \frac{L_{WS1}}{2}$ $\qquad x_{WS1} = 23.6\,\text{ft}$

$W_{WS1_i} := (\gamma_{sat}) \cdot h_{WS1_i} \cdot L_{WS1}$ $\qquad W_{WS1} = \begin{pmatrix} 50.1 \\ 40.5 \\ 30.8 \\ 21.1 \\ 11.4 \end{pmatrix} \text{klf}$

$h_{WS2_i} := h_{WS1_i}$

$L_{WS2_i} := \frac{t_{w\_bot} - t_{w\_top}}{h_{wall}} \cdot h_{WS2_i}$ $\qquad L_{WS2} = \begin{pmatrix} 2.75 \\ 2.22 \\ 1.69 \\ 1.16 \\ 0.63 \end{pmatrix} \text{ft}$

$x_{WS2_i} := L_{toe} + t_{w\_bot} - \frac{L_{WS2_i}}{3}$ $\qquad x_{WS2} = \begin{pmatrix} 13.7 \\ 13.9 \\ 14.1 \\ 14.2 \\ 14.4 \end{pmatrix} \text{ft}$

$$W_{WS2_i} := (\gamma_{sat}) \cdot \frac{h_{WS2_i} \cdot L_{WS2_i}}{2}$$

$W_{WS2_i} =$

3.9	klf
2.5	
1.5	
0.7	
0.2	

$$h_{WS3_i} := E_{grade} - E_{wheel_i}$$

$h_{WS3_i} =$

0.0	ft
4.3	
8.5	
12.8	
17.0	

$$L_{WS3_i} := L_{WS1} + L_{WS2_i}$$

$L_{WS3_i} =$

20.6	ft
20.1	
19.6	
19.0	
18.5	

$$x_{WS3_i} := L_{ftg} - \frac{L_{WS3_i}}{2}$$

$x_{WS3_i} =$

22.2	ft
22.5	
22.7	
23.0	
23.3	

$$W_{WS3_i} := \gamma_{fill} \cdot h_{WS3_i} \cdot L_{WS3_i}$$

$W_{WS3_i} =$

0.0	klf
11.1	
21.6	
31.5	
40.9	

$$h_{WS4_i} := h_{WS3_i}$$

$$L_{WS4_i} := \frac{t_{w\_bot} - t_{w\_top}}{h_{wall}} \cdot h_{WS4_i}$$

$L_{WS4_i} =$

0.0	ft
0.5	
1.1	
1.6	
2.1	

$$x_{WS4_i} := L_{ftg} - L_{WS3_i} - \frac{L_{WS4_i}}{3}$$

$x_{WS4_i} =$

11.9	ft
12.2	
12.6	
12.9	
13.3	

$$W_{WS4_i} := \gamma_{fill} \cdot \frac{h_{WS4_i} \cdot L_{WS4_i}}{2}$$

$W_{WS4_i} =$

0.0	klf
0.1	
0.6	
1.3	
2.3	

$$L_{WS5} := \min\left(\left[\left[\frac{t_{w\_bot} - t_{w\_top}}{h_{wall}} \cdot (E_{grade} - E_{ftg}) + L_{WS1}\right] \quad \frac{h_\beta}{\tan(\beta)}\right]\right)$$

$L_{WS5} = 15.00\,ft$

$$h_{WS5} := L_{WS5} \cdot \tan(\beta)$$ $h_{WS5} = 10.00\,ft$

$$x_{WS5} := \frac{2}{3} \cdot L_{WS5} + L_{toe} + t_{w\_top} + \frac{(E_{wall} - E_{grade})}{E_{wall} - E_{ftg}} \cdot (t_{w\_bot} - t_{w\_top})$$ $x_{WS5} = 21.88\,ft$

$$W_{WS5} := \gamma_{fill} \cdot \frac{h_{WS5} \cdot L_{WS5}}{2}$$ $W_{WS5} = 9.8\,klf$

$$L_{WS6} := \frac{E_{grade} - E_{ftg}}{h_{wall}} \cdot (t_{w\_bot} - t_{w\_top}) + L_{WS1} - L_{WS5}$$ $L_{WS6} = 5.6\,ft$

$$h_{WS6} := h_{WS5}$$ $h_{WS6} = 10.0\,ft$

$$x_{WS6} := L_{ftg} - \frac{L_{WS6}}{2}$$ $x_{WS6} = 29.7\,ft$

$$W_{WS6} := \gamma_{fill} \cdot (h_{WS6} \cdot L_{WS6})$$ $W_{WS6} = 7.3\,klf$

Uplift:

$u_{toe_i} := \gamma_w \left(E_{wtoe_i} - E_{bftg}\right)$

$u_{heel_i} := \gamma_w \cdot \left(E_{wheel_i} - E_{bftg}\right)$

$\delta_{seep_i} := \dfrac{u_{heel_i} - u_{toe_i}}{L_{ftg} - L_{uplift_i}}$

$u_{ktt_i} := u_{heel_i} + \left(x_{key} - \dfrac{L_{key}}{2}\right) \cdot \delta_{seep_i}$

$u_{kht_i} := u_{ktt_i} + L_{key} \cdot \delta_{seep_i}$

$u_{ktb_i} := u_{ktt_i} + \gamma_w \cdot h_{key}$

$u_{khb_i} := u_{ktb_i} + L_{key} \cdot \delta_{seep_i}$

$x_{U1} := \dfrac{L_{ftg} - L_{uplift}}{2}$

$U1_i := u_{toe_i} \cdot L_{ftg}$

$x_{U2_i} := \dfrac{2}{3} \cdot \left(L_{ftg} - L_{uplift_i}\right)$

$U2_i := \left(u_{heel_i} - u_{toe_i}\right) \cdot \dfrac{L_{ftg}}{2}$

$x_{U3} := x_{key}$

$U3_i := \left(u_{ktb_i} - u_{ktt_i}\right) \cdot L_{key}$

$x_{U4_i} := L_{ftg} - \dfrac{L_{uplift_i}}{2}$

$L_{U4_i} := L_{uplift_i}$

$U4_i := u_{heel_i} \cdot L_{U4_i}$

Results:

u_{toe_i} (ksf)	u_{heel_i} (ksf)	δ_{seep_i} (psf/ft)	u_{ktt_i} (ksf)	u_{kht_i} (ksf)
1.125	1.750	19.231	1.954	2.031
0.859	1.484	19.231	1.689	1.766
0.594	1.219	19.231	1.423	1.500
0.375	0.953	17.788	1.142	1.213
0.375	0.688	9.615	0.790	0.828

u_{ktb_i} (ksf)	u_{khb_i} (ksf)	x_{U1_i} (ft)	$U1_i$ (klf)	x_{U2_i} (ft)	$U2_i$ (klf)
2.392	2.469	16.3	36.6	21.67	10.2
2.126	2.203	16.3	27.9	21.67	10.2
1.861	1.938	16.3	19.3	21.67	10.2
1.580	1.651	16.3	12.2	21.67	9.4
1.227	1.266	16.3	12.2	21.67	5.1

$x_{U3} = 12.6\,\text{ft}$

$U3 = \begin{pmatrix} 1.8 \\ 1.8 \\ 1.8 \\ 1.8 \\ 1.8 \end{pmatrix} \text{klf}$

Lateral load due to water at toe:

$h_{H1_i} := E_{wtoe_i} - E_{bftg}$

$y_{H1_i} := \frac{h_{H1_i}}{3}$

$H1_i := \gamma_w \cdot \frac{(h_{H1_i})^2}{2}$

$h_{H2_i} := E_{wheel_i} - E_{bftg}$

$y_{H2_i} := \frac{h_{H2_i}}{3}$

$H2_i := \gamma_w \frac{(h_{H2_i})^2}{2}$

$h_{H3} := h_{key}$ $h_{H3} = 7.0\,ft$

$y_{H3} := \frac{-h_{key}}{2}$ $y_{H3} = -3.5\,ft$

$H3_i := (u_{khb_i} - u_{ktb_i}) \cdot h_{H3}$

$h_{K1} := h_{key}$ $h_{K1} = 7.0\,ft$

$K1_i := u_{ktt_i} \cdot h_{K1}$

$h_{K2} := h_{key}$ $h_{K2} = 7.0\,ft$

$K2_i := (u_{ktb_i} - u_{ktt_i}) \cdot \frac{h_{K2}}{2}$

$y_{K1} := \frac{-h_{key}}{2}$ $y_{K1} = -3.5\,ft$

$y_{K2} := \frac{-2}{3} h_{key}$ $y_{K2} = -4.7\,ft$

$xU4_i$ (ft)	$U4_i$ (klf)
32.5	0.0
32.5	0.0
32.5	0.0
32.5	0.0
32.5	0.0

h_{H1_i} (ft)	y_{H1_i} (ft)	$H1_i$ (klf)	h_{H2_i} (ft)	$H2_i$ (klf)	y_{H2_i} (ft)	$H3_i$ (klf)	$K1_i$ (klf)	$K2_i$ (klf)
18.00	6.00	10.1	28.00	24.5	9.3	0.54	13.7	1.5
13.75	4.58	5.9	23.75	17.6	7.9	0.54	11.8	1.5
9.50	3.17	2.8	19.50	11.9	6.5	0.54	10.0	1.5
6.00	2.00	1.1	15.25	7.3	5.1	0.50	8.0	1.5
6.00	2.00	1.1	11.00	3.8	3.7	0.27	5.5	1.5

Lateral load due to retained soil/water:

$h_{A1_i} := E_{grade} - E_{wheel_i}$

$y_{A1_i} := E_{grade} - E_{bftg} - \frac{2}{3} \cdot h_{A1_i}$

$A1_i := k_{0\beta} \cdot \gamma_{fill} \cdot \frac{(h_{A1_i})^2}{2}$

h_{A1_i} = (ft)	y_{A1_i} = (ft)	$A1_i$ = (klf)
0.00	28.00	0.0
4.25	25.17	0.9
8.50	22.33	3.7
12.75	19.50	8.2
17.00	16.67	14.6

$h_{A2_i} := E_{wheel_i} - E_{bftg}$

$y_{A2_i} := \frac{h_{A2_i}}{2}$

$A2_i := k_{0\beta} \cdot \gamma_{fill} \cdot h_{A1_i} \cdot h_{A2_i}$

h_{A2_i} = (ft)	y_{A2_i} = (ft)	$A2_i$ = (klf)
28.00	14.00	0.0
23.75	11.88	10.2
19.50	9.75	16.7
15.25	7.63	19.6
11.00	5.50	18.9

$h_{A3_i} := h_{A2_i}$

$y_{A3_i} := \frac{h_{A3_i}}{3}$

$A3_i := k_{0\beta} \cdot \gamma_{fill\_eff} \cdot \frac{(h_{A3_i})^2}{2}$

h_{A3_i} = (ft)	y_{A3_i} = (ft)	$A3_i$ = (klf)
28.00	9.33	19.8
23.75	7.92	14.3
19.50	6.50	9.6
15.25	5.08	5.9
11.00	3.67	3.1

Shear force due to sloped backfill: (EM 1110-2-2502, Fig. 4-7)

$h_2 := E_{grade} - E_{ftg}$ $\quad h_2 = 22.0\,ft$

$h_1 := h_2 + \tan(\beta) \cdot L_{WS5}$ $\quad h_1 = 32.0\,ft$

$P_i := k_{0\beta} \cdot \gamma_{fill} \cdot h_{A1_i} \cdot (h_{A2_i} - t_{base}) + k_{0\beta} \cdot \gamma_{fill\_eff} \cdot \frac{(h_{A3_i} - t_{base})^2}{2}$

$S_{\beta_i} := if\left[h_1 > h_2, \left|\frac{P_i \cdot (h_1 - h_2)}{3 \cdot L_{WS5}}\right|, 0 \cdot klf\right]$

$x_{S\beta} := L_{ftg}$ $\quad x_{S\beta} = 32.5\,ft$

Sum forces:

$$\Sigma V_i := \sum_{i=1}^{4} W_{C_i} + W_{W1_i} + W_{WS1_i} + W_{WS2_i} + W_{WS3_i} + W_{WS4_i} + W_{WS5} + W_{WS6} + S_{\beta_i} - \left(U1_i + U2_i + U3_i + U4_i\right)$$

$$\Sigma M_{grav_i} := \left(\sum_{i=1}^{4} W_{C_i} \cdot x_{C_i} + W_{W1_i} \cdot x_{W1} + W_{WS1_i} \cdot x_{WS1} + W_{WS2_i} \cdot x_{WS2_i} + W_{WS3_i} \cdot x_{WS3_i} + W_{WS4_i} \cdot x_{WS4_i}\right) \cdots$$
$$+ W_{WS5} \cdot x_{WS5} + W_{WS6} \cdot x_{WS6} + S_{\beta_i} \cdot x_{S\beta} - \left(U1_i \cdot x_{U1_i} + U2_i \cdot x_{U2_i} + U3_i \cdot x_{U3} + U4_i \cdot x_{U4_i}\right)$$

$$R_{key_i} := -H1_i - K1_i - K2_i + H2_i + H3_i + A1_i + A2_i + A3_i$$

$$y_{Rkey} := \frac{-h_{key}}{2} \qquad y_{Rkey} = -3.5\,\text{ft}$$

$P_i =$		$S_{\beta_i} =$		$R_{key_i} =$	
12.2	klf	2.7	klf	19.5	klf
15.6		3.5		24.3	
16.2		3.6		28.1	
14.1		3.1		30.9	
9.2		2.0		32.4	

$$\Sigma H_i := -H1_i - K1_i - K2_i + H2_i + H3_i + A1_i + A2_i + A3_i - R_{key_i}$$

$$\Sigma M_{lat_i} := -H1_i \cdot y_{H1_i} - K1_i \cdot y_{K1} - K2_i \cdot y_{K2} + H2_i \cdot y_{H2_i} + H3_i \cdot y_{H3} \cdots$$
$$+ A1_i \cdot y_{A1_i} + A2_i \cdot y_{A2_i} + A3_i \cdot y_{A3_i} - R_{key_i} \cdot y_{Rkey}$$

$$\Sigma M_i := \Sigma M_{grav_i} - \Sigma M_{lat_i}$$

$$x_{R_i} := \frac{\Sigma M_i}{\Sigma V_i}$$

$$L_{brg_i} := \max\left[\min\left(\begin{pmatrix} 3 \cdot x_{R_i} \\ L_{ftg} \end{pmatrix}\right), 0 \cdot \text{ft}\right]$$

$\Sigma V_i =$		$\Sigma M_{grav_i} =$		$\Sigma M_{lat_i} =$		$\Sigma M_i =$		$\Sigma H_i =$		$R_{key_i} =$		$x_{R_i} =$		$L_{brg_i} =$	
77.7	klf	1616	kip	474	kip	1142	kip	0.0	klf	19.5	klf	14.69	ft	32.500	ft
84.7		1773		501		1272		0.0		24.3		15.02		32.500	
91.0		1909		514		1395		0.0		28.1		15.32		32.500	
96.4		2019		516		1503		0.0		30.9		15.59		32.500	
99.9		2082		509		1573		0.0		32.4		15.75		32.500	

Bearing Capacity: (per EM 1110-1-1905)

$c := c_{fill}$ $c = 0.0\,psf$

$\phi := \phi_{fill}$ $\phi = 32.0\,deg$

$\gamma_{eff} := \gamma_{fill\_eff}$ $\gamma_{eff} = 65.0\,pcf$

$\gamma_{H\_eff} := \gamma_{eff}$ $\gamma_{H\_eff} = 65.0\,pcf$

$B_{eff_i} := L_{ftg} - 2 \cdot \left| \frac{L_{brg_i}}{2} - x_{R_i} \right|$ $B_{eff} = \begin{pmatrix} 29.4 \\ 30.0 \\ 30.6 \\ 31.2 \\ 31.5 \end{pmatrix} ft$

Table 4-3·

$N_\phi := \tan\left(45 \cdot deg + \frac{\phi}{2}\right)^2$ $N_\phi = 3.255$

$N_q := if\left(\phi = 0, 1.0, N_\phi \cdot e^{\pi \tan(\phi)}\right)$ $N_q = 23.2$

$N_c := if\left[\phi = 0, 5.14, (N_q - 1) \cdot \cot(\phi)\right]$ $N_c = 35.5$

$N_\gamma := if\left[\phi = 0, 0.00, (N_q - 1) \cdot \tan(1.4 \cdot \phi)\right]$ $N_\gamma = 22.0$

Inclined loading correction:

$\theta_i := atan\left(\frac{R_{key_i} + K1_i + K2_i}{\Sigma V_i}\right)$ $\theta = \begin{pmatrix} 24.07 \\ 23.95 \\ 23.52 \\ 22.72 \\ 21.57 \end{pmatrix} deg$

$\xi_{ci_i} := if\left[\phi = 0, \left(1 - \frac{\theta_i}{90 \cdot deg}\right), \left(1 - \frac{\theta_i}{90 \cdot deg}\right)^2\right]$ $\xi_{ci} = \begin{pmatrix} 0.537 \\ 0.539 \\ 0.546 \\ 0.559 \\ 0.578 \end{pmatrix}$

$\xi_{\gamma i_i} := if\left[\phi = 0, 1.0, if\left[\theta_i \le \phi, \left(1 - \frac{\theta_i}{\phi}\right)^2, 0.0\right]\right]$ $\xi_{\gamma i} = \begin{pmatrix} 0.061 \\ 0.063 \\ 0.070 \\ 0.084 \\ 0.106 \end{pmatrix}$

$\xi_{qi_i} := if\left[\phi = 0, \left(1 - \frac{\theta_i}{90 \cdot deg}\right), \left(1 - \frac{\theta_i}{90 \cdot deg}\right)^2\right]$ $\xi_{qi} = \begin{pmatrix} 0.537 \\ 0.539 \\ 0.546 \\ 0.559 \\ 0.578 \end{pmatrix}$

$B_i := L_{brg_i}$ $B = \begin{pmatrix} 32.5 \\ 32.5 \\ 32.5 \\ 32.5 \\ 32.5 \end{pmatrix} ft$

$W := 100 \cdot ft$

Foundation depth correction: (at toe)

$D := t_{base}$ $D = 6.0\,ft$

$\sigma_{D\_eff} := \gamma_{eff} \cdot D$ $\sigma_{D\_eff} = 390.0\,psf$

$\xi_{cd_i} := 1 + 0.2 \cdot (N_\phi)^{\frac{1}{2}} \cdot \frac{D}{B_i}$ $\xi_{cd} = \begin{pmatrix} 1.067 \\ 1.067 \\ 1.067 \\ 1.067 \\ 1.067 \end{pmatrix}$

$\xi_{\gamma d\_10_i} := 1 + 0.1 \cdot \left(\tan\left(45 \cdot deg + \frac{10 \cdot deg}{2}\right)^2\right)^{\frac{1}{2}} \cdot \frac{D}{B_i}$ $\xi_{\gamma d\_10} = \begin{pmatrix} 1.022 \\ 1.022 \\ 1.022 \\ 1.022 \\ 1.022 \end{pmatrix}$

$\xi_{\gamma d_i} := \text{if}\left[\phi \le 10 \cdot deg, \xi_{\gamma d\_0} + \frac{\phi}{10 \cdot deg} \cdot \left(\xi_{\gamma d\_10_i} - \xi_{\gamma d\_0}\right), 1 + 0.1 \cdot (N_\phi)^{\frac{1}{2}} \cdot \frac{D}{B_i}\right]$ $\xi_{\gamma d} = \begin{pmatrix} 1.033 \\ 1.033 \\ 1.033 \\ 1.033 \\ 1.033 \end{pmatrix}$

$\xi_{qd_i} := \xi_{\gamma d_i}$ $\xi_{qd} = \begin{pmatrix} 1.033 \\ 1.033 \\ 1.033 \\ 1. \\ 1 \end{pmatrix}$

USACE EM 1110-1-1905, Eq. 4-16:

$q_{u\_toe_i} := c \cdot N_c \cdot \xi_{cd} \cdot \xi_{ci} + \frac{1}{2} \cdot B_{eff_i} \cdot \gamma_{H\_eff} \cdot N_\gamma \cdot \xi_{\gamma d} \cdot \xi_{\gamma i} + \sigma_{D\_eff} \cdot N_q \cdot \xi_{qd} \cdot \xi_{qi}$ $q_{u\_toe} = \begin{pmatrix} 34.127 \\ 34.311 \\ 34.487 \\ 34.639 \\ 34.731 \end{pmatrix} ksf$

Foundation depth correction: (at heel)

$D := E_{grade} - E_{ftg} + t_{base} + h_\beta$ $D = 38.0\,ft$

$\sigma_{D\_eff\_heel} := \gamma_{eff} \cdot D$ $\sigma_{D\_eff} = 0.390\,ksf$

$\xi_{cd_i} := 1 + 0.2 \cdot (N_\phi)^{\frac{1}{2}} \cdot \frac{D}{\;}$ $\xi_{cd} = \begin{pmatrix} 1.422 \\ 1.422 \\ 1.422 \\ 1.422 \\ 1.422 \end{pmatrix}$

$\xi_{\gamma d\_10_i} := 1 + 0.1 \cdot \left(\tan\left(45 \cdot deg + \frac{10 \cdot deg}{2}\right)^2\right)^{\frac{1}{2}} \cdot \frac{D}{B_i}$ $\xi_{\gamma d\_10} = \begin{pmatrix} 1.139 \\ 1.139 \\ 1.139 \\ 1.139 \\ 1.139 \end{pmatrix}$

$\xi_{\gamma d_i} := \text{if}\left[\phi \le 10 \cdot deg, \xi_{\gamma d\_0} + \frac{\phi}{10 \cdot deg} \cdot \left(\xi_{\gamma d\_10_i} - \xi_{\gamma d\_0}\right), 1 + 0.1 \cdot (N_\phi)^{\frac{1}{2}} \cdot \frac{D}{B_i}\right]$ $\xi_{\gamma d} = \begin{pmatrix} 1.211 \\ 1.211 \\ 1.211 \\ 1.211 \\ 1.211 \end{pmatrix}$

$\xi_{qd_i} := \xi_{\gamma d_i}$ $\xi_{qd} = \begin{pmatrix} 1.211 \\ 1.211 \\ 1.211 \\ 1. \\ 1. \end{pmatrix}$

USACE EM 1110-1-1905, Eq 4-16:

$q_{u\_heel_i} := c \cdot N_c \cdot \xi_{cd} \cdot \xi_{ci} + \frac{1}{2} \cdot B_{eff_i} \cdot \gamma_{H\_eff} \cdot N_\gamma \cdot \xi_{\gamma d} \cdot \xi_{\gamma i} + \sigma_{D\_eff} \cdot N_q \cdot \xi_{qd} \cdot \xi_{qi}$ $q_{u\_heel} = \begin{pmatrix} 39.994 \\ 40.210 \\ 40.416 \\ 40.593 \\ 40.702 \end{pmatrix} ksf$

$check\_uplift_i := L_{ftg} - L_{brg_i} - L_{uplift_i}$

$check\_uplift_i =$

0.0000 ft
0.0000
0.0000
0.0000
0.0000

ok := if(max(|check_uplift|) < 0.001 · ft, ok, "Uplift assumptions do not match bearing area.")

ok = "Ok"

$$e_{brg_i} := \frac{L_{brg_i}}{2} - x_{R_i}$$

$$\sigma_{brg\_toe_i} := \frac{\Sigma V_i}{L_{brg_i}} + \frac{\Sigma V_i \cdot e_{brg_i}}{\frac{\left(L_{brg_i}\right)^2}{6}}$$

$$\sigma_{brg\_heel_i} := \frac{\Sigma V_i}{L_{brg_i}} - \frac{\Sigma V_i \cdot e_{brg_i}}{\frac{\left(L_{brg_i}\right)^2}{6}}$$

$$FS_{brg_i} := \min\left(\frac{q_{u\_toe_i}}{\sigma_{brg\_toe_i}}, \frac{q_{u\_heel_i}}{\sigma_{brg\_heel_i}}\right)$$

$$\%_{brg_i} := \frac{L_{brg_i}}{L_{ftg}}$$

$$\%_{brg_i} = \begin{pmatrix} 100.0 \\ 100.0 \\ 100.0 \\ 100.0 \\ 100.0 \end{pmatrix} \%$$

ok := if($\%_{brg_1} \geq 75 \cdot \%$, ok, "OT instability: LC#1")

$L_{ftg} = 32.5\,ft$

ok := if($\%_{brg_n} \geq 100\%$, ok, "OT instability: LC#n")

$t_{w\_bot} = 4.6\,ft$

$\frac{L_{ftg}}{4} = 8.125\,ft$

e_{brg_i} = (ft)	$\sigma_{brg\_toe_i}$ = (ksf)	$\sigma_{brg\_heel_i}$ = (ksf)	FS_{brg_i} =	$L_{ftg} - L_{brg_i}$ = (ft)
1.56	3.080	1.705	11.08	0.000
1.23	3.199	2.012	10.73	0.000
0.93	3.278	2.322	10.52	0.000
0.66	3.328	2.606	10.41	0.000
0.50	3.354	2.791	10.35	0.000

$$L_{uplift} \equiv \begin{pmatrix} 0 \\ 0 \\ 0 \\ 0 \\ 0 \end{pmatrix} \cdot ft$$

ok := if[max[|$L_{brg} - (L_{ftg} - L_{uplift})$|] < 0.001 · ft, ok, "Uplift area does not match

ok := if($FS_{brg_1} < 2$, "Bearing problem LC#1", ok)

$L_{ftg} = 32.5\,ft$

ok := if($FS_{brg_n} < 3$, "Bearing problem LC#n", ok)

ok = "Ok"

Base Pressures:

$e_{ftg_i} := \frac{L_{ftg}}{2} - x_{R_i}$ (eccentricity with respect to the footing centroid)

$\Sigma H_i + R_{key_i}$ = (klf)	ΣV_i = (klf)	e_{ftg_i} = (ft)	x_{R_i} = (ft)	$\sigma_{brg\_heel_i}$ = (ksf)	$\sigma_{brg\_toe_i}$ = (ksf)
19.5	77.7	1.56	14.69	1.705	3.080
24.3	84.7	1.23	15.02	2.012	3.199
28.1	91.0	0.93	15.32	2.322	3.278
30.9	96.4	0.66	15.59	2.606	3.328
32.4	99.9	0.50	15.75	2.791	3.354

$L_{brg_1} = 32.50\,ft$

$$\frac{L_{brg}}{L_{ftg}} = \begin{pmatrix} 100.0 \\ 100.0 \\ 100.0 \\ 100.0 \\ 100.0 \end{pmatrix} \%$$

Sliding Analysis:

Function Definitions·

$c_1(\phi_d) := 2 \cdot \tan(\phi_d)$

$c_2(\phi_d, \beta) := 1 - \tan(\phi_d) \cdot \tan(\beta) - \left(\frac{\tan(\beta)}{\tan(\phi_d)}\right)$

$\alpha_{driving}(\phi_d, \beta) := -\text{atan}\left(\frac{c_1(\phi_d) + \sqrt{c_1(\phi_d)^2 + 4 \cdot c_2(\phi_d, \beta)}}{2}\right)$

$L_\beta := \max\left(\begin{pmatrix} \frac{h_\beta}{\tan(\beta)} - L_{WS5} - L_{WS6} \\ 0 \cdot ft \end{pmatrix}\right)$ $L_\beta = 0.0\,ft$

Sliding Analysis #1:

$\beta_w := \beta$ $\beta_w = 33.7\,deg$

$\phi_i := \phi_{fill}$ $\phi = \begin{pmatrix} 32.0 \\ 32.0 \\ 32.0 \\ 32.0 \\ 32.0 \end{pmatrix} deg$

$c := 0 \cdot ksf$

$\phi_{d_i} := \text{atan}\left(\frac{\tan(\phi_i)}{FS1_i}\right)$ $\phi_{d_i} = \begin{pmatrix} 19.9 \\ 19.3 \\ 18.8 \\ 18.2 \\ 17.5 \end{pmatrix} deg$

$\text{atan}(\tan(\beta) \cdot FS1_i) = \begin{pmatrix} 49.1 \\ 49.9 \\ 50\ 8 \\ 51.7 \\ 52.9 \end{pmatrix} deg$ (back solve for minimum ϕ value for stable slope β, EM 1110-2-2502, pg. 3-31)

$\phi_i := \text{if}\left[\left(c_1(\phi_{d_i})^2 + 4 \cdot c_2(\phi_{d_i}, \beta_w) < 0\right), \text{atan}(\tan(\beta_w) \cdot FS1_i), \phi_i\right]$ $\phi = \begin{pmatrix} 49.1 \\ 49.9 \\ 50.8 \\ 51.7 \\ 52.9 \end{pmatrix} deg$ (substitue minimum ϕ if slope is unstable)

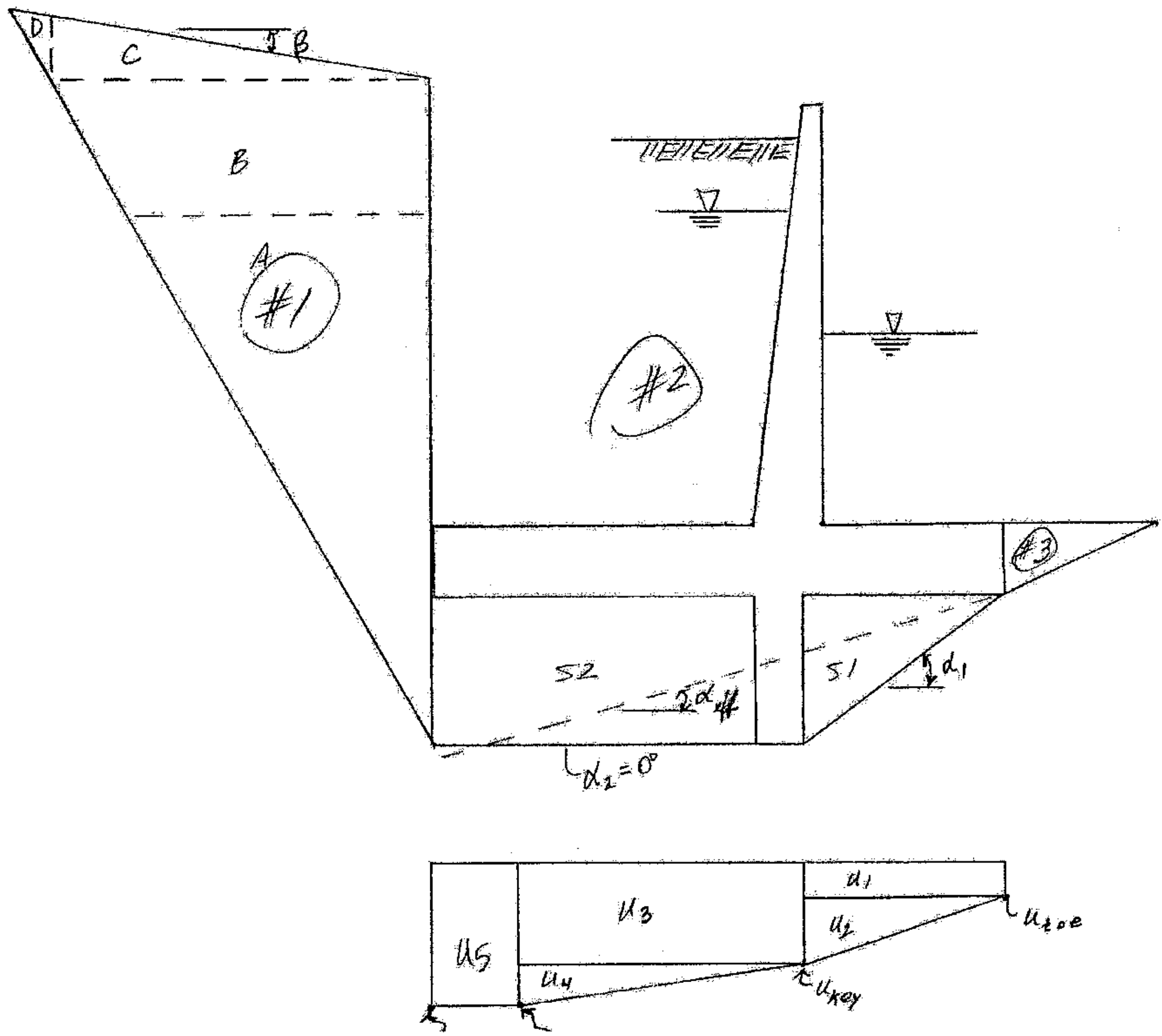
$\phi_{d\_1b_i} := \text{atan}\left(\frac{\tan(\phi_i)}{FS1_i}\right)$ $\phi_{d\_1b_i} = \begin{pmatrix} 33.7 \\ 33\ 7 \\ 33.7 \\ 33.7 \\ 33.7 \end{pmatrix} deg$

$\alpha_{1b_i} := \alpha_{driving}(\phi_{d\_1b_i}, \beta_w)$

$h_{1b} := (E_{grade} + L_{WS5} \cdot \tan(\beta_w)) - (E_{bftg} - h_{key})$ $h_{1b} = 45.0\,ft$

$L_{max_i} := \text{if}\left[-\alpha_{1b_i} = \phi_{d\_1b_i}, 1000 \cdot ft, \frac{\frac{h_{1b}}{\cos(-\alpha_{1b_i}) \cdot (\tan(-\alpha_{1b_i}) - \tan(\beta_w))}}{\cos(-\alpha_{1b_i})}\right]$ $\alpha_{1b} = \begin{pmatrix} -33.7 \\ -33.7 \\ -33\ 7 \\ -33.7 \\ -33.7 \end{pmatrix} deg$ $L_{max} = \begin{pmatrix} 1000\ 0 \\ 1000.0 \\ 1000.0 \\ 1000.0 \\ 1000\ 0 \end{pmatrix} ft$

$h_{1a_i} := \text{if}\left[L_\beta < L_{max_i}, h_{1b} + L_\beta \cdot (\tan(\beta) - \tan(-\alpha_{1b_i})), 0 \cdot ft\right]$



Sliding Analysis #1

Driving Wedge (#1a):

$\beta_w := 0 \cdot deg$ $\beta_w = 0.0\,deg$

$\phi := \phi_{fill}$ $\phi = 32.0\,deg$

$h_{1a} = \begin{pmatrix} 45.0 \\ 45.0 \\ 45.0 \\ 45.0 \\ 45.0 \end{pmatrix} ft$

$c := 0 \cdot ksf$

$\phi_{d_i} := atan\left(\frac{tan(\phi)}{FS_{1_i}}\right)$ $\phi_d = \begin{pmatrix} 19.9 \\ 19.3 \\ 18.8 \\ 18.2 \\ 17.5 \end{pmatrix} deg$

$\alpha_i := \alpha_{driving}\left(\phi_{d_i}, \beta_w\right)$ $\alpha = \begin{pmatrix} -54.9 \\ -54.7 \\ -54.4 \\ -54.1 \\ -53.8 \end{pmatrix} deg$

$h_i := h_{1a_i}$ $h = \begin{pmatrix} 45.0 \\ 45.0 \\ 45.0 \\ 45.0 \\ 45.0 \end{pmatrix} ft$

$L_i := \frac{h_i}{cos(-\alpha_i) \cdot \left(tan(-\alpha_i) - tan(\beta_w)\right)}$ $= \begin{pmatrix} 55.0 \\ 55.2 \\ 55.4 \\ 55.6 \\ 55.8 \end{pmatrix} ft$

$h_{sat_i} := max\left[\begin{bmatrix} E_{wheel_i} - \left(E_{ftg} - t_{base} - h_{key}\right) - L_\beta \cdot tan\left(-\alpha_{1b_i}\right) \\ 0 \cdot ft \end{bmatrix}\right]$ $h_{sat} = \begin{pmatrix} 35.0 \\ 30.8 \\ 26.5 \\ 22.3 \\ 18.0 \end{pmatrix} ft$

$L_{h_i} := \frac{h_i}{tan(-\alpha_i)}$ $L_h = \begin{pmatrix} 31.6 \\ 31.9 \\ 32.2 \\ 32.6 \\ 33.0 \end{pmatrix} ft$

$L_{sat_i} := \frac{h_{sat_i}}{tan(-\alpha_i)}$ $L_{sat} = \begin{pmatrix} 24.6 \\ 21.8 \\ 19.0 \\ 16.1 \\ 13.2 \end{pmatrix} ft$

$h_{left} := 0 \cdot ft$

$h_{right_i} := h_{1a_i}$

$W_i := \gamma_{fill} \cdot \left(L_{h_i} \cdot \frac{h_{left} + h_{right_i}}{2}\right) + \left(\gamma_{sat} - \gamma_{fill}\right) \cdot \frac{L_{sat_i} \cdot h_{sat_i}}{2}$

$W_i =$

91.3	klf
92.5	
93.7	
94.8	
96.2	

$V := 0 \cdot klf$

$H_L := 0 \cdot klf$

$H_R := 0 \cdot klf$

$U_i := \gamma_w \cdot \left(\frac{h_{sat_i}}{2}\right) \cdot \sqrt{\left(h_{sat_i}\right)^2 + \left(L_{sat_i}\right)^2}$ $U = \begin{pmatrix} 46.8 \\ 36.2 \\ 27.0 \\ 19.1 \\ 12.6 \end{pmatrix} klf$

$$\Delta P_{1a_i} := \frac{\left[(W_i + V)\left(\tan(\phi_{d_i})\cdot\cos(\alpha_i) + \sin(\alpha_i)\right) - U_i\cdot\tan(\phi_{d_i}) + (H_L - H_R)\cdot\left(\tan(\phi_{d_i})\cdot\sin(\alpha_i) - \cos(\alpha_i)\right) + \frac{c}{FS_{1_i}}\cdot L_i\right]}{\left(\cos(\alpha_i) - \tan(\phi_{d_i})\cdot\sin(\alpha_i)\right)}$$

Driving Wedge (#1b):

$\beta_w := \beta$ $\qquad \beta_w = 33.7\,deg$

$\alpha := \alpha_{1b}$ $\qquad \alpha = \begin{pmatrix} -33.7 \\ -33.7 \\ -33.7 \\ -33.7 \\ -33.7 \end{pmatrix} deg$

$\phi_d := \phi_{d\_1b}$ $\qquad \phi_d = \begin{pmatrix} 33.7 \\ 33.7 \\ 33.7 \\ 33.7 \\ 33.7 \end{pmatrix} deg$

$h = \begin{pmatrix} 45.0 \\ 45.0 \\ 45.0 \\ 45.0 \\ 45.0 \end{pmatrix} ft$

$L_h := L_\beta$ $\qquad L_h = 0.0\,ft$

$L_i := \frac{L_\beta}{\cos(\alpha_i)}$ $\qquad = \begin{pmatrix} 0.0 \\ 0.0 \\ 0.0 \\ 0.0 \\ 0.0 \end{pmatrix} ft$

$h_{satr_i} := \max\left[\begin{bmatrix} E_{wheel_i} - (E_{ftg} - t_{base} - h_{key}) \\ 0\cdot ft \end{bmatrix}\right]$ $\qquad h_{satr} = \begin{pmatrix} 35.0 \\ 30.8 \\ 26.5 \\ 22.3 \\ 18.0 \end{pmatrix} ft$

$h_{satl_i} := \max\left[\begin{bmatrix} E_{wheel_i} - (E_{ftg} - t_{base} - h_{key}) - \frac{L_\beta}{\cos(\alpha_i)} \\ 0\cdot ft \end{bmatrix}\right]$ $\qquad h_{satl} = \begin{pmatrix} 35.0 \\ 30.8 \\ 26.5 \\ 22.3 \\ 18.0 \end{pmatrix} ft$

$L_{sat_i} := \min\left[\begin{bmatrix} L_\beta \\ \frac{h_{satr_i}}{\tan\left[(-\alpha)_i\right]} \end{bmatrix}\right]$ $\qquad L_{sat} = \begin{pmatrix} 0.0 \\ 0.0 \\ 0.0 \\ 0.0 \\ 0.0 \end{pmatrix} ft$

$h_{left_i} := h_{1a_i}$ $\qquad h_{left} = \begin{pmatrix} 45.0 \\ 45.0 \\ 45.0 \\ 45.0 \\ 45.0 \end{pmatrix} ft$

$h_{right} := h_{1b}$

$$W_i := \gamma_{fill} \cdot \left(L_h \cdot \frac{h_{left_i} + h_{right_i}}{2} \right) + (\gamma_{sat} - \gamma_{fill}) \cdot L_{sat_i} \cdot \left(\frac{h_{satr_i} + h_{satl_i}}{2} \right)$$

$W_i =$

0.0
0.0
0.0
0.0
0.0

klf

$V := 0 \cdot klf$

$H_L := 0 \cdot klf$

$H_R := 0 \cdot klf$

$$U_i := \gamma_w \cdot \left(\frac{h_{satr_i} + h_{satl_i}}{2} \right) \cdot \sqrt{\left(h_{satr_i} - h_{satl_i}\right)^2 + \left(L_h\right)^2}$$

$$\Delta P_{1b_i} := \frac{\left[(W_i + V) \cdot \left(\tan(\phi_{d_i}) \cdot \cos(\alpha_i) + \sin(\alpha_i) \right) - U_i \cdot \tan(\phi_{d_i}) + (H_L - H_R) \cdot \left(\tan(\phi_{d_i}) \cdot \sin(\alpha_i) - \cos(\alpha_i) \right) + \frac{c}{FS_{1_i}} \cdot L_i \right]}{\left(\cos(\alpha_i) - \tan(\phi_{d_i}) \cdot \sin(\alpha_i) \right)}$$

Structure Wedge (#2)·

$U_i =$

0.000
0.000
0.000
0.000
0.000

klf

$\beta_w := 0 \cdot deg$

$\phi := \phi_{fill}$ $\phi = 32.0\,deg$

$c := 0 \;\; ksf$

$$\phi_{d_i} := atan\left(\frac{\tan(\phi)}{FS_{1_i}} \right)$$

$$\phi_{d_i} = \begin{pmatrix} 19.9 \\ 19.3 \\ 18.8 \\ 18.2 \\ 17.5 \end{pmatrix} deg$$

$$\alpha_1 := atan\left(\frac{h_{key}}{x_{key} - \frac{L_{key}}{2}} \right)$$ $\alpha_1 = 33.4\,deg$ (angle of shear plane between toe and key)

$\alpha_2 := 0 \cdot deg$ (angle of shear plane between key and heel)

$$\alpha := \alpha_1 \cdot \left(\frac{x_{key}}{L_{ftg}} \right) + \alpha_2 \cdot \left(\frac{L_{ftg} - x_{key}}{L_{ftg}} \right)$$ $\alpha = 13.0\,deg$ (average angle of shear plane for structural wedge)

$$L := \frac{L_{ftg}}{\cos(\alpha)}$$ $L = 33.4\,ft$

$h_{S1} := h_{key}$ $h_{S1} = 7.0\,ft$

$$L_{S1} := x_{key} - \frac{L_{key}}{2}$$ $L_{S1} = 10.6\,ft$

$x_{S1} := \frac{2}{3} \cdot L_{S1}$ $\quad x_{S1} = 7.1\,ft$

$S1 := \gamma_{sat} \cdot \frac{h_{S1} \cdot L_{S1}}{2}$ $\quad S1 = 4.7\,klf$

$h_{S2} := h_{key}$ $\quad h_{S2} = 7.0\,ft$

$L_{S2} := L_{ftg} - x_{key} - \frac{L_{key}}{2}$ $\quad L_{S2} = 17.9\,ft$

$x_{S2} := L_{ftg} - \frac{L_{S2}}{2}$ $\quad x_{S2} = 23.6\,ft$

$S2 := \gamma_{sat} \cdot h_{S2} \cdot L_{S2}$ $\quad S2 = 16.0\,klf$

$$W_i := \sum_{i=1}^{4} W_{C_i} + W_{W1_i} + W_{WS1_i} + W_{WS2_i} + W_{WS3_i} + W_{WS4_i} + W_{WS5} + W_{WS6} + S1 + S2 + S_{\beta_i}$$

Uplift below structural wedge·

$u_{toe_i} := \gamma_w \cdot \left(E_{wtoe_i} - E_{bftg}\right)$

$u_{heel_i} := \gamma_w \cdot \left[E_{wheel_i} - \left(E_{bftg} - h_{key}\right)\right]$

$$\delta_{u_i} := \frac{\gamma_w \cdot \left(E_{wheel_i} - E_{wtoe_i}\right)}{L_{ftg} - L_{t1_i}}$$

$u_{key_i} := u_{toe_i} + \delta_{u_i} \cdot \left(x_{key} - \frac{L_{key}}{2}\right) + \gamma_w \cdot h_{key}$

$ok := if\left[\left[u_{key_1} + \delta_{u_1} \cdot \left(L_{ftg} - x_{key} + \frac{L_{key}}{2} - L_{t1_1}\right) = u_{heel_1}\right], ok, \text{"Uplift pressures do not close."}\right]$

ok = "Ok"

$u_{1_i} := u_{toe_i} \cdot \left(x_{key} - \frac{L_{key}}{2}\right)$

$$x_{u1} := \frac{x_{key} - \frac{L_{key}}{2}}{2}$$ $\quad x_{u1} = 5.3\,ft$

$$u_{2_i} := \left(u_{key_i} - u_{toe_i}\right) \cdot \frac{\left(x_{key} - \frac{L_{key}}{2}\right)}{2}$$

$$x_{u2} := \frac{2}{3}\cdot\left(x_{key} - \frac{L_{key}}{2}\right)$$

$x_{u2} = 7.1\ \text{ft}$

$$u3_i := u_{key_i}\cdot\left(L_{ftg} - L_{t1_i} - x_{key} + \frac{L_{key}}{2}\right)$$

$$x_{u3_i} := x_{key} - \frac{L_{key}}{2} + \frac{1}{2}\cdot\left[L_{ftg} - L_{t1_i} - \left(x_{key} - \frac{L_{key}}{2}\right)\right]$$

$$u4_i := \left(u_{heel_i} - u_{key_i}\right)\cdot\frac{\left(L_{ftg} - L_{t1_i} - x_{key} + \frac{L_{key}}{2}\right)}{2}$$

$$x_{u4_i} := x_{key} - \frac{L_{key}}{2} + \frac{2}{3}\cdot\left[L_{ftg} - L_{t1_i} - \left(x_{key} - \frac{L_{key}}{2}\right)\right]$$

$$u5_i := u_{heel_i}\cdot L_{t1_i}$$

$$x_{u5_i} := L_{ftg} - \frac{L_{t1_i}}{2}$$

$$U_i := u1_i + u2_i + u3_i + u4_i + u5_i$$

$$x_{U_i} := \frac{u1_i\cdot x_{u1} + u2_i\cdot x_{u2} + u3_i\cdot x_{u3_i} + u4_i\cdot x_{u4_i} + u5_i\cdot x_{u5_i}}{U_i}$$

$$\Sigma M_{grav_i} := \left(\sum_{i=1}^{4} W_{C_i}\cdot x_{C_i} + W_{W1_i}\cdot x_{W1} + W_{WS1_i}\cdot x_{WS1} + W_{WS2_i}\cdot x_{WS2_i} + W_{WS3_i}\cdot x_{WS3_i}\right)\ldots$$
$$+ W_{WS4_i}\cdot x_{WS4_i} + W_{WS5}\cdot x_{WS5} + W_{WS6}\cdot x_{WS6} + S1\cdot x_{S1} + S2\cdot x_{S2} + S_{\beta_i}\cdot x_{S\beta} - \left(U_i\cdot x_{U_i}\right)$$

$h_{A2_i} := E_{wheel_i} - E_{bftg} + h_{key}$

$y_{A2_i} := \frac{h_{A2_i}}{2} - h_{key}$

$A2_i := k_{0\beta} \cdot \gamma_{fill} \cdot h_{A1_i} \cdot h_{A2_i}$

$h_{A3_i} := h_{A2_i}$

$y_{A3_i} := \frac{h_{A3_i}}{3} - h_{key}$

$A3_i := k_{0\beta} \cdot \gamma_{fill\_eff} \cdot \frac{\left(h_{A3_i}\right)^2}{2}$

$H3_i := 0 \cdot klf$

$h_{H2_i} := E_{wheel_i} - E_{bftg} + h_{key}$

$y_{H2_i} := \frac{h_{H2_i}}{3} - h_{key}$

$H2_i := \gamma_w \frac{\left(h_{H2_i}\right)^2}{2}$

h_{A2_i} = (ft)	y_{A2_i} = (ft)	$A2_i$ = (klf)	h_{A3_i} = (ft)	y_{A3_i} = (ft)	$A3_i$ = (klf)
35.00	10.50	0.0	35.00	4.67	30.9
30.75	8.38	13.2	30.75	3.25	23.9
26.50	6.25	22.8	26.50	1.83	17.7
22.25	4.13	28.7	22.25	0.42	12.5
18.00	2.00	30.9	18.00	-1.00	8.2

$$\Sigma M_{lat_i} := -H1_i \cdot \left(y_{H1_i}\right) - K1_i \cdot \left(y_{K1}\right) - K2_i \cdot \left(y_{K2}\right) + H2_i \cdot \left(y_{H2_i}\right) + H3_i \cdot \left(y_{H3}\right) \ldots$$
$$+ A1_i \cdot \left(y_{A1_i}\right) + A2_i \cdot \left(y_{A2_i}\right) + A3_i \cdot \left(y_{A3_i}\right) - R_{key_i} \cdot \left(y_{Rkey}\right)$$

$x_{R_i} := \frac{\Sigma M_{grav_i} - \Sigma M_{lat_i}}{W_i - U_i}$ $L_{brg_i} := \min\left(3 \cdot x_{R_i}, L_{ftg}\right)$

$ok_{u_i} := \text{if}\left[\left|L_{brg_i} - \left(L_{ftg} - L_{t1_i}\right)\right| > 0.001 \cdot ft, \text{"Uplift assumptions wrong in sliding analysis."}, \text{"Matched."}\right]$

W_i = (klf)	u_{toe_i} = (ksf)	u_{heel_i} = (ksf)	δ_{u_i} = (psf/ft)	u_{key_i} = (ksf)	$u1_i$ = (klf)	$u2_i$ = (klf)	$u3_i$ = (klf)
146.9	1.125	2.188	19.2	1.767	11.953	3.410	38.649
145.2	0.859	1.922	19.2	1.501	9.131	3.410	32.839
142.9	0.594	1.656	19.2	1.236	6.309	3.410	27.028
140.4	0.375	1.391	17.8	1.002	3.984	3.328	21.908
139.6	0.375	1.125	9.6	0.915	3.984	2.867	20.008

$u4_i =$ | $u5_i =$ | $x_{u3_i} =$ | $x_{u4_i} =$ | $x_{u5_i} =$ | $h_{H2_i} =$ | $y_{H2_i} =$ | $H2_i =$

$u4_i$ (klf)	$u5_i$ (klf)	x_{u3_i} (ft)	x_{u4_i} (ft)	x_{u5_i} (ft)	h_{H2_i} (ft)	y_{H2_i} (ft)	$H2_i$ (klf)
4.601	0.0	21.6	25.2	32.5	35.0	4.7	38.3
4.601	0.0	21.6	25.2	32.5	30.8	3.3	29.5
4.601	0.0	21.6	25.2	32.5	26.5	1.8	21.9
4.256	0.0	21.6	25.2	32.5	22.3	0.4	15.5
2.301	0.0	21.6	25.2	32.5	18.0	-1.0	10.1

U_i (klf)	x_{U_i} (ft)	ΣM_{grav_i} (kip)	ΣM_{lat_i} (kip)	x_{R_i} (ft)	L_{brg_i} (ft)
58.6	17.7	1825	386	16.3	32.5
50.0	17.9	1981	414	16.5	32.5
41.3	18.3	2118	428	16.6	32.5
33.5	18.7	2228	431	16.8	32.5
29.2	18.2	2291	425	16.9	32.5

$$H_{L_i} := 0 \cdot klf$$

$$H_{R_i} := \gamma_w \cdot \frac{\left(E_{wtoe_i} - E_{ftg}\right)^2}{2}$$

$$\Delta P_{2_i} := \frac{\left[(W_i + V)\cdot\left(\tan\left(\phi_{d_i}\right)\cdot\cos(\alpha)+\sin(\alpha)\right) - U_i\cdot\tan\left(\phi_{d_i}\right) + \left(H_{L_i} - H_{R_i}\right)\cdot\left(\tan\left(\phi_{d_i}\right)\cdot\sin(\alpha)-\cos(\alpha)\right) + \frac{c}{FS_{1_i}}\cdot L\right]}{\left(\cos(\alpha) - \tan\left(\phi_{d_i}\right)\cdot\sin(\alpha)\right)}$$

$H_{L_i} =$		$H_{R_i} =$	
0.0	klf	4.5	klf
0.0		1.9	
0.0		0.4	
0.0		0.0	
0.0		0.0	

$$ok_{u_i} = \begin{pmatrix} \text{"Matched."} \\ \text{"Matched."} \\ \text{"Matched."} \\ \text{"Matched."} \\ \text{"Matched."} \end{pmatrix}$$

$L_{ftg} - L_{brg_i} =$	
0.000	ft
0.000	
0.000	
0.000	
0.000	

$$L_{t1} \equiv \begin{pmatrix} 0 \\ 0 \\ 0 \\ 0 \\ 0 \end{pmatrix}\cdot ft$$

$$ok := \text{if}\left[\max\left(\left|L_{brg} - \left(L_{ftg} - L_{t1}\right)\right|\right) < 0.001\cdot ft, ok, \text{"Uplift area does not match."}\right]$$

$$ok := \text{if}\left(\min\left(L_{brg}\right) < x_{key} + \frac{L_{key}}{2}, \text{"Uplift assumptions incorrect."}, ok\right) \qquad ok = \text{"Ok"}$$

Resisting Wedge (#3):

$\beta_w := 0 \cdot deg$

$\phi := \phi_{fill}$ $\phi = 32.0\,deg$

$c := 0 \cdot ksf$

$\phi_{d_i} := atan\left(\frac{tan(\phi)}{FS_{1_i}}\right)$ $\phi_{d_i} = \begin{pmatrix} 19.9 \\ 19.3 \\ 18.8 \\ 18.2 \\ 17.5 \end{pmatrix} deg$

$\alpha_i := 45 \cdot deg - \frac{\phi_{d_i}}{2}$ $\alpha_i = \begin{pmatrix} 35.1 \\ 35.3 \\ 35.6 \\ 35.9 \\ 36.2 \end{pmatrix} deg$

$L_i := \frac{t_{base}}{sin(\alpha_i)}$ $L = \begin{pmatrix} 10.442 \\ 10.376 \\ 10.302 \\ 10.233 \\ 10.149 \end{pmatrix} ft$

$W_i := \gamma_{sat} \cdot \frac{L_i \cdot cos(\alpha_i) \cdot t_{base}}{2} + \gamma_w \cdot (E_{wtoe_i} - E_{ftg}) \cdot L_i \cdot cos(\alpha_i)$

$U_i := \gamma_w \cdot \left(E_{wtoe_i} - E_{ftg} + \frac{t_{base}}{2}\right) \cdot L_i$

$H_L := 0 \cdot klf$

$H_R := 0 \cdot klf$

$V := 0 \cdot klf$

$$\Delta P_{3_i} := \frac{\left[(W_i + V)\cdot(tan(\phi_{d_i})\cdot cos(\alpha_i) + sin(\alpha_i)) - U_i \cdot tan(\phi_{d_i}) + (H_L - H_R)\cdot(tan(\phi_{d_i})\cdot sin(\alpha_i) - cos(\alpha_i)) + \frac{c}{FS_{1_i}} \cdot L_i\right]}{(cos(\alpha_i) - tan(\phi_{d_i})\cdot sin(\alpha_i))}$$

$\Sigma P_i := \Delta P_{1a_i} + \Delta P_{1b_i} + \Delta P_{2_i} + \Delta P_{3_i}$

$W_i =$ (klf)	$U_i =$ (klf)	$\Delta P_{1a_i} =$ (klf)	$\Delta P_{1b_i} =$ (klf)	$\Delta P_{2_i} =$ (klf)	$\Delta P_{3_i} =$ (klf)	$\Sigma P_i =$ (klf)
9.7	9.8	-83.5	0.0	75.6	8.0	0.0
7.3	7.0	-80.2	0.0	74.1	6.4	0.2
5.0	4.2	-77.8	0.0	73.1	4.7	0.0
3.2	1.9	-76.0	0.0	72.7	3.4	0.1
3.1	1.9	-75.2	0.0	72.0	3.3	0.1

$FS_1 \equiv \begin{pmatrix} 1.73 \\ 1.78 \\ 1.84 \\ 1.90 \\ 1.98 \end{pmatrix}$

ok := if($FS_{1_1} \geq 1.33$, ok, "Sliding instability: LC#1")

ok := if($FS_{1_n} \geq 1.50$, ok, "Sliding instability: LC#n")

ok = "Ok"

Sliding Analysis #2:

$L_\beta = 0.00\,ft$

$\phi_i := \phi_{fill}$ $\beta_w := \beta$ $\beta_w = 33.7\,deg$

$\phi = \begin{pmatrix} 32.0 \\ 32.0 \\ 32.0 \\ 32.0 \\ 32.0 \end{pmatrix} deg$

$c := 0 \cdot ksf$

$\phi_{d_i} := atan\left(\frac{tan(\phi_i)}{FS2_i}\right)$ $\phi_{d_i} = \begin{pmatrix} 25.2 \\ 24.7 \\ 24.1 \\ 23.5 \\ 22.5 \end{pmatrix} deg$

$atan\left(tan(\beta) \cdot FS2_i\right) = \begin{pmatrix} 41.6 \\ 42.2 \\ 43.0 \\ 43.8 \\ 45.2 \end{pmatrix} deg$ (back solve for minimum ϕ value for stable slope β, EM 1110–2–2502, pg. 3-31)

$\phi_i := if\left[\left(c_1\left(\phi_{d_i}\right)^2 + 4 \cdot c_2\left(\phi_{d_i}, \beta_w\right) < 0\right), atan\left(tan(\beta_w) \cdot FS2_i\right), \phi_i\right]$ $\phi = \begin{pmatrix} 41.6 \\ 42.2 \\ 43.0 \\ 43.8 \\ 45.2 \end{pmatrix} deg$ (substitue minimum ϕ if slope is unstable)

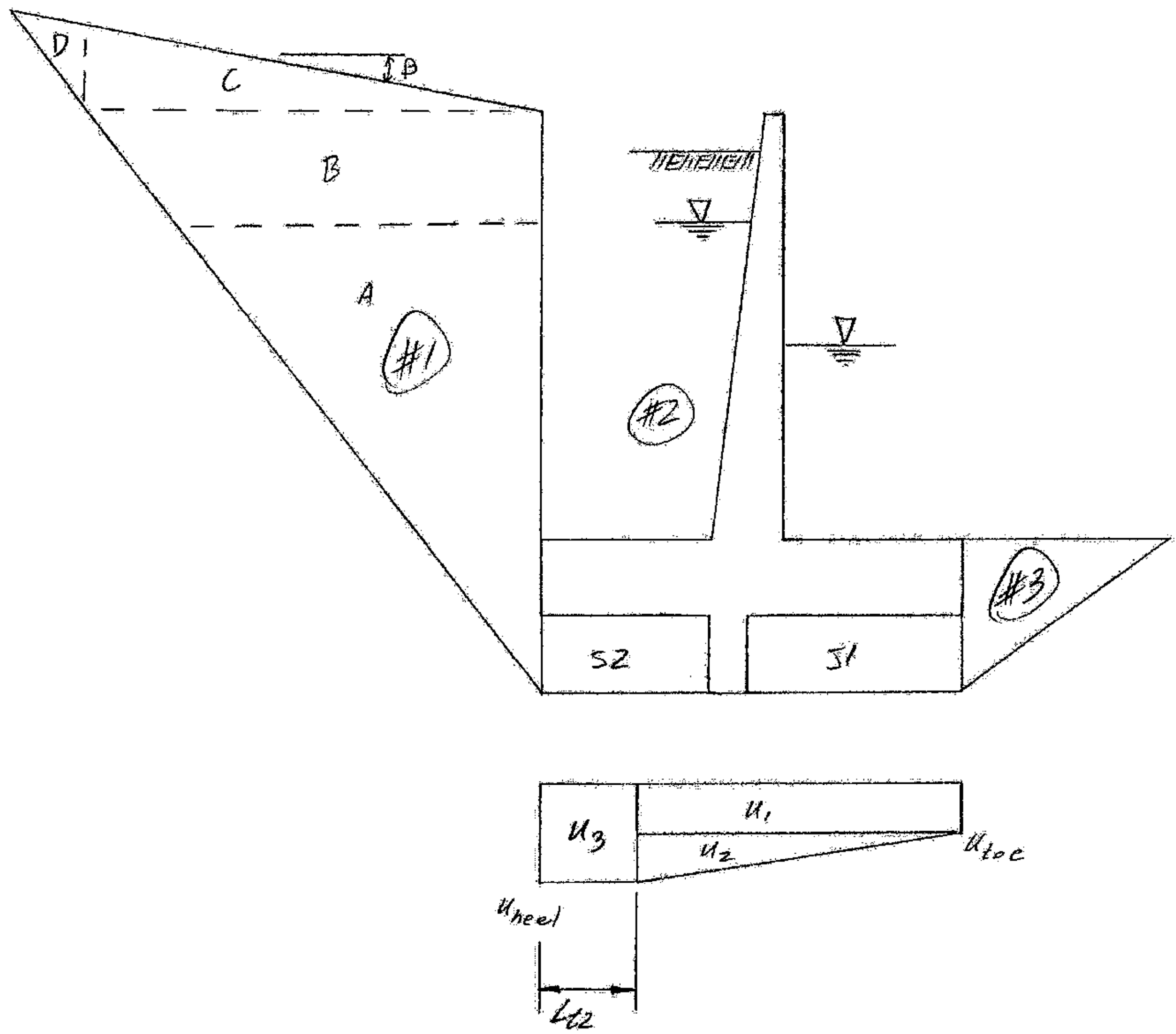
$\phi_{d\_1b_i} := atan\left(\frac{tan(\phi_i)}{FS2_i}\right)$ $\phi_{d\_1b_i} = \begin{pmatrix} 33.7 \\ 33.7 \\ 33.7 \\ 33.7 \\ 33.7 \end{pmatrix} deg$

$\alpha_{1b_i} := \alpha_{driving}\left(\phi_{d\_1b_i}, \beta_w\right)$ $\alpha_{1b} = \begin{pmatrix} -33.7 \\ -33.7 \\ -33.7 \\ -33.7 \\ -33.7 \end{pmatrix} deg$

$h_{1b} := \left(E_{grade} + L_{WS5} \cdot tan(\beta_w)\right) - \left(E_{bftg} - h_{key}\right)$ $h_{1b} = 45.0\,ft$

$L_{max_i} := if\left[-\alpha_{1b_i} = \phi_{d\_1b_i}, 1000 \cdot ft, \frac{\frac{h_{1b}}{cos(-\alpha_{1b_i}) \cdot \left(tan(-\alpha_{1b_i}) - tan(\beta_w)\right)}}{cos(-\alpha_{1b_i})}\right]$ $L_{max} = \begin{pmatrix} 1000.0 \\ 1000.0 \\ 1000.0 \\ 1000.0 \\ 1000.0 \end{pmatrix} ft$

$h_{1a_i} := if\left[L_\beta < L_{max_i}, h_{1b} + L_\beta \cdot \left(tan(\beta) - tan(-\alpha_{1b_i})\right), 0 \cdot ft\right]$ $h_{1a} = \begin{pmatrix} 45.0 \\ 45.0 \\ 45.0 \\ 45.0 \\ 45.0 \end{pmatrix} ft$



Sliding Analysis #2

Driving Wedge (#1a):

$\beta_w := 0 \cdot deg$ $\beta_w = 0.0\,deg$

$\phi := \phi_{fill}$ $\phi = 32.0\,deg$

$c := 0 \cdot ksf$

$\phi_{d_i} := atan\left(\frac{tan(\phi)}{FS_{2_i}}\right)$ $\phi_d = \begin{pmatrix} 25.2 \\ 24.7 \\ 24.1 \\ 23.5 \\ 22.5 \end{pmatrix} deg$

$\alpha_i := \alpha_{driving}\left(\phi_{d_i}, \beta_w\right)$ $\alpha = \begin{pmatrix} -57.58 \\ -57.34 \\ -57.03 \\ -56.73 \\ -56.24 \end{pmatrix} deg$

$h_i := h_{1a_i}$

$h_i := h_{1a_i}$ $h = \begin{pmatrix} 45.0 \\ 45.0 \\ 45.0 \\ 45.0 \\ 45.0 \end{pmatrix} ft$

$L_i := \frac{h_i}{cos(-\alpha_i) \cdot (tan(-\alpha_i) - tan(\beta_w))}$ $= \begin{pmatrix} 53.31 \\ 53.45 \\ 53.64 \\ 53.82 \\ 54.13 \end{pmatrix} ft$

$h_{sat_i} := max\left[\begin{bmatrix} E_{wheel_i} - (E_{ftg} - t_{base} - h_{key}) - L_\beta \cdot tan(-\alpha_{1b_i}) \\ 0 \cdot ft \end{bmatrix}\right]$ $h_{sat} = \begin{pmatrix} 35.0 \\ 30.8 \\ 26.5 \\ 22.3 \\ 18.0 \end{pmatrix} ft$

$L_{h_i} := \frac{h_i}{tan(-\alpha_i)}$ $L_h = \begin{pmatrix} 28.577 \\ 28.847 \\ 29.194 \\ 29.527 \\ 30.079 \end{pmatrix} ft$

$L_{sat_i} := \frac{h_{sat_i}}{tan(-\alpha_i)}$ $L_{sat} = \begin{pmatrix} 22.23 \\ 19.71 \\ 17.19 \\ 14.60 \\ 12.03 \end{pmatrix} ft$

$h_{left} := 0 \cdot ft$

$h_{right_i} := h_{1a_i}$

$W_i := \gamma_{fill} \cdot \left(L_{h_i} \cdot \frac{h_{left} + h_{right_i}}{2}\right) + (\gamma_{sat} - \gamma_{fill}) \cdot \frac{L_{sat_i} \cdot h_{sat_i}}{2}$

$W_i =$

82.615	klf
83.619	
84.822	
85.960	
87.710	

$V := 0 \cdot klf$

$H_L := 0 \cdot klf$

$H_R := 0 \cdot klf$

$$U_i := \gamma_w \cdot \left(\frac{h_{sat_i}}{2}\right) \cdot \sqrt{\left(h_{sat_i}\right)^2 + \left(L_{sat_i}\right)^2}$$

$$U = \begin{pmatrix} 45.348 \\ 35.099 \\ 26.159 \\ 18.504 \\ 12.179 \end{pmatrix} klf$$

$$\Delta P_{1a_i} := \frac{\left[\left(W_i + V\right) \cdot \left(\tan\left(\phi_{d_i}\right) \cdot \cos\left(\alpha_i\right) + \sin\left(\alpha_i\right)\right) - U_i \cdot \tan\left(\phi_{d_i}\right) + \left(H_L - H_R\right) \cdot \left(\tan\left(\phi_{d_i}\right) \cdot \sin\left(\alpha_i\right) - \cos\left(\alpha_i\right)\right) + \frac{c}{FS_{2_i}} \cdot L_i\right]}{\left(\cos\left(\alpha_i\right) - \tan\left(\phi_{d_i}\right) \cdot \sin\left(\alpha_i\right)\right)}$$

Driving Wedge (#1b): $L_\beta = 0.0\,ft$

$\beta_w := \beta$ $\beta_w = 33.7\,deg$

$\alpha := \alpha_{1b}$

$$\alpha = \begin{pmatrix} -33.7 \\ -33.7 \\ -33.7 \\ -33.7 \\ -33.7 \end{pmatrix} deg \qquad \phi_d = \begin{pmatrix} 33.7 \\ 33.7 \\ 33.7 \\ 33.7 \\ 33.7 \end{pmatrix} deg$$

$\phi_d := \phi_{d\_1b}$

$$h = \begin{pmatrix} 45.0 \\ 45.0 \\ 45.0 \\ 45.0 \\ 45.0 \end{pmatrix} ft$$

$L_h := L_\beta$ $L_h = 0.0\,ft$

$$L_i := \frac{L_\beta}{\cos\left(\alpha_i\right)} \qquad L = \begin{pmatrix} 0.0 \\ 0.0 \\ 0.0 \\ 0.0 \\ 0.0 \end{pmatrix} ft$$

$$h_{satr_i} := \max\left[\begin{bmatrix} E_{wheel_i} - \left(E_{ftg} - t_{base} - h_{key}\right) \\ 0\ ft \end{bmatrix}\right] \qquad h_{satr} = \begin{pmatrix} 35.0 \\ 30.8 \\ 26.5 \\ 22.3 \\ 18.0 \end{pmatrix} ft$$

$$h_{satl_i} := \max\left[\begin{bmatrix} E_{wheel_i} - \left(E_{ftg} - t_{base} - h_{key}\right) - \frac{L_\beta}{\cos\left(\alpha_i\right)} \\ 0 \cdot ft \end{bmatrix}\right] \qquad h_{satl} = \begin{pmatrix} 35.0 \\ 30.8 \\ 26.5 \\ 22.3 \\ 18.0 \end{pmatrix} ft$$

$$L_{sat_i} := \min\left[\begin{bmatrix} L_\beta \\ \frac{h_{satr_i}}{\tan\left[\left(-\alpha\right)_i\right]} \end{bmatrix}\right] \qquad L_{sat} = \begin{pmatrix} 0.0 \\ 0.0 \\ 0.0 \\ 0.0 \\ 0.0 \end{pmatrix} ft$$

$h_{left_i} := h_{1a_i}$

$$h_{left} = \begin{pmatrix} 45.0 \\ 45.0 \\ 45.0 \\ 45.0 \\ 45.0 \end{pmatrix} ft$$

$h_{right} := h_{1b}$ $h_{right} = 45.0\,ft$

$$W_i := \gamma_{fill} \cdot \left(L_h \cdot \frac{h_{left_i} + h_{right}}{2}\right) + \left(\gamma_{sat} - \gamma_{fill}\right) \cdot L_{sat_i} \cdot \left(\frac{h_{satr_i} + h_{satl_i}}{2}\right)$$

$V := 0 \cdot klf$

$W_i =$

0.0
0.0
0.0
0.0
0.0

klf

$H_L := 0 \cdot klf$

$H_R := 0 \cdot klf$

$$U_i := \gamma_w \cdot \left(\frac{h_{satr_i} + h_{satl_i}}{2}\right) \cdot \sqrt{\left(h_{satr_i} - h_{satl_i}\right)^2 + \left(L_h\right)^2}$$

$$\Delta P_{1b_i} := \frac{\left[\left(W_i + V\right) \cdot \left(\tan\left(\phi_{d_i}\right) \cdot \cos\left(\alpha_i\right) + \sin\left(\alpha_i\right)\right) - U_i \tan\left(\phi_{d_i}\right) + \left(H_L - H_R\right) \cdot \left(\tan\left(\phi_{d_i}\right) \sin\left(\alpha_i\right) - \cos\left(\alpha_i\right)\right) + \frac{c}{FS_{2_i}} \cdot L_i\right]}{\left(\cos\left(\alpha_i\right) - \tan\left(\phi_{d_i}\right) \cdot \sin\left(\alpha_i\right)\right)}$$

Structure Wedge (#2):

$U_i =$

0.0
0.0
0.0
0.0
0.0

klf

$\beta_w := 0 \ deg$

$\phi := \phi_{fill}$ $\phi = 32.0 \, deg$

$c := 0 \ ksf$

$\phi_{d_i} := atan\left(\frac{\tan(\phi)}{FS_{2_i}}\right)$

$$\phi_{d_i} = \begin{pmatrix} 25.2 \\ 24.7 \\ 24.1 \\ 23.5 \\ 22.5 \end{pmatrix} deg$$

$\alpha := 0 \ deg$ $\alpha = 0.0 \, deg$

$L := \frac{L_{ftg}}{\cos(\alpha)}$ $L = 32.5 \, ft$

$h_{S1} := h_{key}$ $h_{S1} = 7.0 \, ft$

$L_{S1} := x_{key} - \frac{L_{key}}{2}$ $L_{S1} = 10.6 \, ft$

$x_{S1} := \frac{1}{2} \cdot L_{S1}$ $x_{S1} = 5.3 \, ft$

$S1 := \gamma_{sat} \cdot h_{S1} \cdot L_{S1}$ $S1 = 9.5 \, klf$

$h_{S2} := h_{key}$ $\quad h_{S2} = 7.0\,ft$

$L_{S2} := L_{ftg} - x_{key} - \frac{L_{key}}{2}$ $\quad L_{S2} = 17.9\,ft$

$x_{S2} := L_{ftg} - \frac{L_{S2}}{2}$ $\quad x_{S2} = 23.6\,ft$

$S2 := \gamma_{sat} \cdot h_{S2} \cdot L_{S2}$ $\quad S2 = 16.0\,klf$

$$W_i := \sum_{i=1}^{4} W_{C_i} + W_{W1_i} + W_{WS1_i} + W_{WS2_i} + W_{WS3_i} + W_{WS4_i} + W_{WS5} + W_{WS6} + S1 + S2 + S_{\beta_i}$$

Uplift below structural wedge:

$u_{toe_i} := \gamma_w \cdot \left\lfloor E_{wtoe_i} - \left(E_{bftg} - h_{key}\right) \right\rfloor$

$u_{heel_i} := \gamma_w \cdot \left\lfloor E_{wheel_i} - \left(E_{bftg} - h_{key}\right) \right\rfloor$

$$\delta_{u_i} := \frac{\gamma_w \cdot \left(E_{wheel_i} - E_{wtoe_i}\right)}{L_{ftg} - L_{t2_i}}$$

$u_{1_i} := u_{toe_i} \cdot \left(L_{ftg} - L_{t2_i}\right)$

$x_{u1_i} := \frac{L_{ftg} - L_{t2_i}}{2}$ $\qquad x_{u1} = \begin{pmatrix} 16.3 \\ 16.3 \\ 16.3 \\ 16.3 \\ 16.3 \end{pmatrix} ft$

$u_{2_i} := \left(u_{heel_i} - u_{toe_i}\right) \cdot \frac{\left(L_{ftg} - L_{t2_i}\right)}{2}$

$x_{u2_i} := \frac{2}{3} \cdot \left(L_{ftg} - L_{t2_i}\right)$ $\qquad x_{u2} = \begin{pmatrix} 21.7 \\ 21.7 \\ 21.7 \\ 21.7 \\ 21.7 \end{pmatrix} ft$

$u_{3_i} := u_{heel_i} \cdot \left(L_{t2_i}\right)$

$x_{u3_i} := L_{ftg} - \frac{L_{t2_i}}{2}$

$U_i := u_{1_i} + u_{2_i} + u_{3_i}$

$x_{U_i} := \frac{u_{1_i} \cdot x_{u1_i} + u_{2_i} \cdot x_{u2_i} + u_{3_i} \cdot x_{u3_i}}{U_i}$ $\qquad x_U = \begin{pmatrix} 17.2 \\ 17.3 \\ 17.5 \\ 17.7 \\ 17.1 \end{pmatrix} ft$

$$\Sigma M_{grav_i} := \left(\sum_{i=1}^{4} W_{C_i} \cdot x_{C_i} + W_{W1_i} \cdot x_{W1} + W_{WS1_i} \cdot x_{WS1} + W_{WS2_i} \cdot x_{WS2_i} + W_{WS3_i} \cdot x_{WS3_i} \right) \ldots$$
$$+ W_{WS4_i} \cdot x_{WS4_i} + W_{WS5} \cdot x_{WS5} + W_{WS6} \cdot x_{WS6} + S1 \cdot x_{S1} + S2 \cdot x_{S2} + S_{\beta_i} \cdot x_{S\beta} - \left(U_i \cdot x_{U_i}\right)$$

$$h_{H1_i} := E_{wtoe_i} - \left(E_{bftg} - h_{key}\right)$$

$$y_{H1_i} := \frac{h_{H1_i}}{3} - h_{key}$$

$$H1_i := \gamma_w \cdot \frac{\left(h_{H1_i}\right)^2}{2}$$

$h_{H1_i} =$ (ft)

25.00
20.75
16.50
13.00
13.00

$y_{H1_i} =$ (ft)

1.33
-0.08
-1.50
-2.67
-2.67

$H1_i =$ (klf)

19.5
13.5
8.5
5.3
5.3

$$K1_i := 0 \cdot klf$$

$$K2_i := 0 \cdot klf$$

$$\Sigma M_{lat_i} := -H1_i \cdot \left(y_{H1_i}\right) - K1_i \cdot \left(y_{K1}\right) - K2_i \cdot \left(y_{K2}\right) + H2_i \cdot \left(y_{H2_i}\right) + H3_i \cdot \left(y_{H3}\right) \ldots$$
$$+ A1_i \cdot \left(y_{A1_i}\right) + A2_i \cdot \left(y_{A2_i}\right) + A3_i \cdot \left(y_{A3_i}\right) - R_{key_i} \cdot \left(y_{Rkey}\right)$$

$$x_{R_i} := \frac{\Sigma M_{grav_i} - \Sigma M_{lat_i}}{W_i - U_i} \qquad L_{brg_i} := \min\left(3 \cdot x_{R_i}, L_{ftg}\right)$$

$$ok_{u_i} := \text{if}\left[\left|L_{brg_i} - \left(L_{ftg} - L_{t2_i}\right)\right| > 0.001 \cdot ft, \text{"Uplift assumptions wrong in sliding analysis."}, \text{"Matched."}\right]$$

$W_i =$ (klf)	$u_{toe_i} =$ (ksf)	$u_{heel_i} =$ (ksf)	$\delta_{u_i} =$ (psf/ft)	$u_{1_i} =$ (klf)	$u_{2_i} =$ (klf)	$u_{3_i} =$ (klf)
151.6	1.563	2.188	19.2	50.781	10.156	0.000
150.0	1.297	1.922	19.2	42.148	10.156	0.000
147.6	1.031	1.656	19.2	33.516	10.156	0.000
145.2	0.813	1.391	17.8	26.406	9.395	0.000
144.3	0.813	1.125	9.6	26.406	5.078	0.000

$x_{u3_i} =$

32.5 ft
32.5
32.5
32.5
32.5

$h_{H2_i} =$ (ft)	$y_{H2_i} =$ (ft)	$H2_i =$ (klf)
35.0	4.7	38.3
30.8	3.3	29.5
26.5	1.8	21.9
22.3	0.4	15.5
18.0	-1.0	10.1

$U_i =$ (klf)	$x_{U_i} =$ (ft)	$\Sigma M_{grav_i} =$ (kip)	$\Sigma M_{lat_i} =$ (kip)	$x_{R_i} =$ (ft)	$L_{brg_i} =$ (ft)
60.9	17.2	1834	365	16.2	32.5
52.3	17.3	1990	393	16.4	32.5
43.7	17.5	2126	408	16.5	32.5
35.8	17.7	2237	412	16.7	32.5
31.5	17.1	2300	414	16.7	32.5

$$H_{L_i} := 0 \cdot klf$$

$$H_{R_i} := \gamma_w \cdot \frac{\left(E_{wtoe_i} - E_{ftg}\right)^2}{2}$$

$$\Delta P_{2_i} := \frac{\left[\left(W_i + V\right)\cdot\left(\tan\left(\phi_{d_i}\right)\cdot\cos(\alpha) + \sin(\alpha)\right) - U_i\cdot\tan\left(\phi_{d_i}\right) + \left(H_{L_i} - H_{R_i}\right)\cdot\left(\tan\left(\phi_{d_i}\right)\cdot\sin(\alpha) - \cos(\alpha)\right) + \frac{c}{FS_{2_i}}\cdot L\right]}{\left(\cos(\alpha) - \tan\left(\phi_{d_i}\right)\cdot\sin(\alpha)\right)}$$

$H_{L_i} =$ (klf)	$H_{R_i} =$ (klf)	$ok_{u_i} =$	$L_{ftg} - L_{brg_i} =$ (ft)
0.0	4.5	"Matched."	0.000
0.0	1.9	"Matched."	0.000
0.0	0.4	"Matched."	0.000
0.0	0.0	"Matched."	0.000
0.0	0.0	"Matched."	0.000

$$L_{t2} \equiv \begin{pmatrix} 0 \\ 0 \\ 0 \\ 0 \\ 0 \end{pmatrix} \cdot ft$$

$$ok := if\left[\max\left[\left|L_{brg} - \left(L_{ftg} - L_{t2}\right)\right|\right] < 0.001\ ft, ok, \text{"Uplift area does not match."}\right]$$

$$ok := if\left(\min\left(L_{brg}\right) < x_{key} + \frac{L_{key}}{2}, \text{"Uplift assumptions incorrect."}, ok\right) \qquad ok = \text{"Ok"}$$

Resisting Wedge (#3):

$\beta_w := 0 \cdot deg$

$\phi := \phi_{fill}$ $\qquad \phi = 32.0\,deg$

$c := 0 \cdot ksf$

$\phi_{d_i} := atan\left(\frac{tan(\phi)}{FS_{2_i}}\right)$ $\qquad \phi_{d_i} = \begin{pmatrix} 25.2 \\ 24.7 \\ 24.1 \\ 23.5 \\ 22.5 \end{pmatrix} deg$

$\alpha_i := 45 \cdot deg - \frac{\phi_{d_i}}{2}$ $\qquad \alpha_i = \begin{pmatrix} 32.4 \\ 32.7 \\ 33.0 \\ 33.3 \\ 33.8 \end{pmatrix} deg$

$L_i := \frac{t_{base} + h_{key}}{sin(\alpha_i)}$ $\qquad L = \begin{pmatrix} 24.250 \\ 24.089 \\ 23.886 \\ 23.697 \\ 23.394 \end{pmatrix} ft$

$W_i := \gamma_{sat} \cdot \frac{L_i \cdot cos(\alpha_i) \cdot (t_{base} + h_{key})}{2} + \gamma_w \cdot (E_{wtoe_i} - E_{ftg}) \cdot L_i \cdot cos(\alpha_i)$

$U_i := \gamma_w \cdot \left(E_{wtoe_i} - E_{ftg} + \frac{t_{base} + h_{key}}{2}\right) \cdot L_i$

$H_L := 0 \cdot klf$

$H_R := 0 \cdot klf$

$V := 0 \cdot klf$

$$\Delta P_{3_i} := \frac{\left[(W_i + V)\cdot\left(tan(\phi_{d_i})\cdot cos(\alpha_i) + sin(\alpha_i)\right) - U_i \cdot tan(\phi_{d_i}) + (H_L - H_R)\cdot\left(tan(\phi_{d_i})\cdot sin(\alpha_i) - cos(\alpha_i)\right) + \frac{c}{FS_{2_i}} \cdot L_i\right]}{\left(cos(\alpha_i) - tan(\phi_{d_i}) \cdot sin(\alpha_i)\right)}$$

$\Sigma P_i := \Delta P_{1a_i} + \Delta P_{1b_i} + \Delta P_{2_i} + \Delta P_{3_i}$

$FS_2 \equiv \begin{pmatrix} 1.33 \\ 1.36 \\ 1.40 \\ 1.44 \\ 1.51 \end{pmatrix}$

W_i = (klf)	U_i = (klf)	ΔP_{1a_i} = (klf)	ΔP_{1b_i} = (klf)	ΔP_{2_i} = (klf)	ΔP_{3_i} = (klf)	ΣP_i = (klf)
32.3	28.0	-75.3	0.0	47.1	28.7	0.5
26.6	21.5	-71.0	0.0	46.7	24.9	0.7
21.0	14.9	-67.7	0.0	46.8	21.2	0.2
16.4	9.6	-65.2	0.0	47.5	18.0	0.3
16.1	9.5	-64.2	0.0	46.7	17.6	0.0

$L_{heel} \equiv 22.5 \cdot ft$

$h_{key} \equiv 7 \cdot ft$

$L_{ftg} = 32.5\,ft$

ok := if$(FS_{2_1} \geq 1.33$, ok, "Sliding instability: LC#1")

ok := if$(FS_{2_n} \geq 1.50$, ok, "Sliding instability· LC#n") $\qquad L_{ftg} - x_{key} - \frac{L_{key}}{2} = 17.9\,ft$ $\qquad L_{toe} \equiv 10 \cdot ft$

ok = "Ok"

Downstream Training Wall at Right: (Grade = 527.0')

Reference:T:\ST\CALCS\Common geometry.mcd(R)

Geometry:

$E_{wall} := 530 \cdot ft$

$E_{ftg} := E_{sill}$ $\qquad E_{ftg} = 495.0\,ft$

$t_{base} := 6 \cdot ft$

$E_{bftg} := E_{ftg} - t_{base}$ $\qquad E_{bftg} = 489.0\,ft$

$E_{grade} := 527\ \ ft$

$n := 5$

$i := 1..n$

$\Delta_w := 10\ \ ft$ (maximum height of retained water above water in basin)

$$E_{wheel_i} := E_{grade} - \frac{\left[E_{grade} - \left(E_{ftg} + \frac{\Delta_w}{2}\right)\right]}{n-1} \cdot (i-1) \qquad E_{wheel} = \begin{pmatrix} 527.0 \\ 520.3 \\ 513.5 \\ 506.8 \\ 500.0 \end{pmatrix} ft$$

$$E_{wtoe_i} := \max\left(\begin{pmatrix} E_{wheel_i} - \Delta_w \\ E_{ftg} \end{pmatrix}\right) \qquad E_{wtoe} = \begin{pmatrix} 517.0 \\ 510.3 \\ 503.5 \\ 496.8 \\ 495.0 \end{pmatrix} ft$$

$$h := \min\left[\begin{bmatrix} \left[\frac{1.0}{1.5} \cdot 2 \cdot \left(E_{grade} - E_{ftg}\right)\right] + E_{grade} \\ 527 \cdot ft - E_{ftg} \end{bmatrix}\right] \qquad h = 32.0\,ft$$

$\beta := \operatorname{atan}\left(\frac{1.0}{1.5}\right)$ $\qquad \beta = 33.7\,deg$

$h_\beta := 527 \cdot ft - E_{grade}$ $\qquad h_\beta = 0.0\,ft$

$t_{w\_top} := 1.5 \cdot ft$

$t_{w\_bot} := t_{w\_top} + \frac{\left(E_{wall} - E_{ftg}\right)}{8}$ $\qquad t_{w\_bot} = 5.88\,ft$

$L_{toe} = 10.0\,ft$

$L_{heel} = 26.0\,ft$

$L_{ftg} := L_{toe} + L_{heel}$ $\qquad L_{ftg} = 36.0\,ft$

$h_{wall} := E_{wall} - E_{ftg}$ $\qquad h_{wall} = 35.0\,ft$

$h_{key} = 0.0\,ft$

$L_{key} := 4 \cdot ft$ $\qquad L_{key} = 4.0\,ft$

$x_{key} := L_{toe} + t_{w\_bot} - \frac{L_{key}}{2}$ $\qquad x_{key} = 13.9\,ft$

Constants:

$\gamma_w = 62.5\,pcf$

$\gamma_c = 150.0\,pcf$

Soil parameters:

$\gamma_{fill\_eff} = 65.0\,pcf$ $\qquad \gamma_{sat} = 127.5\,pcf$

$\gamma_{fill} = 130.0\,pcf$

$k_{0\_fill} = 0.5$

$\phi_{fill} = 32.0\,deg$

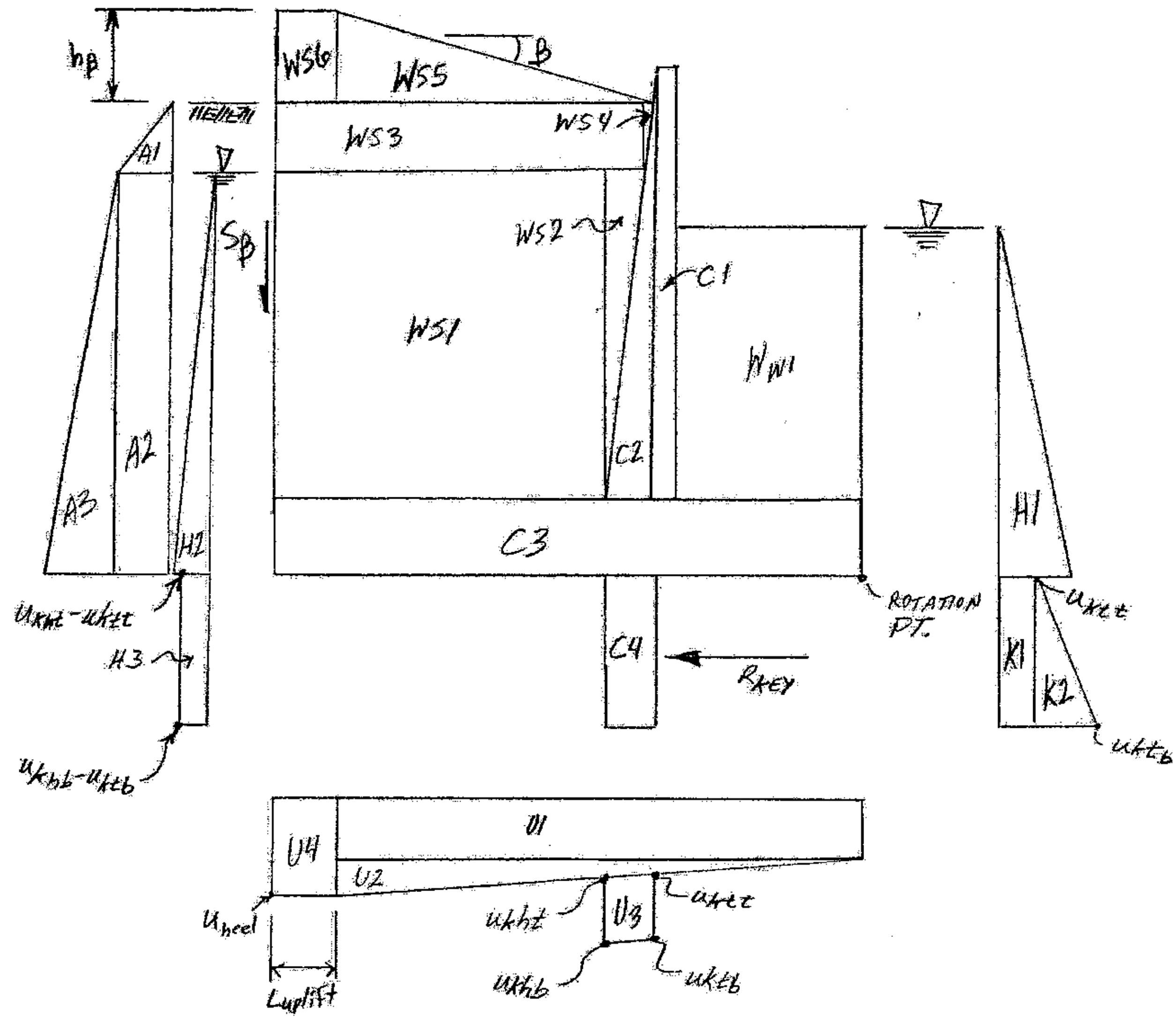
$k_{0\beta} := k_{0\_fill} \cdot (1 + \sin(\beta))$ $\qquad k_{0\beta} = 0.777$ $\qquad$ (USACE EM 1110-2-2502, Eq. 3-5)

Pre-Definitions:

$kip \equiv 1000 \cdot lbf$ $\qquad ksi \equiv 1000 \cdot psi$ $\qquad ok \equiv "Ok"$ $\qquad klf \equiv 1000 \cdot \frac{lbf}{ft}$

$psf \equiv \frac{lbf}{ft^2}$ $\qquad plf \equiv \frac{lbf}{ft}$ $\qquad pcf \equiv \frac{lbf}{ft^3}$

$ORIGIN \equiv 1.0$ (must equal to 1)


hβ
β
WS6
WS5
WS3
WS4
A1
A2
A3
Sβ
WS2
C1
WS1
Ww1
C2
H2
C3
H1
ukht-ukzt
H3
C4
RKEY
ROTATION PT.
ukzt
K1
K2
uktb
ukhb-uktb
U4
U1
U2
Uheel
ukht
U3
uktt
ukhb
uktb
Luplift

Analysis:

Gravity Loads:

$h_{C_1} := h_{wall}$ $h_{C_1} = 35.0\,ft$

$L_{C_1} := t_{w\_top}$ $L_{C_1} = 1.5\,ft$

$x_{C_1} := L_{toe} + \frac{L_{C_1}}{2}$ $x_{C_1} = 10.8\,ft$

$W_{C_1} := \gamma_c \cdot h_{C_1} \cdot L_{C_1}$ $W_{C_1} = 7.9\,klf$

$h_{C_2} := h_{C_1}$ $h_{C_2} = 35.0\,ft$

$L_{C_2} := t_{w\_bot} - t_{w\_top}$ $L_{C_2} = 4.4\,ft$

$x_{C_2} := L_{toe} + L_{C_1} + \frac{L_{C_2}}{3}$ $x_{C_2} = 13.0\,ft$

$W_{C_2} := \gamma_c \cdot \frac{h_{C_2} \cdot L_{C_2}}{2}$ $W_{C_2} = 11.5\,klf$

$h_{C_3} := t_{base}$ $h_{C_3} = 6.0\,ft$

$L_{C_3} := L_{ftg}$ $L_{C_3} = 36.0\,ft$

$x_{C_3} := \frac{L_{C_3}}{2}$ $x_{C_3} = 18.0\,ft$

$W_{C_3} := \gamma_c \cdot h_{C_3} \cdot L_{C_3}$ $W_{C_3} = 32.4\,klf$

$h_{C_4} := h_{key}$ $h_{C_4} = 0.0\,ft$

$L_{C_4} := L_{key}$ $L_{C_4} = 4.0\,ft$

$x_{C_4} := x_{key}$ $x_{C_4} = 13.9\,ft$

$W_{C_4} := \gamma_c \cdot h_{C_4} \cdot L_{C_4}$ $W_{C_4} = 0.0\,\text{klf}$

Weight of water at toe:

$h_{W1_i} := E_{wtoe_i} - E_{ftg}$ $h_{W1} = \begin{pmatrix} 22.00 \\ 15.25 \\ 8.50 \\ 1.75 \\ 0.00 \end{pmatrix} \text{ft}$

$L_{W1} := L_{toe}$ $L_{W1} = 10.0\,\text{ft}$

$x_{W1} := \frac{L_{toe}}{2}$ $x_{W1} = 5.0\,\text{ft}$

$W_{W1_i} := \gamma_w \cdot h_{W1_i} \cdot L_{W1}$ $W_{W1} = \begin{pmatrix} 13.8 \\ 9.5 \\ 5.3 \\ 1.1 \\ 0.0 \end{pmatrix} \text{klf}$

Weight of water/soil at heel:

$h_{WS1_i} := E_{wheel_i} - E_{ftg}$ $h_{WS1} = \begin{pmatrix} 32.00 \\ 25.25 \\ 18.50 \\ 11.75 \\ 5.00 \end{pmatrix} \text{ft}$

$L_{WS1} := L_{heel} - t_{w\_bot}$ $L_{WS1} = 20.1\,\text{ft}$

$x_{WS1} := L_{toe} + t_{w\_bot} + \frac{L_{WS1}}{2}$ $x_{WS1} = 25.9\,\text{ft}$

$W_{WS1_i} := (\gamma_{sat}) \cdot h_{WS1_i} \cdot L_{WS1}$ $W_{WS1} = \begin{pmatrix} 82.1 \\ 64.8 \\ 47.5 \\ 30.1 \\ 12.8 \end{pmatrix} \text{klf}$

$h_{WS2_i} := h_{WS1_i}$

$L_{WS2_i} := \frac{t_{w\_bot} - t_{w\_top}}{h_{wall}} \cdot h_{WS2_i}$ $L_{WS2} = \begin{pmatrix} 4.00 \\ 3.16 \\ 2.31 \\ 1.47 \\ 0.63 \end{pmatrix} \text{ft}$

$x_{WS2_i} := L_{toe} + t_{w\_bot} - \frac{L_{WS2_i}}{3}$ $x_{WS2} = \begin{pmatrix} 14.5 \\ 14.8 \\ 15.1 \\ 15.4 \\ 15.7 \end{pmatrix} \text{ft}$

$$W_{WS2_i} := (\gamma_{sat}) \cdot \frac{h_{WS2_i} \cdot L_{WS2_i}}{2}$$

$W_{WS2_i} =$

8.2
5.1
2.7
1.1
0.2

klf

$$h_{WS3_i} := E_{grade} - E_{wheel_i}$$

$h_{WS3_i} =$

0.0
6.8
13.5
20.3
27.0

ft

$$L_{WS3_i} := L_{WS1} + L_{WS2_i}$$

$L_{WS3_i} =$

24.1
23.3
22.4
21.6
20.8

ft

$$x_{WS3_i} := L_{ftg} - \frac{L_{WS3_i}}{2}$$

$x_{WS3_i} =$

23.9
24.4
24.8
25.2
25.6

ft

$$W_{WS3_i} := \gamma_{fill} \cdot h_{WS3_i} \cdot L_{WS3_i}$$

$W_{WS3_i} =$

0.0
20.4
39.4
56.8
72.8

klf

$$h_{WS4_i} := h_{WS3_i}$$

$$L_{WS4_i} := \frac{t_{w\_bot} - t_{w\_top}}{h_{wall}} \cdot h_{WS4_i}$$

$L_{WS4_i} =$

0.0
0.8
1.7
2.5
3.4

ft

$$x_{WS4_i} := L_{ftg} - L_{WS3_i} - \frac{L_{WS4_i}}{3}$$

$x_{WS4_i} =$

11.9
12.4
13.0
13.6
14.1

ft

$$W_{WS4_i} := \gamma_{fill} \cdot \frac{h_{WS4_i} \cdot L_{WS4_i}}{2}$$

$W_{WS4_i} =$

0.0
0.4
1.5
3.3
5.9

klf

$$L_{WS5} := \min\left(\begin{bmatrix} \left[\frac{t_{w\_bot} - t_{w\_top}}{h_{wall}} \cdot (E_{grade} - E_{ftg}) + L_{WS1}\right] \\ \frac{h_\beta}{\tan(\beta)} \end{bmatrix}\right)$$

$L_{WS5} = 0.00\,ft$

$$h_{WS5} := L_{WS5} \cdot \tan(\beta)$$

$h_{WS5} = 0.00\,ft$

$$x_{WS5} := \frac{2}{3} \cdot L_{WS5} + L_{toe} + t_{w\_top} + \frac{(E_{wall} - E_{grade})}{E_{wall} - E_{ftg}} \cdot (t_{w\_bot} - t_{w\_top})$$

$x_{WS5} = 11.88\,ft$

$$W_{WS5} := \gamma_{fill} \cdot \frac{h_{WS5} \cdot L_{WS5}}{2}$$

$W_{WS5} = 0.0\,klf$

$$L_{WS6} := \frac{E_{grade} - E_{ftg}}{h_{wall}} \cdot (t_{w\_bot} - t_{w\_top}) + L_{WS1} - L_{WS5}$$

$L_{WS6} = 24.1\,ft$

$$h_{WS6} := h_{WS5}$$

$h_{WS6} = 0.0\,ft$

$$x_{WS6} := L_{ftg} - \frac{L_{WS6}}{2}$$

$x_{WS6} = 23.9\,ft$

$$W_{WS6} := \gamma_{fill} \cdot (h_{WS6} \cdot L_{WS6})$$

$W_{WS6} = 0.0\,klf$

Uplift:

$u_{toe_i} := \gamma_w \cdot (E_{wtoe_i} - E_{bftg})$

$u_{heel_i} := \gamma_w \cdot (E_{wheel_i} - E_{bftg})$

$\delta_{seep_i} := \dfrac{u_{heel_i} - u_{toe_i}}{L_{ftg} - L_{uplift_i}}$

$u_{ktt_i} := u_{heel_i} + \left(x_{key} - \dfrac{L_{key}}{2}\right) \cdot \delta_{seep_i}$

$u_{kht_i} := u_{ktt_i} + L_{key} \cdot \delta_{seep_i}$

$u_{ktb_i} := u_{ktt_i} + \gamma_w \cdot h_{key}$

$u_{khb_i} := u_{ktb_i} + L_{key} \cdot \delta_{seep_i}$

$x_{U1} := \dfrac{L_{ftg} - L_{uplift}}{2}$

$U1_i := u_{toe_i} \cdot L_{ftg}$

$x_{U2_i} := \dfrac{2}{3} \cdot (L_{ftg} - L_{uplift_i})$

$U2_i := (u_{heel_i} - u_{toe_i}) \cdot \dfrac{L_{ftg}}{2}$

$x_{U3} := x_{key}$

$U3_i := (u_{ktb_i} - u_{ktt_i}) \cdot L_{key}$

$x_{U4_i} := L_{ftg} - \dfrac{L_{uplift_i}}{2}$

$L_{U4_i} := L_{uplift_i}$

$U4_i := u_{heel_i} \cdot L_{U4_i}$

u_{toe_i} (ksf)	u_{heel_i} (ksf)	δ_{seep_i} (psf/ft)	u_{ktt_i} (ksf)	u_{kht_i} (ksf)
1.750	2.375	20.051	2.613	2.693
1.328	1.953	17.616	2.162	2.233
0.906	1.531	17.361	1.737	1.807
0.484	1.109	17.361	1.316	1.385
0.375	0.688	8.681	0.791	0.825

u_{ktb_i} (ksf)	u_{khb_i} (ksf)	x_{U1_i} (ft)	$U1_i$ (klf)	x_{U2_i} (ft)	$U2_i$ (klf)
2.613	2.693	15.6	63.0	20.8	11.2
2.162	2.233	17.7	47.8	23.7	11.3
1.737	1.807	18.0	32.6	24.0	11.3
1.316	1.385	18.0	17.4	24.0	11.3
0.791	0.825	18.0	13.5	24.0	5.6

$x_{U3} = 13.9\ \text{ft}$

$U3 = \begin{pmatrix} 0.0 \\ 0.0 \\ 0.0 \\ 0.0 \\ 0.0 \end{pmatrix} \text{klf}$

x_{U4_j} =		$U4_i$ =	
33.6	ft	11.5	klf
35.7		1.0	
36.0		0.0	
36.0		0.0	
36.0		0.0	

Lateral load due to water at toe·

$h_{H1_i} := E_{wtoe_i} - E_{bftg}$

$y_{H1_i} := \frac{h_{H1_i}}{3}$

$H1_i := \gamma_w \cdot \frac{\left(h_{H1_i}\right)^2}{2}$

$h_{H2_i} := E_{wheel_i} - E_{bftg}$

$y_{H2_i} := \frac{h_{H2_i}}{3}$

$H2_i := \gamma_w \frac{\left(h_{H2_i}\right)^2}{2}$

$h_{H3} := h_{key}$ $\quad h_{H3} = 0.0\,ft$

$y_{H3} := \frac{-h_{key}}{2}$ $\quad y_{H3} = 0.0\,ft$

$H3_i := \left(u_{khb_i} - u_{ktb_i}\right) \cdot h_{H3}$

$h_{K1} := h_{key}$ $\quad h_{K1} = 0.0\,ft$

$K1_i := u_{ktt_i} \cdot h_{K1}$

$h_{K2} := h_{key}$ $\quad h_{K2} = 0.0\,ft$

$K2_i := \left(u_{ktb_i} - u_{ktt_i}\right) \cdot \frac{h_{K2}}{2}$

$y_{K1} := \frac{-h_{key}}{2}$ $\quad y_{K1} = 0.0\,ft$

$y_{K2} := \frac{-2}{3} \cdot h_{key}$ $\quad y_{K2} = 0.0\,ft$

h_{H1_i} = (ft)	y_{H1_i} = (ft)	$H1_i$ = (klf)	h_{H2_i} = (ft)	$H2_i$ = (klf)	y_{H2_i} = (ft)	$H3_i$ = (klf)	$K1_i$ = (klf)	$K2_i$ = (klf)
28.00	9.33	24.5	38.00	45.1	12.7	0.00	0.0	0.0
21.25	7.08	14.1	31.25	30.5	10.4	0.00	0.0	0.0
14.50	4.83	6.6	24.50	18.8	8.2	0.00	0.0	0.0
7.75	2.58	1.9	17.75	9.8	5.9	0.00	0.0	0.0
6.00	2.00	1.1	11.00	3.8	3.7	0.00	0.0	0.0

Lateral load due to retained soil/water:

$h_{A1_i} := E_{grade} - E_{wheel_i}$

$y_{A1_i} := E_{grade} - E_{bftg} - \frac{2}{3} \cdot h_{A1_i}$

$A1_i := k_{0\beta} \cdot \gamma_{fill} \cdot \frac{(h_{A1_i})^2}{2}$

$h_{A1_i} =$ (ft)

0.00
6.75
13.50
20.25
27.00

$y_{A1_i} =$ (ft)

38.00
33.50
29.00
24.50
20.00

$A1_i =$ (klf)

0.0
2.3
9.2
20.7
36.8

$h_{A2_i} := E_{wheel_i} - E_{bftg}$

$y_{A2_i} := \frac{h_{A2_i}}{2}$

$A2_i := k_{0\beta} \cdot \gamma_{fill} \cdot h_{A1_i} \cdot h_{A2_i}$

$h_{A3_i} := h_{A2_i}$

$y_{A3_i} := \frac{h_{A3_i}}{3}$

$A3_i := k_{0\beta} \cdot \gamma_{fill\_eff} \cdot \frac{(h_{A3_i})^2}{2}$

$h_{A2_i} =$ (ft)

38.00
31.25
24.50
17.75
11.00

$y_{A2_i} =$ (ft)

19.00
15.63
12.25
8.88
5.50

$A2_i =$ (klf)

0.0
21.3
33.4
36.3
30.0

$h_{A3_i} =$ (ft)

38.00
31.25
24.50
17.75
11.00

$y_{A3_i} =$ (ft)

12.67
10.42
8.17
5.92
3.67

$A3_i =$ (klf)

36.5
24.7
15.2
8.0
3.1

Shear force due to sloped backfill: (EM 1110-2-2502, Fig. 4-7)

$h_2 := E_{grade} - E_{ftg}$ $\qquad h_2 = 32.0\,ft$

$h_1 := h_2 + \tan(\beta) \cdot L_{WS5}$ $\qquad h_1 = 32.0\,ft$

$$P_i := k_{0\beta} \cdot \gamma_{fill} \cdot h_{A1_i} \cdot (h_{A2_i} - t_{base}) + k_{0\beta} \cdot \gamma_{fill\_eff} \cdot \frac{(h_{A3_i} - t_{base})^2}{2}$$

$$S_{\beta_i} := \text{if}\left[h_1 > h_2, \left|\frac{P_i \cdot (h_1 - h_2)}{3 \cdot L_{WS5}}\right|, 0 \cdot klf\right]$$

$x_{S\beta} := L_{ftg}$ $\qquad x_{S\beta} = 36.0\,ft$

Sum forces:

$$\Sigma V_i := \sum_{i=1}^{4} W_{C_i} + W_{W1_i} + W_{WS1_i} + W_{WS2_i} + W_{WS3_i} + W_{WS4_i} + W_{WS5} + W_{WS6} + S_{\beta_i} - \left(U1_i + U2_i + U3_i + U4_i\right)$$

$$\Sigma M_{grav_i} := \left(\sum_{i=1}^{4} W_{C_i} \cdot x_{C_i} + W_{W1_i} \cdot x_{W1} + W_{WS1_i} \cdot x_{WS1} + W_{WS2_i} \cdot x_{WS2_i} + W_{WS3_i} \cdot x_{WS3_i} + W_{WS4_i} \cdot x_{WS4_i}\right) \ldots$$
$$+ W_{WS5} \cdot x_{WS5} + W_{WS6} \cdot x_{WS6} + S_{\beta_i} \cdot x_{S\beta} - \left(U1_i \cdot x_{U1_i} + U2_i \cdot x_{U2_i} + U3_i \cdot x_{U3} + U4_i \cdot x_{U4_i}\right)$$

$$R_{key_i} := -H1_i - K1_i - K2_i + H2_i + H3_i + A1_i + A2_i + A3_i$$

$$y_{Rkey} := \frac{-h_{key}}{2} \qquad y_{Rkey} = 0.0\,\text{ft}$$

$$\Sigma H_i := -H1_i - K1_i - K2_i + H2_i + H3_i + A1_i + A2_i + A3_i - R_{key_i}$$

$P_i =$ (klf)	$S_{\beta_i} =$ (klf)	$R_{key_i} =$ (klf)
25.9	0.0	57.1
33.3	0.0	64.7
33.9	0.0	70.0
27.5	0.0	73.0
14.3	0.0	72.6

$$\Sigma M_{lat_i} := -H1_i \cdot y_{H1_i} - K1_i \cdot y_{K1} - K2_i \cdot y_{K2} + H2_i \cdot y_{H2_i} + H3_i \cdot y_{H3} \ldots$$
$$+ A1_i \cdot y_{A1_i} + A2_i \cdot y_{A2_i} + A3_i \cdot y_{A3_i} - R_{key_i} \cdot y_{Rkey}$$

$$\Sigma M_i := \Sigma M_{grav_i} - \Sigma M_{lat_i}$$

$$x_{R_i} := \frac{\Sigma M_i}{\Sigma V_i}$$

$$L_{brg_i} := \max\left[\min\left(\begin{pmatrix} 3 \cdot x_{R_i} \\ L_{ftg} \end{pmatrix}\right), 0 \cdot \text{ft}\right]$$

$\Sigma V_i =$ (klf)	$\Sigma M_{grav_i} =$ (kip)	$\Sigma M_{lat_i} =$ (kip)	$\Sigma M_i =$ (kip)	$\Sigma H_i =$ (klf)	$R_{key_i} =$ (klf)	$x_{R_i} =$ (ft)	$L_{brg_i} =$ (ft)
70.1	1533	805	728	0.0	57.1	10.39	31.170
91.9	1972	885	1087	0.0	64.7	11.83	35.480
104.3	2254	922	1332	0.0	70.0	12.77	36.000
115.6	2515	930	1585	0.0	73.0	13.71	36.000
124.4	2725	925	1800	0.0	72.6	14.47	36.000

Bearing Capacity: (per EM 1110-1-1905)

$c := c_{fill}$ $\quad c = 0.0\,psf$

$\phi := \phi_{fill}$ $\quad \phi = 32.0\,deg$

$\gamma_{eff} := \gamma_{fill\_eff}$ $\quad \gamma_{eff} = 65.0\,pcf$

$\gamma_{H\_eff} := \gamma_{eff}$ $\quad \gamma_{H\_eff} = 65.0\,pcf$

$$B_{eff_i} := L_{ftg} - 2 \cdot \left| \frac{L_{brg_i}}{2} - x_{R_i} \right| \qquad B_{eff} = \begin{pmatrix} 25.6 \\ 24.2 \\ 25.5 \\ 27.4 \\ 28.9 \end{pmatrix} ft$$

Table 4-3:

$$N_\phi := \tan\left(45\ deg + \frac{\phi}{2}\right)^2 \qquad N_\phi = 3.255$$

$$N_q := if\left(\phi = 0, 1.0, N_\phi \cdot e^{\pi \tan(\phi)}\right) \qquad N_q = 23.2$$

$$N_c := if\left[\phi = 0, 5.14, (N_q - 1) \cdot \cot(\phi)\right] \qquad N_c = 35.5$$

$$N_\gamma := if\left[\phi = 0, 0.00, (N_q - 1) \cdot \tan(1.4 \cdot \phi)\right] \qquad N_\gamma = 22.0$$

Inclined loading correction:

$$\theta_i := atan\left(\frac{R_{key_i} + K1_i + K2_i}{\Sigma V_i}\right) \qquad \theta = \begin{pmatrix} 39.18 \\ 35.15 \\ 33.87 \\ 32.26 \\ 30.25 \end{pmatrix} deg$$

$$\xi_{ci_i} := if\left[\phi = 0, \left(1 - \frac{\theta_i}{90 \cdot deg}\right), \left(1 - \frac{\theta_i}{90 \cdot deg}\right)^2\right] \qquad \xi_{ci} = \begin{pmatrix} 0.319 \\ 0.371 \\ 0.389 \\ 0.412 \\ 0.441 \end{pmatrix}$$

$$\xi_{\gamma i_i} := if\left[\phi = 0, 1.0, if\left[\theta_i \le \phi, \left(1 - \frac{\theta_i}{\phi}\right)^2, 0.0\right]\right] \qquad \xi_{\gamma i} = \begin{pmatrix} 0.000 \\ 0.000 \\ 0.000 \\ 0.000 \\ 2.988 \times 10^{-3} \end{pmatrix}$$

$$\xi_{qi_i} := if\left[\phi = 0, \left(1 - \frac{\theta_i}{90 \cdot deg}\right), \left(1 - \frac{\theta_i}{90 \cdot deg}\right)^2\right] \qquad \begin{pmatrix} 0.319 \\ 0.371 \\ 0.389 \\ 0.412 \\ 0.441 \end{pmatrix}$$

$$B_i := L_{brg_i} \qquad B = \begin{pmatrix} 31.2 \\ 35.5 \\ 36.0 \\ 36.0 \\ 36.0 \end{pmatrix} ft$$

$W := 100\ ft$

Foundation depth correction: (at toe)

$D := t_{base}$ $\qquad D = 6.0\,ft$

$\sigma_{D\_eff} := \gamma_{eff} \cdot D$ $\qquad \sigma_{D\_eff} = 390.0\,psf$

$\xi_{cd_i} := 1 + 0.2 \cdot (N_\phi)^{\frac{1}{2}} \cdot \frac{D}{B_i}$ $\qquad \xi_{cd} = \begin{pmatrix} 1.069 \\ 1.061 \\ 1.060 \\ 1.060 \\ 1.060 \end{pmatrix}$

$\xi_{\gamma d\_10_i} := 1 + 0.1 \cdot \left(\tan\left(45 \cdot deg + \frac{10 \cdot deg}{2}\right)^2\right)^{\frac{1}{2}} \cdot \frac{D}{B_i}$ $\qquad \xi_{\gamma d\_10} = \begin{pmatrix} 1.023 \\ 1.020 \\ 1.020 \\ 1.020 \\ 1.020 \end{pmatrix}$

$\xi_{\gamma d_i} := \mathrm{if}\left[\phi \le 10\ deg, \xi_{\gamma d\_0} + \frac{\phi}{10 \cdot deg} \left(\xi_{\gamma d\_10_i} - \xi_{\gamma d\_0}\right), 1 + 0.1 \cdot (N_\phi)^{\frac{1}{2}} \cdot \frac{D}{B_i}\right]$ $\qquad \xi_{\gamma d} = \begin{pmatrix} 1.035 \\ 1.031 \\ 1.030 \\ 1.030 \\ 1.030 \end{pmatrix}$

$\xi_{qd_i} := \xi_{\gamma d_i}$ $\qquad \xi_{qd} = \begin{pmatrix} 1.035 \\ 1.031 \\ 1.030 \\ 1.(\\ 1.(\end{pmatrix}$

USACE EM 1110-1-1905, Eq. 4-16:

$q_{u\_toe_i} := c \cdot N_c \cdot \xi_{cd} \cdot \xi_{ci} + \frac{1}{2} \cdot B_{eff_i} \cdot \gamma_{H\_eff} \cdot N_\gamma \cdot \xi_{\gamma d} \cdot \xi_{\gamma i} + \sigma_{D\_eff} \cdot N_q \cdot \xi_{qd} \cdot \xi_{qi}$ $\qquad q_{u\_toe} = \begin{pmatrix} 18.054 \\ 18.051 \\ 18.054 \\ 18.058 \\ 18.061 \end{pmatrix} ksf$

Foundation depth correction: (at heel)

$D := E_{grade} - E_{ftg} + t_{base} + h_\beta$ $\qquad D = 38.0\,ft$

$\sigma_{D\_eff\_heel} := \gamma_{eff} \cdot D$ $\qquad \sigma_{D\_eff} = 0.390\,ksf$

$\xi_{cd_i} := 1 + 0.2 \cdot (N_\phi)^{\frac{1}{2}} \cdot \frac{D}{\ }$ $\qquad \xi_{cd} = \begin{pmatrix} 1.440 \\ 1.386 \\ 1.381 \\ 1.381 \\ 1.381 \end{pmatrix}$

$\xi_{\gamma d\_10_i} := 1 + 0.1 \cdot \left(\tan\left(45 \cdot deg + \frac{10 \cdot deg}{2}\right)^2\right)^{\frac{1}{2}} \cdot \frac{D}{B_i}$ $\qquad \xi_{\gamma d\_10} = \begin{pmatrix} 1.145 \\ 1.128 \\ 1.126 \\ 1.126 \\ 1.126 \end{pmatrix}$

$\xi_{\gamma d_i} := \mathrm{if}\left[\phi \le 10\ deg, \xi_{\gamma d\_0} + \frac{\phi}{10 \cdot deg} \left(\xi_{\gamma d\_10_i} - \xi_{\gamma d\_0}\right), 1 + 0.1 \cdot (N_\phi)^{\frac{1}{2}} \cdot \frac{D}{B_i}\right]$ $\qquad \xi_{\gamma d} = \begin{pmatrix} 1.220 \\ 1.193 \\ 1.190 \\ 1.190 \\ 1.190 \end{pmatrix}$

$\xi_{qd_i} := \xi_{\gamma d_i}$ $\qquad \xi_{qd} = \begin{pmatrix} 1.220 \\ 1.193 \\ 1.190 \\ 1 \\ 1. \end{pmatrix}$

USACE EM 1110-1-1905, Eq. 4-16:

$q_{u\_heel_i} := c \cdot N_c \cdot \xi_{cd} \cdot \xi_{ci} + \frac{1}{2} \cdot B_{eff_i} \cdot \gamma_{H\_eff} \cdot N_\gamma \cdot \xi_{\gamma d} \cdot \xi_{\gamma i} + \sigma_{D\_eff} \cdot N_q \cdot \xi_{qd} \cdot \xi_{qi}$ $\qquad q_{u\_heel} = \begin{pmatrix} 20.942 \\ 20.938 \\ 20.942 \\ 20.947 \\ 20.950 \end{pmatrix} ksf$

$check\_uplift_i := L_{ftg} - L_{brg_i} - L_{uplift_i}$

check_uplift$_i$ =

-0.0003	ft
0.0001	
0.0000	
0.0000	
0.0000	

ok := if(max(|check_uplift|) < 0.001 · ft, ok, "Uplift assumptions do not match bearing area.")

ok = "Ok"

$$e_{brg_i} := \frac{L_{brg_i}}{2} - x_{R_i}$$

$$\sigma_{brg\_toe_i} := \frac{\Sigma V_i}{L_{brg_i}} + \frac{\Sigma V_i \cdot e_{brg_i}}{\frac{(L_{brg_i})^2}{6}}$$

$$\sigma_{brg\_heel_i} := \frac{\Sigma V_i}{L_{brg_i}} - \frac{\Sigma V_i \cdot e_{brg_i}}{\frac{(L_{brg_i})^2}{6}}$$

$$FS_{brg_i} := \min\left(\frac{q_{u\_toe_i}}{\sigma_{brg\_toe_i}}, \text{if}\left(\sigma_{brg\_heel_i} \neq 0 \cdot psf, \frac{q_{u\_heel_i}}{\sigma_{brg\_heel_i}}, 100\right)\right)$$

$$\%_{brg_i} := \frac{L_{brg_i}}{L_{ftg}}$$

$$\%_{brg_i} = \begin{pmatrix} 86.6 \\ 98.6 \\ 100.0 \\ 100.0 \\ 100.0 \end{pmatrix} \%$$

ok := if($\%_{brg_1} \geq 75 \cdot \%$, ok, "OT instability: LC#1") $L_{ftg} = 36.0$ ft

ok := if($\%_{brg_n} \geq 100\%$, ok, "OT instability: LC#n") $t_{w\_bot} = 5.9$ ft

$\frac{L_{ftg}}{4} = 9.000$ ft

e_{brg_i} = (ft)	$\sigma_{brg\_toe_i}$ = (ksf)	$\sigma_{brg\_heel_i}$ = (ksf)	FS_{brg_i} =	$L_{ftg} - L_{brg_i}$ = (ft)
5.20	4.495	0.000	4.02	4.830
5.91	5.179	0.000	3.49	0.520
5.23	5.418	0.374	3.33	0.000
4.29	5.508	0.914	3.28	0.000
3.53	5.491	1.421	3.29	0.000

$$L_{uplift} \equiv \begin{pmatrix} 4.830 \\ 0.520 \\ 0 \\ 0 \\ 0 \end{pmatrix} \cdot ft$$

ok := if[max[|$L_{brg} - (L_{ftg} - L_{uplift})$|] < 0.001 · ft, ok, "Uplift area does not match

ok := if($FS_{brg_1} < 2$, "Bearing problem LC#1", ok)

$L_{ftg} = 36.0$ ft

ok := if($FS_{brg_n} < 3$, "Bearing problem LC#n", ok)

ok = "Ok"

Base Pressures:

$e_{ftg_i} := \frac{L_{ftg}}{2} - x_{R_i}$ (eccentricity with respect to the footing centroid)

$\Sigma H_i + R_{key_i} =$ (klf)	$\Sigma V_i =$ (klf)	$e_{ftg_i} =$ (ft)	$x_{R_i} =$ (ft)	$\sigma_{brg\_heel_i} =$ (ksf)	$\sigma_{brg\_toe_i} =$ (ksf)
57.1	70.1	7.61	10.39	0.000	4.495
64.7	91.9	6.17	11.83	0.000	5.179
70.0	104.3	5.23	12.77	0.374	5.418
73.0	115.6	4.29	13.71	0.914	5.508
72.6	124.4	3.53	14.47	1.421	5.491

$L_{brg_i} = 31.17\,ft$

$$\frac{L_{brg}}{L_{ftg}} = \begin{pmatrix} 86.6 \\ 98.6 \\ 100.0 \\ 100.0 \\ 100.0 \end{pmatrix} \%$$

Sliding Analysis:

Function Definitions:

$c_1(\phi_d) := 2 \cdot \tan(\phi_d)$

$c_2(\phi_d, \beta) := 1 - \tan(\phi_d) \cdot \tan(\beta) - \left(\frac{\tan(\beta)}{\tan(\phi_d)}\right)$

$\alpha_{driving}(\phi_d, \beta) := -\text{atan}\left(\frac{c_1(\phi_d) + \sqrt{c_1(\phi_d)^2 + 4 \cdot c_2(\phi_d, \beta)}}{2}\right)$

$L_\beta := \max\left(\begin{pmatrix} \frac{h_\beta}{\tan(\beta)} - L_{WS5} - L_{WS6} \\ 0 \cdot ft \end{pmatrix}\right)$ $\qquad L_\beta = 0.0\,ft$

Sliding Analysis #1:

$\beta_w := \beta$ $\qquad \beta_w = 33.7\,deg$

$\phi_i := \phi_{fill}$ $\qquad \phi = \begin{pmatrix} 32.0 \\ 32.0 \\ 32.0 \\ 32.0 \\ 32.0 \end{pmatrix} deg$

$c := 0 \cdot ksf$

$\phi_{d_i} := \text{atan}\left(\frac{\tan(\phi_i)}{FS_{1_i}}\right)$ $\qquad \phi_{d_i} = \begin{pmatrix} 24.7 \\ 23.6 \\ 22.5 \\ 21.2 \\ 19.9 \end{pmatrix} deg$

$\text{atan}\left(\tan(\beta) \cdot FS_{1_i}\right) = \begin{pmatrix} 42.2 \\ 43.6 \\ 45.2 \\ 47.0 \\ 49.1 \end{pmatrix} deg$ (back solve for minimum ϕ value for stable slope β, EM 1110–2–2502, pg. 3-31)

$\phi_i := \text{if}\left[\left(c_1(\phi_{d_i})^2 + 4 \cdot c_2(\phi_{d_i}, \beta_w) < 0\right), \text{atan}\left(\tan(\beta_w) \cdot FS_{1_i}\right), \phi_i\right]$ $\qquad \phi = \begin{pmatrix} 42.2 \\ 43.6 \\ 45.2 \\ 47.0 \\ 49.1 \end{pmatrix} deg$ (substitue minimum ϕ if slope is unstable)

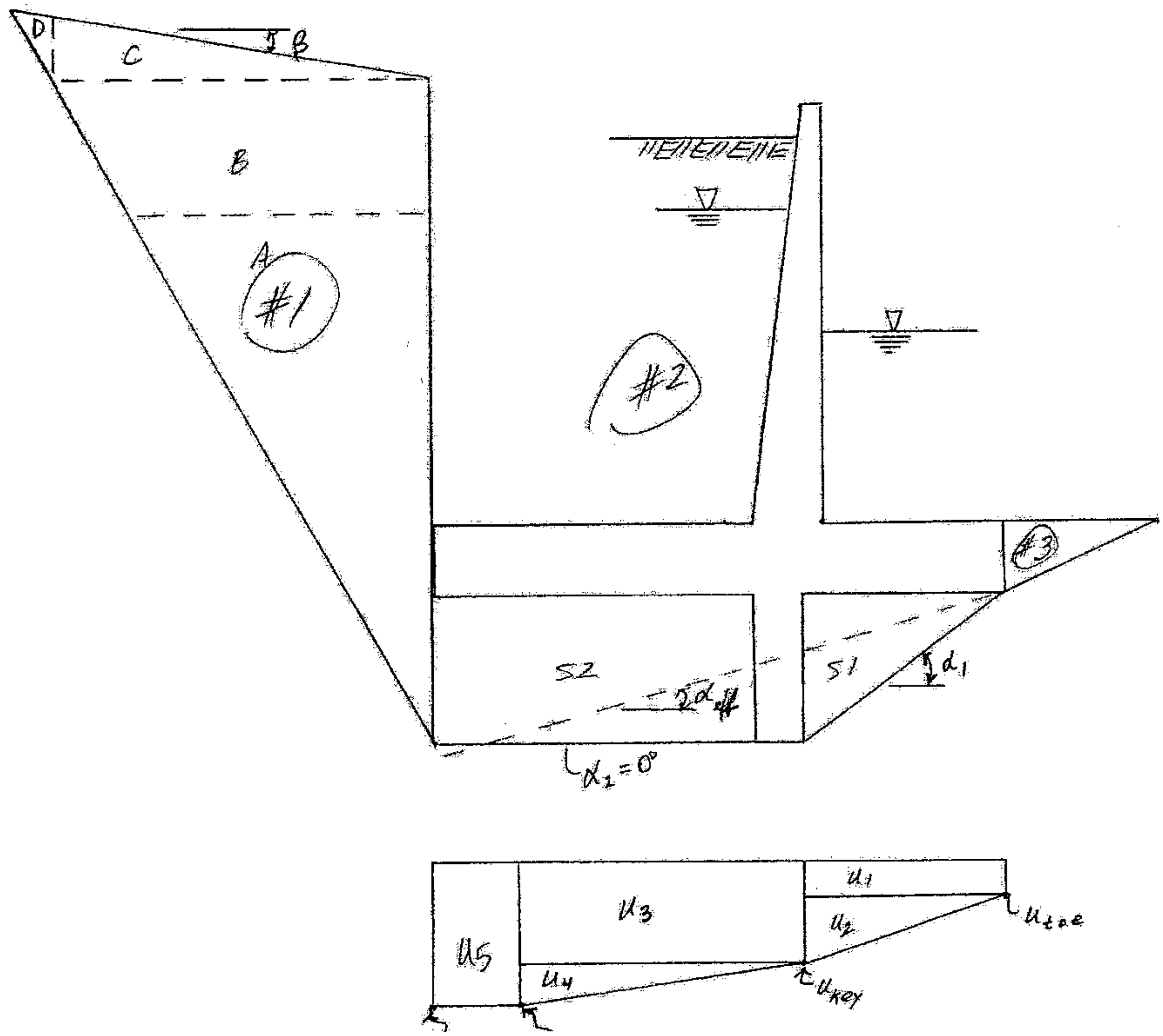
$\phi_{d\_1b_i} := \text{atan}\left(\frac{\tan(\phi_i)}{FS_{1_i}}\right)$ $\qquad \phi_{d\_1b_i} = \begin{pmatrix} 33.7 \\ 33.7 \\ 33.7 \\ 33.7 \\ 33.7 \end{pmatrix} deg$

$\alpha_{1b_i} := \alpha_{driving}(\phi_{d\_1b_i}, \beta_w)$

$h_{1b} := \left(E_{grade} + L_{WS5} \cdot \tan(\beta_w)\right) - \left(E_{bftg} - h_{key}\right)$ $\qquad h_{1b} = 38.0\,ft$

$L_{max_i} := \text{if}\left[-\alpha_{1b_i} = \phi_{d\_1b_i}, 1000 \cdot ft, \frac{\frac{h_{1b}}{\cos(-\alpha_{1b_i}) \cdot \left(\tan(-\alpha_{1b_i}) - \tan(\beta_w)\right)}}{\cos(-\alpha_{1b_i})}\right]$ $\qquad \alpha_{1b} = \begin{pmatrix} -33.7 \\ -33.7 \\ -33.7 \\ -33.7 \\ -33.7 \end{pmatrix} deg$ $\qquad L_{max} = \begin{pmatrix} 3007590483.2 \\ 1000.0 \\ 1000.0 \\ 1000.0 \\ 1000.0 \end{pmatrix} ft$

$h_{1a_i} := \text{if}\left[L_\beta < L_{max_i}, h_{1b} + L_\beta \cdot \left(\tan(\beta) - \tan(-\alpha_{1b_i})\right), 0 \cdot ft\right]$



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Sliding Analysis #1

Driving Wedge (#1a):

$\beta_w := 0 \cdot deg$ $\beta_w = 0.0\,deg$

$h_{1a} = \begin{pmatrix} 38.0 \\ 38.0 \\ 38.0 \\ 38.0 \\ 38.0 \end{pmatrix} ft$

$\phi := \phi_{fill}$ $\phi = 32.0\,deg$

$c := 0 \cdot ksf$

$\phi_{d_i} := atan\left(\frac{tan(\phi)}{FS_{1_i}}\right)$ $\phi_d = \begin{pmatrix} 24.7 \\ 23.6 \\ 22.5 \\ 21.2 \\ 19.9 \end{pmatrix} deg$

$\alpha_i := \alpha_{driving}(\phi_{d_i}, \beta_w)$ $\alpha = \begin{pmatrix} -57.3 \\ -56.8 \\ -56.2 \\ -55.6 \\ -54.9 \end{pmatrix} deg$

$h_i := h_{1a_i}$ $h = \begin{pmatrix} 38.0 \\ 38.0 \\ 38.0 \\ 38.0 \\ 38.0 \end{pmatrix} ft$

$L_i := \frac{h_i}{cos(-\alpha_i) \cdot (tan(-\alpha_i) - tan(\beta_w))}$ $= \begin{pmatrix} 45.1 \\ 45.4 \\ 45.7 \\ 46.1 \\ 46.4 \end{pmatrix} ft$

$h_{sat_i} := max\left[\begin{bmatrix} E_{wheel_i} - (E_{ftg} - t_{base} - h_{key}) - L_\beta \cdot tan(-\alpha_{1b_i}) \\ 0 \cdot ft \end{bmatrix}\right]$ $h_{sat} = \begin{pmatrix} 38.0 \\ 31.3 \\ 24.5 \\ 17.8 \\ 11.0 \end{pmatrix} ft$

$L_{h_i} := \frac{h_i}{tan(-\alpha_i)}$ $L_h = \begin{pmatrix} 24.4 \\ 24.9 \\ 25.4 \\ 26.0 \\ 26.7 \end{pmatrix} ft$

$L_{sat_i} := \frac{h_{sat_i}}{tan(-\alpha_i)}$ $L_{sat} = \begin{pmatrix} 24.4 \\ 20.4 \\ 16.4 \\ 12.2 \\ 7.7 \end{pmatrix} ft$

$h_{left} := 0 \cdot ft$

$h_{right_i} := h_{1a_i}$

$W_i := \gamma_{fill} \cdot \left(L_{h_i} \cdot \frac{h_{left} + h_{right_i}}{2}\right) + (\gamma_{sat} - \gamma_{fill}) \cdot \frac{L_{sat_i} \cdot h_{sat_i}}{2}$

$W_i =$

W_i (klf)
59.0
60.6
62.2
64.0
65.8

$V := 0 \cdot klf$

$H_L := 0 \cdot klf$

$H_R := 0 \cdot klf$

$U_i := \gamma_w \cdot \left(\frac{h_{sat_i}}{2}\right) \cdot \sqrt{(h_{sat_i})^2 + (L_{sat_i})^2}$ $U = \begin{pmatrix} 53.6 \\ 36.5 \\ 22.6 \\ 11.9 \\ 4.6 \end{pmatrix} klf$

$$\Delta P_{1a_i} := \frac{\left[(W_i + V)\cdot\left(\tan(\phi_{d_i})\cdot\cos(\alpha_i) + \sin(\alpha_i)\right) - U_i\cdot\tan(\phi_{d_i}) + (H_L - H_R)\cdot\left(\tan(\phi_{d_i})\cdot\sin(\alpha_i) - \cos(\alpha_i)\right) + \frac{c}{FS_{1_i}}\cdot L_i\right]}{\left(\cos(\alpha_i) - \tan(\phi_{d_i})\cdot\sin(\alpha_i)\right)}$$

Driving Wedge (#1b):

$\beta_w := \beta$ $\qquad \beta_w = 33.7\,deg$

$\alpha := \alpha_{1b}$ $\qquad \alpha = \begin{pmatrix} -33.7 \\ -33.7 \\ -33.7 \\ -33.7 \\ -33.7 \end{pmatrix} deg$

$\phi_d := \phi_{d\_1b}$ $\qquad \phi_d = \begin{pmatrix} 33.7 \\ 33.7 \\ 33.7 \\ 33.7 \\ 33.7 \end{pmatrix} deg$

$h = \begin{pmatrix} 38.0 \\ 38.0 \\ 38.0 \\ 38.0 \\ 38.0 \end{pmatrix} ft$

$L_h := L_\beta$ $\qquad L_h = 0.0\,ft$

$L_i := \frac{L_\beta}{\cos(\alpha_i)}$ $\qquad = \begin{pmatrix} 0.0 \\ 0.0 \\ 0.0 \\ 0.0 \\ 0.0 \end{pmatrix} ft$

$h_{satr_i} := \max\left[\begin{bmatrix} E_{wheel_i} - (E_{ftg} - t_{base} - h_{key}) \\ 0\cdot ft \end{bmatrix}\right]$ $\qquad h_{satr} = \begin{pmatrix} 38.0 \\ 31.3 \\ 24.5 \\ 17.8 \\ 11.0 \end{pmatrix} ft$

$h_{satl_i} := \max\left[\begin{bmatrix} E_{wheel_i} - (E_{ftg} - t_{base} - h_{key}) - \frac{L_\beta}{\cos(\alpha_i)} \\ 0\ ft \end{bmatrix}\right]$ $\qquad h_{satl} = \begin{pmatrix} 38.0 \\ 31.3 \\ 24.5 \\ 17.8 \\ 11.0 \end{pmatrix} ft$

$L_{sat_i} := \min\left[\begin{bmatrix} L_\beta \\ \frac{h_{satr_i}}{\tan\left[(-\alpha)_i\right]} \end{bmatrix}\right]$ $\qquad L_{sat} = \begin{pmatrix} 0.0 \\ 0.0 \\ 0.0 \\ 0.0 \\ 0.0 \end{pmatrix} ft$

$h_{left_i} := h_{1a_i}$ $\qquad h_{left} = \begin{pmatrix} 38.0 \\ 38.0 \\ 38.0 \\ 38.0 \\ 38.0 \end{pmatrix} ft$

$h_{right} := h_{1b}$

$$W_i := \gamma_{fill} \cdot \left(L_h \cdot \frac{h_{left_i} + h_{right_i}}{2} \right) + (\gamma_{sat} - \gamma_{fill}) \cdot L_{sat_i} \cdot \left(\frac{h_{satr_i} + h_{satl_i}}{2} \right)$$

$W_i =$

0.0
0.0
0.0
0.0
0.0

klf

$V := 0 \cdot klf$

$H_L := 0 \cdot klf$

$H_R := 0 \cdot klf$

$$U_i := \gamma_w \cdot \left(\frac{h_{satr_i} + h_{satl_i}}{2} \right) \cdot \sqrt{\left(h_{satr_i} - h_{satl_i}\right)^2 + (L_h)^2}$$

$$\Delta P_{1b_i} := \frac{\left[(W_i + V) \cdot \left(\tan(\phi_{d_i}) \cdot \cos(\alpha_i) + \sin(\alpha_i) \right) - U_i \cdot \tan(\phi_{d_i}) + (H_L - H_R) \cdot \left(\tan(\phi_{d_i}) \cdot \sin(\alpha_i) - \cos(\alpha_i) \right) + \frac{c}{FS_{1_i}} \cdot L_i \right]}{\left(\cos(\alpha_i) - \tan(\phi_{d_i}) \cdot \sin(\alpha_i) \right)}$$

Structure Wedge (#2):

$U_i =$

0.000
0.000
0.000
0.000
0.000

klf

$\beta_w := 0 \ deg$

$\phi := \phi_{fill}$ $\phi = 32.0 \, deg$

$c := 0 \ ksf$

$\phi_{d_i} := \operatorname{atan}\left(\frac{\tan(\phi)}{FS_{1_i}} \right)$

$$\phi_{d_i} = \begin{pmatrix} 24.7 \\ 23.6 \\ 22.5 \\ 21.2 \\ 19.9 \end{pmatrix} deg$$

$\alpha_1 := \operatorname{atan}\left(\frac{h_{key}}{x_{key} - \frac{L_{key}}{2}} \right)$ $\alpha_1 = 0.0 \, deg$ (angle of shear plane between toe and key)

$\alpha_2 := 0 \ deg$ (angle of shear plane between key and heel)

$\alpha := \alpha_1 \cdot \left(\frac{x_{key}}{L_{ftg}} \right) + \alpha_2 \cdot \left(\frac{L_{ftg} - x_{key}}{L_{ftg}} \right)$ $\alpha = 0.0 \, deg$ (average angle of shear plane for structural wedge)

$L := \frac{L_{ftg}}{\cos(\alpha)}$ $L = 36.0 \, ft$

$h_{S1} := h_{key}$ $h_{S1} = 0.0 \, ft$

$L_{S1} := x_{key} - \frac{L_{key}}{2}$ $L_{S1} = 11.9 \, ft$

$x_{S1} := \frac{2}{3} \cdot L_{S1}$ $x_{S1} = 7.9\,\text{ft}$

$S1 := \gamma_{sat} \cdot \frac{h_{S1} \cdot L_{S1}}{2}$ $S1 = 0.0\,\text{klf}$

$h_{S2} := h_{key}$ $h_{S2} = 0.0\,\text{ft}$

$L_{S2} := L_{ftg} - x_{key} - \frac{L_{key}}{2}$ $L_{S2} = 20.1\,\text{ft}$

$x_{S2} := L_{ftg} - \frac{L_{S2}}{2}$ $x_{S2} = 25.9\,\text{ft}$

$S2 := \gamma_{sat} \cdot h_{S2} \cdot L_{S2}$ $S2 = 0.0\,\text{klf}$

$$W_i := \sum_{i=1}^{4} W_{C_i} + W_{W1_i} + W_{WS1_i} + W_{WS2_i} + W_{WS3_i} + W_{WS4_i} + W_{WS5} + W_{WS6} + S1 + S2 + S_{\beta_i}$$

Uplift below structural wedge:

$u_{toe_i} := \gamma_w \cdot \left(E_{wtoe_i} - E_{bftg}\right)$

$u_{heel_i} := \gamma_w \cdot \left[E_{wheel_i} - \left(E_{bftg} - h_{key}\right)\right]$

$\delta_{u_i} := \frac{\gamma_w \cdot \left(E_{wheel_i} - E_{wtoe_i}\right)}{L_{ftg} - L_{t1_i}}$

$u_{key_i} := u_{toe_i} + \delta_{u_i} \cdot \left(x_{key} - \frac{L_{key}}{2}\right) + \gamma_w \cdot h_{key}$

$ok := \text{if}\left[\left[u_{key_1} + \delta_{u_1} \cdot \left(L_{ftg} - x_{key} + \frac{L_{key}}{2} - L_{t1_1}\right) = u_{heel_1}\right], \text{ok}, \text{"Uplift pressures do not close "}\right]$

ok = "Ok"

$u_{1_i} := u_{toe_i} \cdot \left(x_{key} - \frac{L_{key}}{2}\right)$

$x_{u1} := \frac{x_{key} - \frac{L_{key}}{2}}{2}$ $x_{u1} = 5.9\,\text{ft}$

$u_{2_i} := \left(u_{key_i} - u_{toe_i}\right) \frac{\left(x_{key} - \frac{L_{key}}{2}\right)}{2}$

$$x_{u2} := \frac{2}{3} \cdot \left(x_{key} - \frac{L_{key}}{2} \right) \qquad x_{u2} = 7.9\,ft$$

$$u_{3_i} := u_{key_i} \cdot \left(L_{ftg} - L_{t1_i} - x_{key} + \frac{L_{key}}{2} \right)$$

$$x_{u3_i} := x_{key} - \frac{L_{key}}{2} + \frac{1}{2} \cdot \left[L_{ftg} - L_{t1_i} - \left(x_{key} - \frac{L_{key}}{2} \right) \right]$$

$$u_{4_i} := \left(u_{heel_i} - u_{key_i} \right) \cdot \frac{\left(L_{ftg} - L_{t1_i} - x_{key} + \frac{L_{key}}{2} \right)}{2}$$

$$x_{u4_i} := x_{key} - \frac{L_{key}}{2} + \frac{2}{3} \cdot \left[L_{ftg} - L_{t1_i} - \left(x_{key} - \frac{L_{key}}{2} \right) \right]$$

$$u_{5_i} := u_{heel_i} \cdot L_{t1_i}$$

$$x_{u5_i} := L_{ftg} - \frac{L_{t1_i}}{2}$$

$$U_i := u_{1_i} + u_{2_i} + u_{3_i} + u_{4_i} + u_{5_i}$$

$$x_{U_i} := \frac{u_{1_i} \cdot x_{u1} + u_{2_i} \cdot x_{u2} + u_{3_i} \cdot x_{u3_i} + u_{4_i} \cdot x_{u4_i} + u_{5_i} \cdot x_{u5_i}}{U_i}$$

$$\Sigma M_{grav_i} := \left(\sum_{i=1}^{4} W_{C_i} \cdot x_{C_i} + W_{W1_i} \cdot x_{W1} + W_{WS1_i} \cdot x_{WS1} + W_{WS2_i} \cdot x_{WS2_i} + W_{WS3_i} \cdot x_{WS3_i} \right) \cdots$$
$$+ W_{WS4_i} \cdot x_{WS4_i} + W_{WS5} \cdot x_{WS5} + W_{WS6} \cdot x_{WS6} + S1 \cdot x_{S1} + S2 \cdot x_{S2} + S_{\beta_i} \cdot x_{S\beta} - \left(U_i \cdot x_{U_i} \right)$$

$h_{A2_i} := E_{wheel_i} - E_{bftg} + h_{key}$

$y_{A2_i} := \frac{h_{A2_i}}{2} - h_{key}$

$A2_i := k_{0\beta} \cdot \gamma_{fill} \cdot h_{A1_i} \cdot h_{A2_i}$

$h_{A3_i} := h_{A2_i}$

$y_{A3_i} := \frac{h_{A3_i}}{3} - h_{key}$

$A3_i := k_{0\beta} \cdot \gamma_{fill\_eff} \cdot \frac{(h_{A3_i})^2}{2}$

$H3_i := 0 \cdot klf$

$h_{H2_i} := E_{wheel_i} - E_{bftg} + h_{key}$

$y_{H2_i} := \frac{h_{H2_i}}{3} - h_{key}$

$H2_i := \gamma_w \cdot \frac{(h_{H2_i})^2}{2}$

h_{A2_i} = (ft)	y_{A2_i} = (ft)	$A2_i$ = (klf)	h_{A3_i} = (ft)	y_{A3_i} = (ft)	$A3_i$ = (klf)
38.00	19.00	0.0	38.00	12.67	36.5
31.25	15.63	21.3	31.25	10.42	24.7
24.50	12.25	33.4	24.50	8.17	15.2
17.75	8.88	36.3	17.75	5.92	8.0
11.00	5.50	30.0	11.00	3.67	3.1

$$\Sigma M_{lat_i} := -H1_i \cdot (y_{H1_i}) - K1_i \cdot (y_{K1}) - K2_i \cdot (y_{K2}) + H2_i \cdot (y_{H2_i}) + H3_i \cdot (y_{H3}) \ldots$$
$$+ A1_i \cdot (y_{A1_i}) + A2_i \cdot (y_{A2_i}) + A3_i \cdot (y_{A3_i}) - R_{key_i} \cdot (y_{Rkey})$$

$x_{R_i} := \frac{\Sigma M_{grav_i} - \Sigma M_{lat_i}}{W_i - U_i}$ $\qquad L_{brg_i} := \min(3 \cdot x_{R_i}, L_{ftg})$

$ok_{u_i} :=$ if$\left[\left|L_{brg_i} - (L_{ftg} - L_{t1_i})\right| > 0.001 \cdot ft,\right.$ "Uplift assumptions wrong in sliding analysis ", "Matched " $\left.\right]$

W_i = (klf)	u_{toe_i} = (ksf)	u_{heel_i} = (ksf)	δ_{u_i} = (psf/ft)	u_{key_i} = (ksf)	u_{1_i} = (klf)	u_{2_i} = (klf)	u_{3_i} = (klf)
155.8	1.750	2.375	18.5	1.970	20.781	1.307	43.026
152.0	1.328	1.953	17.5	1.536	15.771	1.234	36.596
148.1	0.906	1.531	17.4	1.112	10.762	1.224	26.837
144.3	0.484	1.109	17.4	0.691	5.752	1.224	16.659
143.5	0.375	0.688	8.7	0.478	4.453	0.612	11.534

$u4_i =$ (klf)	$u5_i =$ (klf)	$x_{u3_i} =$ (ft)	$x_{u4_i} =$ (ft)	$x_{u5_i} =$ (ft)	$h_{H2_i} =$ (ft)	$y_{H2_i} =$ (ft)	$I2_i =$ (klf)
4.421	5.4	22.8	26.4	34.9	38.0	12.7	45.1
4.969	0.6	23.8	27.8	35.9	31.3	10.4	30.5
5.052	0.0	23.9	28.0	36.0	24.5	8.2	18.8
5.052	0.0	23.9	28.0	36.0	17.8	5.9	9.8
2.526	0.0	23.9	28.0	36.0	11.0	3.7	3.8

$U_i =$ (klf)	$x_{U_i} =$ (ft)	$\Sigma M_{grav_i} =$ (kip)	$\Sigma M_{lat_i} =$ (kip)	$x_{R_i} =$ (ft)	$L_{brg_i} =$ (ft)
75.0	19.0	1713	805	11.2	33.7
59.2	19.2	1990	885	11.9	35.7
43.9	19.5	2254	922	12.8	36.0
28.7	20.4	2515	930	13.7	36.0
19.1	19.8	2725	925	14.5	36.0

$H_{L_i} := 0 \cdot klf$

$$H_{R_i} := \gamma_w \cdot \frac{\left(E_{wtoe_i} - E_{ftg}\right)^2}{2}$$

$$\Delta P_{2_i} := \frac{\left[\left(W_i + V\right)\cdot\left(\tan\left(\phi_{d_i}\right)\cdot\cos(\alpha) + \sin(\alpha)\right) - U_i\cdot\tan\left(\phi_{d_i}\right) + \left(H_{L_i} - H_{R_i}\right)\cdot\left(\tan\left(\phi_{d_i}\right)\cdot\sin(\alpha) - \cos(\alpha)\right) + \frac{c}{FS_{1_i}}\cdot L\right]}{\left(\cos(\alpha) - \tan\left(\phi_{d_i}\right)\cdot\sin(\alpha)\right)}$$

$H_{L_i} =$ (klf)	$H_{R_i} =$ (klf)
0.0	15.1
0.0	7.3
0.0	2.3
0.0	0.1
0.0	0.0

$$ok_{u_i} = \begin{pmatrix} \text{"Matched."} \\ \text{"Matched."} \\ \text{"Matched."} \\ \text{"Matched."} \\ \text{"Matched."} \end{pmatrix}$$

$L_{ftg} - L_{brg_i} =$ (ft)
2.286
0.300
0.000
0.000
0.000

$$L_{t1} \equiv \begin{pmatrix} 2.286 \\ 0.300 \\ 0 \\ 0 \\ 0 \end{pmatrix}\cdot ft$$

$$ok := \text{if}\left[\max\left(\left|L_{brg} - \left(L_{ftg} - L_{t1}\right)\right|\right) < 0.001\cdot ft, ok, \text{"Uplift area does not match."}\right]$$

$$ok := \text{if}\left(\min\left(L_{brg}\right) < x_{key} + \frac{L_{key}}{2}, \text{"Uplift assumptions incorrect."}, ok\right)$$

$ok = \text{"Ok"}$

Resisting Wedge (#3):

$\beta_W := 0 \cdot deg$

$\phi := \phi_{fill}$ $\phi = 32.0\,deg$

$c := 0 \cdot ksf$

$\phi_{d_i} := atan\left(\frac{tan(\phi)}{FS1_i}\right)$ $\phi_{d_i} = \begin{pmatrix} 24.7 \\ 23.6 \\ 22.5 \\ 21.2 \\ 19.9 \end{pmatrix} deg$

$\alpha_i := 45 \cdot deg - \frac{\phi_{d_i}}{2}$ $\alpha_i = \begin{pmatrix} 32.7 \\ 33.2 \\ 33.8 \\ 34.4 \\ 35.1 \end{pmatrix} deg$

$L_i := \frac{t_{base}}{sin(\alpha_i)}$ $L = \begin{pmatrix} 11.118 \\ 10.958 \\ 10.797 \\ 10.622 \\ 10.442 \end{pmatrix} ft$

$W_i := \gamma_{sat} \cdot \frac{L_i \cdot cos(\alpha_i) \cdot t_{base}}{2} + \gamma_w \cdot (E_{wtoe_i} - E_{ftg}) \cdot L_i \cdot cos(\alpha_i)$

$U_i := \gamma_w \cdot \left(E_{wtoe_i} - E_{ftg} + \frac{t_{base}}{2}\right) \cdot L_i$

$H_L := 0 \cdot klf$

$H_R := 0 \cdot klf$

$V := 0 \cdot klf$

$$\Delta P3_i := \frac{\left[(W_i + V) \cdot (tan(\phi_{d_i}) \cdot cos(\alpha_i) + sin(\alpha_i)) - U_i \cdot tan(\phi_{d_i}) + (H_L - H_R) \cdot (tan(\phi_{d_i}) \cdot sin(\alpha_i) - cos(\alpha_i)) + \frac{c}{FS1_i} \cdot L_i\right]}{(cos(\alpha_i) - tan(\phi_{d_i}) \cdot sin(\alpha_i))}$$

$\Sigma P_i := \Delta P1a_i + \Delta P1b_i + \Delta P2_i + \Delta P3_i$

W_i = (klf)	U_i = (klf)	$\Delta P1a_i$ = (klf)	$\Delta P1b_i$ = (klf)	$\Delta P2_i$ = (klf)	$\Delta P3_i$ = (klf)	ΣP_i = (klf)
16.4	17.4	-64.4	0.0	52.3	12.2	0.1
12.2	12.5	-57.1	0.0	47.8	9.6	0.3
8.2	7.8	-52.0	0.0	45.4	6.9	0.4
4.3	3.2	-49.0	0.0	45.0	4.3	0.2
3.3	2.0	-48.1	0.0	44.9	3.5	0.3

$FS_1 \equiv \begin{pmatrix} 1.36 \\ 1.43 \\ 1.51 \\ 1.61 \\ 1.73 \end{pmatrix}$

ok := if$(FS1_1 \geq 1.33$, ok, "Sliding instability: LC#1")

ok := if$(FS1_n \geq 1.50$, ok, "Sliding instability: LC#n")

ok = "Ok"

Sliding Analysis #2:

$L_\beta = 0.00\,\text{ft}$

$\phi_i := \phi_{fill}$ $\quad \beta_w := \beta \quad \beta_w = 33.7\,\text{deg}$

$$\phi = \begin{pmatrix} 32.0 \\ 32.0 \\ 32.0 \\ 32.0 \\ 32.0 \end{pmatrix} \text{deg}$$

$c := 0 \cdot \text{ksf}$

$$\phi_{d_i} := \text{atan}\left(\frac{\tan(\phi_i)}{FS2_i}\right) \qquad \phi_{d_i} = \begin{pmatrix} 24.7 \\ 23.6 \\ 22.5 \\ 21.2 \\ 19.9 \end{pmatrix} \text{deg}$$

$$\text{atan}\left(\tan(\beta) \cdot FS2_i\right) = \begin{pmatrix} 42.2 \\ 43.6 \\ 45.2 \\ 47.0 \\ 49.1 \end{pmatrix} \text{deg}$$

(back solve for minimum ϕ value for stable slope β, EM 1110–2–2502, pg. 3-31)

$$\phi_i := \text{if}\left[\left(c_1\left(\phi_{d_i}\right)^2 + 4 \cdot c_2\left(\phi_{d_i}, \beta_w\right) < 0\right), \text{atan}\left(\tan(\beta_w) \cdot FS2_i\right), \phi_i\right] \qquad \phi = \begin{pmatrix} 42.2 \\ 43.6 \\ 45.2 \\ 47.0 \\ 49.1 \end{pmatrix} \text{deg}$$

(substitue minimum ϕ if slope is unstable)

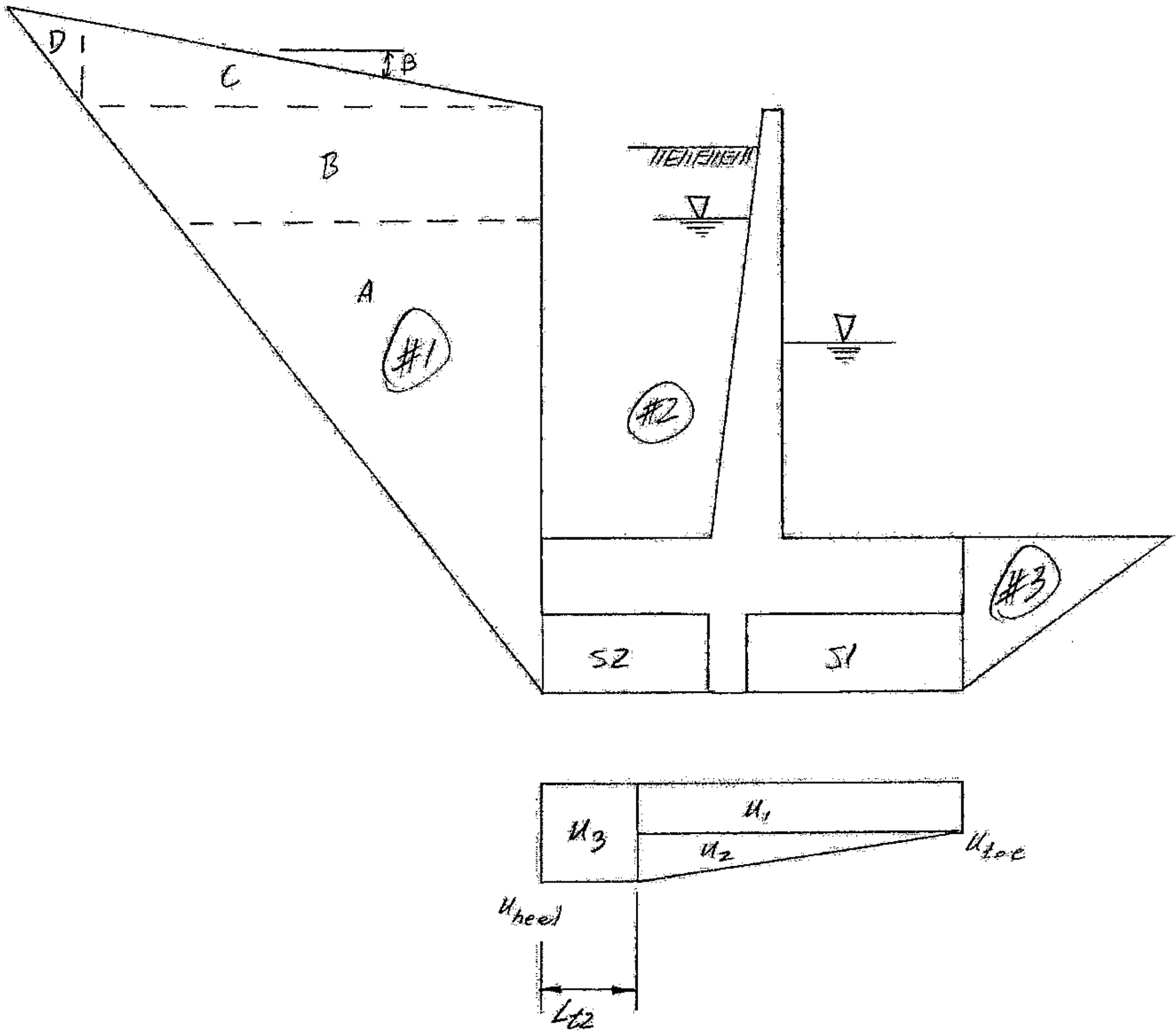
$$\phi_{d\_1b_i} := \text{atan}\left(\frac{\tan(\phi_i)}{FS2_i}\right) \qquad \phi_{d\_1b_i} = \begin{pmatrix} 33.7 \\ 33.7 \\ 33.7 \\ 33.7 \\ 33.7 \end{pmatrix} \text{deg}$$

$$\alpha_{1b_i} := \alpha_{driving}\left(\phi_{d\_1b_i}, \beta_w\right) \qquad \alpha_{1b} = \begin{pmatrix} -33.7 \\ -33.7 \\ -33.7 \\ -33.7 \\ -33.7 \end{pmatrix} \text{deg}$$

$$h_{1b} := \left(E_{grade} + L_{WS5} \cdot \tan(\beta_w)\right) - \left(E_{bftg} - h_{key}\right) \qquad h_{1b} = 38.0\,\text{ft}$$

$$L_{max_i} := \text{if}\left[-\alpha_{1b_i} = \phi_{d\_1b_i}, 1000 \cdot \text{ft}, \frac{\dfrac{h_{1b}}{\cos(-\alpha_{1b_i}) \cdot \left(\tan(-\alpha_{1b_i}) - \tan(\beta_w)\right)}}{\cos(-\alpha_{1b_i})}\right] \qquad L_{max} = \begin{pmatrix} 3.0 \times 10^{9} \\ 1000.0 \\ 1000.0 \\ 1000.0 \\ 1000.0 \end{pmatrix} \text{ft}$$

$$h_{1a_i} := \text{if}\left[L_\beta < L_{max_i}, h_{1b} + L_\beta \cdot \left(\tan(\beta) - \tan(-\alpha_{1b_i})\right), 0\ \text{ft}\right] \qquad h_{1a} = \begin{pmatrix} 3 \\ 38.0 \\ 38.0 \\ 38.0 \\ 38.0 \end{pmatrix} \text{ft}$$



Sliding Analysis #2

Driving Wedge (#1a):

$\beta_w := 0 \cdot deg$ $\qquad \beta_w = 0.0\,deg$

$\phi := \phi_{fill}$ $\qquad \phi = 32.0\,deg$

$c := 0 \cdot ksf$

$\phi_{d_i} := atan\left(\frac{tan(\phi)}{FS_{2_i}}\right)$ $\qquad \phi_d = \begin{pmatrix} 24.7 \\ 23.6 \\ 22.5 \\ 21.2 \\ 19.9 \end{pmatrix} deg$

$\alpha_i := \alpha_{driving}\left(\phi_{d_i}, \beta_w\right)$ $\qquad \alpha = \begin{pmatrix} -57.34 \\ -56.80 \\ -56.24 \\ -55.61 \\ -54.93 \end{pmatrix} deg$

$h_i := h_{1a_i}$

$h_i := h_{1a_i}$ $\qquad h = \begin{pmatrix} 38.0 \\ 38.0 \\ 38.0 \\ 38.0 \\ 38.0 \end{pmatrix} ft$

$L_i := \frac{h_i}{cos(-\alpha_i) \cdot \left(tan(-\alpha_i) - tan(\beta_w)\right)}$ $\qquad = \begin{pmatrix} 45.14 \\ 45.41 \\ 45.71 \\ 46.05 \\ 46.43 \end{pmatrix} ft$

$h_{sat_i} := max\left[\begin{bmatrix} E_{wheel_i} - \left(E_{ftg} - t_{base} - h_{key}\right) - L_\beta \cdot tan\left(-\alpha_{1b_i}\right) \\ 0 \cdot ft \end{bmatrix}\right]$ $\qquad h_{sat} = \begin{pmatrix} 38.0 \\ 31.3 \\ 24.5 \\ 17.8 \\ 11.0 \end{pmatrix} ft$

$L_{h_i} := \frac{h_i}{tan(-\alpha_i)}$ $\qquad L_h = \begin{pmatrix} 24.360 \\ 24.865 \\ 25.400 \\ 26.013 \\ 26.677 \end{pmatrix} ft$

$L_{sat_i} := \frac{h_{sat_i}}{tan(-\alpha_i)}$ $\qquad L_{sat} = \begin{pmatrix} 24.36 \\ 20.45 \\ 16.38 \\ 12.15 \\ 7.72 \end{pmatrix} ft$

$h_{left} := 0 \cdot ft$

$h_{right_i} := h_{1a_i}$

$W_i := \gamma_{fill} \cdot \left(L_{h_i} \cdot \frac{h_{left} + h_{right_i}}{2}\right) + \left(\gamma_{sat} - \gamma_{fill}\right) \cdot \frac{L_{sat_i} \cdot h_{sat_i}}{2}$

$W_i =$

59.011
60.617
62.236
63.983
65.787

klf

$V := 0 \cdot klf$

$H_L := 0 \cdot klf$

$H_R := 0 \cdot klf$

$$U_i := \gamma_w \cdot \left(\frac{h_{sat_i}}{2}\right) \cdot \sqrt{\left(h_{sat_i}\right)^2 + \left(L_{sat_i}\right)^2}$$

$$U = \begin{pmatrix} 53.601 \\ 36.470 \\ 22.562 \\ 11.932 \\ 4.620 \end{pmatrix} \text{klf}$$

$$\Delta P_{1a_i} := \frac{\left[\left(W_i + V\right) \cdot \left(\tan\left(\phi_{d_i}\right) \cos\left(\alpha_i\right) + \sin\left(\alpha_i\right)\right) - U_i \cdot \tan\left(\phi_{d_i}\right) + \left(H_L - H_R\right) \cdot \left(\tan\left(\phi_{d_i}\right) \cdot \sin\left(\alpha_i\right) - \cos\left(\alpha_i\right)\right) + \frac{c}{FS_{2_i}} \cdot L_i\right]}{\left(\cos\left(\alpha_i\right) - \tan\left(\phi_{d_i}\right) \sin\left(\alpha_i\right)\right)}$$

Driving Wedge (#1b): $L_\beta = 0.0\,\text{ft}$

$\beta_w := \beta$ $\beta_w = 33.7\,\text{deg}$

$\alpha := \alpha_{1b}$

$$\alpha = \begin{pmatrix} -33.7 \\ -33.7 \\ -33.7 \\ -33.7 \\ -33.7 \end{pmatrix} \text{deg}$$

$\phi_d := \phi_{d\_1b}$

$$\phi_d = \begin{pmatrix} 33.7 \\ 33.7 \\ 33.7 \\ 33.7 \\ 33.7 \end{pmatrix} \text{deg}$$

$$h = \begin{pmatrix} 38.0 \\ 38.0 \\ 38.0 \\ 38.0 \\ 38.0 \end{pmatrix} \text{ft}$$

$L_h := L_\beta$ $L_h = 0.0\,\text{ft}$

$$L_i := \frac{L_\beta}{\cos\left(\alpha_i\right)}$$

$$L = \begin{pmatrix} 0.0 \\ 0.0 \\ 0.0 \\ 0.0 \\ 0.0 \end{pmatrix} \text{ft}$$

$$h_{satr_i} := \max\left[\begin{bmatrix} E_{wheel_i} - \left(E_{ftg} - t_{base} - h_{key}\right) \\ 0 \cdot \text{ft} \end{bmatrix}\right]$$

$$h_{satr} = \begin{pmatrix} 38.0 \\ 31.3 \\ 24.5 \\ 17.8 \\ 11.0 \end{pmatrix} \text{ft}$$

$$h_{satl_i} := \max\left[\begin{bmatrix} E_{wheel_i} - \left(E_{ftg} - t_{base} - h_{key}\right) - \frac{L_\beta}{\cos\left(\alpha_i\right)} \\ 0 \cdot \text{ft} \end{bmatrix}\right]$$

$$h_{satl} = \begin{pmatrix} 38.0 \\ 31.3 \\ 24.5 \\ 17.8 \\ 11.0 \end{pmatrix} \text{ft}$$

$$L_{sat_i} := \min\left[\begin{bmatrix} L_\beta \\ \dfrac{h_{satr_i}}{\tan\left[(-\alpha)_i\right]} \end{bmatrix}\right]$$

$$L_{sat} = \begin{pmatrix} 0.0 \\ 0.0 \\ 0.0 \\ 0.0 \\ 0.0 \end{pmatrix} \text{ft}$$

$h_{left_i} := h_{1a_i}$

$$h_{left} = \begin{pmatrix} 38.0 \\ 38.0 \\ 38.0 \\ 38.0 \\ 38.0 \end{pmatrix} \text{ft}$$

$h_{right} := h_{1b}$ $h_{right} = 38.0\,\text{ft}$

$$W_i := \gamma_{fill} \cdot \left(L_h \cdot \frac{h_{left_i} + h_{right}}{2}\right) + \left(\gamma_{sat} - \gamma_{fill}\right) \cdot L_{sat_i} \cdot \left(\frac{h_{satr_i} + h_{satl_i}}{2}\right)$$

$V := 0 \cdot klf$

$H_L := 0 \cdot klf$

$H_R := 0 \cdot klf$

$U_i := \gamma_w \cdot \left(\frac{h_{satr_i} + h_{satl_i}}{2}\right) \sqrt{\left(h_{satr_i} - h_{satl_i}\right)^2 + \left(L_h\right)^2}$

$W_i =$

0.0
0.0
0.0
0.0
0.0

klf

$$\Delta P_{1b_i} := \frac{\left[\left(W_i + V\right) \cdot \left(\tan\left(\phi_{d_i}\right) \cos\left(\alpha_i\right) + \sin\left(\alpha_i\right)\right) - U_i \cdot \tan\left(\phi_{d_i}\right) + \left(H_L - H_R\right) \cdot \left(\tan\left(\phi_{d_i}\right) \cdot \sin\left(\alpha_i\right) - \cos\left(\alpha_i\right)\right) + \frac{c}{FS_{2_i}} \cdot L_i\right]}{\left(\cos\left(\alpha_i\right) - \tan\left(\phi_{d_i}\right) \cdot \sin\left(\alpha_i\right)\right)}$$

Structure Wedge (#2)

$U_i =$

0.0
0.0
0.0
0.0
0.0

klf

$\beta_w := 0 \cdot deg$

$\phi := \phi_{fill}$ $\phi = 32.0\,deg$

$c := 0 \cdot ksf$

$\phi_{d_i} := atan\left(\frac{\tan(\phi)}{FS_{2_i}}\right)$ $\phi_{d_i} = \begin{pmatrix} 24.7 \\ 23.6 \\ 22.5 \\ 21.2 \\ 19.9 \end{pmatrix} deg$

$\alpha := 0 \cdot deg$ $\alpha = 0.0\,deg$

$L := \frac{L_{ftg}}{\cos(\alpha)}$ $L = 36.0\,ft$

$h_{S1} := h_{key}$ $h_{S1} = 0.0\,ft$

$L_{S1} := x_{key} - \frac{L_{key}}{2}$ $L_{S1} = 11.9\,ft$

$x_{S1} := \frac{1}{2} \cdot L_{S1}$ $x_{S1} = 5.9\,ft$

$S1 := \gamma_{sat} \cdot h_{S1} \cdot L_{S1}$ $S1 = 0.0\,klf$

$h_{S2} := h_{key}$ $\qquad h_{S2} = 0.0\,\text{ft}$

$L_{S2} := L_{ftg} - x_{key} - \dfrac{L_{key}}{2}$ $\qquad L_{S2} = 20.1\,\text{ft}$

$x_{S2} := L_{ftg} - \dfrac{L_{S2}}{2}$ $\qquad x_{S2} = 25.9\,\text{ft}$

$S2 := \gamma_{sat} \cdot h_{S2} \cdot L_{S2}$ $\qquad S2 = 0.0\,\text{klf}$

$$W_i := \sum_{i=1}^{4} W_{C_i} + W_{W1_i} + W_{WS1_i} + W_{WS2_i} + W_{WS3_i} + W_{WS4_i} + W_{WS5} + W_{WS6} + S1 + S2 + S_{\beta_i}$$

Uplift below structural wedge:

$u_{toe_i} := \gamma_w \left\lfloor E_{wtoe_i} - \left(E_{bftg} - h_{key}\right)\right\rfloor$

$u_{heel_i} := \gamma_w \cdot \left\lfloor E_{wheel_i} - \left(E_{bftg} - h_{key}\right)\right\rfloor$

$\delta_{u_i} := \dfrac{\gamma_w \cdot \left(E_{wheel_i} - E_{wtoe_i}\right)}{L_{ftg} - L_{t2_i}}$

$u_{1_i} := u_{toe_i} \cdot \left(L_{ftg} - L_{t2_i}\right)$

$x_{u1_i} := \dfrac{L_{ftg} - L_{t2_i}}{2}$ $\qquad x_{u1} = \begin{pmatrix} 16.9 \\ 17.9 \\ 18.0 \\ 18.0 \\ 18.0 \end{pmatrix} \text{ft}$

$u_{2_i} := \left(u_{heel_i} - u_{toe_i}\right) \cdot \dfrac{\left(L_{ftg} - L_{t2_i}\right)}{2}$

$x_{u2_i} := \dfrac{2}{3} \cdot \left(L_{ftg} - L_{t2_i}\right)$ $\qquad x_{u2} = \begin{pmatrix} 22.5 \\ 23.8 \\ 24.0 \\ 24.0 \\ 24.0 \end{pmatrix} \text{ft}$

$u_{3_i} := u_{heel_i} \cdot \left(L_{t2_i}\right)$

$x_{u3_i} := L_{ftg} - \dfrac{L_{t2_i}}{2}$

$U_i := u_{1_i} + u_{2_i} + u_{3_i}$

$x_{U_i} := \dfrac{u_{1_i} \cdot x_{u1_i} + u_{2_i} \cdot x_{u2_i} + u_{3_i} \cdot x_{u3_i}}{U_i}$ $\qquad x_U = \begin{pmatrix} 19.0 \\ 19.2 \\ 19.5 \\ 20.4 \\ 19.8 \end{pmatrix} \text{ft}$

$$\Sigma M_{grav_i} := \left(\sum_{i=1}^{4} W_{C_i} \cdot x_{C_i} + W_{W1_i} \cdot x_{W1} + W_{WS1_i} \cdot x_{WS1} + W_{WS2_i} \cdot x_{WS2_i} + W_{WS3_i} \cdot x_{WS3_i} \right) \cdots + W_{WS4_i} \cdot x_{WS4_i} + W_{WS5} \cdot x_{WS5} + W_{WS6} \cdot x_{WS6} + S1 \cdot x_{S1} + S2 \cdot x_{S2} + S_{\beta_i} \cdot x_{S\beta} - \left(U_i \cdot x_{U_i}\right)$$

$$h_{H1_i} := E_{wtoe_i} - \left(E_{bftg} - h_{key}\right)$$

$$y_{H1_i} := \frac{h_{H1_i}}{3} - h_{key}$$

$$H1_i := \gamma_w \cdot \frac{\left(h_{H1_i}\right)^2}{2}$$

h_{H1_i} = (ft)	y_{H1_i} = (ft)	$H1_i$ = (klf)
28.00	9.33	24.5
21.25	7.08	14.1
14.50	4.83	6.6
7.75	2.58	1.9
6.00	2.00	1.1

$$K1_i := 0 \cdot \text{klf}$$

$$K2_i := 0 \cdot \text{klf}$$

$$\Sigma M_{lat_i} := -H1_i \cdot \left(y_{H1_i}\right) - K1_i \cdot \left(y_{K1}\right) - K2_i \cdot \left(y_{K2}\right) + H2_i \cdot \left(y_{H2_i}\right) + H3_i \cdot \left(y_{H3}\right) \cdots + A1_i \cdot \left(y_{A1_i}\right) + A2_i \cdot \left(y_{A2_i}\right) + A3_i \cdot \left(y_{A3_i}\right) - R_{key_i} \cdot \left(y_{Rkey}\right)$$

$$x_{R_i} := \frac{\Sigma M_{grav_i} - \Sigma M_{lat_i}}{W_i - U_i} \qquad L_{brg_i} := \min\left(3 \cdot x_{R_i}, L_{ftg}\right)$$

$$ok_{u_i} := \text{if}\left[\left|L_{brg_i} - \left(L_{ftg} - L_{t2_i}\right)\right| > 0.001 \cdot \text{ft}, \text{"Uplift assumptions wrong in sliding analysis."}, \text{"Matched."}\right]$$

W_i = (klf)	u_{toe_i} = (ksf)	u_{heel_i} = (ksf)	δ_{u_i} = (psf/ft)	$u1_i$ = (klf)	$u2_i$ = (klf)	$u3_i$ = (klf)
155.8	1.750	2.375	18.5	58.999	10.536	5.429
152.0	1.328	1.953	17.5	47.414	11.156	0.586
148.1	0.906	1.531	17.4	32.625	11.250	0.000
144.3	0.484	1.109	17.4	17.438	11.250	0.000
143.5	0.375	0.688	8.7	13.500	5.625	0.000

$x_{u3_i} =$

34.9	ft
35.9	
36.0	
36.0	
36.0	

h_{H2_i} =	y_{H2_i} =	$H2_i$ =
38.0 ft	12.7 ft	45.1 klf
31.3	10.4	30.5
24.5	8.2	18.8
17.8	5.9	9.8
11.0	3.7	3.8

U_i =	x_{U_i} =	ΣM_{grav_i} =	ΣM_{lat_i} =	x_{R_i} =	L_{brg_i} =
75.0 klf	19.0 ft	1713 kip	805 kip	11.2 ft	33.7 ft
59.2	19.2	1990	885	11.9	35.7
43.9	19.5	2254	922	12.8	36.0
28.7	20.4	2515	930	13.7	36.0
19.1	19.8	2725	925	14.5	36.0

$$H_{L_i} := 0 \cdot klf$$

$$H_{R_i} := \gamma_w \cdot \frac{\left(E_{wtoe_i} - E_{ftg}\right)^2}{2}$$

$$\Delta P_{2_i} := \frac{\left[\left(W_i + V\right)\left(\tan\left(\phi_{d_i}\right)\cdot\cos(\alpha) + \sin(\alpha)\right) - U_i \cdot \tan\left(\phi_{d_i}\right) + \left(H_{L_i} - H_{R_i}\right)\left(\tan\left(\phi_{d_i}\right)\cdot\sin(\alpha) - \cos(\alpha)\right) + \frac{c}{FS_{2_i}} \cdot L\right]}{\left(\cos(\alpha) - \tan\left(\phi_{d_i}\right)\cdot\sin(\alpha)\right)}$$

H_{L_i} =	H_{R_i} =
0.0 klf	15.1 klf
0.0	7.3
0.0	2.3
0.0	0.1
0.0	0.0

$$ok_{u_i} = \begin{pmatrix} \text{"Matched."} \\ \text{"Matched."} \\ \text{"Matched."} \\ \text{"Matched."} \\ \text{"Matched."} \end{pmatrix}$$

$L_{ftg} - L_{brg_i} =$

2.286	ft
0.300	
0.000	
0.000	
0.000	

$$L_{t2} \equiv \begin{pmatrix} 2.286 \\ 0.300 \\ 0 \\ 0 \\ 0 \end{pmatrix} \cdot ft$$

$$ok := \text{if}\left[\max\left(\left|L_{brg} - \left(L_{ftg} - L_{t2}\right)\right|\right) < 0.001 \cdot ft, ok, \text{"Uplift area does not match."}\right]$$

$$ok := \text{if}\left(\min\left(L_{brg}\right) < x_{key} + \frac{L_{key}}{2}, \text{"Uplift assumptions incorrect."}, ok\right) \qquad ok = \text{"Ok"}$$

Resisting Wedge (#3):

$\beta_w := 0 \cdot deg$

$\phi := \phi_{fill}$ $\qquad \phi = 32.0\,deg$

$c := 0 \cdot ksf$

$$\phi_{d_i} := atan\left(\frac{tan(\phi)}{FS_{2_i}}\right) \qquad \phi_{d_i} = \begin{pmatrix} 24.7 \\ 23.6 \\ 22.5 \\ 21.2 \\ 19.9 \end{pmatrix} deg$$

$$\alpha_i := 45 \cdot deg - \frac{\phi_{d_i}}{2} \qquad \alpha_i = \begin{pmatrix} 32.7 \\ 33.2 \\ 33.8 \\ 34.4 \\ 35.1 \end{pmatrix} deg$$

$$L_i := \frac{t_{base} + h_{key}}{sin(\alpha_i)} \qquad L = \begin{pmatrix} 11.118 \\ 10.958 \\ 10.797 \\ 10.622 \\ 10.442 \end{pmatrix} ft$$

$$W_i := \gamma_{sat} \cdot \frac{L_i \cdot cos(\alpha_i) \cdot (t_{base} + h_{key})}{2} + \gamma_w \cdot (E_{wtoe_i} - E_{ftg}) \cdot L_i \cdot cos(\alpha_i)$$

$$U_i := \gamma_w \cdot \left(E_{wtoe_i} - E_{ftg} + \frac{t_{base} + h_{key}}{2}\right) \cdot L_i$$

$H_L := 0 \cdot klf$

$H_R := 0 \cdot klf$

$V := 0 \cdot klf$

$$\Delta P_{3_i} := \frac{\left[(W_i + V) \cdot (tan(\phi_{d_i}) \cdot cos(\alpha_i) + sin(\alpha_i)) - U_i \cdot tan(\phi_{d_i}) + (H_L - H_R) \cdot (tan(\phi_{d_i}) \cdot sin(\alpha_i) - cos(\alpha_i)) + \frac{c}{FS_{2_i}} \cdot L_i\right]}{(cos(\alpha_i) - tan(\phi_{d_i}) \cdot sin(\alpha_i))}$$

$$\Sigma P_i := \Delta P_{1a_i} + \Delta P_{1b_i} + \Delta P_{2_i} + \Delta P_{3_i}$$

$$FS_2 \equiv \begin{pmatrix} 1.36 \\ 1.43 \\ 1.51 \\ 1.61 \\ 1.73 \end{pmatrix}$$

W_i = (klf)	U_i = (klf)	ΔP_{1a_i} = (klf)	ΔP_{1b_i} = (klf)	ΔP_{2_i} = (klf)	ΔP_{3_i} = (klf)	ΣP_i = (klf)
16.4	17.4	-64.4	0.0	52.3	12.2	0.1
12.2	12.5	-57.1	0.0	47.8	9.6	0.3
8.2	7.8	-52.0	0.0	45.4	6.9	0.4
4.3	3.2	-49.0	0.0	45.0	4.3	0.2
3.3	2.0	-48.1	0.0	44.9	3.5	0.3

$h_{key} \equiv 0 \cdot ft$

$L_{ftg} = 36.0\,ft$

$ok := if(FS_{2_1} \geq 1.33, ok, \text{"Sliding instability: LC\#1"})$

$L_{heel} \equiv 26 \cdot ft$

$ok := if(FS_{2_n} \geq 1.50, ok, \text{"Sliding instability: LC\#n"})$ $\qquad L_{ftg} - x_{key} - \frac{L_{key}}{2} = 20.1\,ft$

$L_{toe} \equiv 10 \cdot ft$

ok = "Ok"

Section 3
Upstream Retaining Walls

Upstream Training Wall at Right: (Grade = 507.0')

Reference:T:\ST\CALCS\Common geometry.mcd(R)

Geometry:

$E_{wall} := 510 \cdot ft$

$E_{ftg} := E_{approach}$ $\quad E_{ftg} = 500.0\,ft$

$t_{base} := 5 \cdot ft$

$E_{bftg} := E_{ftg} - t_{base}$ $\quad E_{bftg} = 495.0\,ft$

$E_{grade} := 507 \cdot ft$

$n := 5$

$i := 1..n$

$\Delta_w := 10 \cdot ft$ (maximum height of retained water above water in basin)

$$E_{wheel_i} := E_{grade} - \frac{\left[E_{grade} - \left(E_{ftg} + \frac{\Delta_w}{2}\right)\right]}{n-1} \cdot (i-1) \qquad E_{wheel} = \begin{pmatrix} 507.0 \\ 506.5 \\ 506.0 \\ 505.5 \\ 505.0 \end{pmatrix} ft$$

$$E_{wtoe_i} := \max\left(\begin{pmatrix} E_{wheel_i} - \Delta_w \\ E_{ftg} \end{pmatrix}\right) \qquad E_{wtoe} = \begin{pmatrix} 500.0 \\ 500.0 \\ 500.0 \\ 500.0 \\ 500.0 \end{pmatrix} ft$$

$$h := \min\left[\left[\begin{matrix} \left[\frac{1.0}{1.5} \cdot 2 \cdot \left(E_{grade} - E_{ftg}\right)\right] + E_{grade} \\ 527 \cdot ft - E_{ftg} \end{matrix}\right]\right] \qquad h = 27.0\,ft$$

$$\beta := \operatorname{atan}\left(\frac{1.0}{1.5}\right) \qquad \beta = 33.7\,deg$$

$h_\beta := 527 \cdot ft - E_{grade}$ $\quad h_\beta = 20.0\,ft$

$t_{w\_top} := 1.5 \cdot ft$

$$t_{w\_bot} := t_{w\_top} + \frac{\left(E_{wall} - E_{ftg}\right)}{8} \qquad t_{w\_bot} = 2.75\,ft$$

$L_{toe} = 8.0\,ft$

$L_{heel} = 20.0\,ft$

$L_{ftg} := L_{toe} + L_{heel}$ $\quad L_{ftg} = 28.0\,ft$

$h_{wall} := E_{wall} - E_{ftg}$ $\quad h_{wall} = 10.0\,ft$

$h_{key} = 8.0\,ft$

$L_{key} := 3 \cdot ft$ $\quad L_{key} = 3.0\,ft$

$x_{key} := L_{toe} + t_{w\_bot} - \frac{L_{key}}{2}$ $\quad x_{key} = 9.250\,ft$

Constants:

$\gamma_w = 62.5\,pcf$

Soil parameters:

$\gamma_{fill\_eff} = 65.0\,pcf$ $\quad \gamma_{sat} = 127.5\,pcf$

$\gamma_{fill} = 130.0\,pcf$

$k_{0\_fill} = 0.5$

$\phi_{fill} = 32.0\,deg$

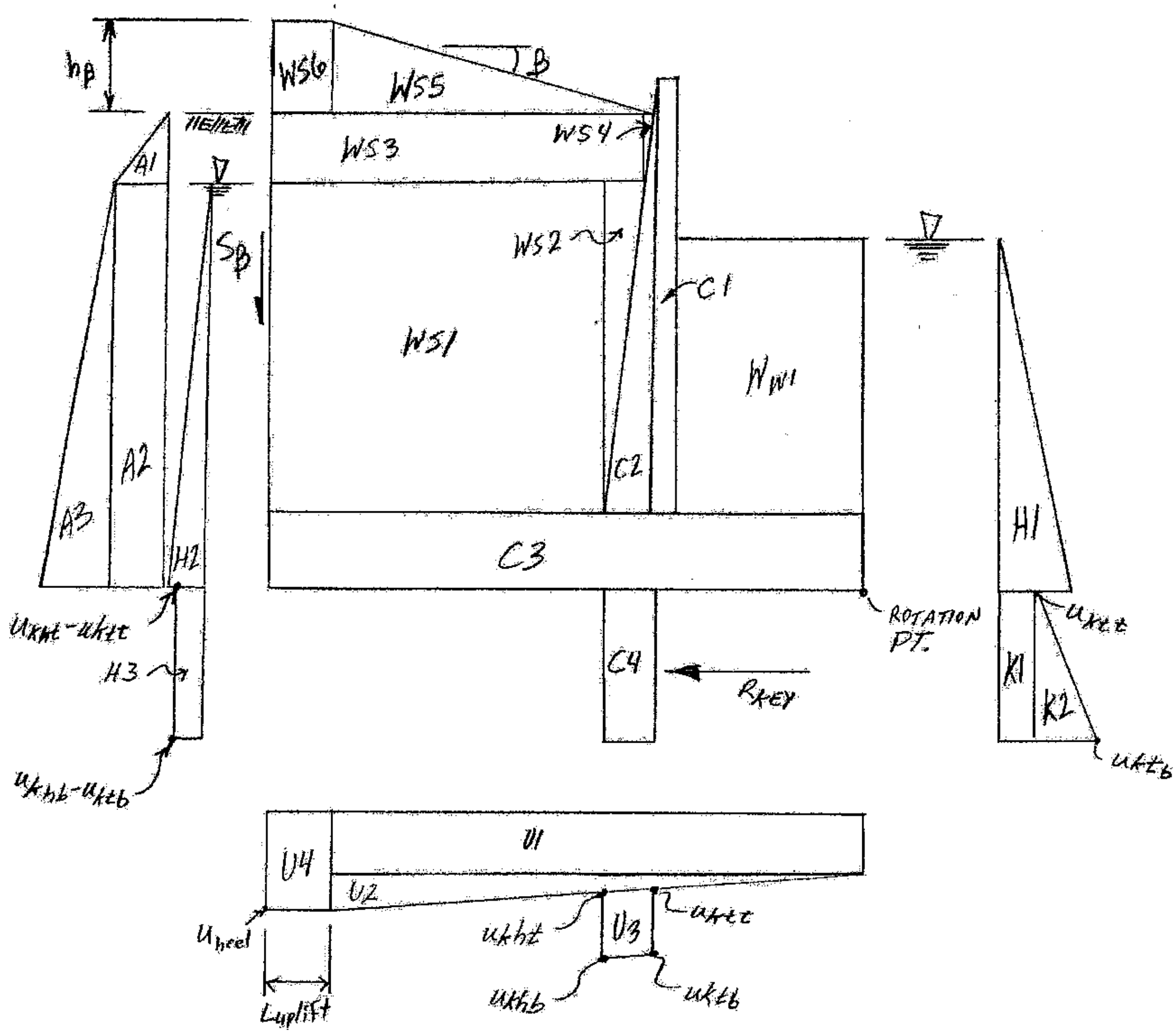
$k_{0\beta} := k_{0\_fill} \cdot (1 + \sin(\beta))$ $\quad k_{0\beta} = 0.777$ (USACE EM 1110-2-2502, Eq. 3-5)

Pre-Definitions:

$kip \equiv 1000 \cdot lbf$ $\quad ksi \equiv 1000\ psi$ $\quad ok \equiv$ "Ok" $\quad klf \equiv 1000 \cdot \frac{lbf}{ft}$

$psf \equiv \frac{lbf}{ft^2}$ $\quad plf \equiv \frac{lbf}{ft}$ $\quad pcf \equiv \frac{lbf}{ft^3}$

$ORIGIN = 1.0$ (must equal to 1)


hβ
β
WS6
WS5
WS3
WS4
A1
A2
A3
Sβ
WS2
C1
WS1
Ww1
C2
H1
H2
C3
ROTATION PT.
ukht-uktt
uktt
H3
C4
RKEY
K1
K2
ukhb-uktb
uktb
U1
U4
U2
U3
uheel
ukht
uktt
ukhb
uktb
Luplift

Analysis:

Gravity Loads:

$h_{C_1} := h_{wall}$ $h_{C_1} = 10.0\,ft$

$L_{C_1} := t_{w\_top}$ $L_{C_1} = 1.5\,ft$

$x_{C_1} := L_{toe} + \frac{L_{C_1}}{2}$ $x_{C_1} = 8.8\,ft$

$W_{C_1} := \gamma_c \cdot h_{C_1} \cdot L_{C_1}$ $W_{C_1} = 2.3\,klf$

$h_{C_2} := h_{C_1}$ $h_{C_2} = 10.0\,ft$

$L_{C_2} := t_{w\_bot} - t_{w\_top}$ $L_{C_2} = 1.3\,ft$

$x_{C_2} := L_{toe} + L_{C_1} + \frac{L_{C_2}}{3}$ $x_{C_2} = 9.9\,ft$

$W_{C_2} := \gamma_c \cdot \frac{h_{C_2} \cdot L_{C_2}}{2}$ $W_{C_2} = 0.9\,klf$

$h_{C_3} := t_{base}$ $h_{C_3} = 5.0\,ft$

$L_{C_3} := L_{ftg}$ $L_{C_3} = 28.0\,ft$

$x_{C_3} := \frac{L_{C_3}}{2}$ $x_{C_3} = 14.0\,ft$

$W_{C_3} := \gamma_c \cdot h_{C_3} \cdot L_{C_3}$ $W_{C_3} = 21.0\,klf$

$h_{C_4} := h_{key}$ $h_{C_4} = 8.0\,ft$

$L_{C_4} := L_{key}$ $L_{C_4} = 3.0\,ft$

$x_{C_4} := x_{key}$ $x_{C_4} = 9.250\,ft$

$W_{C_4} := \gamma_c \cdot h_{C_4} \cdot L_{C_4}$ $\qquad W_{C_4} = 3.6\,\text{klf}$

Weight of water at toe:

$h_{W1_i} := E_{wtoe_i} - E_{ftg}$ $\qquad h_{W1} = \begin{pmatrix} 0.00 \\ 0.00 \\ 0.00 \\ 0.00 \\ 0.00 \end{pmatrix} \text{ft}$

$L_{W1} := L_{toe}$ $\qquad L_{W1} = 8.0\,\text{ft}$

$x_{W1} := \frac{L_{toe}}{2}$ $\qquad x_{W1} = 4.0\,\text{ft}$

$W_{W1_i} := \gamma_w \cdot h_{W1_i} \cdot L_{W1}$ $\qquad W_{W1} = \begin{pmatrix} 0.0 \\ 0.0 \\ 0.0 \\ 0.0 \\ 0.0 \end{pmatrix} \text{klf}$

Weight of water/soil at heel:

$h_{WS1_i} := E_{wheel_i} - E_{ftg}$ $\qquad h_{WS1} = \begin{pmatrix} 7.00 \\ 6.50 \\ 6.00 \\ 5.50 \\ 5.00 \end{pmatrix} \text{ft}$

$L_{WS1} := L_{heel} - t_{w\_bot}$ $\qquad L_{WS1} = 17.3\,\text{ft}$

$x_{WS1} := L_{toe} + t_{w\_bot} + \frac{L_{WS1}}{2}$ $\qquad x_{WS1} = 19.4\,\text{ft}$

$W_{WS1_i} := (\gamma_{sat}) \cdot h_{WS1_i} \cdot L_{WS1}$ $\qquad W_{WS1} = \begin{pmatrix} 15.4 \\ 14.3 \\ 13.2 \\ 12.1 \\ 11.0 \end{pmatrix} \text{klf}$

$h_{WS2_i} := h_{WS1_i}$

$L_{WS2_i} := \frac{t_{w\_bot} - t_{w\_top}}{h_{wall}} \cdot h_{WS2_i}$ $\qquad L_{WS2} = \begin{pmatrix} 0.88 \\ 0.81 \\ 0.75 \\ 0.69 \\ 0.63 \end{pmatrix} \text{ft}$

$x_{WS2_i} := L_{toe} + t_{w\_bot} - \frac{L_{WS2_i}}{3}$ $\qquad x_{WS2} = \begin{pmatrix} 10.5 \\ 10.5 \\ 10.5 \\ 10.5 \\ 10.5 \end{pmatrix} \text{ft}$

$$W_{WS2_i} := (\gamma_{sat}) \cdot \frac{h_{WS2_i} \cdot L_{WS2_i}}{2}$$

$W_{WS2_i} =$

0.4
0.3
0.3
0.2
0.2

klf

$$h_{WS3_i} := E_{grade} - E_{wheel_i}$$

$h_{WS3_i} =$

0.0
0.5
1.0
1.5
2.0

ft

$$L_{WS3_i} := L_{WS1} + L_{WS2_i}$$

$L_{WS3_i} =$

18.1
18.1
18.0
17.9
17.9

ft

$$x_{WS3_i} := L_{ftg} - \frac{L_{WS3_i}}{2}$$

$x_{WS3_i} =$

18.9
19.0
19.0
19.0
19.1

ft

$$W_{WS3_i} := \gamma_{fill} \cdot h_{WS3_i} \cdot L_{WS3_i}$$

$W_{WS3_i} =$

0.0
1.2
2.3
3.5
4.6

klf

$$h_{WS4_i} := h_{WS3_i}$$

$$L_{WS4_i} := \frac{t_{w\_bot} - t_{w\_top}}{h_{wall}} \cdot h_{WS4_i}$$

$L_{WS4_i} =$

0.0
0.1
0.1
0.2
0.3

ft

$$x_{WS4_i} := L_{ftg} - L_{WS3_i} - \frac{L_{WS4_i}}{3}$$

$x_{WS4_i} =$

9.9
9.9
10.0
10.0
10.0

ft

$$W_{WS4_i} := \gamma_{fill} \cdot \frac{h_{WS4_i} \cdot L_{WS4_i}}{2}$$

$W_{WS4_i} =$

0.0
$2.0 \cdot 10^{-3}$
$8.1 \cdot 10^{-3}$
0.0
0.0

klf

$$L_{WS5} := \min\left(\left[\begin{matrix} \frac{t_{w\_bot} - t_{w\_top}}{h_{wall}} \cdot (E_{grade} - E_{ftg}) + L_{WS1} \\ \frac{h_\beta}{\tan(\beta)} \end{matrix}\right]\right)$$

$L_{WS5} = 18.13\,ft$

$$h_{WS5} := L_{WS5} \cdot \tan(\beta)$$ $h_{WS5} = 12.08\,ft$

$$x_{WS5} := \frac{2}{3} \cdot L_{WS5} + L_{toe} + t_{w\_top} + \frac{(E_{wall} - E_{grade})}{E_{wall} - E_{ftg}} \cdot (t_{w\_bot} - t_{w\_top})$$ $x_{WS5} = 21.96\,ft$

$$W_{WS5} := \gamma_{fill} \cdot \frac{h_{WS5} \cdot L_{WS5}}{2}$$ $W_{WS5} = 14.2\,klf$

$$L_{WS6} := \frac{E_{grade} - E_{ftg}}{h_{wall}} \cdot (t_{w\_bot} - t_{w\_top}) + L_{WS1} - L_{WS5}$$ $L_{WS6} = 0.0\,ft$

$$h_{WS6} := h_{WS5}$$ $h_{WS6} = 12.1\,ft$

$$x_{WS6} := L_{ftg} - \frac{L_{WS6}}{2}$$ $x_{WS6} = 28.0\,ft$

$$W_{WS6} := \gamma_{fill} \cdot (h_{WS6} \cdot L_{WS6})$$ $W_{WS6} = 0.0\,klf$

Uplift:

$u_{toe_i} := \gamma_w \cdot (E_{wtoe_i} - E_{bftg})$

$u_{heel_i} := \gamma_w \cdot (E_{wheel_i} - E_{bftg})$

$\delta_{seep_i} := \dfrac{u_{heel_i} - u_{toe_i}}{L_{ftg} - L_{uplift_i}}$

$u_{ktt_i} := u_{heel_i} + \left(x_{key} - \dfrac{L_{key}}{2}\right) \cdot \delta_{seep_i}$

$u_{kht_i} := u_{ktt_i} + L_{key} \cdot \delta_{seep_i}$

$u_{ktb_i} := u_{ktt_i} + \gamma_w \cdot h_{key}$

$u_{khb_i} := u_{ktb_i} + L_{key} \cdot \delta_{seep_i}$

$x_{U1} := \dfrac{L_{ftg} - L_{uplift}}{2}$

$U1_i := u_{toe_i} \cdot L_{ftg}$

$x_{U2_i} := \dfrac{2}{3} \cdot (L_{ftg} - L_{uplift_i})$

$U2_i := (u_{heel_i} - u_{toe_i}) \cdot \dfrac{L_{ftg}}{2}$

$x_{U3} := x_{key}$

$U3_i := (u_{ktb_i} - u_{ktt_i}) \cdot L_{key}$

$x_{U4_i} := L_{ftg} - \dfrac{L_{uplift_i}}{2}$

$L_{U4_i} := L_{uplift_i}$

$U4_i := u_{heel_i} \cdot L_{U4_i}$

u_{toe_i} (ksf)	u_{heel_i} (ksf)	δ_{seep_i} (psf/ft)	u_{ktt_i} (ksf)	u_{kht_i} (ksf)
0.313	0.750	15.625	0.871	0.918
0.313	0.719	14.509	0.831	0.875
0.313	0.688	13.393	0.791	0.831
0.313	0.656	12.277	0.751	0.788
0.313	0.625	11.161	0.711	0.745

u_{ktb_i} (ksf)	u_{khb_i} (ksf)	x_{U1_i} (ft)	$U1_i$ (klf)	x_{U2_i} (ft)
1.371	1.418	14.0	8.8	18.67
1.331	1.375	14.0	8.8	18.67
1.291	1.331	14.0	8.8	18.67
1.251	1.288	14.0	8.8	18.67
1.211	1.245	14.0	8.8	18.67

$U2_i$ (klf)
6.1
5.7
5.3
4.8
4.4

$x_{U3} = 9.3\ \text{ft}$

$U3 = \begin{pmatrix} 1.5 \\ 1.5 \\ 1.5 \\ 1.5 \\ 1.5 \end{pmatrix} \text{klf}$

Lateral load due to water at toe:

$h_{H1_i} := E_{wtoe_i} - E_{bftg}$

$y_{H1_i} := \frac{h_{H1_i}}{3}$

$H1_i := \gamma_w \cdot \frac{(h_{H1_i})^2}{2}$

$h_{H2_i} := E_{wheel_i} - E_{bftg}$

$y_{H2_i} := \frac{h_{H2_i}}{3}$

$H2_i := \gamma_w \cdot \frac{(h_{H2_i})^2}{2}$

$h_{H3} := h_{key}$ $h_{H3} = 8.0\,ft$

$y_{H3} := \frac{-h_{key}}{2}$ $y_{H3} = -4.0\,ft$

$H3_i := (u_{khb_i} - u_{ktb_i}) \cdot h_{H3}$

$h_{K1} := h_{key}$ $h_{K1} = 8.0\,ft$

$K1_i := u_{ktt_i} \cdot h_{K1}$

$h_{K2} := h_{key}$ $h_{K2} = 8.0\,ft$

$K2_i := (u_{ktb_i} - u_{ktt_i}) \cdot \frac{h_{K2}}{2}$

$y_{K1} := \frac{-h_{key}}{2}$ $y_{K1} = -4.0\,ft$

$y_{K2} := \frac{-2}{3} \cdot h_{key}$ $y_{K2} = -5.33\,ft$

x_{U4_i} = (ft)	$U4_i$ = (klf)	h_{H1_i} = (ft)	y_{H1_i} = (ft)	$H1_i$ = (klf)	h_{H2_i} = (ft)	$H2_i$ = (klf)	y_{H2_i} = (ft)	$H3_i$ = (klf)	$K1_i$ = (klf)	$K2_i$ = (klf)
28.0	0.0	5.00	1.67	0.8	12.00	4.5	4.0	0.37	7.0	2.0
28.0	0.0	5.00	1.67	0.8	11.50	4.1	3.8	0.35	6.6	2.0
28.0	0.0	5.00	1.67	0.8	11.00	3.8	3.7	0.32	6.3	2.0
28.0	0.0	5.00	1.67	0.8	10.50	3.4	3.5	0.29	6.0	2.0
28.0	0.0	5.00	1.67	0.8	10.00	3.1	3.3	0.27	5.7	2.0

Lateral load due to retained soil/water:

$h_{A1_i} := E_{grade} - E_{wheel_i}$

$y_{A1_i} := E_{grade} - E_{bftg} - \frac{2}{3} \cdot h_{A1_i}$

$A1_i := k_{0\beta} \cdot \gamma_{fill} \cdot \frac{(h_{A1_i})^2}{2}$

h_{A1_i} = (ft)	y_{A1_i} = (ft)	$A1_i$ = (klf)
0.00	12.00	0.0
0.50	11.67	0.0
1.00	11.33	0.1
1.50	11.00	0.1
2.00	10.67	0.2

$h_{A2_i} := E_{wheel_i} - E_{bftg}$

$y_{A2_i} := \frac{h_{A2_i}}{2}$

$A2_i := k_{0\beta} \cdot \gamma_{fill} \ \ h_{A1_i} \cdot h_{A2_i}$

$h_{A3_i} := h_{A2_i}$

$y_{A3_i} := \frac{h_{A3_i}}{3}$

$A3_i := k_{0\beta} \cdot \gamma_{fill\_eff} \cdot \frac{(h_{A3_i})^2}{2}$

h_{A2_i} = (ft)	y_{A2_i} = (ft)	$A2_i$ = (klf)	h_{A3_i} = (ft)	y_{A3_i} = (ft)	$A3_i$ = (klf)
12.00	6.00	0.0	12.00	4.00	3.6
11.50	5.75	0.6	11.50	3.83	3.3
11.00	5.50	1.1	11.00	3.67	3.1
10.50	5.25	1.6	10.50	3.50	2.8
10.00	5.00	2.0	10.00	3.33	2.5

Shear force due to sloped backfill: (EM 1110-2-2502, Fig 4-7)

$h_2 := E_{grade} - E_{ftg}$ $\qquad h_2 = 7.0\,\text{ft}$

$h_1 := h_2 + \tan(\beta) \cdot L_{WS5}$ $\qquad h_1 = 19.1\,\text{ft}$

$P_i := k_{0\beta} \cdot \gamma_{fill} \cdot h_{A1_i} \cdot (h_{A2_i} - t_{base}) + k_{0\beta} \cdot \gamma_{fill\_eff} \cdot \frac{(h_{A3_i} - t_{base})^2}{2}$

$S_{\beta_i} := \text{if}\left[h_1 > h_2, \left|\frac{P_i \cdot (h_1 - h_2)}{3 \cdot L_{WS5}}\right|, 0 \cdot \text{klf}\right]$

$x_{S\beta} := L_{ftg}$ $\qquad x_{S\beta} = 28.0\,\text{ft}$

Sum forces:

$$\Sigma V_i := \sum_{i=1}^{4} W_{C_i} + W_{W1_i} + W_{WS1_i} + W_{WS2_i} + W_{WS3_i} + W_{WS4_i} + W_{WS5} + W_{WS6} + S_{\beta_i} - \left(U1_i + U2_i + U3_i + U4_i\right)$$

$$\Sigma M_{grav_i} := \left(\sum_{i=1}^{4} W_{C_i} \cdot x_{C_i} + W_{W1_i} \cdot x_{W1} + W_{WS1_i} \cdot x_{WS1} + W_{WS2_i} \cdot x_{WS2_i} + W_{WS3_i} \cdot x_{WS3_i} + W_{WS4_i} \cdot x_{WS4_i}\right) \cdots$$
$$+ W_{WS5} \cdot x_{WS5} + W_{WS6} \cdot x_{WS6} + S_{\beta_i} \cdot x_{S\beta} - \left(U1_i \cdot x_{U1_i} + U2_i \cdot x_{U2_i} + U3_i \cdot x_{U3} + U4_i \cdot x_{U4_i}\right)$$

$$R_{key_i} := -H1_i - K1_i - K2_i + H2_i + H3_i + A1_i + A2_i + A3_i$$

$$y_{Rkey} := \frac{-h_{key}}{2} \qquad y_{Rkey} = -4.0\,\text{ft}$$

$$\Sigma H_i := -H1_i - K1_i - K2_i + H2_i + H3_i + A1_i + A2_i + A3_i - R_{key_i}$$

$$\Sigma M_{lat_i} := -H1_i \cdot y_{H1_i} - K1_i \cdot y_{K1} - K2_i \cdot y_{K2} + H2_i \cdot y_{H2_i} + H3_i \cdot y_{H3} \cdots$$
$$+ A1_i \cdot y_{A1_i} + A2_i \cdot y_{A2_i} + A3_i \cdot y_{A3_i} - R_{key_i} \cdot y_{Rkey}$$

$$\Sigma M_i := \Sigma M_{grav_i} - \Sigma M_{lat_i}$$

$$x_{R_i} := \frac{\Sigma M_i}{\Sigma V_i}$$

$$L_{brg_i} := \max\left[\min\left(\begin{pmatrix} 3 \cdot x_{R_i} \\ L_{ftg} \end{pmatrix}\right), 0 \cdot \text{ft}\right]$$

P_i = (klf)	S_{β_i} = (klf)	R_{key_i} = (klf)
1.2	0.3	-1.2
1.4	0.3	-1.0
1.5	0.3	-0.8
1.6	0.4	-0.6
1.6	0.4	-0.3

ΣV_i = (klf)	ΣM_{grav_i} = (kip)	ΣM_{lat_i} = (kip)	ΣM_i = (kip)	ΣH_i = (klf)	R_{key_i} = (klf)	x_{R_i} = (ft)	L_{brg_i} = (ft)
41.7	728	63	665	0.0	-1.2	15.94	28.000
42.2	738	63	675	0.0	-1.0	16.00	28.000
42.7	747	62	685	0.0	-0.8	16.05	28.000
43.2	756	61	695	0.0	-0.6	16.10	28.000
43.6	765	61	704	0.0	-0.3	16.14	28.000

Bearing Capacity (per EM 1110-1-1905)

$c := c_{fill}$ $\quad c = 0.0\,psf$

$\phi := \phi_{fill}$ $\quad \phi = 32.0\,deg$

$\gamma_{eff} := \gamma_{fill\_eff}$ $\quad \gamma_{eff} = 65.0\,pcf$

$\gamma_{H\_eff} := \gamma_{eff}$ $\quad \gamma_{H\_eff} = 65.0\,pcf$

$$B_{eff_i} := L_{ftg} - 2 \cdot \left| \frac{L_{brg_i}}{2} - x_{R_i} \right| \qquad B_{eff} = \begin{pmatrix} 24.1 \\ 24.0 \\ 23.9 \\ 23.8 \\ 23.7 \end{pmatrix} ft$$

Table 4-3

$$N_\phi := \tan\left(45 \cdot deg + \frac{\phi}{2}\right)^2 \qquad N_\phi = 3.255$$

$$N_q := if\left(\phi = 0, 1.0, N_\phi \cdot e^{\pi \cdot \tan(\phi)}\right) \qquad N_q = 23.2$$

$$N_c := if\left[\phi = 0, 5.14, (N_q - 1) \cdot \cot(\phi)\right] \qquad N_c = 35.5$$

$$N_\gamma := if\left[\phi = 0, 0.00, (N_q - 1) \cdot \tan(1.4 \cdot \phi)\right] \qquad N_\gamma = 22.0$$

Inclined loading correction:

$$\theta_i := atan\left(\frac{R_{key_i} + K1_i + K2_i}{\Sigma V_i}\right) \qquad \theta = \begin{pmatrix} 10.50 \\ 10.25 \\ 10.02 \\ 9.79 \\ 9.57 \end{pmatrix} deg$$

$$\xi_{ci_i} := if\left[\phi = 0, \left(1 - \frac{\theta_i}{90 \cdot deg}\right), \left(1 - \frac{\theta_i}{90 \cdot deg}\right)^2\right] \qquad \xi_{ci} = \begin{pmatrix} 0.780 \\ 0.785 \\ 0.790 \\ 0.794 \\ 0.799 \end{pmatrix}$$

$$\xi_{\gamma i_i} := if\left[\phi = 0, 1.0, if\left[\theta_i \le \phi, \left(1 - \frac{\theta_i}{\phi}\right)^2, 0.0\right]\right] \qquad \xi_{\gamma i} = \begin{pmatrix} 0.451 \\ 0.462 \\ 0.472 \\ 0.482 \\ 0.491 \end{pmatrix}$$

$$\xi_{qi_i} := if\left[\phi = 0, \left(1 - \frac{\theta_i}{90 \cdot deg}\right), \left(1 - \frac{\theta_i}{90 \cdot deg}\right)^2\right] \qquad \xi_{qi} = \begin{pmatrix} 0.780 \\ 0.785 \\ 0.790 \\ 0.794 \\ 0.799 \end{pmatrix}$$

$$B_i := L_{brg_i} \qquad B = \begin{pmatrix} 28.0 \\ 28.0 \\ 28.0 \\ 28.0 \\ 28.0 \end{pmatrix} ft$$

$$W := 100 \cdot ft$$

Foundation depth correction: (at toe)

$D := t_{base}$ $D = 5.0\,ft$

$\sigma_{D\_eff} := \gamma_{eff} \cdot D$ $\sigma_{D\_eff} = 325.0\,psf$

$\xi_{cd_i} := 1 + 0.2 \cdot (N_\phi)^{\frac{1}{2}} \cdot \frac{D}{B_i}$ $\xi_{cd} = \begin{pmatrix} 1.064 \\ 1.064 \\ 1.064 \\ 1.064 \\ 1.064 \end{pmatrix}$

$\xi_{\gamma d\_10_i} := 1 + 0.1 \cdot \left(\tan\left(45 \cdot deg + \frac{10 \cdot deg}{2}\right)^2 \right)^{\frac{1}{2}} \cdot \frac{D}{B_i}$ $\xi_{\gamma d\_10} = \begin{pmatrix} 1.021 \\ 1.021 \\ 1.021 \\ 1.021 \\ 1.021 \end{pmatrix}$

$\xi_{\gamma d_i} := \text{if}\left[\phi \le 10 \cdot deg, \xi_{\gamma d\_0} + \frac{\phi}{10 \cdot deg} \cdot \left(\xi_{\gamma d\_10_i} - \xi_{\gamma d\_0}\right), 1 + 0.1 \cdot (N_\phi)^{\frac{1}{2}} \cdot \frac{D}{B_i} \right]$ $\xi_{\gamma d} = \begin{pmatrix} 1.032 \\ 1.032 \\ 1.032 \\ 1.032 \\ 1.032 \end{pmatrix}$

$\xi_{qd_i} := \xi_{\gamma d_i}$ $\xi_{qd} = \begin{pmatrix} 1.032 \\ 1.032 \\ 1.032 \\ [illegible] \\ [illegible] \end{pmatrix}$

USACE EM 1110-1-1905, Eq. 4-16·

$q_{u\_toe_i} := c \cdot N_c \cdot \xi_{cd} \cdot \xi_{ci} + \frac{1}{2} \cdot B_{eff_i} \cdot \gamma_{H\_eff} \cdot N_\gamma \cdot \xi_{\gamma d} \cdot \xi_{\gamma i} + \sigma_{D\_eff} \cdot N_q \cdot \xi_{qd} \cdot \xi_{qi}$ $q_{u\_toe} = \begin{pmatrix} 72.708 \\ 72.512 \\ 72.332 \\ 72.168 \\ 72.019 \end{pmatrix} ksf$

Foundation depth correction: (at heel)

$D := E_{grade} - E_{ftg} + t_{base} + h_\beta$ $D = 32.0\,ft$

$\sigma_{D\_eff\_heel} := \gamma_{eff} \cdot D$ $\sigma_{D\_eff} = 0.325\,ksf$

[illegible] $\xi_{cd} = \begin{pmatrix} 1.412 \\ 1.412 \\ 1.412 \\ 1.412 \\ 1.412 \end{pmatrix}$

$\xi_{\gamma d\_10_i} := 1 + 0.1 \cdot \left(\tan\left(45 \cdot deg + \frac{10 \cdot deg}{2}\right)^2 \right)^{\frac{1}{2}} \cdot \frac{D}{B_i}$ $\xi_{\gamma d\_10} = \begin{pmatrix} 1.136 \\ 1.136 \\ 1.136 \\ 1.136 \\ 1.136 \end{pmatrix}$

$\xi_{\gamma d_i} := \text{if}\left[\phi \le 10 \cdot deg, \xi_{\gamma d\_0} + \frac{\phi}{10 \cdot deg} \cdot \left(\xi_{\gamma d\_10_i} - \xi_{\gamma d\_0}\right), 1 + 0.1 \cdot (N_\phi)^{\frac{1}{2}} \cdot \frac{D}{B_i} \right]$ $\xi_{\gamma d} = \begin{pmatrix} 1.206 \\ 1.206 \\ 1.206 \\ 1.206 \\ 1.206 \end{pmatrix}$

$\xi_{qd_i} := \xi_{\gamma d_i}$ $\xi_{qd} = \begin{pmatrix} 1.206 \\ 1.206 \\ 1.206 \\ [illegible] \\ [illegible] \end{pmatrix}$

USACE EM 1110-1-1905, Eq. 4-16·

$q_{u\_heel_i} := c \cdot N_c \cdot \xi_{cd} \cdot \xi_{ci} + \frac{1}{2} \cdot B_{eff_i} \cdot \gamma_{H\_eff} \cdot N_\gamma \cdot \xi_{\gamma d} \cdot \xi_{\gamma i} + \sigma_{D\_eff} \cdot N_q \cdot \xi_{qd} \cdot \xi_{qi}$ $q_{u\_heel} = \begin{pmatrix} 84.962 \\ 84.732 \\ 84.522 \\ 84.331 \\ 84.156 \end{pmatrix} ksf$

$check\_uplift_i := L_{ftg} - L_{brg_i} - L_{uplift_i}$

$check\_uplift_i =$

0.0000	ft
0.0000	
0.0000	
0.0000	
0.0000	

ok := if(max(|check_uplift|) < 0.001 · ft, ok, "Uplift assumptions do not match bearing area.")

ok = "Ok"

$$e_{brg_i} := \frac{L_{brg_i}}{2} - x_{R_i}$$

$$\sigma_{brg\_toe_i} := \frac{\Sigma V_i}{L_{brg_i}} + \frac{\Sigma V_i \cdot e_{brg_i}}{\frac{\left(L_{brg_i}\right)^2}{6}}$$

$$\sigma_{brg\_heel_i} := \frac{\Sigma V_i}{L_{brg_i}} - \frac{\Sigma V_i \cdot e_{brg_i}}{\frac{\left(L_{brg_i}\right)^2}{6}}$$

$$FS_{brg_i} := \min\left(\frac{q_{u\_toe_i}}{\sigma_{brg\_toe_i}}, \text{if}\left(\sigma_{brg\_heel_i} \neq 0 \cdot psf, \frac{q_{u\_heel_i}}{\sigma_{brg\_heel_i}}, 100\right)\right)$$

$$\%_{brg_i} := \frac{L_{brg_i}}{L_{ftg}}$$

$$\%_{brg_i} = \begin{pmatrix} 100.0 \\ 100.0 \\ 100.0 \\ 100.0 \\ 100.0 \end{pmatrix} \%$$

ok := if($\%_{brg_1} \geq 75 \cdot \%$, ok, "OT instability: LC#1")

ok := if($\%_{brg_n} \geq 100\%$, ok, "OT instability LC#n")

$t_{w\_bot} = 2.8\,ft$

$\frac{L_{ftg}}{4} = 7\,000\,ft$

e_{brg_i} = (ft)	$\sigma_{brg\_toe_i}$ = (ksf)	$\sigma_{brg\_heel_i}$ = (ksf)	FS_{brg_i} =	$L_{ftg} - L_{brg_i}$ = (ft)
-1.94	0.870	2.109	40.28	0.000
-2.00	0.862	2.153	39.36	0.000
-2.05	0.855	2.194	38.52	0.000
-2.10	0.849	2.234	37.74	0.000
-2.14	0.844	2.273	37.03	0.000

$$L_{uplift} \equiv \begin{pmatrix} 0 \\ 0 \\ 0 \\ 0 \\ 0 \end{pmatrix} \cdot ft$$

ok := if[max[|$L_{brg} - (L_{ftg} - L_{uplift})$|] < 0.001 · ft, ok, "Uplift area does not match

ok := if($FS_{brg_1} < 2$, "Bearing problem LC#1", ok)

$L_{ftg} = 28.0\,ft$

ok := if($FS_{brg_n} < 3$, "Bearing problem LC#n", ok)

ok = "Ok"

Base Pressures:

$e_{ftg_i} := \frac{L_{ftg}}{2} - x_{R_i}$ (eccentricity with respect to the footing centroid)

$\Sigma H_i + R_{key_i} =$ (klf)	$\Sigma V_i =$ (klf)	$e_{ftg_i} =$ (ft)	$x_{R_i} =$ (ft)	$\sigma_{brg\_heel_i} =$ (ksf)	$\sigma_{brg\_toe_i} =$ (ksf)
-1.2	41.7	-1.94	15.94	2.109	0.870
-1.0	42.2	-2.00	16.00	2.153	0.862
-0.8	42.7	-2.05	16.05	2.194	0.855
-0.6	43.2	-2.10	16.10	2.234	0.849
-0.3	43.6	-2.14	16.14	2.273	0.844

$L_{brg_1} = 28.00\,ft$

$$\frac{L_{brg}}{L_{ftg}} = \begin{pmatrix} 100.0 \\ 100.0 \\ 100.0 \\ 100.0 \\ 100.0 \end{pmatrix} \%$$

Sliding Analysis:

Function Definitions:

$c_1(\phi_d) := 2 \cdot \tan(\phi_d)$

$c_2(\phi_d, \beta) := 1 - \tan(\phi_d) \cdot \tan(\beta) - \left(\frac{\tan(\beta)}{\tan(\phi_d)}\right)$

$\alpha_{driving}(\phi_d, \beta) := -\text{atan}\left(\frac{c_1(\phi_d) + \sqrt{c_1(\phi_d)^2 + 4 \cdot c_2(\phi_d, \beta)}}{2}\right)$

$L_\beta := \max\left(\begin{pmatrix} \frac{h_\beta}{\tan(\beta)} - L_{WS5} - L_{WS6} \\ 0 \cdot ft \end{pmatrix}\right)$ $L_\beta = 11.9\ ft$

Sliding Analysis #1:

$\beta_w := \beta$ $\beta_w = 33.7\ deg$

$\phi_i := \phi_{fill}$ $\phi = \begin{pmatrix} 32.0 \\ 32.0 \\ 32.0 \\ 32.0 \\ 32.0 \end{pmatrix} deg$

$c := 0 \cdot ksf$

$\phi_{d_i} := \text{atan}\left(\frac{\tan(\phi_i)}{FS1_i}\right)$ $\phi_{d_i} = \begin{pmatrix} 18.6 \\ 18.3 \\ 18.0 \\ 17.8 \\ 17.5 \end{pmatrix} deg$

$\text{atan}(\tan(\beta) \cdot FS1_i) = \begin{pmatrix} 51.1 \\ 51.6 \\ 52.0 \\ 52.4 \\ 52.9 \end{pmatrix} deg$ (back solve for minimum ϕ value for stable slope β, EM 1110–2–2502, pg. 3-31)

$\phi_i := \text{if}\left[\left(c_1(\phi_{d_i})^2 + 4 \cdot c_2(\phi_{d_i}, \beta_w) < 0\right), \text{atan}(\tan(\beta_w) \cdot FS1_i), \phi_i\right]$ $\phi = \begin{pmatrix} 51.1 \\ 51.6 \\ 52.0 \\ 52.4 \\ 52.9 \end{pmatrix} deg$ (substitue minimum ϕ if slope is unstable)

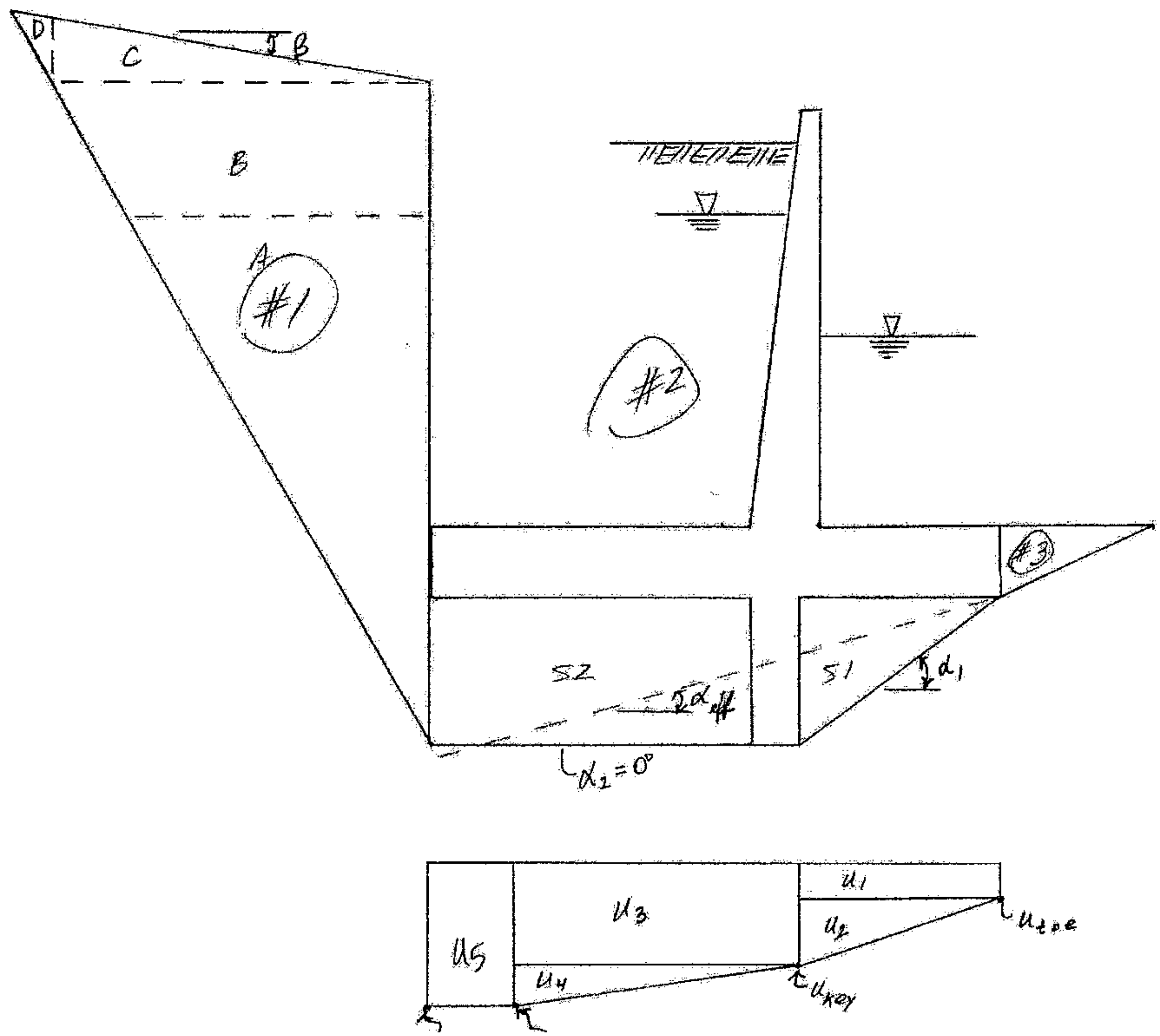
$\phi_{d\_1b_i} := \text{atan}\left(\frac{\tan(\phi_i)}{FS1_i}\right)$ $\phi_{d\_1b_i} = \begin{pmatrix} 33.7 \\ 33.7 \\ 33.7 \\ 33.7 \\ 33.7 \end{pmatrix} deg$

$\alpha_{1b_i} := \alpha_{driving}(\phi_{d\_1b_i}, \beta_w)$

$h_{1b} := (E_{grade} + L_{WS5} \cdot \tan(\beta_w)) - (E_{bftg} - h_{key})$ $h_{1b} = 32.1\ ft$

$L_{max_j} := \text{if}\left[-\alpha_{1b_i} = \phi_{d\_1b_i}, 1000 \cdot ft, \frac{\frac{h_{1b}}{\cos(-\alpha_{1b_i}) \cdot (\tan(-\alpha_{1b_i}) - \tan(\beta_w))}}{\cos(-\alpha_{1b_i})}\right]$ $\alpha_{1b} = \begin{pmatrix} -33.7 \\ -33.7 \\ -33.7 \\ -33.7 \\ -33.7 \end{pmatrix} deg$ $L_{max} = \begin{pmatrix} 1000.0 \\ 1000.0 \\ 1000.0 \\ 1000.0 \\ 1000.0 \end{pmatrix} ft$

$h_{1a_i} := \text{if}\left[L_\beta < L_{max_j}, h_{1b} + L_\beta \cdot (\tan(\beta) - \tan(-\alpha_{1b_i})), 0 \cdot ft\right]$



Sliding Analysis #1

Driving Wedge (#1a):

$\beta_w := 0 \cdot deg$ $\beta_w = 0.0\,deg$

$\phi := \phi_{fill}$ $\phi = 32.0\,deg$

$c := 0 \cdot ksf$

$\phi_{d_i} := atan\left(\frac{tan(\phi)}{FS_{1_i}}\right)$

$\alpha_i := \alpha_{driving}\left(\phi_{d_i}, \beta_w\right)$

$h_i := h_{1a_i}$

$L_i := \frac{h_i}{cos(-\alpha_i) \cdot \left(tan(-\alpha_i) - tan(\beta_w)\right)}$

$h_{sat_i} := max\left[\begin{bmatrix} E_{wheel_i} - \left(E_{ftg} - t_{base} - h_{key}\right) - L_\beta \cdot tan\left(-\alpha_{1b_i}\right) \\ 0 \cdot ft \end{bmatrix}\right]$

$L_{h_i} := \frac{h_i}{tan(-\alpha_i)}$

$L_{sat_i} := \frac{h_{sat_i}}{tan(-\alpha_i)}$

$h_{left} := 0 \cdot ft$

$h_{right_i} := h_{1a_i}$

$W_i := \gamma_{fill} \cdot \left(L_{h_i} \cdot \frac{h_{left} + h_{right_i}}{2}\right) + \left(\gamma_{sat} - \gamma_{fill}\right) \cdot \frac{L_{sat_i} \cdot h_{sat_i}}{2}$

$V := 0\ klf$

$H_L := 0 \cdot klf$

$H_R := 0\ klf$

$U_i := \gamma_w \cdot \left(\frac{h_{sat_i}}{2}\right) \cdot \sqrt{\left(h_{sat_i}\right)^2 + \left(L_{sat_i}\right)^2}$

$h_{1a} = \begin{pmatrix} 32.1 \\ 32.1 \\ 32.1 \\ 32.1 \\ 32.1 \end{pmatrix} ft$

$\phi_d = \begin{pmatrix} 18.6 \\ 18.3 \\ 18.0 \\ 17.8 \\ 17.5 \end{pmatrix} deg$

$\alpha = \begin{pmatrix} -54.3 \\ -54.1 \\ -54.0 \\ -53.9 \\ -53.8 \end{pmatrix} deg$

$h = \begin{pmatrix} 32.1 \\ 32.1 \\ 32.1 \\ 32.1 \\ 32.1 \end{pmatrix} ft$

$L = \begin{pmatrix} 39.5 \\ 39.6 \\ 39.7 \\ 39.7 \\ 39.8 \end{pmatrix} ft$

$h_{sat} = \begin{pmatrix} 12.1 \\ 11.6 \\ 11.1 \\ 10.6 \\ 10.1 \end{pmatrix} ft$

$L_h = \begin{pmatrix} 23.1 \\ 23.2 \\ 23.3 \\ 23.4 \\ 23.5 \end{pmatrix} ft$

$L_{sat} = \begin{pmatrix} 8.7 \\ 8.4 \\ 8.0 \\ 7.7 \\ 7.4 \end{pmatrix} ft$

$W_i =$

W_i (klf)
48.0
48.2
48.5
48.7
49.0

$U = \begin{pmatrix} 5.6 \\ 5.2 \\ 4.7 \\ 4.3 \\ 3.9 \end{pmatrix} klf$

$$\Delta P_{1a_i} := \frac{\left[\left(W_i + V\right)\cdot\left(\tan\left(\phi_{d_i}\right)\cdot\cos\left(\alpha_i\right) + \sin\left(\alpha_i\right)\right) - U_i\cdot\tan\left(\phi_{d_i}\right) + \left(H_L - H_R\right)\cdot\left(\tan\left(\phi_{d_i}\right)\cdot\sin\left(\alpha_i\right) - \cos\left(\alpha_i\right)\right) + \frac{c}{FS_{1_i}}\cdot L_i\right]}{\left(\cos\left(\alpha_i\right) - \tan\left(\phi_{d_i}\right)\cdot\sin\left(\alpha_i\right)\right)}$$

Driving Wedge (#1b):

$\beta_w := \beta$ $\qquad \beta_w = 33.7\,deg$

$\alpha := \alpha_{1b}$ $\qquad \alpha = \begin{pmatrix} -33.7 \\ -33.7 \\ -33.7 \\ -33.7 \\ -33.7 \end{pmatrix} deg$

$\phi_d := \phi_{d\_1b}$ $\qquad \phi_d = \begin{pmatrix} 33.7 \\ 33.7 \\ 33.7 \\ 33.7 \\ 33.7 \end{pmatrix} deg$

$h = \begin{pmatrix} 32.1 \\ 32.1 \\ 32.1 \\ 32.1 \\ 32.1 \end{pmatrix} ft$

$L_h := L_\beta$ $\qquad L_h = 11.9\,ft$

$L_i := \frac{L_\beta}{\cos\left(\alpha_i\right)}$ $\qquad = \begin{pmatrix} 14.3 \\ 14.3 \\ 14.3 \\ 14.3 \\ 14.3 \end{pmatrix} ft$

$h_{satr_i} := \max\left[\begin{bmatrix} E_{wheel_i} - \left(E_{ftg} - t_{base} - h_{key}\right) \\ 0\cdot ft \end{bmatrix}\right]$ $\qquad h_{satr} = \begin{pmatrix} 20.0 \\ 19.5 \\ 19.0 \\ 18.5 \\ 18.0 \end{pmatrix} ft$

$h_{satl_i} := \max\left[\begin{bmatrix} E_{wheel_i} - \left(E_{ftg} - t_{base} - h_{key}\right) - \frac{L_\beta}{\cos\left(\alpha_i\right)} \\ 0\cdot ft \end{bmatrix}\right]$ $\qquad h_{satl} = \begin{pmatrix} 5.7 \\ 5.2 \\ 4.7 \\ 4.2 \\ 3.7 \end{pmatrix} ft$

$L_{sat_i} := \min\left[\begin{bmatrix} L_\beta \\ \frac{h_{satr_i}}{\tan\left[\left(-\alpha\right)_i\right]} \end{bmatrix}\right]$ $\qquad L_{sat} = \begin{pmatrix} 11.9 \\ 11.9 \\ 11.9 \\ 11.9 \\ 11.9 \end{pmatrix} ft$

$h_{left_i} := h_{1a_i}$ $\qquad h_{left} = \begin{pmatrix} 32.1 \\ 32.1 \\ 32.1 \\ 32.1 \\ 32.1 \end{pmatrix} ft$

$h_{right} := h_{1b}$

$$W_i := \gamma_{fill} \cdot \left(L_h \cdot \frac{h_{left_i} + h_{right}}{2} \right) + (\gamma_{sat} - \gamma_{fill}) \cdot L_{sat_i} \cdot \left(\frac{h_{satr_i} + h_{satl_i}}{2} \right)$$

$W_i =$

49.1
49.2
49.2
49.2
49.2

klf

$V := 0 \cdot klf$

$H_L := 0 \cdot klf$

$H_R := 0 \cdot klf$

$$U_i := \gamma_w \left(\frac{h_{satr_i} + h_{satl_i}}{2} \right) \cdot \sqrt{(h_{satr_i} - h_{satl_i})^2 + (L_h)^2}$$

$$\Delta P_{1b_i} := \frac{\left[(W_i + V) \cdot (\tan(\phi_{d_i}) \cdot \cos(\alpha_i) + \sin(\alpha_i)) - U_i \cdot \tan(\phi_{d_i}) + (H_L - H_R) \cdot (\tan(\phi_{d_i}) \cdot \sin(\alpha_i) - \cos(\alpha_i)) + \frac{c}{FS_{1_i}} \cdot L_i \right]}{(\cos(\alpha_i) - \tan(\phi_{d_i}) \sin(\alpha_i))}$$

Structure Wedge (#2):

$U_i =$

14.927
14.347
13.767
13.187
12.606

klf

$\beta_W := 0 \cdot deg$

$\phi := \phi_{fill}$ $\qquad \phi = 32.0\,deg$

$c := 0 \cdot ksf$

$$\phi_{d_i} := \operatorname{atan}\left(\frac{\tan(\phi)}{FS_{1_i}} \right) \qquad \phi_{d_i} = \begin{pmatrix} 18.6 \\ 18.3 \\ 18.0 \\ 17.8 \\ 17.5 \end{pmatrix} deg$$

$$\alpha_1 := \operatorname{atan}\left(\frac{h_{key}}{x_{key} - \frac{L_{key}}{2}} \right) \qquad \alpha_1 = 45.9\,deg$$ (angle of shear plane between toe and key)

$\alpha_2 := 0 \cdot deg$ (angle of shear plane between key and heel)

$$\alpha := \alpha_1 \cdot \left(\frac{x_{key}}{L_{ftg}} \right) + \alpha_2 \left(\frac{L_{ftg} - x_{key}}{L_{ftg}} \right) \qquad \alpha = 15.2\,deg$$ (average angle of shear plane for structural wedge)

$$L := \frac{L_{ftg}}{\cos(\alpha)} \qquad L = 29.0\,ft$$

$$h_{S1} := h_{key} \qquad h_{S1} = 8.0\,ft$$

$$L_{S1} := x_{key} - \frac{L_{key}}{2} \qquad L_{S1} = 7.8\,ft$$

$x_{S1} := \frac{2}{3} \cdot L_{S1}$ $x_{S1} = 5.2\,ft$

$S1 := \gamma_{sat} \cdot \frac{h_{S1} \cdot L_{S1}}{2}$ $S1 = 4.0\,klf$

$h_{S2} := h_{key}$ $h_{S2} = 8.0\,ft$

$L_{S2} := L_{ftg} - x_{key} - \frac{L_{key}}{2}$ $L_{S2} = 17.3\,ft$

$x_{S2} := L_{ftg} - \frac{L_{S2}}{2}$ $x_{S2} = 19.4\,ft$

$S2 := \gamma_{sat} \cdot h_{S2} \cdot L_{S2}$ $S2 = 17.6\,klf$

$$W_i := \sum_{i=1}^{4} W_{C_i} + W_{W1_i} + W_{WS1_i} + W_{WS2_i} + W_{WS3_i} + W_{WS4_i} + W_{WS5} + W_{WS6} + S1 + S2 + S_{\beta_i}$$

Uplift below structural wedge:

$u_{toe_i} := \gamma_w \cdot \left(E_{wtoe_i} - E_{bftg}\right)$

$u_{heel_i} := \gamma_w \cdot \left[E_{wheel_i} - \left(E_{bftg} - h_{key}\right)\right]$

$$\delta_{u_i} := \frac{\gamma_w \cdot \left(E_{wheel_i} - E_{wtoe_i}\right)}{L_{ftg} - L_{t1_i}}$$

$$u_{key_i} := u_{toe_i} + \delta_{u_i} \cdot \left(x_{key} - \frac{L_{key}}{2}\right) + \gamma_w \cdot h_{key}$$

$$ok := if\left[\left[u_{key_1} + \delta_{u_1} \cdot \left(L_{ftg} - x_{key} + \frac{L_{key}}{2} - L_{t1_1}\right) = u_{heel_1}\right], ok, \text{"Uplift pressures do not close."}\right]$$

ok = "Ok"

$$u_{1_i} := u_{toe_i} \cdot \left(x_{key} - \frac{L_{key}}{2}\right)$$

$$x_{u1} := \frac{x_{key} - \frac{L_{key}}{2}}{2}$$ $x_{u1} = 3.9\,ft$

$$u_{2_i} := \left(u_{key_i} - u_{toe_i}\right) \cdot \frac{\left(x_{key} - \frac{L_{key}}{2}\right)}{2}$$

$$x_{u2} := \frac{2}{3}\cdot\left(x_{key} - \frac{L_{key}}{2}\right) \qquad x_{u2} = 5.2\,ft$$

$$u3_i := u_{key_i}\cdot\left(L_{ftg} - L_{t1_i} - x_{key} + \frac{L_{key}}{2}\right)$$

$$x_{u3_i} := x_{key} - \frac{L_{key}}{2} + \frac{1}{2}\cdot\left[L_{ftg} - L_{t1_i} - \left(x_{key} - \frac{L_{key}}{2}\right)\right]$$

$$u4_i := \left(u_{heel_i} - u_{key_i}\right)\cdot\frac{\left(L_{ftg} - L_{t1_i} - x_{key} + \frac{L_{key}}{2}\right)}{2}$$

$$x_{u4_i} := x_{key} - \frac{L_{key}}{2} + \frac{2}{3}\cdot\left[L_{ftg} - L_{t1_i} - \left(x_{key} - \frac{L_{key}}{2}\right)\right]$$

$$u5_i := u_{heel_i}\cdot L_{t1_i}$$

$$x_{u5_i} := L_{ftg} - \frac{L_{t1_i}}{2}$$

$$U_i := u1_i + u2_i + u3_i + u4_i + u5_i$$

$$x_{U_i} := \frac{u1_i\cdot x_{u1} + u2_i\cdot x_{u2} + u3_i\cdot x_{u3_i} + u4_i\cdot x_{u4_i} + u5_i\cdot x_{u5_i}}{U_i}$$

$$\Sigma M_{grav_i} := \left(\sum_{i=1}^{4} W_{C_i}\, x_{C_i} + W_{W1_i}\cdot x_{W1} + W_{WS1_i}\cdot x_{WS1} + W_{WS2_i}\cdot x_{WS2_i} + W_{WS3_i}\cdot x_{WS3_i}\right)\ldots$$
$$+ W_{WS4_i}\cdot x_{WS4_i} + W_{WS5}\cdot x_{WS5} + W_{WS6}\cdot x_{WS6} + S1\cdot x_{S1} + S2\cdot x_{S2} + S_{\beta_i}\cdot x_{S\beta} - \left(U_i\, x_{U_i}\right)$$

$h_{A2_i} := E_{wheel_i} - E_{bftg} + h_{key}$

$y_{A2_i} := \frac{h_{A2_i}}{2} - h_{key}$

$A2_i := k_{0\beta} \cdot \gamma_{fill} \cdot h_{A1_i} \cdot h_{A2_i}$

$h_{A3_i} := h_{A2_i}$

$y_{A3_i} := \frac{h_{A3_i}}{3} - h_{key}$

$A3_i := k_{0\beta} \cdot \gamma_{fill\_eff} \cdot \frac{\left(h_{A3_i}\right)^2}{2}$

$H3_i := 0 \cdot klf$

$h_{H2_i} := E_{wheel_i} - E_{bftg} + h_{key}$

$y_{H2_i} := \frac{h_{H2_i}}{3} - h_{key}$

$h_{A2_i} =$ (ft)	$y_{A2_i} =$ (ft)	$A2_i =$ (klf)	$h_{A3_i} =$ (ft)	$y_{A3_i} =$ (ft)	$A3_i =$ (klf)
20.00	2.00	0.0	20.00	-1.33	10.1
19.50	1.75	1.0	19.50	-1.50	9.6
19.00	1.50	1.9	19.00	-1.67	9.1
18.50	1.25	2.8	18.50	-1.83	8.6
18.00	1.00	3.6	18.00	-2.00	8.2

$H2_i := \gamma_w \cdot \frac{\left(h_{H2_i}\right)^2}{2}$

$\Sigma M_{lat_i} := -H1_i \cdot \left(y_{H1_i}\right) - K1_i \cdot \left(y_{K1}\right) - K2_i \cdot \left(y_{K2}\right) + H2_i \cdot \left(y_{H2_i}\right) + H3_i \cdot \left(y_{H3}\right) \ldots$
$\quad + A1_i \cdot \left(y_{A1_i}\right) + A2_i \cdot \left(y_{A2_i}\right) + A3_i \cdot \left(y_{A3_i}\right) - R_{key_i} \cdot \left(y_{Rkey}\right)$

$x_{R_i} := \frac{\Sigma M_{grav_i} - \Sigma M_{lat_i}}{W_i - U_i}$ $\qquad L_{brg_i} := \min\left(3 \cdot x_{R_i}, L_{ftg}\right)$

$ok_{u_i} := \text{if}\left[\left|L_{brg_i} - \left(L_{ftg} - L_{t1_i}\right)\right| > 0.001 \cdot ft, \text{"Uplift assumptions wrong in sliding analysis."}, \text{"Matched."}\right]$

$W_i =$ (klf)	$u_{toe_i} =$ (ksf)	$u_{heel_i} =$ (ksf)	$\delta u_i =$ (psf/ft)	$u_{key_i} =$ (ksf)	$u1_i =$ (klf)	$u2_i =$ (klf)	$u3_i =$ (klf)
79.6	0.313	1.250	15.6	0.934	2.422	2.407	18.905
79.7	0.313	1.219	14.5	0.925	2.422	2.373	18.730
79.7	0.313	1.188	13.4	0.916	2.422	2.340	18.555
79.8	0.313	1.156	12.3	0.908	2.422	2.306	18.380
79.8	0.313	1.125	11.2	0.899	2.422	2.273	18.205

$u4_i =$ (klf)	$u5_i =$ (klf)	$x_{u3_i} =$ (ft)	$x_{u4_i} =$ (ft)	$x_{u5_i} =$ (ft)	$h_{H2_i} =$ (ft)	$y_{H2_i} =$ (ft)	$H2_i =$ (klf)
3.204	0.0	17.9	21.3	28.0	20.0	-1.3	12.5
2.975	0.0	17.9	21.3	28.0	19.5	-1.5	11.9
2.746	0.0	17.9	21.3	28.0	19.0	-1.7	11.3
2.517	0.0	17.9	21.3	28.0	18.5	-1.8	10.7
2.288	0.0	17.9	21.3	28.0	18.0	-2.0	10.1

$U_i =$ (klf)	$x_{U_i} =$ (ft)	$\Sigma M_{grav_i} =$ (kip)	$\Sigma M_{lat_i} =$ (kip)	$x_{R_i} =$ (ft)	$L_{brg_i} =$ (ft)
26.9	15.9	912	2	17.3	28.0
26.5	15.8	922	2	17.3	28.0
26.1	15.8	931	1	17.3	28.0
25.6	15.7	940	0	17.4	28.0
25.2	15.7	949	-0	17.4	28.0

$H_{L_i} := 0 \cdot klf$

$$H_{R_i} := \gamma_w \cdot \frac{\left(E_{wtoe_i} - E_{ftg}\right)^2}{2}$$

$$\Delta P_{2_i} := \frac{\left[\left(W_i + V\right)\cdot\left(\tan\left(\phi_{d_i}\right)\cdot\cos(\alpha) + \sin(\alpha)\right) - U_i \cdot \tan\left(\phi_{d_i}\right) + \left(H_{L_i} - H_{R_i}\right)\cdot\left(\tan\left(\phi_{d_i}\right)\cdot\sin(\alpha) - \cos(\alpha)\right) + \frac{c}{FS_{1_i}}\cdot L\right]}{\left(\cos(\alpha) - \tan\left(\phi_{d_i}\right)\cdot\sin(\alpha)\right)}$$

$H_{L_i} =$

0.0	klf
0.0	
0.0	
0.0	
0.0	

$H_{R_i} =$

0.0	klf
0.0	
0.0	
0.0	
0.0	

$$ok_{u_i} = \begin{pmatrix} \text{"Matched."} \\ \text{"Matched."} \\ \text{"Matched."} \\ \text{"Matched."} \\ \text{"Matched."} \end{pmatrix}$$

$L_{ftg} - L_{brg_i} =$

0.000	ft
0.000	
0.000	
0.000	
0.000	

$$L_{t1} \equiv \begin{pmatrix} 0 \\ 0 \\ 0 \\ 0 \\ 0 \end{pmatrix} \cdot ft$$

$$ok := \text{if}\left[\max\left[\left|L_{brg} - \left(L_{ftg} - L_{t1}\right)\right|\right] < 0.001 \cdot ft, ok, \text{"Uplift area does not match."}\right]$$

$$ok := \text{if}\left(\min\left(L_{brg}\right) < x_{key} + \frac{L_{key}}{2}, \text{"Uplift assumptions incorrect."}, ok\right) \qquad ok = \text{"Ok"}$$

Resisting Wedge (#3):

$\beta_w := 0 \cdot deg$

$\phi := \phi_{fill}$ $\phi = 32.0\,deg$

$c := 0 \cdot ksf$

$\phi_{d_i} := atan\left(\frac{tan(\phi)}{FS1_i}\right)$ $\phi_{d_i} = \begin{pmatrix} 18.6 \\ 18.3 \\ 18.0 \\ 17.8 \\ 17.5 \end{pmatrix} deg$

$\alpha_i := 45 \cdot deg - \frac{\phi_{d_i}}{2}$ $\alpha_i = \begin{pmatrix} 35.7 \\ 35.9 \\ 36.0 \\ 36.1 \\ 36.2 \end{pmatrix} deg$

$L_i := \frac{t_{base}}{sin(\alpha_i)}$ $L = \begin{pmatrix} 8.565 \\ 8.537 \\ 8.509 \\ 8.483 \\ 8.457 \end{pmatrix} ft$

$W_i := \gamma_{sat} \frac{L_i \cdot cos(\alpha_i) \cdot t_{base}}{2} + \gamma_w \cdot (E_{wtoe_i} - E_{ftg}) \cdot L_i \cdot cos(\alpha_i)$

$U_i := \gamma_w \cdot \left(E_{wtoe_i} - E_{ftg} + \frac{t_{base}}{2}\right) \cdot L_i$

$H_L := 0 \cdot klf$

$H_R := 0 \cdot klf$

$V := 0 \cdot klf$

$$\Delta P_{3_i} := \frac{\left[(W_i + V) \cdot (tan(\phi_{d_i}) \cdot cos(\alpha_i) + sin(\alpha_i)) - U_i \cdot tan(\phi_{d_i}) + (H_L - H_R) \cdot (tan(\phi_{d_i}) \cdot sin(\alpha_i) - cos(\alpha_i)) + \frac{c}{FS1_i} \cdot L_i\right]}{(cos(\alpha_i) - tan(\phi_{d_i}) \cdot sin(\alpha_i))}$$

$\Sigma P_i := \Delta P_{1a_i} + \Delta P_{1b_i} + \Delta P_{2_i} + \Delta P_{3_i}$

W_i = (klf)	U_i = (klf)	ΔP_{1a_i} = (klf)	ΔP_{1b_i} = (klf)	ΔP_{2_i} = (klf)	ΔP_{3_i} = (klf)	ΣP_i = (klf)
2.2	1.3	-36.7	-8.3	42.9	2.4	0.2
2.2	1.3	-36.9	-8.0	42.7	2.3	0.2
2.2	1.3	-37.0	-7.6	42.5	2.3	0.2
2.2	1.3	-37.2	-7.3	42.4	2.3	0.2
2.2	1.3	-37.4	-7.0	42.2	2.3	0.1

$FS_1 \equiv \begin{pmatrix} 1.86 \\ 1.89 \\ 1.92 \\ 1.95 \\ 1.98 \end{pmatrix}$

ok := if($FS1_1 \geq 1.33$, ok, "Sliding instability: LC#1")

ok := if($FS1_n \geq 1.50$, ok, "Sliding instability: LC#n")

ok = "Ok"

Sliding Analysis #2:

$L_\beta = 11.88\,ft$

$\phi_i := \phi_{fill}$ $\quad \beta_w := \beta \quad \beta_w = 33.7\,deg$

$$\phi = \begin{pmatrix} 32.0 \\ 32.0 \\ 32.0 \\ 32.0 \\ 32.0 \end{pmatrix} deg$$

$c := 0 \cdot ksf$

$$\phi_{d_i} := atan\left(\frac{tan(\phi_i)}{FS2_i}\right) \qquad \phi_{d_i} = \begin{pmatrix} 22.8 \\ 22.5 \\ 22.2 \\ 22.0 \\ 21.7 \end{pmatrix} deg$$

$$atan\left(tan(\beta) \cdot FS2_i\right) = \begin{pmatrix} 44.8 \\ 45.2 \\ 45.6 \\ 45.9 \\ 46.3 \end{pmatrix} deg$$

(back solve for minimum ϕ value for stable slope β, EM 1110-2-2502, pg. 3-31)

$$\phi_i := if\left[\left(c_1\left(\phi_{d_i}\right)^2 + 4 \cdot c_2\left(\phi_{d_i}, \beta_w\right) < 0\right), atan\left(tan(\beta_w) \cdot FS2_i\right), \phi_i\right] \qquad \phi = \begin{pmatrix} 44.8 \\ 45.2 \\ 45.6 \\ 45.9 \\ 46.3 \end{pmatrix} deg$$

(substitue minimum ϕ if slope is unstable)

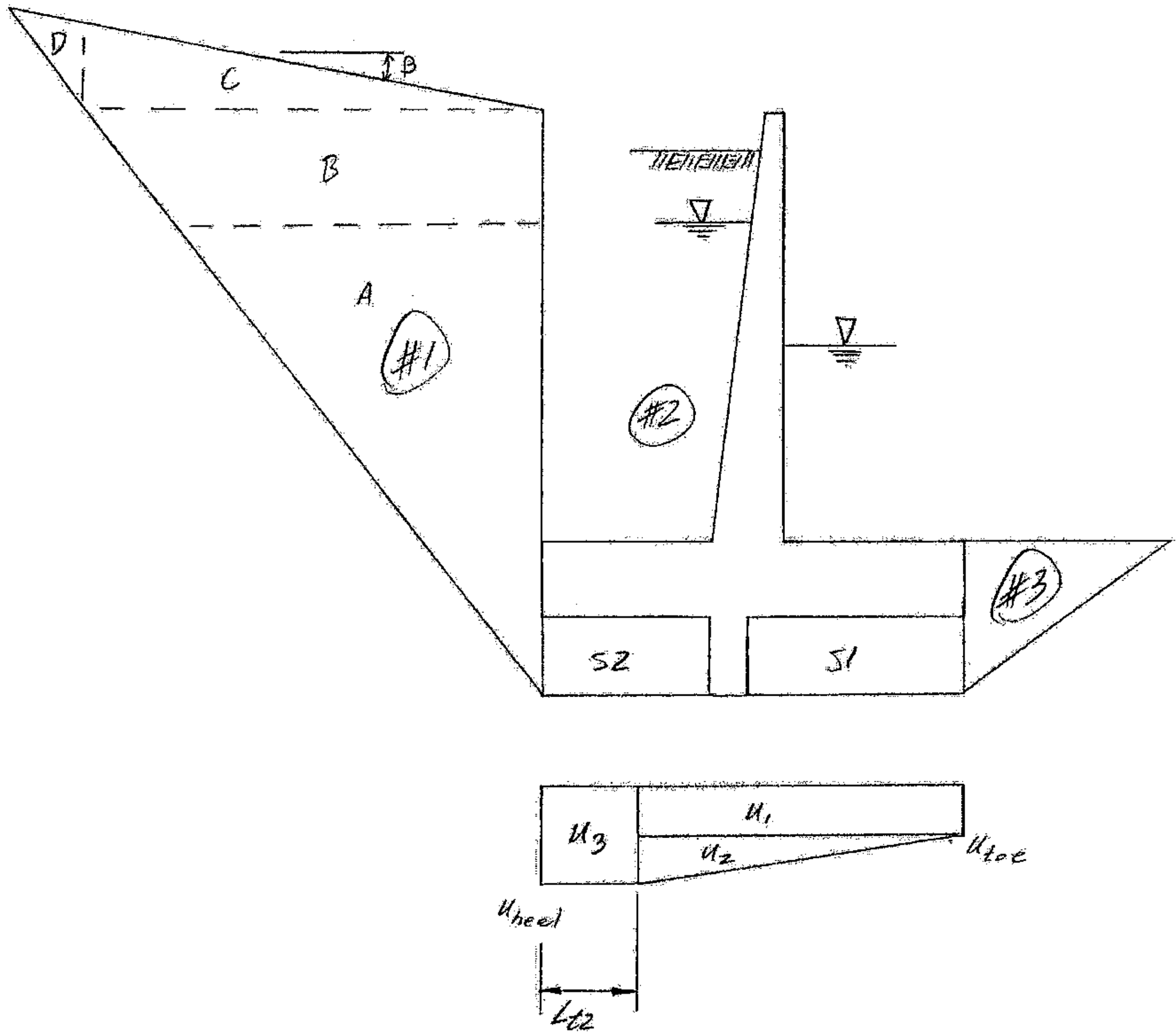
$$\phi_{d\_1b_i} := atan\left(\frac{tan(\phi_i)}{FS2_i}\right) \qquad \phi_{d\_1b_i} = \begin{pmatrix} 33.7 \\ 33.7 \\ 33.7 \\ 33.7 \\ 33.7 \end{pmatrix} deg$$

$$\alpha_{1b_i} := \alpha_{driving}\left(\phi_{d\_1b_i}, \beta_w\right) \qquad \alpha_{1b} = \begin{pmatrix} -33.7 \\ -33.7 \\ -33.7 \\ -33.7 \\ -33.7 \end{pmatrix} deg$$

$$h_{1b} := \left(E_{grade} + L_{WS5}\ tan(\beta_w)\right) - \left(E_{bftg} - h_{key}\right) \qquad h_{1b} = 32.1\,ft$$

$$L_{max_i} := if\left[-\alpha_{1b_i} = \phi_{d\_1b_i}, 1000 \cdot ft, \frac{\dfrac{h_{1b}}{cos(-\alpha_{1b_i})\left(tan(-\alpha_{1b_i}) - tan(\beta_w)\right)}}{cos(-\alpha_{1b_i})}\right] \qquad L_{max} = \begin{pmatrix} 1000.0 \\ 1000.0 \\ 1000.0 \\ 1000.0 \\ 1000.0 \end{pmatrix} ft$$

$$h_{1a_i} := if\left[L_\beta < L_{max_i}, h_{1b} + L_\beta\ \left(tan(\beta) - tan(-\alpha_{1b_i})\right), 0 \cdot ft\right] \qquad h_{1a} = \begin{pmatrix} 32.1 \\ 32.1 \\ 32.1 \\ 32.1 \\ 32.1 \end{pmatrix} ft$$



Sliding Analysis #2

Driving Wedge (#1a):

$\beta_w := 0 \cdot deg$ $\beta_w = 0.0\,deg$

$\phi := \phi_{fill}$ $\phi = 32.0\,deg$

$c := 0 \cdot ksf$

$\phi_{d_i} := atan\left(\frac{tan(\phi)}{FS2_i}\right)$ $\phi_d = \begin{pmatrix} 22.8 \\ 22.5 \\ 22.2 \\ 22.0 \\ 21.7 \end{pmatrix} deg$

$\alpha_i := \alpha_{driving}(\phi_{d_i}, \beta_w)$ $\alpha = \begin{pmatrix} -56.38 \\ -56.24 \\ -56.11 \\ -55.98 \\ -55.85 \end{pmatrix} deg$

$h_i := h_{1a_i}$

$h_i := h_{1a_i}$ $h = \begin{pmatrix} 32.1 \\ 32.1 \\ 32.1 \\ 32.1 \\ 32.1 \end{pmatrix} ft$

$L_i := \frac{h_i}{cos(-\alpha_i) \cdot (tan(-\alpha_i) - tan(\beta_w))}$ $= \begin{pmatrix} 38.53 \\ 38.59 \\ 38.65 \\ 38.71 \\ 38.77 \end{pmatrix} ft$

$h_{sat_i} := max\left[\begin{bmatrix} E_{wheel_i} - (E_{ftg} - t_{base} - h_{key}) - L_\beta \cdot tan(-\alpha_{1b_i}) \\ 0 \cdot ft \end{bmatrix}\right]$ $h_{sat} = \begin{pmatrix} 12.1 \\ 11.6 \\ 11.1 \\ 10.6 \\ 10.1 \end{pmatrix} ft$

$L_{h_i} := \frac{h_i}{tan(-\alpha_i)}$ $L_h = \begin{pmatrix} 21.336 \\ 21.445 \\ 21.553 \\ 21.658 \\ 21.762 \end{pmatrix} ft$

$L_{sat_i} := \frac{h_{sat_i}}{tan(-\alpha_i)}$ $L_{sat} = \begin{pmatrix} 8.04 \\ 7.74 \\ 7.45 \\ 7.14 \\ 6.84 \end{pmatrix} ft$

$h_{left} := 0 \cdot ft$

$h_{right_i} := h_{1a_i}$

$W_i := \gamma_{fill} \cdot \left(L_{h_i} \cdot \frac{h_{left} + h_{right_i}}{2}\right) + (\gamma_{sat} - \gamma_{fill}) \cdot \frac{L_{sat_i} \cdot h_{sat_i}}{2}$

$W_i =$

44.372	klf
44.610	
44.843	
45.072	
45.296	

$V := 0 \cdot klf$

$H_L := 0 \cdot klf$

$H_R := 0 \cdot klf$

$U_i := \gamma_w \cdot \left(\frac{h_{sat_i}}{2}\right) \cdot \sqrt{\left(h_{sat_i}\right)^2 + \left(L_{sat_i}\right)^2}$

$U = \begin{pmatrix} 5.479 \\ 5.043 \\ 4.625 \\ 4.223 \\ 3.839 \end{pmatrix} \text{klf}$

$$\Delta P_{1a_i} := \frac{\left[\left(W_i + V\right) \cdot \left(\tan\left(\phi_{d_i}\right) \cos\left(\alpha_i\right) + \sin\left(\alpha_i\right)\right) - U_i \tan\left(\phi_{d_i}\right) + \left(H_L - H_R\right) \cdot \left(\tan\left(\phi_{d_i}\right) \cdot \sin\left(\alpha_i\right) - \cos\left(\alpha_i\right)\right) + \frac{c}{FS2_i} \cdot L_i\right]}{\left(\cos\left(\alpha_i\right) - \tan\left(\phi_{d_i}\right) \cdot \sin\left(\alpha_i\right)\right)}$$

Driving Wedge (#1b): $L_\beta = 11.9\,\text{ft}$

$\beta_w := \beta$ $\beta_w = 33\ 7\,\text{deg}$

$\alpha := \alpha_{1b}$ $\alpha = \begin{pmatrix} -33.7 \\ -33.7 \\ -33.7 \\ -33.7 \\ -33.7 \end{pmatrix} \text{deg}$

$\phi_d := \phi_{d\_1b}$ $\phi_d = \begin{pmatrix} 33.7 \\ 33.7 \\ 33\ 7 \\ 33.7 \\ 33.7 \end{pmatrix} \text{deg}$

$h = \begin{pmatrix} 32.1 \\ 32.1 \\ 32.1 \\ 32.1 \\ 32.1 \end{pmatrix} \text{ft}$

$L_h := L_\beta$ $L_h = 11.9\,\text{ft}$

$L_i := \frac{L_\beta}{\cos\left(\alpha_i\right)}$ $L = \begin{pmatrix} 14.3 \\ 14.3 \\ 14.3 \\ 14.3 \\ 14.3 \end{pmatrix} \text{ft}$

$h_{satr_i} := \max\left[\begin{bmatrix} E_{wheel_i} - \left(E_{ftg} - t_{base} - h_{key}\right) \\ 0 \cdot \text{ft} \end{bmatrix}\right]$ $h_{satr} = \begin{pmatrix} 20.0 \\ 19.5 \\ 19.0 \\ 18.5 \\ 18.0 \end{pmatrix} \text{ft}$

$h_{satl_i} := \max\left[\begin{bmatrix} E_{wheel_i} - \left(E_{ftg} - t_{base} - h_{key}\right) - \frac{L_\beta}{\cos\left(\alpha_i\right)} \\ 0 \cdot \text{ft} \end{bmatrix}\right]$ $h_{satl} = \begin{pmatrix} 5\ 7 \\ 5.2 \\ 4.7 \\ 4.2 \\ 3.7 \end{pmatrix} \text{ft}$

$L_{sat_i} := \min\left[\begin{bmatrix} L_\beta \\ \frac{h_{satr_i}}{\tan\left[\left(-\alpha\right)_i\right]} \end{bmatrix}\right]$ $L_{sat} = \begin{pmatrix} 11.9 \\ 11.9 \\ 11.9 \\ 11.9 \\ 11.9 \end{pmatrix} \text{ft}$

$h_{left_i} := h_{1a_i}$ $h_{left} = \begin{pmatrix} 32.1 \\ 32.1 \\ 32.1 \\ 32.1 \\ 32.1 \end{pmatrix} \text{ft}$

$h_{right} := h_{1b}$ $h_{right} = 32.1\,\text{ft}$

$W_i := \gamma_{fill} \cdot \left(L_h \cdot \frac{h_{left_i} + h_{right}}{2}\right) + \left(\gamma_{sat} - \gamma_{fill}\right) \cdot L_{sat_i} \cdot \left(\frac{h_{satr_i} + h_{satl_i}}{2}\right)$

$V := 0 \cdot \text{klf}$

$H_L := 0 \cdot klf$

$H_R := 0 \cdot klf$

$U_i := \gamma_w \cdot \left(\frac{h_{satr_i} + h_{satl_i}}{2}\right) \cdot \sqrt{\left(h_{satr_i} - h_{satl_i}\right)^2 + \left(L_h\right)^2}$

$W_i =$

49.1
49.2
49.2
49.2
49.2

klf

$$\Delta P_{1b_i} := \frac{\left[\left(W_i + V\right)\left(\tan\left(\phi_{d_i}\right) \cdot \cos\left(\alpha_i\right) + \sin\left(\alpha_i\right)\right) - U_i \cdot \tan\left(\phi_{d_i}\right) + \left(H_L - H_R\right) \cdot \left(\tan\left(\phi_{d_i}\right) \cdot \sin\left(\alpha_i\right) - \cos\left(\alpha_i\right)\right) + \frac{c}{FS_{2_i}} \cdot L_i\right]}{\left(\cos\left(\alpha_i\right) - \tan\left(\phi_{d_i}\right) \cdot \sin\left(\alpha_i\right)\right)}$$

Structure Wedge (#2)

$U_i =$

14.9
14.3
13.8
13.2
12.6

klf

$\beta_w := 0 \cdot deg$

$\phi := \phi_{fill}$ $\phi = 32.0\,deg$

$c := 0$ ksf

$\phi_{d_i} := \operatorname{atan}\left(\frac{\tan(\phi)}{FS_{2_i}}\right)$ $\phi_{d_i} = \begin{pmatrix} 22.8 \\ 22.5 \\ 22.2 \\ 22.0 \\ 21.7 \end{pmatrix} deg$

$\alpha := 0 \cdot deg$ $\alpha = 0.0\,deg$

$L := \frac{L_{ftg}}{\cos(\alpha)}$ $L = 28.0\,ft$

$h_{S1} := h_{key}$ $h_{S1} = 8.0\,ft$

$L_{S1} := x_{key} - \frac{L_{key}}{2}$ $L_{S1} = 7.8\,ft$

$x_{S1} := \frac{1}{2} \cdot L_{S1}$ $x_{S1} = 3.9\,ft$

$S1 := \gamma_{sat} \cdot h_{S1} \cdot L_{S1}$ $S1 = 7.9\,klf$

$h_{S2} := h_{key}$ $h_{S2} = 8.0\,ft$

$L_{S2} := L_{ftg} - x_{key} - \frac{L_{key}}{2}$ $L_{S2} = 17.3\,ft$

$x_{S2} := L_{ftg} - \frac{L_{S2}}{2}$ $\quad x_{S2} = 19.4\,ft$

$S2 := \gamma_{sat} \cdot h_{S2} \cdot L_{S2}$ $\quad S2 = 17.6\,klf$

$$W_i := \sum_{i=1}^{4} W_{C_i} + W_{W1_i} + W_{WS1_i} + W_{WS2_i} + W_{WS3_i} + W_{WS4_i} + W_{WS5} + W_{WS6} + S1 + S2 + S_{\beta_i}$$

Uplift below structural wedge

$u_{toe_i} := \gamma_w \left\lfloor E_{wtoe_i} - \left(E_{bftg} - h_{key}\right)\right\rfloor$

$u_{heel_i} := \gamma_w \cdot \left\lfloor E_{wheel_i} - \left(E_{bftg} - h_{key}\right)\right\rfloor$

$\delta_{u_i} := \frac{\gamma_w \cdot \left(E_{wheel_i} - E_{wtoe_i}\right)}{L_{ftg} - L_{t2_i}}$

$u_{1_i} := u_{toe_i} \cdot \left(L_{ftg} - L_{t2_i}\right)$

$x_{u1_i} := \frac{L_{ftg} - L_{t2_i}}{2}$ $\quad x_{u1} = \begin{pmatrix} 14.0 \\ 14.0 \\ 14.0 \\ 14.0 \\ 14.0 \end{pmatrix} ft$

$u_{2_i} := \left(u_{heel_i} - u_{toe_i}\right) \cdot \frac{\left(L_{ftg} - L_{t2_i}\right)}{2}$

$x_{u2_i} := \frac{2}{3} \cdot \left(L_{ftg} - L_{t2_i}\right)$ $\quad x_{u2} = \begin{pmatrix} 18.7 \\ 18.7 \\ 18.7 \\ 18.7 \\ 18.7 \end{pmatrix} ft$

$u_{3_i} := u_{heel_i} \cdot \left(L_{t2_i}\right)$

$x_{u3_i} := L_{ftg} - \frac{L_{t2_i}}{2}$

$U_i := u_{1_i} + u_{2_i} + u_{3_i}$

$x_{U_i} := \frac{u_{1_i} \cdot x_{u1_i} + u_{2_i} \cdot x_{u2_i} + u_{3_i} \cdot x_{u3_i}}{U_i}$ $\quad x_U = \begin{pmatrix} 15.0 \\ 14.9 \\ 14.9 \\ 14.8 \\ 14.8 \end{pmatrix} ft$

$$\Sigma M_{grav_i} := \left(\sum_{i=1}^{4} W_{C_i} \cdot x_{C_i} + W_{W1_i} \cdot x_{W1} + W_{WS1_i} \cdot x_{WS1} + W_{WS2_i} \cdot x_{WS2_i} + W_{WS3_i} \cdot x_{WS3_i} \ldots\right.$$
$$\left. + W_{WS4_i} \cdot x_{WS4_i} + W_{WS5} \cdot x_{WS5} + W_{WS6} \cdot x_{WS6} + S1 \cdot x_{S1} + S2 \cdot x_{S2} + S_{\beta_i} \cdot x_{S\beta} - \left(U_i \cdot x_{U_i}\right)\right)$$

$h_{H1_i} := E_{wtoe_i} - (E_{bftg} - h_{key})$

$y_{H1_i} := \frac{h_{H1_i}}{3} - h_{key}$

$H1_i := \gamma_w \cdot \frac{(h_{H1_i})^2}{2}$

$K1_i := 0 \cdot klf$

$K2_i := 0 \cdot klf$

$h_{H1_i} =$ (ft)

13.00
13.00
13.00
13.00
13.00

$y_{H1_i} =$ (ft)

-3.67
-3.67
-3.67
-3.67
-3.67

$H1_i =$ (klf)

5.3
5.3
5.3
5.3
5.3

$\Sigma M_{lat_i} := -H1_i \cdot (y_{H1_i}) - K1_i \cdot (y_{K1}) - K2_i \cdot (y_{K2}) + H2_i \cdot (y_{H2_i}) + H3_i \cdot (y_{H...}$
$+ A1_i \cdot (y_{A1_i}) + A2_i \cdot (y_{A2_i}) + A3_i \cdot (y_{A3_i}) - R_{key_i} \cdot (y_{Rkey})$

$x_{R_i} := \frac{\Sigma M_{grav_i} - \Sigma M_{lat_i}}{W_i - U_i}$ $\quad L_{brg_i} := \min(3 \cdot x_{R_i}, L_{ftg})$

$ok_{u_i} :=$ if$\left[\left|L_{brg_i} - (L_{ftg} - L_{t2_i})\right| > 0.001 \cdot ft,$ "Uplift assumptions wrong in sliding analysis." , "Matched."$\right]$

W_i = (klf)	u_{toe_i} = (ksf)	u_{heel_i} = (ksf)	δ_{u_i} = (psf/ft)	u_{1_i} = (klf)	u_{2_i} = (klf)	u_{3_i} = (klf)
83.6	0.813	1.250	15.6	22.750	6.125	0.000
83.6	0.813	1.219	14.5	22.750	5.688	0.000
83.7	0.813	1.188	13.4	22.750	5.250	0.000
83.7	0.813	1.156	12.3	22.750	4.812	0.000
83.8	0.813	1.125	11.2	22.750	4.375	0.000

x_{u3_i} = (ft)	h_{H2_i} = (ft)	y_{H2_i} = (ft)	$H2_i$ = (klf)
28.0	20.0	-1.3	12.5
28.0	19.5	-1.5	11.9
28.0	19.0	-1.7	11.3
28.0	18.5	-1.8	10.7
28.0	18.0	-2.0	10.1

U_i = (klf)	x_{U_i} = (ft)	ΣM_{grav_i} = (kip)	ΣM_{lat_i} = (kip)	x_{R_i} = (ft)	L_{brg_i} = (ft)
28.9	15.0	918	-16	17.1	28.0
28.4	14.9	927	-15	17.1	28.0
28.0	14.9	937	-14	17.1	28.0
27.6	14.8	946	-14	17.1	28.0
27.1	14.8	955	-13	17.1	28.0

$H_{L_i} := 0 \cdot klf$

$$H_{R_i} := \gamma_w \cdot \frac{\left(E_{wtoe_i} - E_{ftg}\right)^2}{2}$$

$$\Delta P_{2_i} := \frac{\left[\left(W_i + V\right)\left(\tan\left(\phi_{d_i}\right)\cdot\cos(\alpha) + \sin(\alpha)\right) - U_i \cdot \tan\left(\phi_{d_i}\right) + \left(H_{L_i} - H_{R_i}\right)\cdot\left(\tan\left(\phi_{d_i}\right)\cdot\sin(\alpha) - \cos(\alpha)\right) + \frac{c}{FS_{2_i}}\cdot L\right]}{\left(\cos(\alpha) - \tan\left(\phi_{d_i}\right)\cdot\sin(\alpha)\right)}$$

$H_{L_i} =$

0.0	klf
0.0	
0.0	
0.0	
0.0	

$H_{R_i} =$

0.0	klf
0.0	
0.0	
0.0	
0.0	

$ok_{u_i} =$ ("Matched." "Matched." "Matched." "Matched." "Matched.")

$L_{ftg} - L_{brg_i} =$

0.000	ft
0.000	
0.000	
0.000	
0.000	

$$L_{t2} \equiv \begin{pmatrix} 0 \\ 0 \\ 0 \\ 0 \\ 0 \end{pmatrix} \cdot ft$$

$ok := if\left[max\left(\left|L_{brg} - \left(L_{ftg} - L_{t2}\right)\right|\right) < 0.001 \cdot ft, ok, \text{"Uplift area does not match."}\right]$

$ok := if\left(min\left(L_{brg}\right) < x_{key} + \frac{L_{key}}{2}, \text{"Uplift assumptions incorrect."}, ok\right)$ $\quad ok = \text{"Ok"}$

Resisting Wedge (#3)

$\beta_w := 0 \cdot deg$

$\phi := \phi_{fill}$ $\phi = 32.0\ deg$

$c := 0 \cdot ksf$

$\phi_{d_i} := atan\left(\frac{tan(\phi)}{FS_{2_i}}\right)$ $\phi_{d_i} = \begin{pmatrix} 22.8 \\ 22.5 \\ 22.2 \\ 22.0 \\ 21.7 \end{pmatrix} deg$

$\alpha_i := 45 \cdot deg - \frac{\phi_{d_i}}{2}$ $\alpha_i = \begin{pmatrix} 33.6 \\ 33.8 \\ 33.9 \\ 34.0 \\ 34.1 \end{pmatrix} deg$

$L_i := \frac{t_{base} + h_{key}}{sin(\alpha_i)}$ $L = \begin{pmatrix} 23.477 \\ 23.394 \\ 23.313 \\ 23.235 \\ 23.159 \end{pmatrix} ft$

$W_i := \gamma_{sat} \cdot \frac{L_i \cdot cos(\alpha_i) \cdot (t_{base} + h_{key})}{2} + \gamma_w \cdot (E_{wtoe_i} - E_{ftg}) \cdot L_i \cdot cos(\alpha_i)$

$U_i := \gamma_w \cdot \left(E_{wtoe_i} - E_{ftg} + \frac{t_{base} + h_{key}}{2}\right) \cdot L_i$

$H_L := 0 \cdot klf$

$H_R := 0 \cdot klf$

$V := 0 \cdot klf$

$$\Delta P_{3_i} := \frac{\left[(W_i + V) \cdot (tan(\phi_{d_i}) \cdot cos(\alpha_i) + sin(\alpha_i)) - U_i \cdot tan(\phi_{d_i}) + (H_L - H_R) \cdot (tan(\phi_{d_i}) \cdot sin(\alpha_i) - cos(\alpha_i)) + \frac{c}{FS_{2_i}} \cdot L_i\right]}{(cos(\alpha_i) - tan(\phi_{d_i}) \cdot sin(\alpha_i))}$$

$\Sigma P_i := \Delta P_{1a_i} + \Delta P_{1b_i} + \Delta P_{2_i} + \Delta P_{3_i}$

$FS_2 \equiv \begin{pmatrix} 1.49 \\ 1.51 \\ 1.53 \\ 1.55 \\ 1.57 \end{pmatrix}$

W_i = (klf)	U_i = (klf)	ΔP_{1a_i} = (klf)	ΔP_{1b_i} = (klf)	ΔP_{2_i} = (klf)	ΔP_{3_i} = (klf)	ΣP_i = (klf)
16.2	9.5	-32.1	-8.3	22.9	17.7	0.3
16.1	9.5	-32.1	-8.0	22.8	17.6	0.3
16.0	9.5	-32.2	-7.6	22.7	17.5	0.3
16.0	9.4	-32.3	-7.3	22.6	17.3	0.3
15.9	9.4	-32.4	-7.0	22.5	17.2	0.3

$L_{heel} \equiv 20 \cdot ft$

$h_{key} \equiv 8 \cdot ft$

$L_{ftg} = 28.0\ ft$

$L_{toe} \equiv 8 \cdot ft$

$L_{ftg} - x_{key} - \frac{L_{key}}{2} = 17.3\ ft$

ok := if($FS_{2_1} \geq 1.33$, ok, "Sliding instability: LC#1")

ok := if($FS_{2_n} \geq 1.50$, ok, "Sliding instability: LC#n")

ok = "Ok"

Upstream Training Wall at Right: (Grade = 517.0')

Reference:T:\ST\CALCS\Common geometry.mcd(R)

Geometry:

$E_{wall} := 520 \cdot ft$

$E_{ftg} := E_{approach}$ $\qquad E_{ftg} = 500.0\,ft$

$t_{base} := 5 \cdot ft$

$E_{bftg} := E_{ftg} - t_{base}$ $\qquad E_{bftg} = 495.0\,ft$

$E_{grade} := 517 \cdot ft$

$n := 5$

$i := 1 .. n$

$\Delta_w := 10 \cdot ft$ (maximum height of retained water above water in basin)

$$E_{wheel_i} := E_{grade} - \frac{\left[E_{grade} - \left(E_{ftg} + \frac{\Delta_w}{2}\right)\right]}{n-1} \cdot (i-1) \qquad E_{wheel} = \begin{pmatrix} 517.0 \\ 514.0 \\ 511.0 \\ 508.0 \\ 505.0 \end{pmatrix} ft$$

$$E_{wtoe_i} := \max\left(\begin{pmatrix} E_{wheel_i} - \Delta_w \\ E_{ftg} \end{pmatrix}\right) \qquad E_{wtoe} = \begin{pmatrix} 507.0 \\ 504.0 \\ 501.0 \\ 500.0 \\ 500.0 \end{pmatrix} ft$$

$$h := \min\left[\left[\begin{matrix} \left[\frac{1.0}{1.5} \quad 2 \cdot (E_{grade} - E_{ftg})\right] + E_{grade} \\ 527 \cdot ft - E_{ftg} \end{matrix}\right]\right] \qquad h = 27.0\,ft$$

$$\beta := \operatorname{atan}\left(\frac{1.0}{1.5}\right) \qquad \beta = 33.7\,deg$$

$h_\beta := 527 \cdot ft - E_{grade}$ $\qquad h_\beta = 10.0\,ft$

$t_{w\_top} := 1.5 \cdot ft$

$$t_{w\_bot} := t_{w\_top} + \frac{(E_{wall} - E_{ftg})}{8} \qquad t_{w\_bot} = 4.00\,ft$$

$L_{toe} = 8.0\,ft$

$L_{heel} = 21.0\,ft$

$L_{ftg} := L_{toe} + L_{heel}$ $\qquad L_{ftg} = 29.0\,ft$

$h_{wall} := E_{wall} - E_{ftg}$ $\qquad h_{wall} = 20.0\,ft$

$h_{key} = 5.0\,ft$

$L_{key} := 3 \cdot ft$ $\qquad L_{key} = 3.0\,ft$

$x_{key} := L_{toe} + t_{w\_bot} - \frac{L_{key}}{2}$ $\qquad x_{key} = 10.5\,ft$

Constants:

$\gamma_w = 62.5\,pcf$

Soil parameters:

$\gamma_{fill\_eff} = 65.0\,pcf$ $\qquad \gamma_{sat} = 127.5\,pcf$

$\gamma_{fill} = 130.0\,pcf$

$k_{0\_fill} = 0.5$

$\phi_{fill} = 32.0\,deg$

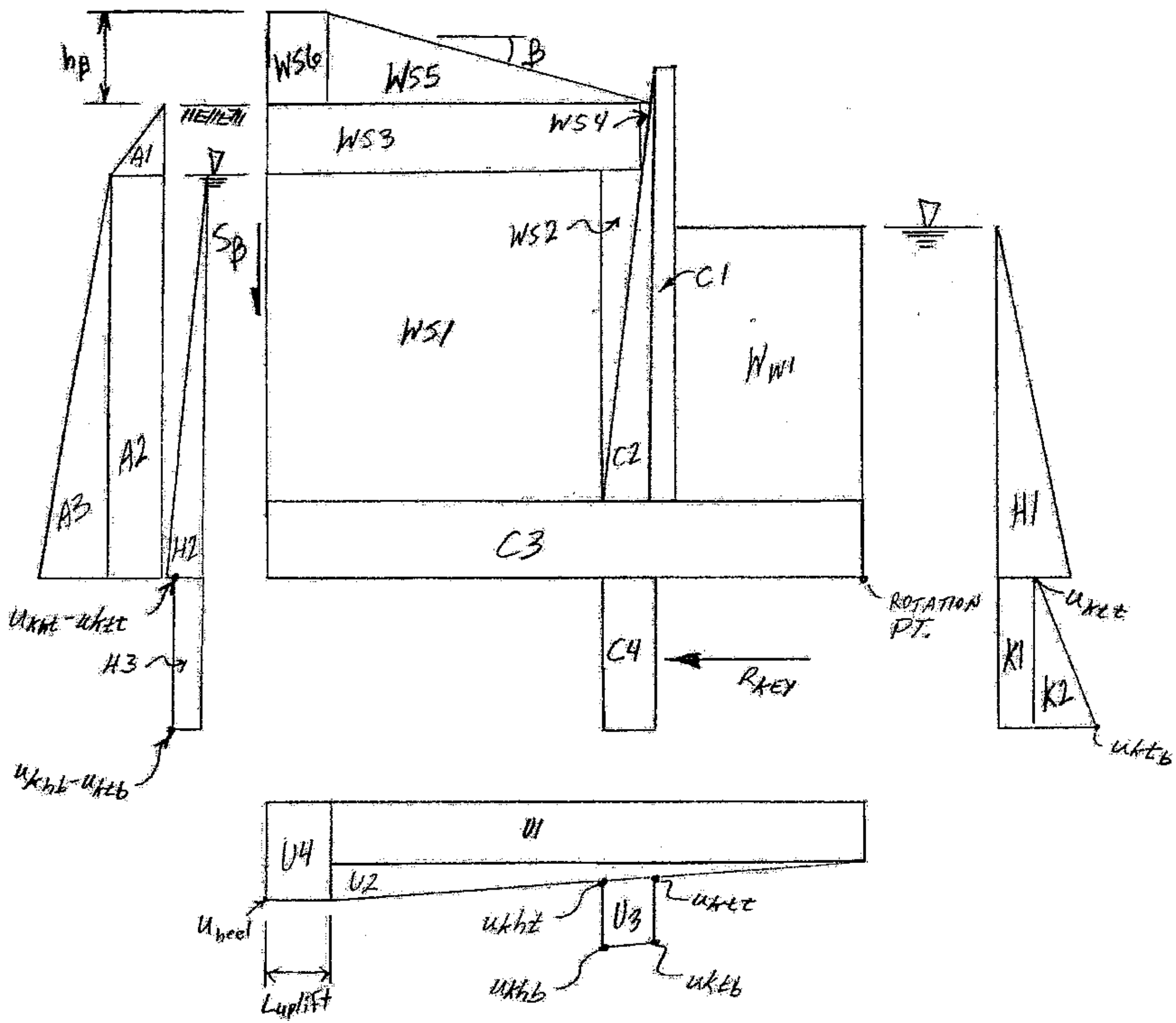
$k_{0\beta} := k_{0\_fill} \cdot (1 + \sin(\beta))$ $\qquad k_{0\beta} = 0.777$ $\qquad$ (USACE EM 1110-2-2502, Eq. 3-5)

Pre-Definitions:

$kip \equiv 1000 \cdot lbf$ $\qquad ksi \equiv 1000\ psi$ $\qquad ok \equiv "Ok"$ $\qquad klf \equiv 1000 \cdot \frac{lbf}{ft}$

$psf \equiv \frac{lbf}{ft^2}$ $\qquad plf \equiv \frac{lbf}{ft}$ $\qquad pcf \equiv \frac{lbf}{ft^3}$

$ORIGIN = 1.0$ $\qquad$ (must equal to 1)



h_β
β
WS6
WS5
WS4
WS3
WS2
WS1
A1
A2
A3
H2
H3
S_β
C1
C2
C3
C4
W_{W1}
H1
K1
K2
ROTATION PT.
R_{KEY}
$u_{kht}-u_{ktt}$
$u_{khb}-u_{ktb}$
u_{ktt}
u_{ktb}
U1
U2
U3
U4
u_{heel}
u_{kht}
u_{khb}
L_{uplift}

Analysis:

Gravity Loads:

$h_{C_1} := h_{wall}$ $h_{C_1} = 20.0\,ft$

$L_{C_1} := t_{w\_top}$ $L_{C_1} = 1.5\,ft$

$x_{C_1} := L_{toe} + \frac{L_{C_1}}{2}$ $x_{C_1} = 8.8\,ft$

$W_{C_1} := \gamma_c \cdot h_{C_1} \cdot L_{C_1}$ $W_{C_1} = 4.5\,klf$

$h_{C_2} := h_{C_1}$ $h_{C_2} = 20.0\,ft$

$L_{C_2} := t_{w\_bot} - t_{w\_top}$ $L_{C_2} = 2.5\,ft$

$x_{C_2} := L_{toe} + L_{C_1} + \frac{L_{C_2}}{3}$ $x_{C_2} = 10.3\,ft$

$W_{C_2} := \gamma_c \cdot \frac{h_{C_2} \cdot L_{C_2}}{2}$ $W_{C_2} = 3.8\,klf$

$h_{C_3} := t_{base}$ $h_{C_3} = 5.0\,ft$

$L_{C_3} := L_{ftg}$ $L_{C_3} = 29.0\,ft$

$x_{C_3} := \frac{L_{C_3}}{2}$ $x_{C_3} = 14.5\,ft$

$W_{C_3} := \gamma_c \cdot h_{C_3} \cdot L_{C_3}$ $W_{C_3} = 21.7\,klf$

$h_{C_4} := h_{key}$ $h_{C_4} = 5.0\,ft$

$L_{C_4} := L_{key}$ $L_{C_4} = 3.0\,ft$

$x_{C_4} := x_{key}$ $x_{C_4} = 10.5\,ft$

$W_{C_4} := \gamma_c \cdot h_{C_4} \cdot L_{C_4}$ $W_{C_4} = 2.3\,klf$

Weight of water at toe:

$h_{W1_i} := E_{wtoe_i} - E_{ftg}$ $h_{W1} = \begin{pmatrix} 7.00 \\ 4.00 \\ 1.00 \\ 0.00 \\ 0.00 \end{pmatrix} ft$

$L_{W1} := L_{toe}$ $L_{W1} = 8.0\,ft$

$x_{W1} := \frac{L_{toe}}{2}$ $x_{W1} = 4.0\,ft$

$W_{W1_i} := \gamma_w \cdot h_{W1_i} \cdot L_{W1}$ $W_{W1} = \begin{pmatrix} 3.5 \\ 2.0 \\ 0.5 \\ 0.0 \\ 0.0 \end{pmatrix} klf$

Weight of water/soil at heel:

$h_{WS1_i} := E_{wheel_i} - E_{ftg}$ $h_{WS1} = \begin{pmatrix} 17.00 \\ 14.00 \\ 11.00 \\ 8.00 \\ 5.00 \end{pmatrix} ft$

$L_{WS1} := L_{heel} - t_{w\_bot}$ $L_{WS1} = 17.0\,ft$

$x_{WS1} := L_{toe} + t_{w\_bot} + \frac{L_{WS1}}{2}$ $x_{WS1} = 20.5\,ft$

$W_{WS1_i} := (\gamma_{sat}) \cdot h_{WS1_i} \cdot L_{WS1}$ $W_{WS1} = \begin{pmatrix} 36.8 \\ 30.3 \\ 23.8 \\ 17.3 \\ 10.8 \end{pmatrix} klf$

$h_{WS2_i} := h_{WS1_i}$

$L_{WS2_i} := \frac{t_{w\_bot} - t_{w\_top}}{h_{wall}} \cdot h_{WS2_i}$ $L_{WS2} = \begin{pmatrix} 2.13 \\ 1.75 \\ 1.38 \\ 1.00 \\ 0.63 \end{pmatrix} ft$

$x_{WS2_i} := L_{toe} + t_{w\_bot} - \frac{L_{WS2_i}}{3}$ $x_{WS2} = \begin{pmatrix} 11.3 \\ 11.4 \\ 11.5 \\ 11.7 \\ 11.8 \end{pmatrix} ft$

$$W_{WS2_i} := (\gamma_{sat}) \cdot \frac{h_{WS2_i} \cdot L_{WS2_i}}{2}$$

$W_{WS2_i} =$

2.3
1.6
1.0
0.5
0.2

klf

$$h_{WS3_i} := E_{grade} - E_{wheel_i}$$

$h_{WS3_i} =$

0.0
3.0
6.0
9.0
12.0

ft

$$L_{WS3_i} := L_{WS1} + L_{WS2_i}$$

$L_{WS3_i} =$

19.1
18.8
18.4
18.0
17.6

ft

$$x_{WS3_i} := L_{ftg} - \frac{L_{WS3_i}}{2}$$

$x_{WS3_i} =$

19.4
19.6
19.8
20.0
20.2

ft

$$W_{WS3_i} := \gamma_{fill} \cdot h_{WS3_i} \cdot L_{WS3_i}$$

$W_{WS3_i} =$

0.0
7.3
14.3
21.1
27.5

klf

$$h_{WS4_i} := h_{WS3_i}$$

$$L_{WS4_i} := \frac{t_{w\_bot} - t_{w\_top}}{h_{wall}} \cdot h_{WS4_i}$$

$L_{WS4_i} =$

0.0
0.4
0.8
1.1
1.5

ft

$$x_{WS4_i} := L_{ftg} - L_{WS3_i} - \frac{L_{WS4_i}}{3}$$

$x_{WS4_i} =$

9.9
10.1
10.4
10.6
10.9

ft

$$W_{WS4_i} := \gamma_{fill} \cdot \frac{h_{WS4_i} \cdot L_{WS4_i}}{2}$$

$W_{WS4_i} =$

0.0
0.1
0.3
0.7
1.2

klf

$$L_{WS5} := \min\left(\left[\left[\frac{t_{w\_bot} - t_{w\_top}}{h_{wall}} \cdot (E_{grade} - E_{ftg}) + L_{WS1}\right], \frac{h_\beta}{\tan(\beta)}\right]\right)$$

$L_{WS5} = 15.00\,ft$

$$h_{WS5} := L_{WS5} \cdot \tan(\beta)$$ $h_{WS5} = 10.00\,ft$

$$x_{WS5} := \frac{2}{3} \cdot L_{WS5} + L_{toe} + t_{w\_top} + \frac{(E_{wall} - E_{grade})}{E_{wall} - E_{ftg}} \cdot (t_{w\_bot} - t_{w\_top})$$ $x_{WS5} = 19.88\,ft$

$$W_{WS5} := \gamma_{fill} \cdot \frac{h_{WS5} \cdot L_{WS5}}{2}$$ $W_{WS5} = 9.8\,klf$

$$L_{WS6} := \frac{E_{grade} - E_{ftg}}{h_{wall}} \cdot (t_{w\_bot} - t_{w\_top}) + L_{WS1} - L_{WS5}$$ $L_{WS6} = 4.1\,ft$

$$h_{WS6} := h_{WS5}$$ $h_{WS6} = 10.0\,ft$

$$x_{WS6} := L_{ftg} - \frac{L_{WS6}}{2}$$ $x_{WS6} = 26.9\,ft$

$$W_{WS6} := \gamma_{fill} \cdot (h_{WS6} \cdot L_{WS6})$$ $W_{WS6} = 5.4\,klf$

Uplift:

$u_{toe_i} := \gamma_w \cdot \left(E_{wtoe_i} - E_{bftg}\right)$

$u_{toe_i} =$

0.750
0.563
0.375
0.313
0.313

ksf

$u_{heel_i} := \gamma_w \cdot \left(E_{wheel_i} - E_{bftg}\right)$

$u_{heel_i} =$

1.375
1.188
1.000
0.813
0.625

ksf

$\delta_{seep_i} := \dfrac{u_{heel_i} - u_{toe_i}}{L_{ftg} - L_{uplift_i}}$

$\delta_{seep_i} =$

21.552
21.552
21.552
17.241
10.776

$\frac{psf}{ft}$

$u_{ktt_i} := u_{heel_i} + \left(x_{key} - \dfrac{L_{key}}{2}\right) \cdot \delta_{seep_i}$

$u_{ktt_i} =$

1.569
1.381
1.194
0.968
0.722

ksf

$u_{kht_i} := u_{ktt_i} + L_{key} \cdot \delta_{seep_i}$

$u_{kht_i} =$

1.634
1.446
1.259
1.019
0.754

ksf

$u_{ktb_i} := u_{ktt_i} + \gamma_w \cdot h_{key}$

$u_{ktb_i} =$

1.881
1.694
1.506
1.280
1.034

ksf

$u_{khb_i} := u_{ktb_i} + L_{key} \cdot \delta_{seep_i}$

$u_{khb_i} =$

1.946
1.759
1.571
1.332
1.067

ksf

$x_{U1} := \dfrac{L_{ftg} - L_{uplift}}{2}$

$x_{U1_i} =$

14.5
14.5
14.5
14.5
14.5

ft

$U1_i := u_{toe_i} \cdot L_{ftg}$

$U1_i =$

21.7
16.3
10.9
9.1
9.1

klf

$x_{U2_i} := \dfrac{2}{3} \cdot \left(L_{ftg} - L_{uplift_i}\right)$

$x_{U2_i} =$

19.33
19.33
19.33
19.33
19.33

ft

$U2_i := \left(u_{heel_i} - u_{toe_i}\right) \cdot \dfrac{L_{ftg}}{2}$

$U2_i =$

9.1
9.1
9.1
7.3
4.5

klf

$x_{U3} := x_{key}$

$x_{U3} = 10.5\,ft$

$U3_i := \left(u_{ktb_i} - u_{ktt_i}\right) \cdot L_{key}$

$$U3 = \begin{pmatrix} 0.9 \\ 0.9 \\ 0.9 \\ 0.9 \\ 0.9 \end{pmatrix} klf$$

$x_{U4_i} := L_{ftg} - \dfrac{L_{uplift_i}}{2}$

$L_{U4_i} := L_{uplift_i}$

$U4_i := u_{heel_i} \cdot L_{U4_i}$

Lateral load due to water at toe:

$h_{H1_i} := E_{wtoe_i} - E_{bftg}$

$y_{H1_i} := \frac{h_{H1_i}}{3}$

$H1_i := \gamma_w \cdot \frac{(h_{H1_i})^2}{2}$

$h_{H2_i} := E_{wheel_i} - E_{bftg}$

$y_{H2_i} := \frac{h_{H2_i}}{3}$

$H2_i := \gamma_w \cdot \frac{(h_{H2_i})^2}{2}$

$h_{H3} := h_{key}$ $\qquad h_{H3} = 5.0\,ft$

$y_{H3} := \frac{-h_{key}}{2}$ $\qquad y_{H3} = -2.5\,ft$

$H3_i := (u_{khb_i} - u_{ktb_i}) \cdot h_{H3}$

$h_{K1} := h_{key}$ $\qquad h_{K1} = 5.0\,ft$

$K1_i := u_{ktt_i} \cdot h_{K1}$

$h_{K2} := h_{key}$ $\qquad h_{K2} = 5\ 0\,ft$

$K2_i := (u_{ktb_i} - u_{ktt_i}) \cdot \frac{h_{K2}}{2}$

$y_{K1} := \frac{-h_{key}}{2}$ $\qquad y_{K1} = -2.5\,ft$

$y_{K2} := \frac{-2}{3} \cdot h_{key}$ $\qquad y_{K2} = -3.3\,ft$

x_{U4_i} = (ft)	$U4_i$ = (klf)
29.0	0.0
29.0	0.0
29.0	0.0
29.0	0.0
29.0	0.0

h_{H1_i} = (ft)	y_{H1_i} = (ft)	$H1_i$ = (klf)	h_{H2_i} = (ft)	$H2_i$ = (klf)
12.00	4.00	4.5	22.00	15.1
9.00	3.00	2.5	19.00	11.3
6.00	2.00	1.1	16.00	8.0
5.00	1.67	0.8	13.00	5.3
5.00	1.67	0.8	10.00	3.1

y_{H2_i} = (ft)	$H3_i$ = (klf)	$K1_i$ = (klf)	$K2_i$ = (klf)
7.3	0.32	7.8	0.8
6.3	0.32	6.9	0.8
5.3	0.32	6.0	0.8
4.3	0.26	4.8	0.8
3.3	0.16	3.6	0.8

Lateral load due to retained soil/water:

$h_{A1_i} := E_{grade} - E_{wheel_i}$

$y_{A1_i} := E_{grade} - E_{bftg} - \frac{2}{3} \cdot h_{A1_i}$

$A1_i := k_{0\beta} \cdot \gamma_{fill} \cdot \frac{\left(h_{A1_i}\right)^2}{2}$

h_{A1_i} = (ft)	y_{A1_i} = (ft)	$A1_i$ = (klf)
0.00	22.00	0.0
3.00	20.00	0.5
6.00	18.00	1.8
9.00	16.00	4.1
12.00	14.00	7.3

$h_{A2_i} := E_{wheel_i} - E_{bftg}$

$y_{A2_i} := \frac{h_{A2_i}}{2}$

$A2_i := k_{0\beta} \cdot \gamma_{fill} \cdot h_{A1_i} \cdot h_{A2_i}$

$h_{A3_i} := h_{A2_i}$

$y_{A3_i} := \frac{h_{A3_i}}{3}$

$A3_i := k_{0\beta} \cdot \gamma_{fill\_eff} \cdot \frac{\left(h_{A3_i}\right)^2}{2}$

h_{A2_i} = (ft)	y_{A2_i} = (ft)	$A2_i$ = (klf)	h_{A3_i} = (ft)	y_{A3_i} = (ft)	$A3_i$ = (klf)
22.00	11.00	0.0	22.00	7.33	12.2
19.00	9.50	5.8	19.00	6.33	9.1
16.00	8.00	9.7	16.00	5.33	6.5
13.00	6.50	11.8	13.00	4.33	4.3
10.00	5.00	12.1	10.00	3.33	2.5

Shear force due to sloped backfill: (EM 1110-2-2502, Fig. 4-7)

$h_2 := E_{grade} - E_{ftg}$ $\qquad h_2 = 17.0\,ft$

$h_1 := h_2 + \tan(\beta) \cdot L_{WS5}$ $\qquad h_1 = 27.0\,ft$

$P_i := k_{0\beta} \cdot \gamma_{fill} \cdot h_{A1_i} \cdot \left(h_{A2_i} - t_{base}\right) + k_{0\beta} \cdot \gamma_{fill\_eff} \cdot \frac{\left(h_{A3_i} - t_{base}\right)^2}{2}$

$S_{\beta_i} := \text{if}\left[h_1 > h_2, \left[\frac{P_i \cdot (h_1 - h_2)}{3 \cdot L_{WS5}}\right], 0 \cdot klf\right]$

$x_{S\beta} := L_{ftg}$ $\qquad x_{S\beta} = 29.0\,ft$

Sum forces:

$$\Sigma V_i := \sum_{i=1}^{4} W_{C_i} + W_{W1_i} + W_{WS1_i} + W_{WS2_i} + W_{WS3_i} + W_{WS4_i} + W_{WS5} + W_{WS6} + S_{\beta_i} - \left(U1_i + U2_i + U3_i + U4_i\right)$$

$$\Sigma M_{grav_i} := \left(\sum_{i=1}^{4} W_{C_i} \cdot x_{C_i} + W_{W1_i} \cdot x_{W1} + W_{WS1_i} \cdot x_{WS1} + W_{WS2_i} \cdot x_{WS2_i} + W_{WS3_i} \cdot x_{WS3_i} + W_{WS4_i} \cdot x_{WS4_i}\right) \ldots$$
$$+ W_{WS5} \cdot x_{WS5} + W_{WS6} \cdot x_{WS6} + S_{\beta_i} \cdot x_{S\beta} - \left(U1_i \cdot x_{U1_i} + U2_i \cdot x_{U2_i} + U3_i \cdot x_{U3} + U4_i \cdot x_{U4_i}\right)$$

$$R_{key_i} := -H1_i - K1_i - K2_i + H2_i + H3_i + A1_i + A2_i + A3_i$$

$$y_{Rkey} := \frac{-h_{key}}{2} \qquad y_{Rkey} = -2.5\,\text{ft}$$

$$\Sigma H_i := -H1_i - K1_i - K2_i + H2_i + H3_i + A1_i + A2_i + A3_i - R_{key_i}$$

$$\Sigma M_{lat_i} := -H1_i \cdot y_{H1_i} - K1_i \cdot y_{K1} - K2_i \cdot y_{K2} + H2_i \cdot y_{H2_i} + H3_i \cdot y_{H3} \ldots$$
$$+ A1_i \cdot y_{A1_i} + A2_i \cdot y_{A2_i} + A3_i \cdot y_{A3_i} - R_{key_i} \cdot y_{Rkey}$$

$$\Sigma M_i := \Sigma M_{grav_i} - \Sigma M_{lat_i}$$

$$x_{R_i} := \frac{\Sigma M_i}{\Sigma V_i}$$

$P_i =$		$S_{\beta_i} =$		$R_{key_i} =$	
7.3	klf	1.6	klf	14.5	klf
9.2		2.0		16.7	
9.7		2.2		18.4	
8.9		2.0		19.3	
6.7		1.5		20.0	

$$L_{brg_i} := \max\left[\min\left(\begin{pmatrix} 3 \cdot x_{R_i} \\ L_{ftg} \end{pmatrix}\right), 0 \cdot ft\right]$$

$\Sigma V_i =$		$\Sigma M_{grav_i} =$		$\Sigma M_{lat_i} =$		$\Sigma M_i =$		$\Sigma H_i =$		$R_{key_i} =$		$x_{R_j} =$		$L_{brg_i} =$	
59.9	klf	1097	kip	240	kip	857	ki	0.0	klf	14.5	klf	14.31	ft	29.000	ft
64.4		1185		246		939		0.0		16.7		14.58		29.000	
68.6		1264		248		1016		0.0		18.4		14.82		29.000	
71.7		1321		245		1076		0.0		19.3		15.02		29.000	
74.0		1362		241		1121		0.0		20.0		15.14		29.000	

Bearing Capacity: (per EM 1110-1-1905)

$c := c_{fill}$ $c = 0.0\,psf$

$\phi := \phi_{fill}$ $\phi = 32.0\,deg$

$\gamma_{eff} := \gamma_{fill\_eff}$ $\gamma_{eff} = 65.0\,pcf$

$\gamma_{H\_eff} := \gamma_{eff}$ $\gamma_{H\_eff} = 65.0\,pcf$

$B_{eff_i} := L_{ftg} - 2 \cdot \left| \frac{L_{brg_i}}{2} - x_{R_i} \right|$ $B_{eff} = \begin{pmatrix} 28.6 \\ 28.8 \\ 28.4 \\ 28.0 \\ 27.7 \end{pmatrix} ft$

Table 4-3:

$N_\phi := \tan\left(45 \cdot deg + \frac{\phi}{2}\right)^2$ $N_\phi = 3.255$

$N_q := if\left(\phi = 0, 1.0, N_\phi \cdot e^{\pi \cdot \tan(\phi)}\right)$ $N_q = 23.2$

$N_c := if\left[\phi = 0, 5.14, (N_q - 1) \cdot \cot(\phi)\right]$ $N_c = 35.5$

$N_\gamma := if\left[\phi = 0, 0.00, (N_q - 1) \cdot \tan(1.4 \cdot \phi)\right]$ $N_\gamma = 22.0$

Inclined loading correction:

$\theta_i := atan\left(\frac{R_{key_i} + K1_i + K2_i}{\Sigma V_i}\right)$ $\theta = \begin{pmatrix} 21.16 \\ 20.76 \\ 20.17 \\ 19.19 \\ 18.27 \end{pmatrix} deg$

$\xi_{ci_i} := if\left[\phi = 0, \left(1 - \frac{\theta_i}{90 \cdot deg}\right), \left(1 - \frac{\theta_i}{90 \cdot deg}\right)^2\right]$ $\xi_{ci} = \begin{pmatrix} 0.585 \\ 0.592 \\ 0.602 \\ 0.619 \\ 0.635 \end{pmatrix}$

$\xi_{\gamma i_i} := if\left[\phi = 0, 1.0, if\left[\theta_i \le \phi, \left(1 - \frac{\theta_i}{\phi}\right)^2, 0.0\right]\right]$ $\xi_{\gamma i} = \begin{pmatrix} 0.115 \\ 0.123 \\ 0.137 \\ 0.160 \\ 0.184 \end{pmatrix}$

$\xi_{qi_i} := if\left[\phi = 0, \left(1 - \frac{\theta_i}{90 \cdot deg}\right), \left(1 - \frac{\theta_i}{90 \cdot deg}\right)^2\right]$ $\xi_{qi} = \begin{pmatrix} 0.585 \\ 0.592 \\ 0.602 \\ 0.619 \\ 0.635 \end{pmatrix}$

$B_i := L_{brg_i}$ $B = \begin{pmatrix} 29.0 \\ 29.0 \\ 29.0 \\ 29.0 \\ 29.0 \end{pmatrix} ft$

$W := 100 \cdot ft$

Foundation depth correction: (at toe)

$D := t_{base}$ $D = 5.0\,ft$

$\sigma_{D\_eff} := \gamma_{eff} \cdot D$ $\sigma_{D\_eff} = 325.0\,psf$

$\xi_{cd_i} := 1 + 0.2 \cdot (N_\phi)^{\frac{1}{2}} \cdot \frac{D}{B_i}$ $\xi_{cd} = \begin{pmatrix} 1.062 \\ 1.062 \\ 1.062 \\ 1.062 \\ 1.062 \end{pmatrix}$

$\xi_{\gamma d\_10_i} := 1 + 0.1 \cdot \left(\tan\left(45 \cdot deg + \frac{10 \cdot deg}{2}\right)^2\right)^{\frac{1}{2}} \cdot \frac{D}{B_i}$ $\xi_{\gamma d\_10} = \begin{pmatrix} 1.021 \\ 1.021 \\ 1.021 \\ 1.021 \\ 1.021 \end{pmatrix}$

$\xi_{\gamma d_i} := \text{if}\left[\phi \le 10 \cdot deg, \xi_{\gamma d\_0} + \frac{\phi}{10 \cdot deg} \cdot \left(\xi_{\gamma d\_10_i} - \xi_{\gamma d\_0}\right), 1 + 0.1 \cdot (N_\phi)^{\frac{1}{2}} \cdot \frac{D}{B_i}\right]$ $\xi_{\gamma d} = \begin{pmatrix} 1.031 \\ 1.031 \\ 1.031 \\ 1.031 \\ 1.031 \end{pmatrix}$

$\xi_{qd_i} := \xi_{\gamma d_i}$ $\xi_{qd} = \begin{pmatrix} 1.031 \\ 1.031 \\ 1.031 \\ 1.\ldots \\ 1.\ldots \end{pmatrix}$

USACE EM 1110-1-1905, Eq. 4-16:

$q_{u\_toe_i} := c \cdot N_c \cdot \xi_{cd} \cdot \xi_{ci} + \frac{1}{2} \cdot B_{eff_i} \cdot \gamma_{H\_eff} \cdot N_\gamma \cdot \xi_{\gamma d} \cdot \xi_{\gamma i} + \sigma_{D\_eff} \cdot N_q \cdot \xi_{qd} \cdot \xi_{qi}$ $q_{u\_toe} = \begin{pmatrix} 38.750 \\ 38.864 \\ 38.615 \\ 38.402 \\ 38.273 \end{pmatrix} ksf$

Foundation depth correction: (at heel)

$D := E_{grade} - E_{ftg} + t_{base} + h_\beta$ $D = 32.0\,ft$

$\sigma_{D\_eff\_heel} := \gamma_{eff} \cdot D$ $\sigma_{D\_eff} = 0.325\,ksf$

$\xi_{cd_i} := 1 + 0.2 \cdot (N_\phi)^{\frac{1}{2}} \cdot \frac{D}{\ldots}$ $\xi_{cd} = \begin{pmatrix} 1.398 \\ 1.398 \\ 1.398 \\ 1.398 \\ 1.398 \end{pmatrix}$

$\xi_{\gamma d\_10_i} := 1 + 0.1 \cdot \left(\tan\left(45 \cdot deg + \frac{10 \cdot deg}{2}\right)^2\right)^{\frac{1}{2}} \cdot \frac{D}{B_i}$ $\xi_{\gamma d\_10} = \begin{pmatrix} 1.132 \\ 1.132 \\ 1.132 \\ 1.132 \\ 1.132 \end{pmatrix}$

$\xi_{\gamma d_i} := \text{if}\left[\phi \le 10 \cdot deg, \xi_{\gamma d\_0} + \frac{\phi}{10 \cdot deg} \cdot \left(\xi_{\gamma d\_10_i} - \xi_{\gamma d\_0}\right), 1 + 0.1 \cdot (N_\phi)^{\frac{1}{2}} \cdot \frac{D}{B_i}\right]$ $\xi_{\gamma d} = \begin{pmatrix} 1.199 \\ 1.199 \\ 1.199 \\ 1.199 \\ 1.199 \end{pmatrix}$

$\xi_{qd_i} := \xi_{\gamma d_i}$ $\xi_{qd} = \begin{pmatrix} 1.199 \\ 1.199 \\ 1.199 \\ 1.\ldots \\ 1.\ldots \end{pmatrix}$

USACE EM 1110-1-1905, Eq. 4-16:

$q_{u\_heel_i} := c \cdot N_c \cdot \xi_{cd} \cdot \xi_{ci} + \frac{1}{2} \cdot B_{eff_i} \cdot \gamma_{H\_eff} \cdot N_\gamma \cdot \xi_{\gamma d} \cdot \xi_{\gamma i} + \sigma_{D\_eff} \cdot N_q \cdot \xi_{qd} \cdot \xi_{qi}$ $q_{u\_heel} = \begin{pmatrix} 45.063 \\ 45.195 \\ 44.906 \\ 44.658 \\ 44.508 \end{pmatrix} ksf$

$check\_uplift_i := L_{ftg} - L_{brg_i} - L_{uplift_i}$

check_uplift_i =

0.0000 ft
0.0000
0.0000
0.0000
0.0000

ok := if(max(|check_uplift|) < 0.001 · ft, ok, "Uplift assumptions do not match bearing area.")

ok = "Ok"

$$e_{brg_i} := \frac{L_{brg_i}}{2} - x_{R_i}$$

$$\sigma_{brg\_toe_i} := \frac{\Sigma V_i}{L_{brg_i}} + \frac{\Sigma V_i \cdot e_{brg_i}}{\frac{\left(L_{brg_i}\right)^2}{6}}$$

$$\sigma_{brg\_heel_i} := \frac{\Sigma V_i}{L_{brg_i}} - \frac{\Sigma V_i \cdot e_{brg_i}}{\frac{\left(L_{brg_i}\right)^2}{6}}$$

$$FS_{brg_i} := \min\left(\frac{q_{u\_toe_i}}{\sigma_{brg\_toe_i}}, \frac{q_{u\_heel_i}}{\sigma_{brg\_heel_i}}\right)$$

$$\%_{brg_i} := \frac{L_{brg_i}}{L_{ftg}}$$

$$\%_{brg_i} = \begin{pmatrix} 100.0 \\ 100\ 0 \\ 100.0 \\ 100.0 \\ 100.0 \end{pmatrix} \%$$

ok := if($\%_{brg_1} \geq 75 \cdot \%$, ok, "OT instability: LC#1")

$L_{ftg} = 29.0\ ft$

ok := if($\%_{brg_n} \geq 100\%$, ok, "OT instability: LC#n")

$t_{w\_bot} = 4.0\ ft$

$\frac{L_{ftg}}{4} = 7.250\ ft$

e_{brg_i} = (ft)	$\sigma_{brg\_toe_i}$ = (ksf)	$\sigma_{brg\_heel_i}$ = (ksf)	FS_{brg_i} =	$L_{ftg} - L_{brg_i}$ = (ft)
0.19	2.146	1.984	18.06	0.000
-0.08	2.182	2.258	17.81	0.000
-0.32	2.210	2.520	17.47	0.000
-0.52	2.207	2.735	16.33	0.000
-0.64	2.215	2.890	15.40	0.000

$$L_{uplift} \equiv \begin{pmatrix} 0 \\ 0 \\ 0 \\ 0 \\ 0 \end{pmatrix} \cdot ft$$

ok := if[max[|$L_{brg} - (L_{ftg} - L_{uplift})$|] < 0.001 · ft, ok, "Uplift area does not match

ok := if($FS_{brg_1} < 2$, "Bearing problem LC#1", ok)

$L_{ftg} = 29.0\ ft$

ok := if($FS_{brg_n} < 3$, "Bearing problem LC#n", ok)

$L_{toe} \equiv 8 \cdot ft$

ok = "Ok"

Base Pressures:

$$e_{ftg_i} := \frac{L_{ftg}}{2} - x_{R_i}$$ (eccentricity with respect to the footing centroid)

$\Sigma H_i + R_{key_i}$ = (klf)	ΣV_i = (klf)	e_{ftg_i} = (ft)	x_{R_i} = (ft)	$\sigma_{brg\_heel_i}$ = (ksf)	$\sigma_{brg\_toe_i}$ = (ksf)
14.5	59.9	0.19	14.31	1.984	2.146
16.7	64.4	-0.08	14.58	2.258	2.182
18.4	68.6	-0.32	14.82	2.520	2.210
19.3	71.7	-0.52	15.02	2.735	2.207
20.0	74.0	-0.64	15.14	2.890	2.215

$L_{brg_1} = 29.00\,\text{ft}$

$$\frac{L_{brg}}{L_{ftg}} = \begin{pmatrix} 100.0 \\ 100.0 \\ 100.0 \\ 100\ 0 \\ 100.0 \end{pmatrix} \%$$

Sliding Analysis:

Function Definitions:

$c_1(\phi_d) := 2 \cdot \tan(\phi_d)$

$c_2(\phi_d, \beta) := 1 - \tan(\phi_d) \cdot \tan(\beta) - \left(\frac{\tan(\beta)}{\tan(\phi_d)}\right)$

$\alpha_{driving}(\phi_d, \beta) := -\text{atan}\left(\frac{c_1(\phi_d) + \sqrt{c_1(\phi_d)^2 + 4 \cdot c_2(\phi_d, \beta)}}{2}\right)$

$L_\beta := \max\left(\begin{pmatrix} \frac{h_\beta}{\tan(\beta)} - L_{WS5} - L_{WS6} \\ 0 \cdot ft \end{pmatrix}\right)$ $\quad L_\beta = 0.0\,ft$

Sliding Analysis #1:

$\beta_w := \beta$ $\quad \beta_w = 33.7\,deg$

$\phi_i := \phi_{fill}$ $\quad \phi = \begin{pmatrix} 32.0 \\ 32.0 \\ 32.0 \\ 32.0 \\ 32.0 \end{pmatrix} deg$

$c := 0 \cdot ksf$

$\phi_{d_i} := \text{atan}\left(\frac{\tan(\phi_i)}{FS1_i}\right)$ $\quad \phi_{d_i} = \begin{pmatrix} 20.7 \\ 20.0 \\ 19.3 \\ 18.6 \\ 17.9 \end{pmatrix} deg$

$\text{atan}(\tan(\beta) \cdot FS1_i) = \begin{pmatrix} 47.7 \\ 48.9 \\ 49.9 \\ 51.1 \\ 52.1 \end{pmatrix} deg$ (back solve for minimum ϕ value for stable slope β, EM 1110-2-2502, pg 3-31)

$\phi_i := \text{if}\left[\left(c_1(\phi_{d_i})^2 + 4 \cdot c_2(\phi_{d_i}, \beta_w) < 0\right), \text{atan}(\tan(\beta_w) \cdot FS1_i), \phi_i\right]$ $\quad \phi = \begin{pmatrix} 47.7 \\ 48.9 \\ 49.9 \\ 51.1 \\ 52.1 \end{pmatrix} deg$ (substitue minimum ϕ if slope is unstable)

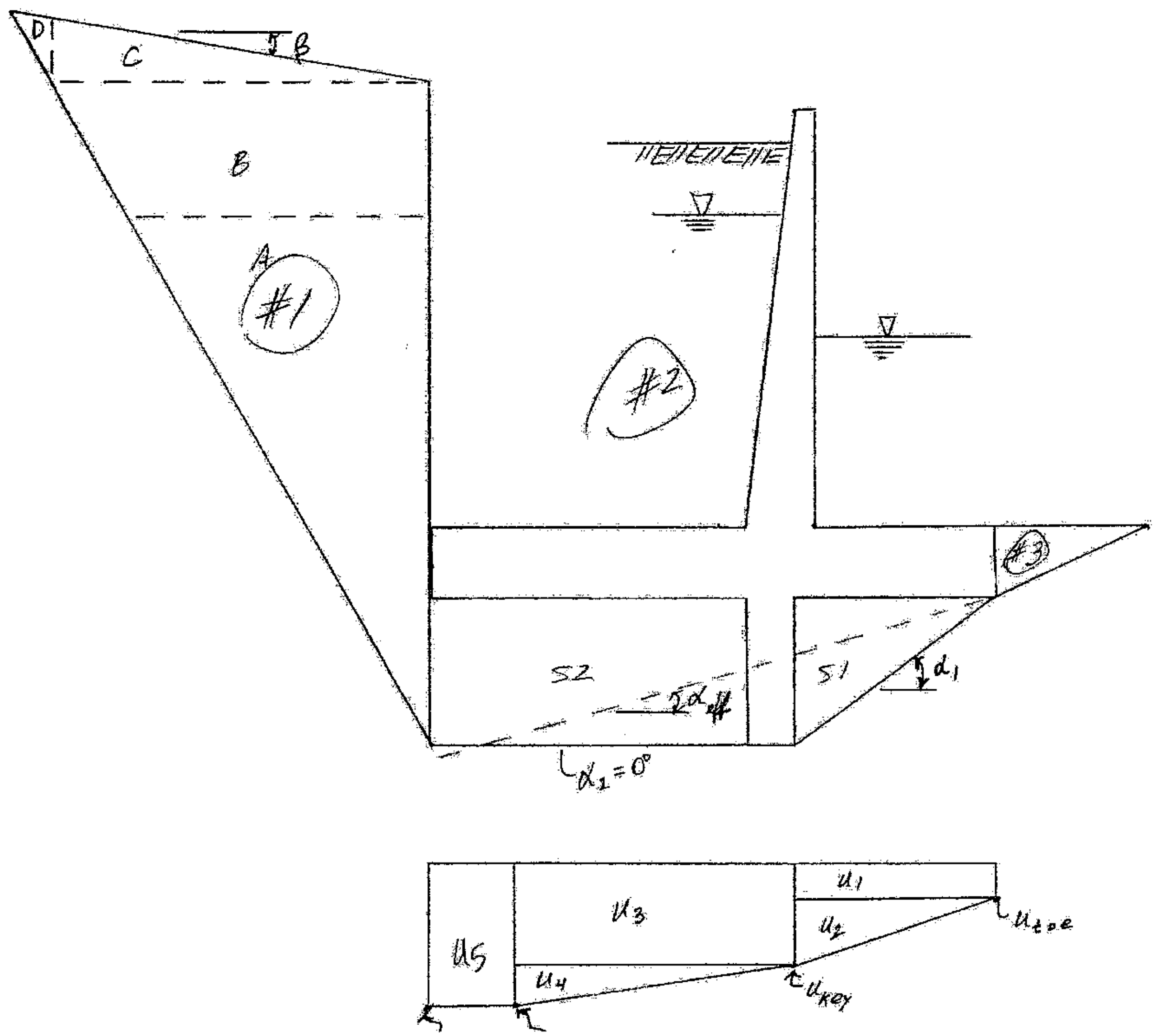
$\phi_{d\_1b_i} := \text{atan}\left(\frac{\tan(\phi_i)}{FS1_i}\right)$ $\quad \phi_{d\_1b_i} = \begin{pmatrix} 33.7 \\ 33.7 \\ 33.7 \\ 33.7 \\ 33.7 \end{pmatrix} deg$

$\alpha_{1b_i} := \alpha_{driving}(\phi_{d\_1b_i}, \beta_w)$

$h_{1b} := (E_{grade} + L_{WS5} \cdot \tan(\beta_w)) - (E_{bftg} - h_{key})$ $\quad h_{1b} = 37.0\,ft$

$L_{max_i} := \text{if}\left[-\alpha_{1b_i} = \phi_{d\_1b_i}, 1000 \cdot ft, \frac{\frac{h_{1b}}{\cos(-\alpha_{1b_i}) \cdot (\tan(-\alpha_{1b_i}) - \tan(\beta_w))}}{\cos(-\alpha_{1b_i})}\right]$ $\quad \alpha_{1b} = \begin{pmatrix} -33.7 \\ -33.7 \\ -33.7 \\ -33.7 \\ -33.7 \end{pmatrix} deg$ $\quad L_{max} = \begin{pmatrix} 1000.0 \\ 1000.0 \\ 1000.0 \\ 1000.0 \\ 2.9 \times 10^9 \end{pmatrix} ft$

$h_{1a_i} := \text{if}\left[L_\beta < L_{max_i}, h_{1b} + L_\beta \cdot (\tan(\beta) - \tan(-\alpha_{1b_i})), 0 \cdot ft\right]$



Sliding Analysis #1

Title Samuels Ave. Dam
Training wall at right
CDM04188

Date: ________
By: ________
✔ ________

Freese and Nichols

Driving Wedge (#1a):

$\beta_w := 0 \cdot deg$ $\quad\beta_w = 0.0\,deg$

$\phi := \phi_{fill}$ $\quad\phi = 32.0\,deg$

$c := 0 \cdot ksf$

$h_{1a} = \begin{pmatrix} 37.0 \\ 37.0 \\ 37.0 \\ 37.0 \\ 37.0 \end{pmatrix} ft$

$\phi_{d_i} := atan\left(\frac{tan(\phi)}{FS1_i}\right)$ $\quad\phi_d = \begin{pmatrix} 20.7 \\ 20.0 \\ 19.3 \\ 18.6 \\ 17.9 \end{pmatrix} deg$

$\alpha_i := \alpha_{driving}\left(\phi_{d_i}, \beta_w\right)$ $\quad\alpha = \begin{pmatrix} -55.4 \\ -55.0 \\ -54.7 \\ -54.3 \\ -54.0 \end{pmatrix} deg$

$h_i := h_{1a_i}$ $\quad h = \begin{pmatrix} 37.0 \\ 37.0 \\ 37.0 \\ 37.0 \\ 37.0 \end{pmatrix} ft$

$L_i := \frac{h_i}{cos(-\alpha_i) \cdot \left(tan(-\alpha_i) - tan(\beta_w)\right)}$ $\quad = \begin{pmatrix} 45.0 \\ 45.2 \\ 45.4 \\ 45.6 \\ 45.8 \end{pmatrix} ft$

$h_{sat_i} := max\left[\begin{bmatrix} E_{wheel_i} - \left(E_{ftg} - t_{base} - h_{key}\right) - L_\beta \cdot tan\left(-\alpha_{1b_i}\right) \\ 0 \cdot ft \end{bmatrix}\right]$ $\quad h_{sat} = \begin{pmatrix} 27.0 \\ 24.0 \\ 21.0 \\ 18.0 \\ 15.0 \end{pmatrix} ft$

$L_{h_i} := \frac{h_i}{tan(-\alpha_i)}$ $\quad L_h = \begin{pmatrix} 25.6 \\ 25.9 \\ 26.2 \\ 26.6 \\ 26.9 \end{pmatrix} ft$

$L_{sat_i} := \frac{h_{sat_i}}{tan(-\alpha_i)}$ $\quad L_{sat} = \begin{pmatrix} 18.6 \\ 16.8 \\ 14.9 \\ 12.9 \\ 10.9 \end{pmatrix} ft$

$h_{left} := 0 \cdot ft$

$h_{right_i} := h_{1a_i}$

$W_i := \gamma_{fill} \cdot \left(L_{h_i} \cdot \frac{h_{left} + h_{right_i}}{2}\right) + \left(\gamma_{sat} - \gamma_{fill}\right) \cdot \frac{L_{sat_i} \cdot h_{sat_i}}{2}$

$W_i =$

60.8
61.8
62.7
63.7
64.5

klf

$V := 0 \cdot klf$

$H_L := 0 \cdot klf$

$H_R := 0 \cdot klf$

$U_i := \gamma_w \cdot \left(\frac{h_{sat_i}}{2}\right) \cdot \sqrt{\left(h_{sat_i}\right)^2 + \left(L_{sat_i}\right)^2}$ $\quad U = \begin{pmatrix} 27.7 \\ 22.0 \\ 16.9 \\ 12.5 \\ 8.7 \end{pmatrix} klf$

$$\Delta P_{1a_i} := \frac{\left[\left(W_i + V\right)\cdot\left(\tan\left(\phi_{d_i}\right)\cdot\cos\left(\alpha_i\right)+\sin\left(\alpha_i\right)\right) - U_i\cdot\tan\left(\phi_{d_i}\right) + \left(H_L - H_R\right)\cdot\left(\tan\left(\phi_{d_i}\right)\cdot\sin\left(\alpha_i\right)-\cos\left(\alpha_i\right)\right) + \frac{c}{FS_{1_i}}\cdot L_i\right]}{\left(\cos\left(\alpha_i\right) - \tan\left(\phi_{d_i}\right)\cdot\sin\left(\alpha_i\right)\right)}$$

Driving Wedge (#1b)·

$\beta_w := \beta$ $\qquad \beta_w = 33.7\,deg$

$\alpha := \alpha_{1b}$ $\qquad \alpha = \begin{pmatrix}-33.7\\-33.7\\-33.7\\-33.7\\-33.7\end{pmatrix} deg$

$\phi_d := \phi_{d\_1b}$ $\qquad \phi_d = \begin{pmatrix}33.7\\33.7\\33.7\\33.7\\33.7\end{pmatrix} deg$

$h = \begin{pmatrix}37.0\\37.0\\37.0\\37.0\\37.0\end{pmatrix} ft$

$L_h := L_\beta$ $\qquad L_h = 0.0\,ft$

$L_i := \frac{L_\beta}{\cos\left(\alpha_i\right)}$ $\qquad = \begin{pmatrix}0.0\\0.0\\0.0\\0.0\\0.0\end{pmatrix} ft$

$h_{satr_i} := \max\left[\begin{bmatrix}E_{wheel_i} - \left(E_{ftg} - t_{base} - h_{key}\right)\\0\cdot ft\end{bmatrix}\right]$ $\qquad h_{satr} = \begin{pmatrix}27.0\\24.0\\21.0\\18.0\\15.0\end{pmatrix} ft$

$h_{satl_i} := \max\left[\begin{bmatrix}E_{wheel_i} - \left(E_{ftg} - t_{base} - h_{key}\right) - \frac{L_\beta}{\cos\left(\alpha_i\right)}\\0\cdot ft\end{bmatrix}\right]$ $\qquad h_{satl} = \begin{pmatrix}27.0\\24.0\\21.0\\18.0\\15.0\end{pmatrix} ft$

$L_{sat_i} := \min\left[\begin{bmatrix}L_\beta\\\frac{h_{satr_i}}{\tan\left[\left(-\alpha\right)_i\right]}\end{bmatrix}\right]$ $\qquad L_{sat} = \begin{pmatrix}0.0\\0.0\\0.0\\0.0\\0.0\end{pmatrix} ft$

$h_{left_i} := h_{1a_i}$ $\qquad h_{left} = \begin{pmatrix}37.0\\37.0\\37.0\\37.0\\37.0\end{pmatrix} ft$

$h_{right} := h_{1b}$

$$W_i := \gamma_{fill} \cdot \left(L_h \cdot \frac{h_{left_i} + h_{right}}{2} \right) + (\gamma_{sat} - \gamma_{fill}) \cdot L_{sat_i} \cdot \left(\frac{h_{satr_i} + h_{satl_i}}{2} \right)$$

$W_i =$

W_i (klf)
0.0
0.0
0.0
0.0
0.0

$V := 0 \cdot klf$

$H_L := 0 \cdot klf$

$H_R := 0 \cdot klf$

$$U_i := \gamma_w \cdot \left(\frac{h_{satr_i} + h_{satl_i}}{2} \right) \cdot \sqrt{\left(h_{satr_i} - h_{satl_i}\right)^2 + (L_h)^2}$$

$$\Delta P_{1b_i} := \frac{\left[(W_i + V) \cdot \left(\tan(\phi_{d_i}) \cdot \cos(\alpha_i) + \sin(\alpha_i) \right) - U_i \cdot \tan(\phi_{d_i}) + (H_L - H_R) \cdot \left(\tan(\phi_{d_i}) \cdot \sin(\alpha_i) - \cos(\alpha_i) \right) + \frac{c}{FS_{1_i}} \cdot L_i \right]}{\left(\cos(\alpha_i) - \tan(\phi_{d_i}) \cdot \sin(\alpha_i) \right)}$$

Structure Wedge (#2)

$U_i =$

U_i (klf)
0.000
0.000
0.000
0.000
0.000

$\beta_w := 0 \cdot deg$

$\phi := \phi_{fill}$ $\phi = 32.0\,deg$

$c := 0 \cdot ksf$

$$\phi_{d_i} := \operatorname{atan}\left(\frac{\tan(\phi)}{FS_{1_i}} \right)$$

$$\phi_{d_i} = \begin{pmatrix} 20.7 \\ 20.0 \\ 19.3 \\ 18.6 \\ 17.9 \end{pmatrix} deg$$

$$\alpha_1 := \operatorname{atan}\left(\frac{h_{key}}{x_{key} - \frac{L_{key}}{2}} \right)$$ $\alpha_1 = 29.1\,deg$ (angle of shear plane between toe and key)

$\alpha_2 := 0 \cdot deg$ (angle of shear plane between key and heel)

$$\alpha := \alpha_1 \cdot \left(\frac{x_{key}}{L_{ftg}} \right) + \alpha_2 \cdot \left(\frac{L_{ftg} - x_{key}}{L_{ftg}} \right)$$ $\alpha = 10.5\,deg$ (average angle of shear plane for structural wedge)

$$L := \frac{L_{ftg}}{\cos(\alpha)}$$ $L = 29.5\,ft$

$h_{S1} := h_{key}$ $h_{S1} = 5.0\,ft$

$$L_{S1} := x_{key} - \frac{L_{key}}{2}$$ $L_{S1} = 9.0\,ft$

$x_{S1} := \frac{2}{3} \cdot L_{S1}$ $x_{S1} = 6.0\,ft$

$S1 := \gamma_{sat} \cdot \frac{h_{S1} \cdot L_{S1}}{2}$ $S1 = 2.9\,klf$

$h_{S2} := h_{key}$ $h_{S2} = 5.0\,ft$

$L_{S2} := L_{ftg} - x_{key} - \frac{L_{key}}{2}$ $L_{S2} = 17.0\,ft$

$x_{S2} := L_{ftg} - \frac{L_{S2}}{2}$ $x_{S2} = 20.5\,ft$

$S2 := \gamma_{sat} \cdot h_{S2} \cdot L_{S2}$ $S2 = 10.8\,klf$

$$W_i := \sum_{i=1}^{4} W_{C_i} + W_{W1_i} + W_{WS1_i} + W_{WS2_i} + W_{WS3_i} + W_{WS4_i} + W_{WS5} + W_{WS6} + S1 + S2 + S_{\beta_i}$$

Uplift below structural wedge:

$u_{toe_i} := \gamma_w \cdot \left(E_{wtoe_i} - E_{bftg}\right)$

$u_{heel_i} := \gamma_w \cdot \left[E_{wheel_i} - \left(E_{bftg} - h_{key}\right)\right]$

$$\delta_{u_i} := \frac{\gamma_w \cdot \left(E_{wheel_i} - E_{wtoe_i}\right)}{L_{ftg} - L_{t1_i}}$$

$$u_{key_i} := u_{toe_i} + \delta_{u_i} \cdot \left(x_{key} - \frac{L_{key}}{2}\right) + \gamma_w \cdot h_{key}$$

$$ok := if\left[\left[u_{key_1} + \delta_{u_1} \cdot \left(L_{ftg} - x_{key} + \frac{L_{key}}{2} - L_{t1_1}\right) = u_{heel_1}\right], ok, \text{"Uplift pressures do not close."}\right]$$

ok = "Ok"

$$u_{1_i} := u_{toe_i} \cdot \left(x_{key} - \frac{L_{key}}{2}\right)$$

$$x_{u1} := \frac{x_{key} - \frac{L_{key}}{2}}{2}$$ $x_{u1} = 4.5\,ft$

$$u_{2_i} := \left(u_{key_i} - u_{toe_i}\right) \cdot \frac{\left(x_{key} - \frac{L_{key}}{2}\right)}{2}$$

$$x_{u2} := \frac{2}{3}\cdot\left(x_{key} - \frac{L_{key}}{2}\right) \qquad x_{u2} = 6.0\,\text{ft}$$

$$u3_i := u_{key_i}\cdot\left(L_{ftg} - L_{t1_i} - x_{key} + \frac{L_{key}}{2}\right)$$

$$x_{u3_i} := x_{key} - \frac{L_{key}}{2} + \frac{1}{2}\cdot\left[L_{ftg} - L_{t1_i} - \left(x_{key} - \frac{L_{key}}{2}\right)\right]$$

$$u4_i := \left(u_{heel_i} - u_{key_i}\right)\cdot\frac{\left(L_{ftg} - L_{t1_i} - x_{key} + \frac{L_{key}}{2}\right)}{2}$$

$$x_{u4_i} := x_{key} - \frac{L_{key}}{2} + \frac{2}{3}\cdot\left[L_{ftg} - L_{t1_i} - \left(x_{key} - \frac{L_{key}}{2}\right)\right]$$

$$u5_i := u_{heel_i}\cdot L_{t1_i}$$

$$x_{u5_i} := L_{ftg} - \frac{L_{t1_i}}{2}$$

$$U_i := u1_i + u2_i + u3_i + u4_i + u5_i$$

$$x_{U_i} := \frac{u1_i\cdot x_{u1} + u2_i\cdot x_{u2} + u3_i\cdot x_{u3_i} + u4_i\cdot x_{u4_i} + u5_i\cdot x_{u5_i}}{U_i}$$

$$\Sigma M_{grav_i} := \left(\sum_{i=1}^{4} W_{C_i}\cdot x_{C_i} + W_{W1_i}\cdot x_{W1} + W_{WS1_i}\cdot x_{WS1} + W_{WS2_i}\cdot x_{WS2_i} + W_{WS3_i}\cdot x_{WS3_i}\right) \ldots$$
$$+ W_{WS4_i}\cdot x_{WS4_i} + W_{WS5}\cdot x_{WS5} + W_{WS6}\cdot x_{WS6} + S1\cdot x_{S1} + S2\cdot x_{S2} + S_{\beta_i}\cdot x_{S\beta} - \left(U_i\cdot x_{U_i}\right)$$

$h_{A2_i} := E_{wheel_i} - E_{bftg} + h_{key}$

$y_{A2_i} := \frac{h_{A2_i}}{2} - h_{key}$

$A2_i := k_{0\beta} \cdot \gamma_{fill} \cdot h_{A1_i} \cdot h_{A2_i}$

$h_{A3_i} := h_{A2_i}$

$y_{A3_i} := \frac{h_{A3_i}}{3} - h_{key}$

$A3_i := k_{0\beta} \cdot \gamma_{fill\_eff} \cdot \frac{\left(h_{A3_i}\right)^2}{2}$

$H3_i := 0 \cdot klf$

$h_{H2_i} := E_{wheel_i} - E_{bftg} + h_{key}$

$y_{H2_i} := \frac{h_{H2_i}}{3} - h_{key}$

$h_{A2_i} =$ (ft)

27.00
24.00
21.00
18.00
15.00

$y_{A2_i} =$ (ft)

8.50
7.00
5.50
4.00
2.50

$A2_i =$ (klf)

0.0
7.3
12.7
16.4
18.2

$h_{A3_i} =$ (ft)

27.00
24.00
21.00
18.00
15.00

$y_{A3_i} =$ (ft)

4.00
3.00
2.00
1.00
0.00

$A3_i =$ (klf)

18.4
14.6
11.1
8.2
5.7

$H2_i := \gamma_w \cdot \frac{\left(h_{H2_i}\right)^2}{2}$

$\Sigma M_{lat_i} := -H1_i \cdot \left(y_{H1_i}\right) - K1_i \cdot \left(y_{K1}\right) - K2_i \cdot \left(y_{K2}\right) + H2_i \cdot \left(y_{H2_i}\right) + H3_i \cdot \left(y_{H3}\right) \ldots$
$+ A1_i \cdot \left(y_{A1_i}\right) + A2_i \cdot \left(y_{A2_i}\right) + A3_i \cdot \left(y_{A3_i}\right) - R_{key_i} \cdot \left(y_{Rkey}\right)$

$x_{R_i} := \frac{\Sigma M_{grav_i} - \Sigma M_{lat_i}}{W_i - U_i}$ $\qquad L_{brg_i} := \min\left(3 \cdot x_{R_i}, L_{ftg}\right)$

$ok_{u_i} :=$ if$\left[\left|L_{brg_i} - \left(L_{ftg} - L_{t1_i}\right)\right| > 0.001 \cdot ft,\right.$ "Uplift assumptions wrong in sliding analysis." , "Matched." $\left.\right]$

W_i (klf)	u_{toe_i} (ksf)	u_{heel_i} (ksf)	δ_{u_i} (psf/ft)	u_{key_i} (ksf)	$u1_i$ (klf)	$u2_i$ (klf)	$u3_i$ (klf)
105.3	0.750	1.688	21.6	1.256	6.750	2.279	25.129
104.4	0.563	1.500	21.6	1.069	5.063	2.279	21.379
103.2	0.375	1.313	21.6	0.881	3.375	2.279	17.629
102.6	0.313	1.125	17.2	0.780	2.813	2.105	15.603
102.3	0.313	0.938	10.8	0.722	2.813	1.843	14.440

$u4_i$ (klf)	$u5_i$ (klf)	x_{u3_i} (ft)	x_{u4_i} (ft)	x_{u5_i} (ft)	h_{H2_i} (ft)	y_{H2_i} (ft)	$H2_i$ (klf)
4.310	0.0	19.0	22.3	29.0	27.0	4.0	22.8
4.310	0.0	19.0	22.3	29.0	24.0	3.0	18.0
4.310	0.0	19.0	22.3	29.0	21.0	2.0	13.8
3.448	0.0	19.0	22.3	29.0	18.0	1.0	10.1
2.155	0.0	19.0	22.3	29.0	15.0	0.0	7.0

U_i (klf)	x_{U_i} (ft)	ΣM_{grav_i} (kip)	ΣM_{lat_i} (kip)	x_{R_i} (ft)	L_{brg_i} (ft)
38.5	16.1	1219	205	15.2	29.0
33.0	16.3	1307	212	15.3	29.0
27.6	16.7	1386	214	15.5	29.0
24.0	16.6	1443	211	15.7	29.0
21.3	16.3	1484	208	15.8	29.0

$H_{L_i} := 0 \cdot klf$

$$H_{R_i} := \gamma_w \cdot \frac{\left(E_{wtoe_i} - E_{ftg}\right)^2}{2}$$

$$\Delta P_{2_i} := \frac{\left[\left(W_i + V\right)\cdot\left(\tan\left(\phi_{d_i}\right)\cdot\cos(\alpha) + \sin(\alpha)\right) - U_i \cdot \tan\left(\phi_{d_i}\right) + \left(H_{L_i} - H_{R_i}\right)\cdot\left(\tan\left(\phi_{d_i}\right)\cdot\sin(\alpha) - \cos(\alpha)\right) + \frac{c}{FS_{1_i}} \cdot L\right]}{\left(\cos(\alpha) - \tan\left(\phi_{d_i}\right)\cdot\sin(\alpha)\right)}$$

$H_{L_i} =$ (klf)	$H_{R_i} =$ (klf)
0.0	1.5
0.0	0.5
0.0	0.0
0.0	0.0
0.0	0.0

$$ok_{u_i} = \begin{pmatrix} \text{"Matched."} \\ \text{"Matched."} \\ \text{"Matched."} \\ \text{"Matched."} \\ \text{"Matched."} \end{pmatrix}$$

$L_{ftg} - L_{brg_i} =$ (ft)
0.000
0.000
0.000
0.000
0.000

$$L_{t1} \equiv \begin{pmatrix} 0 \\ 0 \\ 0 \\ 0 \\ 0 \end{pmatrix} \cdot ft$$

$ok := if\left[\max\left[\left|L_{brg} - \left(L_{ftg} - L_{t1}\right)\right|\right] < 0.001 \cdot ft, ok, \text{"Uplift area does not match."}\right]$

$ok := if\left(\min\left(L_{brg}\right) < x_{key} + \frac{L_{key}}{2}, \text{"Uplift assumptions incorrect."}, ok\right)$ $ok = \text{"Ok"}$

Resisting Wedge (#3):

$\beta_w := 0 \cdot deg$

$\phi := \phi_{fill}$ $\phi = 32.0\,deg$

$c := 0 \cdot ksf$

$\phi_{d_i} := atan\left(\frac{tan(\phi)}{FS1_i}\right)$ $\phi_{d_i} = \begin{pmatrix} 20.7 \\ 20.0 \\ 19.3 \\ 18.6 \\ 17.9 \end{pmatrix} deg$

$\alpha_i := 45 \cdot deg - \frac{\phi_{d_i}}{2}$ $\alpha_i = \begin{pmatrix} 34.6 \\ 35.0 \\ 35.3 \\ 35.7 \\ 36.0 \end{pmatrix} deg$

$L_i := \frac{t_{base}}{sin(\alpha_i)}$ $L = \begin{pmatrix} 8.799 \\ 8.714 \\ 8.647 \\ 8.565 \\ 8.500 \end{pmatrix} ft$

$W_i := \gamma_{sat} \cdot \frac{L_i \cdot cos(\alpha_i) \cdot t_{base}}{2} + \gamma_w \cdot (E_{wtoe_i} - E_{ftg}) \cdot L_i \cdot cos(\alpha_i)$

$U_i := \gamma_w \cdot \left(E_{wtoe_i} - E_{ftg} + \frac{t_{base}}{2}\right) \cdot L_i$

$H_L := 0 \cdot klf$

$H_R := 0 \cdot klf$

$V := 0 \cdot klf$

$$\Delta P3_i := \frac{\left[(W_i + V) \cdot (tan(\phi_{d_i}) \cdot cos(\alpha_i) + sin(\alpha_i)) - U_i \cdot tan(\phi_{d_i}) + (H_L - H_R) \cdot (tan(\phi_{d_i}) \cdot sin(\alpha_i) - cos(\alpha_i)) + \frac{c}{FS1_i} \cdot L_i\right]}{(cos(\alpha_i) - tan(\phi_{d_i}) \cdot sin(\alpha_i))}$$

$\Sigma P_i := \Delta P1a_i + \Delta P1b_i + \Delta P2_i + \Delta P3_i$

W_i = (klf)	U_i = (klf)	$\Delta P1a_i$ = (klf)	$\Delta P1b_i$ = (klf)	$\Delta P2_i$ = (klf)	$\Delta P3_i$ = (klf)	ΣP_i = (klf)	FS_1 ≡
5.5	5.2	-53.9	0.0	49.5	4.7	0.3	1.65
4.1	3.5	-52.5	0.0	48.9	3.7	0.1	1.72
2.7	1.9	-51.3	0.0	48.7	2.7	0.2	1.78
2.2	1.3	-50.7	0.0	48.4	2.4	0.0	1.86
2.2	1.3	-50.2	0.0	48.0	2.3	0.1	1.93

ok := if($FS1_1 \geq 1.33$, ok, "Sliding instability: LC#1")

ok := if($FS1_n \geq 1.50$, ok, "Sliding instability: LC#n")

ok = "Ok"

Sliding Analysis #2:

$L_\beta = 0.00\,ft$

$\phi_i := \phi_{fill}$ $\quad \beta_w := \beta \quad \beta_w = 33.7\,deg$

$$\phi = \begin{pmatrix} 32.0 \\ 32.0 \\ 32.0 \\ 32.0 \\ 32.0 \end{pmatrix} deg$$

$c := 0 \cdot ksf$

$$\phi_{d_i} := atan\left(\frac{tan(\phi_i)}{FS2_i}\right) \qquad \phi_{d_i} = \begin{pmatrix} 25.2 \\ 24.5 \\ 23.9 \\ 23.0 \\ 22.2 \end{pmatrix} deg$$

$$atan\left(tan(\beta) \cdot FS2_i\right) = \begin{pmatrix} 41.6 \\ 42.4 \\ 43.2 \\ 44.4 \\ 45.6 \end{pmatrix} deg$$

(back solve for minimum ϕ value for stable slope β, EM 1110-2-2502, pg. 3-31)

$$\phi_i := if\left[\left(c_1(\phi_{d_i})^2 + 4 \cdot c_2(\phi_{d_i}, \beta_w) < 0\right), atan\left(tan(\beta_w) \cdot FS2_i\right), \phi_i\right] \qquad \phi = \begin{pmatrix} 41.6 \\ 42.4 \\ 43.2 \\ 44.4 \\ 45.6 \end{pmatrix} deg$$

(substitue minimum ϕ if slope is unstable)

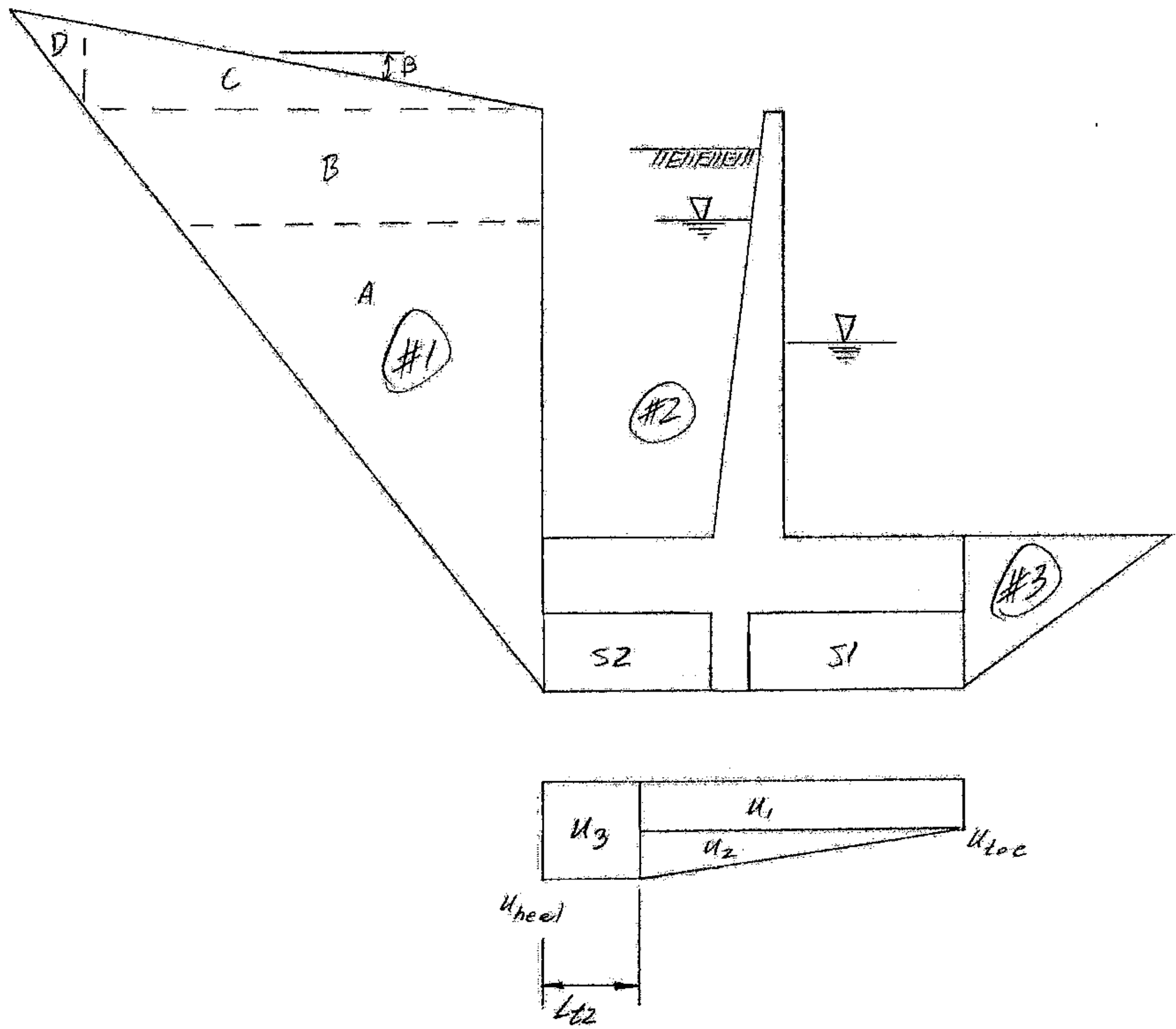
$$\phi_{d\_1b_i} := atan\left(\frac{tan(\phi_i)}{FS2_i}\right) \qquad \phi_{d\_1b_i} = \begin{pmatrix} 33.7 \\ 33.7 \\ 33.7 \\ 33.7 \\ 33.7 \end{pmatrix} deg$$

$$\alpha_{1b_i} := \alpha_{driving}(\phi_{d\_1b_i}, \beta_w) \qquad \alpha_{1b} = \begin{pmatrix} -33.7 \\ -33.7 \\ -33.7 \\ -33.7 \\ -33.7 \end{pmatrix} deg$$

$$h_{1b} := \left(E_{grade} + L_{WS5} \cdot tan(\beta_w)\right) - \left(E_{bftg} - h_{key}\right) \qquad h_{1b} = 37.0\,ft$$

$$L_{max_i} := if\left[-\alpha_{1b_i} = \phi_{d\_1b_i}, 1000 \cdot ft, \frac{\dfrac{h_{1b}}{cos(-\alpha_{1b_i})\left(tan(-\alpha_{1b_i}) - tan(\beta_w)\right)}}{cos(-\alpha_{1b_i})}\right] \qquad L_{max} = \begin{pmatrix} 1000.0 \\ 1000.0 \\ 1000.0 \\ 1000.0 \\ 2.9 \times 10^9 \end{pmatrix} ft$$

$$h_{1a_i} := if\left[L_\beta < L_{max_i}, h_{1b} + L_\beta \cdot \left(tan(\beta) - tan(-\alpha_{1b_i})\right), 0 \cdot ft\right] \qquad h_{1a} = \begin{pmatrix} 3 \\ 37.0 \\ 37.0 \\ 37.0 \\ 37.0 \end{pmatrix} ft$$



Sliding Analysis #2

Driving Wedge (#1a):

$\beta_w := 0 \cdot deg$ $\beta_w = 0.0\,deg$

$\phi := \phi_{fill}$ $\phi = 32.0\,deg$

$c := 0 \cdot ksf$

$\phi_{d_i} := atan\left(\frac{tan(\phi)}{FS_{2_i}}\right)$ $\phi_d = \begin{pmatrix} 25.2 \\ 24.5 \\ 23.9 \\ 23.0 \\ 22.2 \end{pmatrix} deg$

$\alpha_i := \alpha_{driving}\left(\phi_{d_i}, \beta_w\right)$ $\alpha = \begin{pmatrix} -57.58 \\ -57.26 \\ -56.95 \\ -56.51 \\ -56.11 \end{pmatrix} deg$

$h_i := h_{1a_i}$

$h_i := h_{1a_i}$ $h = \begin{pmatrix} 37.0 \\ 37.0 \\ 37.0 \\ 37.0 \\ 37.0 \end{pmatrix} ft$

$L_i := \frac{h_i}{cos(-\alpha_i) \cdot \left(tan(-\alpha_i) - tan(\beta_w)\right)}$ $= \begin{pmatrix} 43.83 \\ 43.99 \\ 44.14 \\ 44.36 \\ 44.57 \end{pmatrix} ft$

$h_{sat_i} := max\left[\begin{bmatrix} E_{wheel_i} - \left(E_{ftg} - t_{base} - h_{key}\right) - L_\beta \cdot tan\left(-\alpha_{1b_i}\right) \\ 0\ ft \end{bmatrix}\right]$ $h_{sat} = \begin{pmatrix} 27.0 \\ 24.0 \\ 21.0 \\ 18.0 \\ 15.0 \end{pmatrix} ft$

$L_{h_i} := \frac{h_i}{tan(-\alpha_i)}$ $L_h = \begin{pmatrix} 23.497 \\ 23.791 \\ 24.073 \\ 24.476 \\ 24.856 \end{pmatrix} ft$

$L_{sat_i} := \frac{h_{sat_i}}{tan(-\alpha_i)}$ $L_{sat} = \begin{pmatrix} 17.15 \\ 15.43 \\ 13.66 \\ 11.91 \\ 10.08 \end{pmatrix} ft$

$h_{left} := 0 \cdot ft$

$h_{right_i} := h_{1a_i}$

$W_i := \gamma_{fill} \cdot \left(L_{h_i} \cdot \frac{h_{left} + h_{right_i}}{2}\right) + \left(\gamma_{sat} - \gamma_{fill}\right) \cdot \frac{L_{sat_i} \cdot h_{sat_i}}{2}$

$W_i =$

55.931	klf
56.754	
57.538	
58.597	
59.589	

$V := 0 \cdot klf$

$H_L := 0 \cdot klf$

$H_R := 0 \cdot klf$

$$U_i := \gamma_w \cdot \left(\frac{h_{sat_i}}{2}\right) \cdot \sqrt{\left(h_{sat_i}\right)^2 + \left(L_{sat_i}\right)^2} \qquad U = \begin{pmatrix} 26.987 \\ 21.400 \\ 16.441 \\ 12.140 \\ 8.470 \end{pmatrix} \text{klf}$$

$$\Delta P_{1a_i} := \frac{\left[\left(W_i + V\right) \cdot \left(\tan\left(\phi_{d_i}\right) \cdot \cos\left(\alpha_i\right) + \sin\left(\alpha_i\right)\right) - U_i \cdot \tan\left(\phi_{d_i}\right) + \left(H_L - H_R\right) \cdot \left(\tan\left(\phi_{d_i}\right) \cdot \sin\left(\alpha_i\right) - \cos\left(\alpha_i\right)\right) + \frac{c}{FS_{2_i}} \cdot L_i\right]}{\left(\cos\left(\alpha_i\right) - \tan\left(\phi_{d_i}\right) \cdot \sin\left(\alpha_i\right)\right)}$$

Driving Wedge (#1b): $L_\beta = 0.0\,ft$

$\beta_w := \beta \qquad \beta_w = 33.7\,deg$

$\alpha := \alpha_{1b} \qquad \alpha = \begin{pmatrix} -33.7 \\ -33.7 \\ -33.7 \\ -33.7 \\ -33.7 \end{pmatrix} deg$

$\phi_d := \phi_{d\_1b} \qquad \phi_d = \begin{pmatrix} 33.7 \\ 33.7 \\ 33.7 \\ 33.7 \\ 33.7 \end{pmatrix} deg$

$h = \begin{pmatrix} 37.0 \\ 37.0 \\ 37.0 \\ 37.0 \\ 37.0 \end{pmatrix} ft$

$L_h := L_\beta \qquad L_h = 0.0\,ft$

$L_i := \frac{L_\beta}{\cos\left(\alpha_i\right)} \qquad L = \begin{pmatrix} 0.0 \\ 0.0 \\ 0.0 \\ 0.0 \\ 0.0 \end{pmatrix} ft$

$h_{satr_i} := \max\left[\begin{bmatrix} E_{wheel_i} - \left(E_{ftg} - t_{base} - h_{key}\right) \\ 0\ ft \end{bmatrix}\right] \qquad h_{satr} = \begin{pmatrix} 27.0 \\ 24.0 \\ 21.0 \\ 18.0 \\ 15.0 \end{pmatrix} ft$

$h_{satl_i} := \max\left[\begin{bmatrix} E_{wheel_i} - \left(E_{ftg} - t_{base} - h_{key}\right) - \frac{L_\beta}{\cos\left(\alpha_i\right)} \\ 0\ ft \end{bmatrix}\right] \qquad h_{satl} = \begin{pmatrix} 27.0 \\ 24.0 \\ 21.0 \\ 18.0 \\ 15.0 \end{pmatrix} ft$

$L_{sat_i} := \min\left[\begin{bmatrix} L_\beta \\ \frac{h_{satr_i}}{\tan\left[\left(-\alpha\right)_i\right]} \end{bmatrix}\right] \qquad L_{sat} = \begin{pmatrix} 0.0 \\ 0.0 \\ 0.0 \\ 0.0 \\ 0.0 \end{pmatrix} ft$

$h_{left_i} := h_{1a_i} \qquad h_{left} = \begin{pmatrix} 37.0 \\ 37.0 \\ 37.0 \\ 37.0 \\ 37.0 \end{pmatrix} ft$

$h_{right} := h_{1b} \qquad h_{right} = 37.0\,ft$

$$W_i := \gamma_{fill} \cdot \left(L_h \cdot \frac{h_{left_i} + h_{right}}{2}\right) + \left(\gamma_{sat} - \gamma_{fill}\right) \cdot L_{sat_i} \cdot \left(\frac{h_{satr_i} + h_{satl_i}}{2}\right)$$

$V := 0 \cdot klf$

$H_L := 0 \cdot klf$

$H_R := 0 \cdot klf$

$U_i := \gamma_w \cdot \left(\frac{h_{satr_i} + h_{satl_i}}{2}\right) \cdot \sqrt{\left(h_{satr_i} - h_{satl_i}\right)^2 + \left(L_h\right)^2}$

$W_i =$

0.0
0.0
0.0
0.0
0.0

klf

$$\Delta P_{1b_i} := \frac{\left[\left(W_i + V\right)\left(\tan\left(\phi_{d_i}\right) \cdot \cos\left(\alpha_i\right) + \sin\left(\alpha_i\right)\right) - U_i \cdot \tan\left(\phi_{d_i}\right) + \left(H_L - H_R\right) \cdot \left(\tan\left(\phi_{d_i}\right) \cdot \sin\left(\alpha_i\right) - \cos\left(\alpha_i\right)\right) + \frac{c}{FS_{2_i}} \cdot L_i\right]}{\left(\cos\left(\alpha_i\right) - \tan\left(\phi_{d_i}\right) \cdot \sin\left(\alpha_i\right)\right)}$$

Structure Wedge (#2):

$U_i =$

0.0
0.0
0.0
0.0
0.0

klf

$\beta_w := 0 \ deg$

$\phi := \phi_{fill}$ $\phi = 32.0 \, deg$

$c := 0 \ ksf$

$\phi_{d_i} := atan\left(\frac{\tan(\phi)}{FS_{2_i}}\right)$ $\phi_{d_i} = \begin{pmatrix} 25.2 \\ 24.5 \\ 23.9 \\ 23.0 \\ 22.2 \end{pmatrix} deg$

$\alpha := 0 \cdot deg$ $\alpha = 0.0 \, deg$

$L := \frac{L_{ftg}}{\cos(\alpha)}$ $L = 29.0 \, ft$

$h_{S1} := h_{key}$ $h_{S1} = 5.0 \, ft$

$L_{S1} := x_{key} - \frac{L_{key}}{2}$ $L_{S1} = 9.0 \, ft$

$x_{S1} := \frac{1}{2} \cdot L_{S1}$ $x_{S1} = 4.5 \, ft$

$S1 := \gamma_{sat} \cdot h_{S1} \cdot L_{S1}$ $S1 = 5.7 \, klf$

$h_{S2} := h_{key}$ $h_{S2} = 5.0 \, ft$

$L_{S2} := L_{ftg} - x_{key} - \frac{L_{key}}{2}$ $L_{S2} = 17.0 \, ft$

$x_{S2} := L_{ftg} - \frac{L_{S2}}{2}$ $\qquad x_{S2} = 20.5\,ft$

$S2 := \gamma_{sat} \cdot h_{S2} \cdot L_{S2}$ $\qquad S2 = 10.8\,klf$

$$W_i := \sum_{i=1}^{4} W_{C_i} + W_{W1_i} + W_{WS1_i} + W_{WS2_i} + W_{WS3_i} + W_{WS4_i} + W_{WS5} + W_{WS6} + S1 + S2 + S_{\beta_i}$$

Uplift below structural wedge:

$u_{toe_i} := \gamma_w \cdot \left[E_{wtoe_i} - \left(E_{bftg} - h_{key}\right)\right]$

$u_{heel_i} := \gamma_w \cdot \left[E_{wheel_i} - \left(E_{bftg} - h_{key}\right)\right]$

$$\delta_{u_i} := \frac{\gamma_w \cdot \left(E_{wheel_i} - E_{wtoe_i}\right)}{L_{ftg} - L_{t2_i}}$$

$u_{1_i} := u_{toe_i} \cdot \left(L_{ftg} - L_{t2_i}\right)$

$x_{u1_i} := \frac{L_{ftg} - L_{t2_i}}{2}$ $\qquad x_{u1} = \begin{pmatrix} 14.5 \\ 14.5 \\ 14.5 \\ 14.5 \\ 14.5 \end{pmatrix} ft$

$u_{2_i} := \left(u_{heel_i} - u_{toe_i}\right) \cdot \frac{\left(L_{ftg} - L_{t2_i}\right)}{2}$

$x_{u2_i} := \frac{2}{3} \cdot \left(L_{ftg} - L_{t2_i}\right)$ $\qquad x_{u2} = \begin{pmatrix} 19.3 \\ 19.3 \\ 19.3 \\ 19.3 \\ 19.3 \end{pmatrix} ft$

$u_{3_i} := u_{heel_i} \cdot \left(L_{t2_i}\right)$

$x_{u3_i} := L_{ftg} - \frac{L_{t2_i}}{2}$

$U_i := u_{1_i} + u_{2_i} + u_{3_i}$

$x_{U_i} := \frac{u_{1_i} \cdot x_{u1_i} + u_{2_i} \cdot x_{u2_i} + u_{3_i} \cdot x_{u3_i}}{U_i}$ $\qquad x_U = \begin{pmatrix} 15.6 \\ 15.8 \\ 16.0 \\ 15.9 \\ 15.5 \end{pmatrix} ft$

$$\Sigma M_{grav_i} := \left(\sum_{i=1}^{4} W_{C_i} \cdot x_{C_i} + W_{W1_i} \cdot x_{W1} + W_{WS1_i} \cdot x_{WS1} + W_{WS2_i} \cdot x_{WS2_i} + W_{WS3_i} \cdot x_{WS3_i} \ldots \right.$$
$$\left. + W_{WS4_i} \cdot x_{WS4_i} + W_{WS5} \cdot x_{WS5} + W_{WS6} \cdot x_{WS6} + S1 \cdot x_{S1} + S2 \cdot x_{S2} + S_{\beta_i} \cdot x_{S\beta} - \left(U_i \cdot x_{U_i}\right)\right)$$

$h_{H1_i} := E_{wtoe_i} - (E_{bftg} - h_{key})$

$y_{H1_i} := \dfrac{h_{H1_i}}{3} - h_{key}$

$H1_i := \gamma_w \dfrac{(h_{H1_i})^2}{2}$

$K1_i := 0 \cdot klf$

$K2_i := 0 \cdot klf$

h_{H1_i} = (ft)	y_{H1_i} = (ft)	$H1_i$ = (klf)
17.00	0.67	9.0
14.00	-0.33	6.1
11.00	-1.33	3.8
10.00	-1.67	3.1
10.00	-1.67	3.1

$\Sigma M_{lat_i} := -H1_i \cdot (y_{H1_i}) - K1_i \cdot (y_{K1}) - K2_i \cdot (y_{K2}) + H2_i \cdot (y_{H2_i}) + H3_i \cdot (y_{H..}$
$+ A1_i \cdot (y_{A1_i}) + A2_i \cdot (y_{A2_i}) + A3_i \cdot (y_{A3_i}) - R_{key_i} \cdot (y_{Rkey})$

$x_{R_i} := \dfrac{\Sigma M_{grav_i} - \Sigma M_{lat_i}}{W_i - U_i}$ $\quad L_{brg_i} := \min(3 \cdot x_{R_i}, L_{ftg})$

$ok_{u_i} :=$ if$\left[\left|L_{brg_i} - (L_{ftg} - L_{t2_i})\right| > 0.001 \cdot ft,\right.$ "Uplift assumptions wrong in sliding analysis." , "Matched." $\left.\right]$

W_i = (klf)	u_{toe_i} = (ksf)	u_{heel_i} = (ksf)	δ_{u_i} = (psf/ft)	u_{1_i} = (klf)	u_{2_i} = (klf)	u_{3_i} = (klf)
108.2	1.063	1.688	21.6	30.813	9.063	0.000
107.3	0.875	1.500	21.6	25.375	9.062	0.000
106.0	0.688	1.313	21.6	19.938	9.062	0.000
105.5	0.625	1.125	17.2	18.125	7.250	0.000
105.1	0.625	0.938	10.8	18.125	4.531	0.000

x_{u3_i} = (ft)	h_{H2_i} = (ft)	y_{H2_i} = (ft)	$H2_i$ = (klf)
29.0	27.0	4.0	22.8
29.0	24.0	3.0	18.0
29.0	21.0	2.0	13.8
29.0	18.0	1.0	10.1
29.0	15.0	0.0	7.0

U_i = (klf)	x_{U_i} = (ft)	ΣM_{grav_i} = (kip)	ΣM_{lat_i} = (kip)	x_{R_i} = (ft)	L_{brg_i} = (ft)
39.9	15.6	1224	195	15.1	29.0
34.4	15.8	1312	202	15.2	29.0
29.0	16.0	1391	204	15.4	29.0
25.4	15.9	1447	203	15.5	29.0
22.7	15.5	1488	203	15.6	29.0

$H_{L_i} := 0 \cdot klf$

$$H_{R_i} := \gamma_w \cdot \frac{\left(E_{wtoe_i} - E_{ftg}\right)^2}{2}$$

$$\Delta P_{2_i} := \frac{\left[\left(W_i + V\right) \cdot \left(\tan\left(\phi_{d_i}\right) \cdot \cos(\alpha) + \sin(\alpha)\right) - U_i \cdot \tan\left(\phi_{d_i}\right) + \left(H_{L_i} - H_{R_i}\right) \cdot \left(\tan\left(\phi_{d_i}\right) \cdot \sin(\alpha) - \cos(\alpha)\right) + \frac{c}{FS_{2_i}} \cdot L\right]}{\left(\cos(\alpha) - \tan\left(\phi_{d_i}\right) \cdot \sin(\alpha)\right)}$$

$H_{L_i} =$ (klf)	$H_{R_i} =$ (klf)
0.0	1.5
0.0	0.5
0.0	0.0
0.0	0.0
0.0	0.0

$$ok_{u_i} = \begin{pmatrix} \text{"Matched."} \\ \text{"Matched."} \\ \text{"Matched."} \\ \text{"Matched."} \\ \text{"Matched."} \end{pmatrix}$$

$L_{ftg} - L_{brg_i} =$

$L_{ftg} - L_{brg_i}$ (ft)
0.000
0.000
0.000
0.000
0.000

$$L_{t2} \equiv \begin{pmatrix} 0 \\ 0 \\ 0 \\ 0 \\ 0 \end{pmatrix} \cdot ft$$

$$ok := \text{if}\left[\max\left[\left|L_{brg} - \left(L_{ftg} - L_{t2}\right)\right|\right] < 0.001 \cdot ft, ok, \text{"Uplift area does not match."}\right]$$

$$ok := \text{if}\left(\min\left(L_{brg}\right) < x_{key} + \frac{L_{key}}{2}, \text{"Uplift assumptions incorrect."}, ok\right) \qquad ok = \text{"Ok"}$$

Resisting Wedge (#3)

$\beta_w := 0 \cdot deg$

$\phi := \phi_{fill}$ $\phi = 32.0\,deg$

$c := 0\ \ ksf$

$\phi_{d_i} := atan\left(\frac{tan(\phi)}{FS_2}\right)$

$\phi_{d_i} = \begin{pmatrix} 25.2 \\ 24.5 \\ 23.9 \\ 23.0 \\ 22.2 \end{pmatrix} deg$

$\alpha_i := 45 \cdot deg - \frac{\phi_{d_i}}{2}$

$\alpha_i = \begin{pmatrix} 32.4 \\ 32.7 \\ 33.0 \\ 33.5 \\ 33.9 \end{pmatrix} deg$

$L_i := \frac{t_{base} + h_{key}}{sin(\alpha_i)}$

$L = \begin{pmatrix} 18.654 \\ 18.490 \\ 18.337 \\ 18.125 \\ 17.933 \end{pmatrix} ft$

$W_i := \gamma_{sat} \cdot \frac{L_i \cdot cos(\alpha_i) \cdot (t_{base} + h_{key})}{2} + \gamma_w \cdot (E_{wtoe_i} - E_{ftg}) \cdot L_i \cdot cos(\alpha_i)$

$U_i := \gamma_w \cdot \left(E_{wtoe_i} - E_{ftg} + \frac{t_{base} + h_{key}}{2}\right) \cdot L_i$

$H_L := 0 \cdot klf$

$H_R := 0 \cdot klf$

$V := 0 \cdot klf$

$$\Delta P_{3_i} := \frac{\left[(W_i + V) \cdot \left(tan(\phi_{d_i}) \cdot cos(\alpha_i) + sin(\alpha_i)\right) - U_i \cdot tan(\phi_{d_i}) + (H_L - H_R) \cdot \left(tan(\phi_{d_i}) \cdot sin(\alpha_i) - cos(\alpha_i)\right) + \frac{c}{FS_{2_i}} \cdot L_i\right]}{\left(cos(\alpha_i) - tan(\phi_{d_i}) \cdot sin(\alpha_i)\right)}$$

$\Sigma P_i := \Delta P_{1a_i} + \Delta P_{1b_i} + \Delta P_{2_i} + \Delta P_{3_i}$

$FS_2 \equiv \begin{pmatrix} 1.33 \\ 1.37 \\ 1.41 \\ 1.47 \\ 1.53 \end{pmatrix}$

W_i = (klf)	U_i = (klf)	ΔP_{1a_i} = (klf)	ΔP_{1b_i} = (klf)	ΔP_{2_i} = (klf)	ΔP_{3_i} = (klf)	ΣP_i = (klf)
16.9	14.0	-49.1	0.0	33.6	15.6	0.1
13.8	10.4	-47.1	0.0	33.7	13.5	0.2
10.8	6.9	-45.4	0.0	34.2	11.4	0.2
9.6	5.7	-44.5	0.0	34.1	10.6	0.1
9.5	5.6	-43.9	0.0	33.7	10.3	0.1

$L_{heel} \equiv 21 \cdot ft$

$h_{key} \equiv 5 \cdot ft$

$L_{ftg} = 29.0\,ft$

$L_{toe} = 8.0\,ft$

$L_{ftg} - x_{key} - \frac{L_{key}}{2} = 17.0\,ft$

ok := if$(FS_{2_1} \geq 1.33$, ok, "Sliding instability: LC#1")

ok := if$(FS_{2_n} \geq 1.50$, ok, "Sliding instability: LC#n")

ok = "Ok"

Upstream Training Wall at Right: (Grade = 527.0')

Reference:T:\ST\CALCS\Common geometry.mcd(R)

Geometry:

$E_{wall} := 530 \cdot ft$

$E_{ftg} := E_{approach}$ $\quad E_{ftg} = 500.0\,ft$

$t_{base} := 5 \cdot ft$

$E_{bftg} := E_{ftg} - t_{base}$ $\quad E_{bftg} = 495.0\,ft$

$E_{grade} := 527 \cdot ft$

$n := 5$

$i := 1 .. n$

$\Delta_w := 10 \cdot ft$ (maximum height of retained water above water in basin)

$$E_{wheel_i} := E_{grade} - \frac{\left[E_{grade} - \left(E_{ftg} + \frac{\Delta_w}{2}\right)\right]}{n-1} \cdot (i-1) \qquad E_{wheel} = \begin{pmatrix} 527.0 \\ 521.5 \\ 516.0 \\ 510.5 \\ 505.0 \end{pmatrix} ft$$

$$E_{wtoe_i} := \max\left(\begin{pmatrix} E_{wheel_i} - \Delta_w \\ E_{ftg} \end{pmatrix}\right) \qquad E_{wtoe} = \begin{pmatrix} 517.0 \\ 511.5 \\ 506.0 \\ 500.5 \\ 500.0 \end{pmatrix} ft$$

$$h := \min\left[\left[\begin{matrix} \left[\frac{1.0}{1.5} \cdot 2 \cdot \left(E_{grade} - E_{ftg}\right)\right] + E_{grade} \\ 527 \quad ft - E_{ftg} \end{matrix}\right]\right] \qquad h = 27.0\,ft$$

$\beta := \operatorname{atan}\left(\frac{1.0}{1.5}\right)$ $\quad \beta = 33.7\,deg$

$h_\beta := 527 \cdot ft - E_{grade}$ $\quad h_\beta = 0.0\,ft$

$t_{w\_top} := 1.5 \cdot ft$

$$t_{w\_bot} := t_{w\_top} + \frac{\left(E_{wall} - E_{ftg}\right)}{8} \qquad t_{w\_bot} = 5.25\,ft$$

$L_{toe} = 8.0\,ft$

$L_{heel} = 24.0\,ft$

$L_{ftg} := L_{toe} + L_{heel}$ $\quad L_{ftg} = 32.0\,ft$

$h_{wall} := E_{wall} - E_{ftg}$ $\quad h_{wall} = 30.0\,ft$

$h_{key} = 0.0\,ft$

$L_{key} := 4 \cdot ft$ $\quad L_{key} = 4.0\,ft$

$x_{key} := L_{toe} + t_{w\_bot} - \frac{L_{key}}{2}$ $\quad x_{key} = 11.3\,ft$

Constants:

$\gamma_w = 62.5\,pcf$

Soil parameters:

$\gamma_{fill\_eff} = 65.0\,pcf$ $\quad \gamma_{sat} = 127.5\,pcf$

$\gamma_{fill} = 130.0\,pcf$

$k_{0\_fill} = 0.5$

$\phi_{fill} = 32.0\,deg$

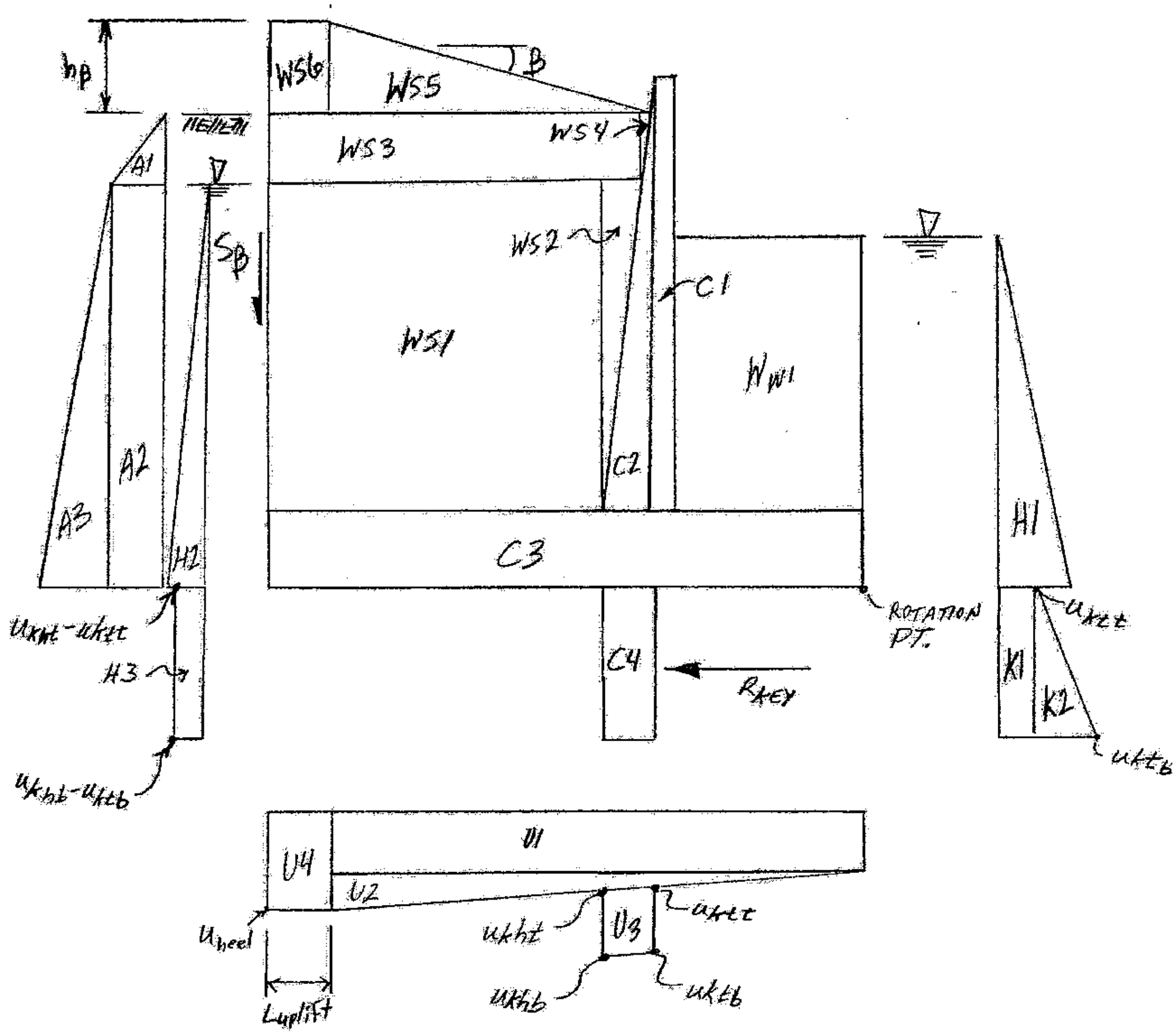
$k_{0\beta} := k_{0\_fill} \cdot (1 + \sin(\beta))$ $\quad k_{0\beta} = 0.777$ (USACE EM 1110-2-2502, Eq 3-5)

Pre-Definitions:

$kip \equiv 1000 \cdot lbf$ $\quad ksi \equiv 1000 \cdot psi$ $\quad ok \equiv$ "Ok" $\quad klf \equiv 1000 \cdot \frac{lbf}{ft}$

$psf \equiv \frac{lbf}{ft^2}$ $\quad plf \equiv \frac{lbf}{ft}$ $\quad pcf \equiv \frac{lbf}{ft^3}$

ORIGIN = 1.0 (must equal to 1)


hp
B
WS6
WS5
WS4
WS3
WS2
WS1
C1
C2
C3
C4
Ww1
A1
A2
A3
H1
H2
H3
K1
K2
Sp
ROTATION PT.
RKEY
uxht - uktt
ukhb - uktb
uktt
uktb
U1
U2
U3
U4
uheel
ukht
ukhb
uktb
Luplift

Analysis:

Gravity Loads:

$h_{C_1} := h_{wall}$ $h_{C_1} = 30.0\,ft$

$L_{C_1} := t_{w\_top}$ $L_{C_1} = 1.5\,ft$

$x_{C_1} := L_{toe} + \frac{L_{C_1}}{2}$ $x_{C_1} = 8.8\,ft$

$W_{C_1} := \gamma_c \cdot h_{C_1} \cdot L_{C_1}$ $W_{C_1} = 6.8\,klf$

$h_{C_2} := h_{C_1}$ $h_{C_2} = 30.0\,ft$

$L_{C_2} := t_{w\_bot} - t_{w\_top}$ $L_{C_2} = 3.8\,ft$

$x_{C_2} := L_{toe} + L_{C_1} + \frac{L_{C_2}}{3}$ $x_{C_2} = 10.8\,ft$

$W_{C_2} := \gamma_c \cdot \frac{h_{C_2} \cdot L_{C_2}}{2}$ $W_{C_2} = 8.4\,klf$

$h_{C_3} := t_{base}$ $h_{C_3} = 5.0\,ft$

$L_{C_3} := L_{ftg}$ $L_{C_3} = 32.0\,ft$

$x_{C_3} := \frac{L_{C_3}}{2}$ $x_{C_3} = 16.0\,ft$

$W_{C_3} := \gamma_c \cdot h_{C_3} \cdot L_{C_3}$ $W_{C_3} = 24.0\,klf$

$h_{C_4} := h_{key}$ $h_{C_4} = 0.0\,ft$

$L_{C_4} := L_{key}$ $L_{C_4} = 4.0\,ft$

$x_{C_4} := x_{key}$ $x_{C_4} = 11.3\,ft$

$W_{C_4} := \gamma_c \cdot h_{C_4} \cdot L_{C_4}$ $\qquad W_{C_4} = 0.0\,\text{klf}$

Weight of water at toe·

$h_{W1_i} := E_{wtoe_i} - E_{ftg}$ $\qquad h_{W1} = \begin{pmatrix} 17.00 \\ 11.50 \\ 6.00 \\ 0.50 \\ 0.00 \end{pmatrix} \text{ft}$

$L_{W1} := L_{toe}$ $\qquad L_{W1} = 8.0\,\text{ft}$

$x_{W1} := \dfrac{L_{toe}}{2}$ $\qquad x_{W1} = 4.0\,\text{ft}$

$W_{W1_i} := \gamma_w \cdot h_{W1_i} \cdot L_{W1}$ $\qquad W_{W1} = \begin{pmatrix} 8.5 \\ 5.8 \\ 3.0 \\ 0.3 \\ 0.0 \end{pmatrix} \text{klf}$

Weight of water/soil at heel·

$h_{WS1_i} := E_{wheel_i} - E_{ftg}$ $\qquad h_{WS1} = \begin{pmatrix} 27.00 \\ 21.50 \\ 16.00 \\ 10.50 \\ 5.00 \end{pmatrix} \text{ft}$

$L_{WS1} := L_{heel} - t_{w\_bot}$ $\qquad L_{WS1} = 18.8\,\text{ft}$

$x_{WS1} := L_{toe} + t_{w\_bot} + \dfrac{L_{WS1}}{2}$ $\qquad x_{WS1} = 22.6\,\text{ft}$

$W_{WS1_i} := (\gamma_{sat}) \cdot h_{WS1_i} \cdot L_{WS1}$ $\qquad W_{WS1} = \begin{pmatrix} 64.5 \\ 51.4 \\ 38.3 \\ 25.1 \\ 12.0 \end{pmatrix} \text{klf}$

$h_{WS2_i} := h_{WS1_i}$

$L_{WS2_i} := \dfrac{t_{w\_bot} - t_{w\_top}}{h_{wall}} \cdot h_{WS2_i}$ $\qquad L_{WS2} = \begin{pmatrix} 3.38 \\ 2.69 \\ 2.00 \\ 1.31 \\ 0.63 \end{pmatrix} \text{ft}$

$x_{WS2_i} := L_{toe} + t_{w\_bot} - \dfrac{L_{WS2_i}}{3}$ $\qquad x_{WS2} = \begin{pmatrix} 12.1 \\ 12.4 \\ 12.6 \\ 12.8 \\ 13.0 \end{pmatrix} \text{ft}$

$W_{WS2_i} := (\gamma_{sat}) \cdot \dfrac{h_{WS2_i} \cdot L_{WS2_i}}{2}$

$W_{WS2_i} =$

5.8
3.7
2.0
0.9
0.2

klf

$h_{WS3_i} := E_{grade} - E_{wheel_i}$

$h_{WS3_i} =$

0.0
5.5
11.0
16.5
22.0

ft

$L_{WS3_i} := L_{WS1} + L_{WS2_i}$

$L_{WS3_i} =$

22.1
21.4
20.8
20.1
19.4

ft

$x_{WS3_i} := L_{ftg} - \dfrac{L_{WS3_i}}{2}$

$x_{WS3_i} =$

20.9
21.3
21.6
22.0
22.3

ft

$W_{WS3_i} := \gamma_{fill} \cdot h_{WS3_i} \cdot L_{WS3_i}$

$W_{WS3_i} =$

0.0
15.3
29.7
43.0
55.4

klf

$h_{WS4_i} := h_{WS3_i}$

$L_{WS4_i} := \dfrac{t_{w\_bot} - t_{w\_top}}{h_{wall}} \cdot h_{WS4_i}$

$L_{WS4_i} =$

0.0
0.7
1.4
2.1
2.8

ft

$x_{WS4_i} := L_{ftg} - L_{WS3_i} - \dfrac{L_{WS4_i}}{3}$

$x_{WS4_i} =$

9.9
10.3
10.8
11.3
11.7

ft

$W_{WS4_i} := \gamma_{fill} \cdot \dfrac{h_{WS4_i} \cdot L_{WS4_i}}{2}$

$W_{WS4_i} =$

0.0
0.2
1.0
2.2
3.9

klf

$L_{WS5} := \min\left[\left[\begin{array}{c}\left[\dfrac{t_{w\_bot} - t_{w\_top}}{h_{wall}} \cdot (E_{grade} - E_{ftg}) + L_{WS1}\right] \\ \dfrac{h_\beta}{\tan(\beta)}\end{array}\right]\right]$ $\quad L_{WS5} = 0.00\,ft$

$h_{WS5} := L_{WS5} \cdot \tan(\beta)$ $\quad h_{WS5} = 0.00\,ft$

$x_{WS5} := \dfrac{2}{3} \cdot L_{WS5} + L_{toe} + t_{w\_top} + \dfrac{(E_{wall} - E_{grade})}{E_{wall} - E_{ftg}} \cdot (t_{w\_bot} - t_{w\_top})$ $\quad x_{WS5} = 9.88\,ft$

$W_{WS5} := \gamma_{fill} \cdot \dfrac{h_{WS5} \cdot L_{WS5}}{2}$ $\quad W_{WS5} = 0.0\,klf$

$L_{WS6} := \dfrac{E_{grade} - E_{ftg}}{h_{wall}} \cdot (t_{w\_bot} - t_{w\_top}) + L_{WS1} - L_{WS5}$ $\quad L_{WS6} = 22.1\,ft$

$h_{WS6} := h_{WS5}$ $\quad h_{WS6} = 0.0\,ft$

$x_{WS6} := L_{ftg} - \dfrac{L_{WS6}}{2}$ $\quad x_{WS6} = 20.9\,ft$

$W_{WS6} := \gamma_{fill} \cdot (h_{WS6} \cdot L_{WS6})$ $\quad W_{WS6} = 0.0\,klf$

Uplift:

$u_{toe_i} := \gamma_w \cdot \left(E_{wtoe_i} - E_{bftg}\right)$

$u_{heel_i} := \gamma_w \cdot \left(E_{wheel_i} - E_{bftg}\right)$

$\delta_{seep_i} := \dfrac{u_{heel_i} - u_{toe_i}}{L_{ftg} - L_{uplift_i}}$

$u_{ktt_i} := u_{heel_i} + \left(x_{key} - \dfrac{L_{key}}{2}\right) \cdot \delta_{seep_i}$

$u_{kht_i} := u_{ktt_i} + L_{key} \cdot \delta_{seep_i}$

$u_{ktb_i} := u_{ktt_i} + \gamma_w \cdot h_{key}$

$u_{khb_i} := u_{ktb_i} + L_{key} \cdot \delta_{seep_i}$

$x_{U1} := \dfrac{L_{ftg} - L_{uplift}}{2}$

$U1_i := u_{toe_i} \cdot L_{ftg}$

$x_{U2_i} := \dfrac{2}{3} \cdot \left(L_{ftg} - L_{uplift_i}\right)$

$U2_i := \left(u_{heel_i} - u_{toe_i}\right) \cdot \dfrac{L_{ftg}}{2}$

$x_{U3} := x_{key}$

$U3_i := \left(u_{ktb_i} - u_{ktt_i}\right) \cdot L_{key}$

$x_{U4_i} := L_{ftg} - \dfrac{L_{uplift_i}}{2}$

$L_{U4_i} := L_{uplift_i}$

$U4_i := u_{heel_i} \cdot L_{U4_i}$

u_{toe_i} = (ksf)	u_{heel_i} = (ksf)	δ_{seep_i} = (psf/ft)	u_{ktt_i} = (ksf)	u_{kht_i} = (ksf)
1.375	2.000	20.208	2.187	2.268
1.031	1.656	19.531	1.837	1.915
0.688	1.313	19.531	1.493	1.571
0.344	0.969	19.531	1.149	1.228
0.313	0.625	9.766	0.715	0.754

u_{ktb_i} = (ksf)	u_{khb_i} = (ksf)	x_{U1_i} = (ft)	$U1_i$ = (klf)	x_{U2_i} = (ft)	$U2_i$ = (klf)
2.187	2.268	15.5	44.0	20.62	10.0
1.837	1.915	16.0	33.0	21.33	10.0
1.493	1.571	16.0	22.0	21.33	10.0
1.149	1.228	16.0	11.0	21.33	10.0
0.715	0.754	16.0	10.0	21.33	5.0

$x_{U3} = 11.3\,\text{ft}$

$U3 = \begin{pmatrix} 0.0 \\ 0.0 \\ 0.0 \\ 0.0 \\ 0.0 \end{pmatrix} \text{klf}$

Lateral load due to water at toe:

$h_{H1_i} := E_{wtoe_i} - E_{bftg}$

$y_{H1_i} := \frac{h_{H1_i}}{3}$

$H1_i := \gamma_w \cdot \frac{(h_{H1_i})^2}{2}$

$h_{H2_i} := E_{wheel_i} - E_{bftg}$

$y_{H2_i} := \frac{h_{H2_i}}{3}$

$H2_i := \gamma_w \cdot \frac{(h_{H2_i})^2}{2}$

$h_{H3} := h_{key}$ $\qquad h_{H3} = 0.0\,ft$

$y_{H3} := \frac{-h_{key}}{2}$ $\qquad y_{H3} = 0.0\,ft$

$H3_i := (u_{khb_i} - u_{ktb_i}) \cdot h_{H3}$

$h_{K1} := h_{key}$ $\qquad h_{K1} = 0.0\,ft$

$K1_i := u_{ktt_i} \cdot h_{K1}$

$h_{K2} := h_{key}$ $\qquad h_{K2} = 0.0\,ft$

$K2_i := (u_{ktb_i} - u_{ktt_i}) \cdot \frac{h_{K2}}{2}$

$y_{K1} := \frac{-h_{key}}{2}$ $\qquad y_{K1} = 0.0\,ft$

$y_{K2} := \frac{-2}{3} h_{key}$ $\qquad y_{K2} = 0.0\,ft$

x_{U4_i} (ft)	$U4_i$ (klf)
31.5	2.1
32.0	0.0
32.0	0.0
32.0	0.0
32.0	0.0

h_{H1_i} (ft)	y_{H1_i} (ft)	$H1_i$ (klf)	h_{H2_i} (ft)	$H2_i$ (klf)	y_{H2_i} (ft)
22.00	7.33	15.1	32.00	32.0	10.7
16.50	5.50	8.5	26.50	21.9	8.8
11.00	3.67	3.8	21.00	13.8	7.0
5.50	1.83	0.9	15.50	7.5	5.2
5.00	1.67	0.8	10.00	3.1	3.3

$H3_i$ (klf)	$K1_i$ (klf)	$K2_i$ (klf)
0.00	0.0	0.0
0.00	0.0	0.0
0.00	0.0	0.0
0.00	0.0	0.0
0.00	0.0	0.0

Lateral load due to retained soil/water:

$h_{A1_i} := E_{grade} - E_{wheel_i}$

$y_{A1_i} := E_{grade} - E_{bftg} - \frac{2}{3} \cdot h_{A1_i}$

$A1_i := k_{0\beta} \cdot \gamma_{fill} \cdot \frac{(h_{A1_i})^2}{2}$

$h_{A1_i} =$

0.00 ft
5.50
11.00
16.50
22.00

$y_{A1_i} =$

32.00 ft
28.33
24.67
21.00
17.33

$A1_i =$

0.0 klf
1.5
6.1
13.8
24.5

$h_{A2_i} := E_{wheel_i} - E_{bftg}$

$y_{A2_i} := \frac{h_{A2_i}}{2}$

$A2_i := k_{0\beta} \cdot \gamma_{fill} \cdot h_{A1_i} \cdot h_{A2_i}$

$h_{A2_i} =$

32.00 ft
26.50
21.00
15.50
10.00

$y_{A2_i} =$

16.00 ft
13.25
10.50
7.75
5.00

$A2_i =$

0.0 klf
14.7
23.3
25.8
22.2

$h_{A3_i} := h_{A2_i}$

$y_{A3_i} := \frac{h_{A3_i}}{3}$

$A3_i := k_{0\beta} \cdot \gamma_{fill\_eff} \cdot \frac{(h_{A3_i})^2}{2}$

$h_{A3_i} =$

32.00 ft
26.50
21.00
15.50
10.00

$y_{A3_i} =$

10.67 ft
8.83
7.00
5.17
3.33

$A3_i =$

25.9 klf
17.7
11.1
6.1
2.5

Shear force due to sloped backfill: (EM 1110-2-2502, Fig. 4-7)

$h_2 := E_{grade} - E_{ftg}$ $\qquad h_2 = 27.0\,ft$

$h_1 := h_2 + \tan(\beta) \cdot L_{WS5}$ $\qquad h_1 = 27.0\,ft$

$$P_i := k_{0\beta} \cdot \gamma_{fill} \cdot h_{A1_i} \cdot (h_{A2_i} - t_{base}) + k_{0\beta} \cdot \gamma_{fill\_eff} \cdot \frac{(h_{A3_i} - t_{base})^2}{2}$$

$$S_{\beta_i} := \text{if}\left[h_1 > h_2, \left[\frac{P_i \cdot (h_1 - h_2)}{3 \cdot L_{WS5}}\right], 0 \cdot klf\right]$$

$x_{S\beta} := L_{ftg}$ $\qquad x_{S\beta} = 32.0\,ft$

Sum forces:

$$\Sigma V_i := \sum_{i=1}^{4} W_{C_i} + W_{W1_i} + W_{WS1_i} + W_{WS2_i} + W_{WS3_i} + W_{WS4_i} + W_{WS5} + W_{WS6} + S_{\beta_i} - \left(U1_i + U2_i + U3_i + U4_i\right)$$

$$\Sigma M_{grav_i} := \left(\sum_{i=1}^{4} W_{C_i} \cdot x_{C_i} + W_{W1_i} \cdot x_{W1} + W_{WS1_i} \cdot x_{WS1} + W_{WS2_i} \cdot x_{WS2_i} + W_{WS3_i} \cdot x_{WS3_i} + W_{WS4_i} \cdot x_{WS4_i}\right) \dots$$
$$+ W_{WS5} \cdot x_{WS5} + W_{WS6} \cdot x_{WS6} + S_{\beta_i} \cdot x_{S\beta} - \left(U1_i \cdot x_{U1_i} + U2_i \cdot x_{U2_i} + U3_i \cdot x_{U3} + U4_i \cdot x_{U4_i}\right)$$

$$R_{key_i} := -H1_i - K1_i - K2_i + H2_i + H3_i + A1_i + A2_i + A3_i$$

$$y_{Rkey} := \frac{-h_{key}}{2} \qquad y_{Rkey} = 0.0\,\text{ft}$$

$$\Sigma H_i := -H1_i - K1_i - K2_i + H2_i + H3_i + A1_i + A2_i + A3_i - R_{key_i}$$

$$\Sigma M_{lat_i} := -H1_i \cdot y_{H1_i} - K1_i \cdot y_{K1} - K2_i \cdot y_{K2} + H2_i \cdot y_{H2_i} + H3_i \cdot y_{H3} \dots$$
$$+ A1_i \cdot y_{A1_i} + A2_i \cdot y_{A2_i} + A3_i \cdot y_{A3_i} - R_{key_i} \cdot y_{Rkey}$$

$$\Sigma M_i := \Sigma M_{grav_i} - \Sigma M_{lat_i}$$

$$x_{R_i} := \frac{\Sigma M_i}{\Sigma V_i}$$

$$L_{brg_i} := \max\left[\min\left(\begin{pmatrix} 3 \cdot x_{R_i} \\ L_{ftg} \end{pmatrix}\right), 0 \cdot \text{ft}\right]$$

P_i = (klf)	S_{β_i} = (klf)	R_{key_i} = (klf)
18.4	0.0	42.7
23.6	0.0	47.4
24.3	0.0	50.6
20.3	0.0	52.2
11.7	0.0	51.6

ΣV_i = (klf)	ΣM_{grav_i} = (kip)	ΣM_{lat_i} = (kip)	ΣM_i = (kip)	ΣH_i = (klf)	R_{key_i} = (klf)	x_{R_i} = (ft)	L_{brg_i} = (ft)
61.9	1145	506	638	0.0	42.7	10.31	30.928
72.6	1353	542	810	0.0	47.4	11.16	32.000
81.1	1524	557	967	0.0	50.6	11.92	32.000
89.7	1695	558	1137	0.0	52.2	12.68	32.000
95.7	1823	553	1270	0.0	51.6	13.27	32.000

Bearing Capacity: (per EM 1110-1-1905)

$c := c_{fill}$ $c = 0.0\,psf$

$\phi := \phi_{fill}$ $\phi = 32.0\,deg$

$\gamma_{eff} := \gamma_{fill\_eff}$ $\gamma_{eff} = 65.0\,pcf$

$\gamma_{H\_eff} := \gamma_{eff}$ $\gamma_{H\_eff} = 65.0\,pcf$

$B_{eff_i} := L_{ftg} - 2\left|\frac{L_{brg_i}}{2} - x_{R_i}\right|$ $B_{eff} = \begin{pmatrix} 21.7 \\ 22.3 \\ 23.8 \\ 25.4 \\ 26.5 \end{pmatrix} ft$

Table 4-3:

$N_\phi := \tan\left(45\cdot deg + \frac{\phi}{2}\right)^2$ $N_\phi = 3.255$

$N_q := if\left(\phi = 0, 1.0, N_\phi \cdot e^{\pi\tan(\phi)}\right)$ $N_q = 23.2$

$N_c := if\left[\phi = 0, 5.14, (N_q - 1)\cdot\cot(\phi)\right]$ $N_c = 35.5$

$N_\gamma := if\left[\phi = 0, 0.00, (N_q - 1)\cdot\tan(1.4\cdot\phi)\right]$ $N_\gamma = 22.0$

Inclined loading correction:

$\theta_i := atan\left(\frac{R_{key_i} + K1_i + K2_i}{\Sigma V_i}\right)$ $\theta = \begin{pmatrix} 34.63 \\ 33.16 \\ 31.95 \\ 30.22 \\ 28.32 \end{pmatrix} deg$

$\xi_{ci_i} := if\left[\phi = 0, \left(1 - \frac{\theta_i}{90\cdot deg}\right), \left(1 - \frac{\theta_i}{90\cdot deg}\right)^2\right]$ $\xi_{ci} = \begin{pmatrix} 0.379 \\ 0.399 \\ 0.416 \\ 0.441 \\ 0.470 \end{pmatrix}$

$\xi_{\gamma i_i} := if\left[\phi = 0, 1.0, if\left[\theta_i \le \phi, \left(1 - \frac{\theta_i}{\phi}\right)^2, 0.0\right]\right]$ $\xi_{\gamma i} = \begin{pmatrix} 0.000 \\ 0.000 \\ 2.449\times10^{-6} \\ 3.084\times10^{-3} \\ 0.013 \end{pmatrix}$

$\xi_{qi_i} := if\left[\phi = 0, \left(1 - \frac{\theta_i}{90\cdot deg}\right), \left(1 - \frac{\theta_i}{90\cdot deg}\right)^2\right]$ $\begin{pmatrix} 0.379 \\ 0.399 \\ 0.416 \\ 0.441 \\ 0.470 \end{pmatrix}$

$B_i := L_{brg_i}$ $B = \begin{pmatrix} 30.9 \\ 32.0 \\ 32.0 \\ 32.0 \\ 32.0 \end{pmatrix} ft$

$W := 100\cdot ft$

Foundation depth correction: (at toe)

$D := t_{base}$ $\qquad D = 5.0\,ft$

$\sigma_{D\_eff} := \gamma_{eff} \cdot D$ $\qquad \sigma_{D\_eff} = 325.0\,psf$

$$\xi_{cd_i} := 1 + 0.2 \cdot (N_\phi)^{\frac{1}{2}} \cdot \frac{D}{B_i} \qquad \xi_{cd} = \begin{pmatrix} 1.058 \\ 1.056 \\ 1.056 \\ 1.056 \\ 1.056 \end{pmatrix}$$

$$\xi_{\gamma d\_10_i} := 1 + 0.1 \cdot \left(\tan\left(45 \cdot deg + \frac{10 \cdot deg}{2}\right)^2\right)^{\frac{1}{2}} \cdot \frac{D}{B_i} \qquad \xi_{\gamma d\_10} = \begin{pmatrix} 1.019 \\ 1.019 \\ 1.019 \\ 1.019 \\ 1.019 \end{pmatrix}$$

$$\xi_{\gamma d_i} := \text{if}\left[\phi \le 10 \cdot deg, \xi_{\gamma d\_0} + \frac{\phi}{10 \cdot deg} \cdot \left(\xi_{\gamma d\_10_i} - \xi_{\gamma d\_0}\right), 1 + 0.1 \cdot (N_\phi)^{\frac{1}{2}} \cdot \frac{D}{B_i}\right] \qquad \xi_{\gamma d} = \begin{pmatrix} 1.029 \\ 1.028 \\ 1.028 \\ 1.028 \\ 1.028 \end{pmatrix}$$

$$\xi_{qd_i} := \xi_{\gamma d_i} \qquad \xi_{qd} = \begin{pmatrix} 1.029 \\ 1.028 \\ 1.028 \\ 1.(\\ 1.(\end{pmatrix}$$

USACE EM 1110-1-1905, Eq 4-16:

$$q_{u\_toe_i} := c \cdot N_c \cdot \xi_{cd} \cdot \xi_{ci} + \frac{1}{2} \cdot B_{eff_i} \cdot \gamma_{H\_eff} \cdot N_\gamma \cdot \xi_{\gamma d} \cdot \xi_{\gamma i} + \sigma_{D\_eff} \cdot N_q \cdot \xi_{qd} \cdot \xi_{qi} \qquad q_{u\_toe} = \begin{pmatrix} 16.561 \\ 16.568 \\ 16.586 \\ 16.605 \\ 16.619 \end{pmatrix} ksf$$

Foundation depth correction: (at heel)

$D := E_{grade} - E_{ftg} + t_{base} + h_\beta$ $\qquad D = 32.0\,ft$

$\sigma_{D\_eff\_heel} := \gamma_{eff} \cdot D$ $\qquad \sigma_{D\_eff} = 0.325\,ksf$

$$\xi_{cd_i} := 1 + 0.2 \cdot (N_\phi)^{\frac{1}{2}} \cdot \frac{D}{\ } \qquad \xi_{cd} = \begin{pmatrix} 1.373 \\ 1.361 \\ 1.361 \\ 1.361 \\ 1.361 \end{pmatrix}$$

$$\xi_{\gamma d\_10_i} := 1 + 0.1 \cdot \left(\tan\left(45 \cdot deg + \frac{10 \cdot deg}{2}\right)^2\right)^{\frac{1}{2}} \cdot \frac{D}{B_i} \qquad \xi_{\gamma d\_10} = \begin{pmatrix} 1.123 \\ 1.119 \\ 1.119 \\ 1.119 \\ 1.119 \end{pmatrix}$$

$$\xi_{\gamma d_i} := \text{if}\left[\phi \le 10 \cdot deg, \xi_{\gamma d\_0} + \frac{\phi}{10 \cdot deg} \cdot \left(\xi_{\gamma d\_10_i} - \xi_{\gamma d\_0}\right), 1 + 0.1 \cdot (N_\phi)^{\frac{1}{2}} \cdot \frac{D}{B_i}\right] \qquad \xi_{\gamma d} = \begin{pmatrix} 1.187 \\ 1.180 \\ 1.180 \\ 1.180 \\ 1.180 \end{pmatrix}$$

$$\xi_{qd_i} := \xi_{\gamma d_i} \qquad \xi_{qd} = \begin{pmatrix} 1.187 \\ 1.180 \\ 1.180 \\ 1. \\ 1. \end{pmatrix}$$

USACE EM 1110-1-1905, Eq. 4-16:

$$q_{u\_heel_i} := c \cdot N_c \cdot \xi_{cd} \cdot \xi_{ci} + \frac{1}{2} \cdot B_{eff_i} \cdot \gamma_{H\_eff} \cdot N_\gamma \cdot \xi_{\gamma d} \cdot \xi_{\gamma i} + \sigma_{D\_eff} \cdot N_q \cdot \xi_{qd} \cdot \xi_{qi} \qquad q_{u\_heel} = \begin{pmatrix} 19.027 \\ 19.036 \\ 19.057 \\ 19.078 \\ 19.094 \end{pmatrix} ksf$$

$check\_uplift_i := L_{ftg} - L_{brg_i} - L_{uplift_i}$

$check\_uplift_i =$

-0.0002 ft
0.0000
0.0000
0.0000
0.0000

ok := if(max(|check_uplift|) < 0.001 · ft, ok, "Uplift assumptions do not match bearing area.")

ok = "Ok"

$$e_{brg_i} := \frac{L_{brg_i}}{2} - x_{R_i}$$

$$\sigma_{brg\_toe_i} := \frac{\Sigma V_i}{L_{brg_i}} + \frac{\Sigma V_i \cdot e_{brg_i}}{\frac{\left(L_{brg_i}\right)^2}{6}}$$

$$\sigma_{brg\_heel_i} := \frac{\Sigma V_i}{L_{brg_i}} - \frac{\Sigma V_i \cdot e_{brg_i}}{\frac{\left(L_{brg_i}\right)^2}{6}}$$

$$FS_{brg_i} := \min\left(\frac{q_{u\_toe_i}}{\sigma_{brg\_toe_i}}, \text{if}\left(\sigma_{brg\_heel_i} \neq 0 \cdot psf, \frac{q_{u\_heel_i}}{\sigma_{brg\_heel_j}}, 100\right)\right)$$

$$\%_{brg_i} := \frac{L_{brg_i}}{L_{ftg}}$$

$$\%_{brg_i} = \begin{pmatrix} 96.7 \\ 100.0 \\ 100.0 \\ 100.0 \\ 100.0 \end{pmatrix} \%$$

ok := if($\%_{brg_1} \geq 75\%$, ok, "OT instability: LC#1")

$L_{ftg} = 32.0\ ft$

ok := if($\%_{brg_n} \geq 100\%$, ok, "OT instability: LC#n")

$t_{w\_bot} = 5.3\ ft$

$\frac{L_{ftg}}{4} = 8.000\ ft$

e_{brg_i} = (ft)	$\sigma_{brg\_toe_i}$ = (ksf)	$\sigma_{brg\_heel_i}$ = (ksf)	FS_{brg_i} =	$L_{ftg} - L_{brg_i}$ = (ft)
5.15	4.003	0.000	4.14	1.072
4.84	4.326	0.211	3.83	0.000
4.08	4.474	0.597	3.71	0.000
3.32	4.544	1.060	3.65	0.000
2.73	4.519	1.461	3.68	0.000

$$L_{uplift} \equiv \begin{pmatrix} 1.072 \\ 0 \\ 0 \\ 0 \\ 0 \end{pmatrix} \cdot ft$$

ok := if[max[|$L_{brg} - (L_{ftg} - L_{uplift})$|] < 0.001 · ft, ok, "Uplift area does not match

ok := if($FS_{brg_1} < 2$, "Bearing problem LC#1", ok)

$L_{ftg} = 32.0\ ft$

ok := if($FS_{brg_n} < 3$, "Bearing problem LC#n", ok)

ok = "Ok"

Base Pressures:

$$e_{ftg_i} := \frac{L_{ftg}}{2} - x_{R_i}$$

(eccentricity with respect to the footing centroid)

$\Sigma H_i + R_{key_i} =$ (klf)	$\Sigma V_i =$ (klf)	$e_{ftg_i} =$ (ft)	$x_{R_i} =$ (ft)	$\sigma_{brg\_heel_i} =$ (ksf)	$\sigma_{brg\_toe_i} =$ (ksf)
42.7	61.9	5.69	10.31	0.000	4.003
47.4	72.6	4.84	11.16	0.211	4.326
50.6	81.1	4.08	11.92	0.597	4.474
52.2	89.7	3.32	12.68	1.060	4.544
51.6	95.7	2.73	13.27	1.461	4.519

$L_{brg_1} = 30.93\,ft$

$$\frac{L_{brg}}{L_{ftg}} = \begin{pmatrix} 96.7 \\ 100.0 \\ 100.0 \\ 100.0 \\ 100.0 \end{pmatrix} \%$$

Sliding Analysis:

Function Definitions:

$c_1(\phi_d) := 2 \cdot \tan(\phi_d)$

$c_2(\phi_d, \beta) := 1 - \tan(\phi_d) \cdot \tan(\beta) - \left(\frac{\tan(\beta)}{\tan(\phi_d)}\right)$

$\alpha_{driving}(\phi_d, \beta) := -\text{atan}\left(\frac{c_1(\phi_d) + \sqrt{c_1(\phi_d)^2 + 4 \cdot c_2(\phi_d, \beta)}}{2}\right)$

$L_\beta := \max\left(\begin{pmatrix} \frac{h_\beta}{\tan(\beta)} - L_{WS5} - L_{WS6} \\ 0 \cdot ft \end{pmatrix}\right)$ $L_\beta = 0.0\,ft$

Sliding Analysis #1:

$\beta_w := \beta$ $\beta_w = 33.7\,deg$

$\phi_i := \phi_{fill}$ $\phi = \begin{pmatrix} 32.0 \\ 32.0 \\ 32.0 \\ 32.0 \\ 32.0 \end{pmatrix} deg$

$c := 0 \cdot ksf$

$\phi_{d_i} := \text{atan}\left(\frac{\tan(\phi_i)}{FS1_i}\right)$ $\phi_{d_i} = \begin{pmatrix} 24.4 \\ 23.0 \\ 21.7 \\ 20.4 \\ 19.0 \end{pmatrix} deg$

$\text{atan}(\tan(\beta) \cdot FS1_i) = \begin{pmatrix} 42.6 \\ 44.4 \\ 46.3 \\ 48.2 \\ 50.4 \end{pmatrix} deg$ (back solve for minimum ϕ value for stable slope β, EM 1110–2–2502, pg 3-31)

$\phi_i := \text{if}\left[\left(c_1(\phi_{d_i})^2 + 4 \cdot c_2(\phi_{d_i}, \beta_w) < 0\right), \text{atan}(\tan(\beta_w) \cdot FS1_i), \phi_i\right]$ $\phi = \begin{pmatrix} 42.6 \\ 44.4 \\ 46.3 \\ 48.2 \\ 50.4 \end{pmatrix} deg$ (substitue minimum ϕ if slope is unstable)

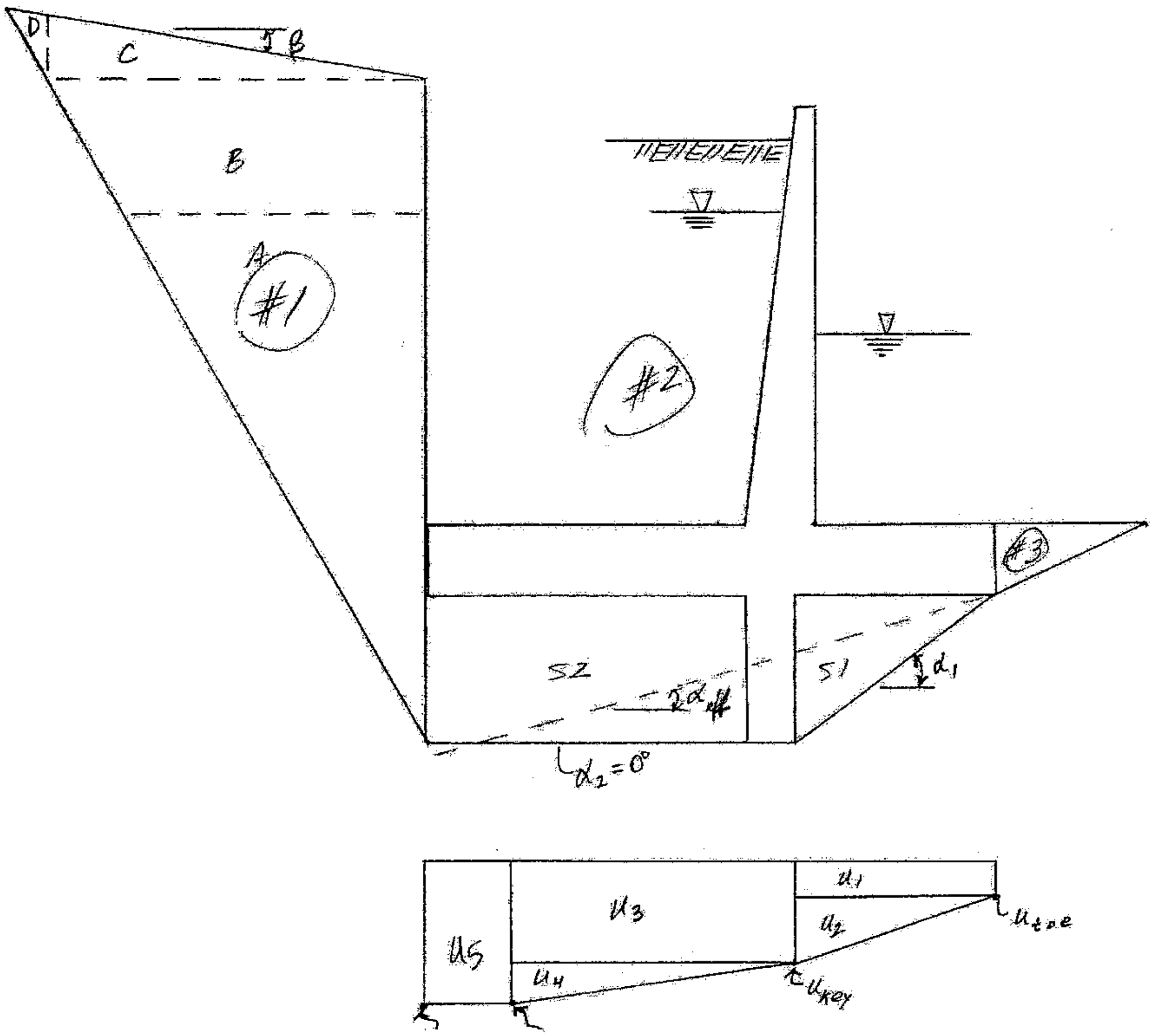
$\phi_{d\_1b_i} := \text{atan}\left(\frac{\tan(\phi_i)}{FS1_i}\right)$ $\phi_{d\_1b_i} = \begin{pmatrix} 33.7 \\ 33.7 \\ 33.7 \\ 33.7 \\ 33.7 \end{pmatrix} deg$

$\alpha_{1b_i} := \alpha_{driving}(\phi_{d\_1b_i}, \beta_w)$

$h_{1b} := (E_{grade} + L_{WS5} \cdot \tan(\beta_w)) - (E_{bftg} - h_{key})$ $h_{1b} = 32.0\,ft$

$L_{max_i} := \text{if}\left[-\alpha_{1b_i} = \phi_{d\_1b_i}, 1000 \cdot ft, \frac{\frac{h_{1b}}{\cos(-\alpha_{1b_i})(\tan(-\alpha_{1b_i}) - \tan(\beta_w))}}{\cos(-\alpha_{1b_i})}\right]$ $\alpha_{1b} = \begin{pmatrix} -33.7 \\ -33.7 \\ -33.7 \\ -33.7 \\ -33.7 \end{pmatrix} deg$ $L_{max} = \begin{pmatrix} 1000.0 \\ 1000.0 \\ 1000.0 \\ 1000.0 \\ 1000.0 \end{pmatrix} ft$

$h_{1a_i} := \text{if}\left[L_\beta < L_{max_i}, h_{1b} + L_\beta \cdot (\tan(\beta) - \tan(-\alpha_{1b_i})), 0 \cdot ft\right]$



Sliding Analysis #1

Driving Wedge (#1a):

$\beta_w := 0 \ \text{deg}$ $\qquad \beta_w = 0.0\,\text{deg}$

$\phi := \phi_{fill}$ $\qquad \phi = 32.0\,\text{deg}$

$h_{1a} = \begin{pmatrix} 32.0 \\ 32.0 \\ 32.0 \\ 32.0 \\ 32.0 \end{pmatrix} \text{ft}$

$c := 0 \ \text{ksf}$

$\phi_{d_i} := \text{atan}\left(\frac{\tan(\phi)}{FS1_i}\right)$ $\qquad \phi_d = \begin{pmatrix} 24.4 \\ 23.0 \\ 21.7 \\ 20.4 \\ 19.0 \end{pmatrix} \text{deg}$

$\alpha_i := \alpha_{driving}\left(\phi_{d_i}, \beta_w\right)$ $\qquad \alpha = \begin{pmatrix} -57.2 \\ -56.5 \\ -55.9 \\ -55.2 \\ -54.5 \end{pmatrix} \text{deg}$

$h_i := h_{1a_i}$ $\qquad h = \begin{pmatrix} 32.0 \\ 32.0 \\ 32.0 \\ 32.0 \\ 32.0 \end{pmatrix} \text{ft}$

$L_i := \frac{h_i}{\cos(-\alpha_i) \cdot (\tan(-\alpha_i) - \tan(\beta_w))}$ $\qquad L = \begin{pmatrix} 38.1 \\ 38.4 \\ 38.7 \\ 39.0 \\ 39.3 \end{pmatrix} \text{ft}$

$h_{sat_i} := \max\left[\begin{bmatrix} E_{wheel_i} - (E_{ftg} - t_{base} - h_{key}) - L_\beta \cdot \tan(-\alpha_{1b_i}) \\ 0 \cdot \text{ft} \end{bmatrix}\right]$ $\qquad h_{sat} = \begin{pmatrix} 32.0 \\ 26.5 \\ 21.0 \\ 15.5 \\ 10.0 \end{pmatrix} \text{ft}$

$L_{h_i} := \frac{h_i}{\tan(-\alpha_i)}$ $\qquad L_h = \begin{pmatrix} 20.6 \\ 21.2 \\ 21.7 \\ 22.2 \\ 22.8 \end{pmatrix} \text{ft}$

$L_{sat_i} := \frac{h_{sat_i}}{\tan(-\alpha_i)}$ $\qquad L_{sat} = \begin{pmatrix} 20.6 \\ 17.5 \\ 14.2 \\ 10.8 \\ 7.1 \end{pmatrix} \text{ft}$

$h_{left} := 0 \cdot \text{ft}$

$h_{right_i} := h_{1a_i}$

$W_i := \gamma_{fill} \cdot \left(L_{h_i} \cdot \frac{h_{left} + h_{right_i}}{2}\right) + (\gamma_{sat} - \gamma_{fill}) \cdot \frac{L_{sat_i} \cdot h_{sat_i}}{2}$

$W_i =$

42.1
43.4
44.8
46.0
47.3

klf

$V := 0 \cdot \text{klf}$

$H_L := 0 \ \text{klf}$

$H_R := 0 \ \text{klf}$

$U_i := \gamma_w \cdot \left(\frac{h_{sat_i}}{2}\right) \cdot \sqrt{\left(h_{sat_i}\right)^2 + \left(L_{sat_i}\right)^2}$ $\qquad U = \begin{pmatrix} 38.1 \\ 26.3 \\ 16.7 \\ 9.1 \\ 3.8 \end{pmatrix} \text{klf}$

$$\Delta P_{1a_i} := \frac{\left[\left(W_i + V\right)\cdot\left(\tan\left(\phi_{d_i}\right)\cdot\cos\left(\alpha_i\right) + \sin\left(\alpha_i\right)\right) - U_i\cdot\tan\left(\phi_{d_i}\right) + \left(H_L - H_R\right)\cdot\left(\tan\left(\phi_{d_i}\right)\cdot\sin\left(\alpha_i\right) - \cos\left(\alpha_i\right)\right) + \frac{c}{FS_{1_i}}\cdot L_i\right]}{\left(\cos\left(\alpha_i\right) - \tan\left(\phi_{d_i}\right)\cdot\sin\left(\alpha_i\right)\right)}$$

Driving Wedge (#1b):

$\beta_w := \beta$ $\qquad \beta_w = 33.7\,\text{deg}$

$\alpha := \alpha_{1b}$ $\qquad \alpha = \begin{pmatrix} -33.7 \\ -33.7 \\ -33.7 \\ -33.7 \\ -33.7 \end{pmatrix}\text{deg}$

$\phi_d := \phi_{d\_1b}$ $\qquad \phi_d = \begin{pmatrix} 33.7 \\ 33.7 \\ 33.7 \\ 33.7 \\ 33.7 \end{pmatrix}\text{deg}$

$h = \begin{pmatrix} 32.0 \\ 32.0 \\ 32.0 \\ 32.0 \\ 32.0 \end{pmatrix}\text{ft}$

$L_h := L_\beta$ $\qquad L_h = 0.0\,\text{ft}$

$L_i := \dfrac{L_\beta}{\cos\left(\alpha_i\right)}$ $\qquad = \begin{pmatrix} 0.0 \\ 0.0 \\ 0.0 \\ 0.0 \\ 0.0 \end{pmatrix}\text{ft}$

$h_{satr_i} := \max\left[\begin{bmatrix} E_{wheel_i} - \left(E_{ftg} - t_{base} - h_{key}\right) \\ 0\cdot\text{ft} \end{bmatrix}\right]$ $\qquad h_{satr} = \begin{pmatrix} 32.0 \\ 26.5 \\ 21.0 \\ 15.5 \\ 10.0 \end{pmatrix}\text{ft}$

$h_{satl_i} := \max\left[\begin{bmatrix} E_{wheel_i} - \left(E_{ftg} - t_{base} - h_{key}\right) - \dfrac{L_\beta}{\cos\left(\alpha_i\right)} \\ 0\cdot\text{ft} \end{bmatrix}\right]$ $\qquad h_{satl} = \begin{pmatrix} 32.0 \\ 26.5 \\ 21.0 \\ 15.5 \\ 10.0 \end{pmatrix}\text{ft}$

$L_{sat_i} := \min\left[\begin{bmatrix} L_\beta \\ \dfrac{h_{satr_i}}{\tan\left[(-\alpha)_i\right]} \end{bmatrix}\right]$ $\qquad L_{sat} = \begin{pmatrix} 0.0 \\ 0.0 \\ 0.0 \\ 0.0 \\ 0.0 \end{pmatrix}\text{ft}$

$h_{left_i} := h_{1a_i}$ $\qquad h_{left} = \begin{pmatrix} 32.0 \\ 32.0 \\ 32.0 \\ 32.0 \\ 32.0 \end{pmatrix}\text{ft}$

$h_{right} := h_{1b}$

$$W_i := \gamma_{fill} \cdot \left(L_h \cdot \frac{h_{left_i} + h_{right}}{2}\right) + \left(\gamma_{sat} - \gamma_{fill}\right) \cdot L_{sat_i} \cdot \left(\frac{h_{satr_i} + h_{satl_i}}{2}\right)$$

$W_i =$

W_i (klf)
0.0
0.0
0.0
0.0
0.0

$V := 0 \cdot klf$

$H_L := 0 \cdot klf$

$H_R := 0 \cdot klf$

$$U_i := \gamma_w \cdot \left(\frac{h_{satr_i} + h_{satl_i}}{2}\right) \cdot \sqrt{\left(h_{satr_i} - h_{satl_i}\right)^2 + \left(L_h\right)^2}$$

$$\Delta P_{1b_i} := \frac{\left[\left(W_i + V\right) \cdot \left(\tan\left(\phi_{d_i}\right) \cdot \cos\left(\alpha_i\right) + \sin\left(\alpha_i\right)\right) - U_i \cdot \tan\left(\phi_{d_i}\right) + \left(H_L - H_R\right) \cdot \left(\tan\left(\phi_{d_i}\right) \cdot \sin\left(\alpha_i\right) - \cos\left(\alpha_i\right)\right) + \frac{c}{FS_{1_i}} \cdot L_i\right]}{\left(\cos\left(\alpha_i\right) - \tan\left(\phi_{d_i}\right) \cdot \sin\left(\alpha_i\right)\right)}$$

Structure Wedge (#2):

$U_i =$

klf
0.000
0.000
0.000
0.000
0.000

$\beta_w := 0 \ deg$

$\phi := \phi_{fill}$ $\qquad \phi = 32.0 \, deg$

$c := 0 \ ksf$

$\phi_{d_i} := \operatorname{atan}\left(\frac{\tan(\phi)}{FS_{1_i}}\right)$

$$\phi_{d_i} = \begin{pmatrix} 24.4 \\ 23.0 \\ 21.7 \\ 20.4 \\ 19.0 \end{pmatrix} deg$$

$\alpha_1 := \operatorname{atan}\left(\frac{h_{key}}{x_{key} - \frac{L_{key}}{2}}\right)$ $\qquad \alpha_1 = 0.0 \, deg$ (angle of shear plane between toe and key)

$\alpha_2 := 0 \ deg$ (angle of shear plane between key and heel)

$\alpha := \alpha_1 \cdot \left(\frac{x_{key}}{L_{ftg}}\right) + \alpha_2 \cdot \left(\frac{L_{ftg} - x_{key}}{L_{ftg}}\right)$ $\qquad \alpha = 0.0 \, deg$ (average angle of shear plane for structural wedge)

$L := \frac{L_{ftg}}{\cos(\alpha)}$ $\qquad L = 32.0 \, ft$

$h_{S1} := h_{key}$ $\qquad h_{S1} = 0.0 \, ft$

$L_{S1} := x_{key} - \frac{L_{key}}{2}$ $\qquad L_{S1} = 9.3 \, ft$

$x_{S1} := \frac{2}{3} \cdot L_{S1}$ $\qquad x_{S1} = 6.2\,ft$

$S1 := \gamma_{sat} \cdot \frac{h_{S1} \cdot L_{S1}}{2}$ $\qquad S1 = 0.0\,klf$

$h_{S2} := h_{key}$ $\qquad h_{S2} = 0.0\,ft$

$L_{S2} := L_{ftg} - x_{key} - \frac{L_{key}}{2}$ $\qquad L_{S2} = 18.8\,ft$

$x_{S2} := L_{ftg} - \frac{L_{S2}}{2}$ $\qquad x_{S2} = 22.6\,ft$

$S2 := \gamma_{sat} \cdot h_{S2} \cdot L_{S2}$ $\qquad S2 = 0.0\,klf$

$$W_i := \sum_{i=1}^{4} W_{C_i} + W_{W1_i} + W_{WS1_i} + W_{WS2_i} + W_{WS3_i} + W_{WS4_i} + W_{WS5} + W_{WS6} + S1 + S2 + S_{\beta_i}$$

Uplift below structural wedge:

$u_{toe_i} := \gamma_w \cdot \left(E_{wtoe_i} - E_{bftg}\right)$

$u_{heel_i} := \gamma_w \cdot \left[E_{wheel_i} - \left(E_{bftg} - h_{key}\right)\right]$

$$\delta_{u_i} := \frac{\gamma_w \cdot \left(E_{wheel_i} - E_{wtoe_i}\right)}{L_{ftg} - L_{t1_i}}$$

$u_{key_i} := u_{toe_i} + \delta_{u_i} \cdot \left(x_{key} - \frac{L_{key}}{2}\right) + \gamma_w \cdot h_{key}$

$ok := if\left[\left[u_{key_1} + \delta_{u_1} \cdot \left(L_{ftg} - x_{key} + \frac{L_{key}}{2} - L_{t1_1}\right) = u_{heel_1}\right], ok, \text{"Uplift pressures do not close."}\right]$

ok = "Ok"

$u_{1_i} := u_{toe_i} \cdot \left(x_{key} - \frac{L_{key}}{2}\right)$

$x_{u1} := \frac{x_{key} - \frac{L_{key}}{2}}{2}$ $\qquad x_{u1} = 4.6\,ft$

$u_{2_i} := \left(u_{key_i} - u_{toe_i}\right) \cdot \frac{\left(x_{key} - \frac{L_{key}}{2}\right)}{2}$

$$x_{u2} := \frac{2}{3} \cdot \left(x_{key} - \frac{L_{key}}{2}\right) \qquad x_{u2} = 6.2\,\text{ft}$$

$$u_{3_i} := u_{key_i} \cdot \left(L_{ftg} - L_{t1_i} - x_{key} + \frac{L_{key}}{2}\right)$$

$$x_{u3_i} := x_{key} - \frac{L_{key}}{2} + \frac{1}{2} \left[L_{ftg} - L_{t1_i} - \left(x_{key} - \frac{L_{key}}{2}\right)\right]$$

$$u_{4_i} := \left(u_{heel_i} - u_{key_i}\right) \cdot \frac{\left(L_{ftg} - L_{t1_i} - x_{key} + \frac{L_{key}}{2}\right)}{2}$$

$$x_{u4_i} := x_{key} - \frac{L_{key}}{2} + \frac{2}{3} \cdot \left[L_{ftg} - L_{t1_i} - \left(x_{key} - \frac{L_{key}}{2}\right)\right]$$

$$u_{5_i} := u_{heel_i} \cdot L_{t1_i}$$

$$x_{u5_i} := L_{ftg} - \frac{L_{t1_i}}{2}$$

$$U_i := u_{1_i} + u_{2_i} + u_{3_i} + u_{4_i} + u_{5_i}$$

$$x_{U_i} := \frac{u_{1_i} \cdot x_{u1} + u_{2_i} \cdot x_{u2} + u_{3_i} \cdot x_{u3_i} + u_{4_i} \cdot x_{u4_i} + u_{5_i} \cdot x_{u5_i}}{U_i}$$

$$\Sigma M_{grav_i} := \left(\sum_{i=1}^{4} W_{C_i} \cdot x_{C_i} + W_{W1_i} \cdot x_{W1} + W_{WS1_i} \cdot x_{WS1} + W_{WS2_i} \cdot x_{WS2_i} + W_{WS3_i} \cdot x_{WS3_i}\right) \cdots$$
$$+ W_{WS4_i} \cdot x_{WS4_i} + W_{WS5} \cdot x_{WS5} + W_{WS6} \cdot x_{WS6} + S1 \cdot x_{S1} + S2 \cdot x_{S2} + S_{\beta_i} \cdot x_{S\beta} - \left(U_i \cdot x_{U_i}\right)$$

$$h_{A2_i} := E_{wheel_i} - E_{bftg} + h_{key}$$

$$y_{A2_i} := \frac{h_{A2_i}}{2} - h_{key}$$

$$A2_i := k_{0\beta} \cdot \gamma_{fill} \cdot h_{A1_i} \cdot h_{A2_i}$$

$$h_{A3_i} := h_{A2_i}$$

$$y_{A3_i} := \frac{h_{A3_i}}{3} - h_{key}$$

$$A3_i := k_{0\beta} \cdot \gamma_{fill\_eff} \cdot \frac{\left(h_{A3_i}\right)^2}{2}$$

$$H3_i := 0 \cdot \text{klf}$$

$$h_{H2_i} := E_{wheel_i} - E_{bftg} + h_{key}$$

h_{A2_i} = (ft)	y_{A2_i} = (ft)	$A2_i$ = (klf)	h_{A3_i} = (ft)	y_{A3_i} = (ft)	A3 = (klf)
32.00	16.00	0.0	32.00	10.67	25.9
26.50	13.25	14.7	26.50	8.83	17.7
21.00	10.50	23.3	21.00	7.00	11.1
15.50	7.75	25.8	15.50	5.17	6.1
10.00	5.00	22.2	10.00	3.33	2.5

$$y_{H2_i} := \frac{h_{H2_i}}{3} - h_{key}$$

$$H2_i := \gamma_w \cdot \frac{\left(h_{H2_i}\right)^2}{2}$$

$$\Sigma M_{lat_i} := -H1_i \cdot \left(y_{H1_i}\right) - K1_i \cdot \left(y_{K1}\right) - K2_i \cdot \left(y_{K2}\right) + H2_i \cdot \left(y_{H2_i}\right) + H3_i \cdot \left(y_{H3}\right) \ldots$$
$$+ A1_i \cdot \left(y_{A1_i}\right) + A2_i \cdot \left(y_{A2_i}\right) + A3_i \cdot \left(y_{A3_i}\right) - R_{key_i} \cdot \left(y_{Rkey}\right)$$

$$x_{R_i} := \frac{\Sigma M_{grav_i} - \Sigma M_{lat_i}}{W_i - U_i} \qquad L_{brg_i} := \min\left(3 \cdot x_{R_i}, L_{ftg}\right)$$

$ok_{u_i} :=$ if$\left[\left|L_{brg_i} - \left(L_{ftg} - L_{t1_i}\right)\right| > 0.001 \cdot ft\right.$, "Uplift assumptions wrong in sliding analysis.", "Matched."$\left.\right]$

W_i (klf)	u_{toe_i} (ksf)	u_{heel_i} (ksf)	δ_{u_i} (psf/ft)	u_{key_i} (ksf)	u_{1_i} (klf)	u_{2_i} (klf)	u_{3_i} (klf)
118.0	1.375	2.000	19.8	1.558	12.719	0.848	34.737
115.6	1.031	1.656	19.5	1.212	9.539	0.836	27.571
113.1	0.688	1.313	19.5	0.868	6.359	0.836	19.751
110.7	0.344	0.969	19.5	0.524	3.180	0.836	11.930
110.7	0.313	0.625	9.8	0.403	2.891	0.418	9.164

u_{4_i} (klf)	u_{5_i} (klf)	x_{u3_i} (ft)	x_{u4_i} (ft)	x_{u5_i} (ft)	h_{H2_i} (ft)	y_{H2_i} (ft)	$H2_i$ (klf)
4.923	0.9	20.4	24.1	31.8	32.0	10.7	32.0
5.054	0.0	20.6	24.4	32.0	26.5	8.8	21.9
5.054	0.0	20.6	24.4	32.0	21.0	7.0	13.8
5.054	0.0	20.6	24.4	32.0	15.5	5.2	7.5
2.527	0.0	20.6	24.4	32.0	10.0	3.3	3.1

U_i (klf)	x_{U_i} (ft)	ΣM_{grav_i} (kip)	ΣM_{lat_i} (kip)	x_{R_i} (ft)	L_{brg_i} (ft)
54.1	17.0	1178	506	10.5	31.5
43.0	17.2	1353	542	11.2	32.0
32.0	17.7	1524	557	11.9	32.0
21.0	18.5	1695	558	12.7	32.0
15.0	17.8	1823	553	13.3	32.0

$H_{L_i} := 0 \cdot \text{klf}$

$$H_{R_i} := \gamma_w \cdot \frac{\left(E_{wtoe_i} - E_{ftg}\right)^2}{2}$$

$$\Delta P_{2_i} := \frac{\left[\left(W_i + V\right)\cdot\left(\tan\left(\phi_{d_i}\right)\cdot\cos(\alpha) + \sin(\alpha)\right) - U_i \cdot \tan\left(\phi_{d_i}\right) + \left(H_{L_i} - H_{R_i}\right)\left(\tan\left(\phi_{d_i}\right)\cdot\sin(\alpha) - \cos(\alpha)\right) + \frac{c}{FS_{1_i}}\cdot L\right]}{\left(\cos(\alpha) - \tan\left(\phi_{d_i}\right)\cdot\sin(\alpha)\right)}$$

H_{L_i} = (klf)	H_{R_i} = (klf)
0.0	9.0
0.0	4.1
0.0	1.1
0.0	7.8 10 -3
0.0	0.0

$$ok_{u_i} = \begin{pmatrix} \text{"Matched."} \\ \text{"Matched."} \\ \text{"Matched."} \\ \text{"Matched."} \\ \text{"Matched."} \end{pmatrix}$$

$L_{ftg} - L_{brg_i}$ = (ft)
0.458
0.000
0.000
0.000
0.000

$$L_{t1} \equiv \begin{pmatrix} 0.458 \\ 0 \\ 0 \\ 0 \\ 0 \end{pmatrix} \cdot \text{ft}$$

$ok := \text{if}\left[\max\left[\left|L_{brg} - \left(L_{ftg} - L_{t1}\right)\right|\right] < 0.001 \cdot \text{ft}, ok, \text{"Uplift area does not match."}\right]$

$ok := \text{if}\left(\min\left(L_{brg}\right) < x_{key} + \frac{L_{key}}{2}, \text{"Uplift assumptions incorrect."}, ok\right)$ $\qquad ok = \text{"Ok"}$

Resisting Wedge (#3)

$\beta_w := 0 \cdot deg$

$\phi := \phi_{fill}$ $\phi = 32.0\,deg$

$c := 0 \cdot ksf$

$\phi_{d_i} := atan\left(\frac{tan(\phi)}{FS1_i}\right)$ $\phi_{d_i} = \begin{pmatrix} 24.4 \\ 23.0 \\ 21.7 \\ 20.4 \\ 19.0 \end{pmatrix} deg$

$\alpha_i := 45 \cdot deg - \frac{\phi_{d_i}}{2}$ $\alpha_i = \begin{pmatrix} 32.8 \\ 33.5 \\ 34.1 \\ 34.8 \\ 35.5 \end{pmatrix} deg$

$L_i := \frac{t_{base}}{sin(\alpha_i)}$ $L = \begin{pmatrix} 9.225 \\ 9.063 \\ 8.907 \\ 8.761 \\ 8.615 \end{pmatrix} ft$

$W_i := \gamma_{sat} \cdot \frac{L_i \cdot cos(\alpha_i) \cdot t_{base}}{2} + \gamma_w \cdot (E_{wtoe_i} - E_{ftg}) \cdot L_i \cdot cos(\alpha_i)$

$U_i := \gamma_w \cdot \left(E_{wtoe_i} - E_{ftg} + \frac{t_{base}}{2}\right) \cdot L_i$

$H_L := 0 \cdot klf$

$H_R := 0 \cdot klf$

$V := 0 \cdot klf$

$$\Delta P3_i := \frac{\left[(W_i + V) \cdot \left(tan(\phi_{d_i}) \cdot cos(\alpha_i) + sin(\alpha_i)\right) - U_i \cdot tan(\phi_{d_i}) + (H_L - H_R) \cdot \left(tan(\phi_{d_i}) \cdot sin(\alpha_i) - cos(\alpha_i)\right) + \frac{c}{FS1_i} \cdot L_i\right]}{\left(cos(\alpha_i) - tan(\phi_{d_i}) \cdot sin(\alpha_i)\right)}$$

$\Sigma P_i := \Delta P1a_i + \Delta P1b_i + \Delta P2_i + \Delta P3_i$

$W_i =$ (klf)	$U_i =$ (klf)	$\Delta P1a_i =$ (klf)	$\Delta P1b_i =$ (klf)	$\Delta P2_i =$ (klf)	$\Delta P3_i =$ (klf)	$\Sigma P_i =$ (klf)
10.7	11.2	-45.8	0.0	38.0	8.0	0.2
7.8	7.9	-41.1	0.0	35.0	6.2	0.1
5.1	4.7	-37.8	0.0	33.4	4.4	0.0
2.5	1.6	-35.9	0.0	33.4	2.6	0.1
2.2	1.3	-35.3	0.0	33.0	2.4	0.1

$FS1 \equiv \begin{pmatrix} 1.38 \\ 1.47 \\ 1.57 \\ 1.68 \\ 1.81 \end{pmatrix}$

ok := if($FS1_1$ ≥ 1.33, ok, "Sliding instability: LC#1")

ok := if($FS1_n$ ≥ 1.50, ok, "Sliding instability: LC#n")

ok = "Ok"

Sliding Analysis #2:

$L_\beta = 0.00\,ft$

$\phi_i := \phi_{fill}$ $\beta_w := \beta$ $\beta_w = 33.7\,deg$

$$\phi = \begin{pmatrix}32.0\\32.0\\32.0\\32.0\\32.0\end{pmatrix} deg$$

$c := 0 \cdot ksf$

$$\phi_{d_i} := atan\left(\frac{tan(\phi_i)}{FS2_i}\right) \qquad \phi_{d_i} = \begin{pmatrix}24.4\\23.0\\21.7\\20.4\\19.0\end{pmatrix} deg$$

$$atan(tan(\beta) \cdot FS2_i) = \begin{pmatrix}42.6\\44.4\\46.3\\48.2\\50.4\end{pmatrix} deg$$

(back solve for minimum ϕ value for stable slope β, EM 1110–2–2502, pg. 3-31)

$$\phi_i := if\left[\left(c_1(\phi_{d_i})^2 + 4 \cdot c_2(\phi_{d_i}, \beta_w) < 0\right), atan(tan(\beta_w) \cdot FS2_i), \phi_i\right] \qquad \phi = \begin{pmatrix}42.6\\44.4\\46.3\\48.2\\50.4\end{pmatrix} deg$$

(substitue minimum ϕ if slope is unstable)

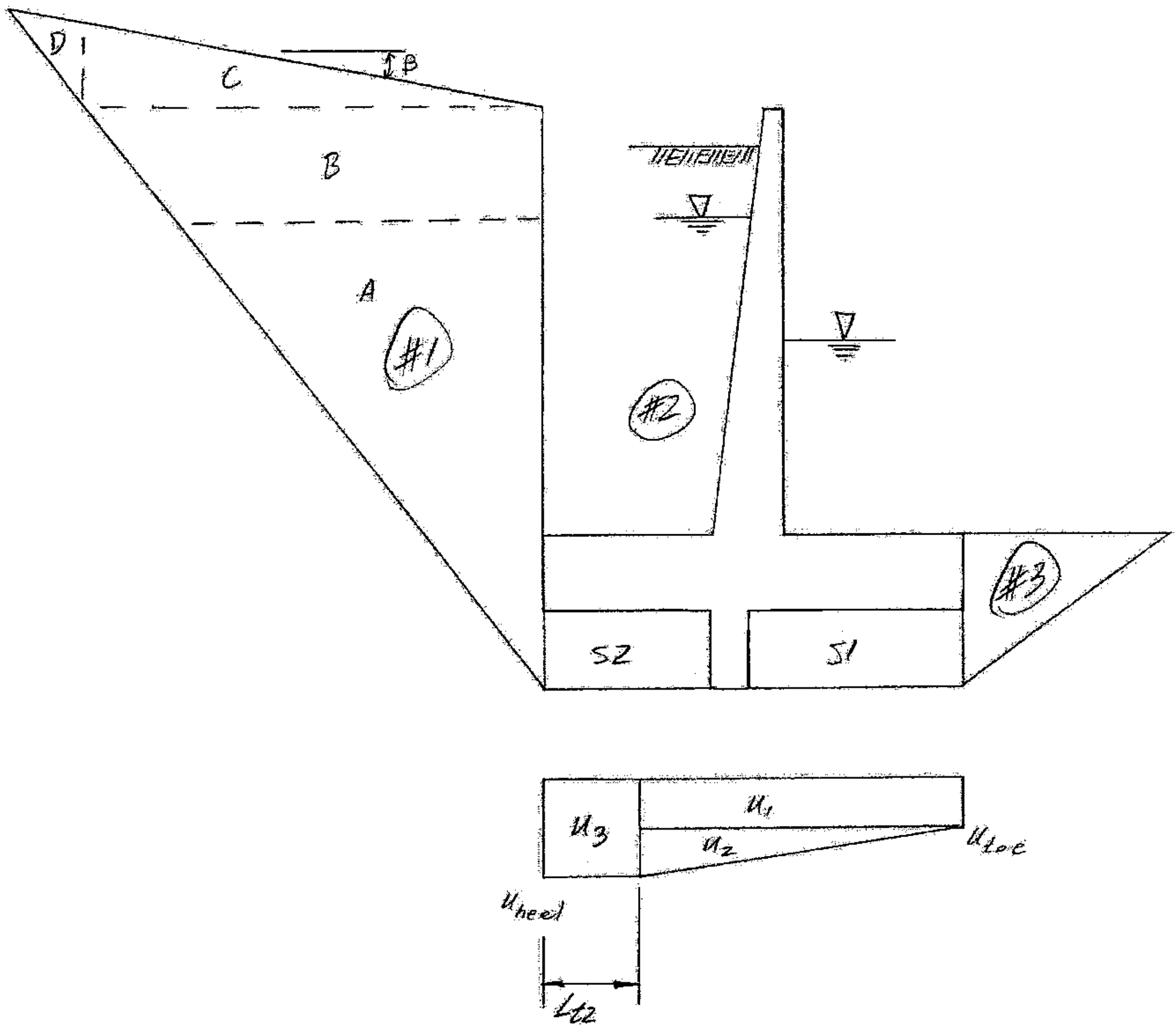
$$\phi_{d\_1b_i} := atan\left(\frac{tan(\phi_i)}{FS2_i}\right) \qquad \phi_{d\_1b_i} = \begin{pmatrix}33.7\\33.7\\33.7\\33.7\\33.7\end{pmatrix} deg$$

$$\alpha_{1b_i} := \alpha_{driving}(\phi_{d\_1b_i}, \beta_w) \qquad \alpha_{1b} = \begin{pmatrix}-33.7\\-33.7\\-33.7\\-33.7\\-33.7\end{pmatrix} deg$$

$$h_{1b} := (E_{grade} + L_{WS5} \cdot tan(\beta_w)) - (E_{bftg} - h_{key}) \qquad h_{1b} = 32.0\,ft$$

$$L_{max_i} := if\left[-\alpha_{1b_i} = \phi_{d\_1b_i}, 1000 \cdot ft, \frac{\dfrac{h_{1b}}{cos(-\alpha_{1b_i}) \cdot (tan(-\alpha_{1b_i}) - tan(\beta_w))}}{cos(-\alpha_{1b_i})}\right] \qquad L_{max} = \begin{pmatrix}1000.0\\1000.0\\1000.0\\1000.0\\1000.0\end{pmatrix} ft$$

$$h_{1a_i} := if\left[L_\beta < L_{max_i}, h_{1b} + L_\beta \cdot (tan(\beta) - tan(-\alpha_{1b_i})), 0 \cdot ft\right] \qquad h_{1a} = \begin{pmatrix}32.0\\32.0\\32.0\\32.0\\32.0\end{pmatrix} ft$$



Sliding Analysis #2

Driving Wedge (#1a):

$\beta_w := 0 \cdot deg$ $\beta_w = 0.0\,deg$

$\phi := \phi_{fill}$ $\phi = 32.0\,deg$

$c := 0 \cdot ksf$

$\phi_{d_i} := atan\left(\dfrac{tan(\phi)}{FS2_i}\right)$ $\phi_d = \begin{pmatrix} 24.4 \\ 23.0 \\ 21.7 \\ 20.4 \\ 19.0 \end{pmatrix} deg$

$\alpha_i := \alpha_{driving}\left(\phi_{d_i}, \beta_w\right)$ $\alpha = \begin{pmatrix} -57.18 \\ -56.51 \\ -55.85 \\ -55.20 \\ -54.52 \end{pmatrix} deg$

$h_i := h_{1a_i}$

$h_i := h_{1a_i}$ $h = \begin{pmatrix} 32.0 \\ 32.0 \\ 32.0 \\ 32.0 \\ 32.0 \end{pmatrix} ft$

$L_i := \dfrac{h_i}{cos(-\alpha_i) \cdot (tan(-\alpha_i) - tan(\beta_w))}$ $= \begin{pmatrix} 38.08 \\ 38.37 \\ 38.67 \\ 38.97 \\ 39.30 \end{pmatrix} ft$

$h_{sat_i} := max\left[\begin{bmatrix} E_{wheel_i} - (E_{ftg} - t_{base} - h_{key}) - L_\beta \cdot tan(-\alpha_{1b_i}) \\ 0 \cdot ft \end{bmatrix}\right]$ $h_{sat} = \begin{pmatrix} 32.0 \\ 26.5 \\ 21.0 \\ 15.5 \\ 10.0 \end{pmatrix} ft$

$L_{h_i} := \dfrac{h_i}{tan(-\alpha_i)}$ $L_h = \begin{pmatrix} 20.638 \\ 21.169 \\ 21.705 \\ 22.240 \\ 22.806 \end{pmatrix} ft$

$L_{sat_i} := \dfrac{h_{sat_i}}{tan(-\alpha_i)}$ $L_{sat} = \begin{pmatrix} 20.64 \\ 17.53 \\ 14.24 \\ 10.77 \\ 7.13 \end{pmatrix} ft$

$h_{left} := 0 \cdot ft$

$h_{right_i} := h_{1a_i}$

$W_i := \gamma_{fill} \cdot \left(L_{h_i} \cdot \dfrac{h_{left} + h_{right_i}}{2}\right) + (\gamma_{sat} - \gamma_{fill}) \cdot \dfrac{L_{sat_i} \cdot h_{sat_i}}{2}$

$W_i =$

W_i (klf)
42.101
43.450
44.773
46.050
47.347

$V := 0\ klf$

$H_L := 0 \cdot klf$

$H_R := 0 \cdot klf$

$$U_i := \gamma_w \cdot \left(\frac{h_{sat_i}}{2}\right) \cdot \sqrt{\left(h_{sat_i}\right)^2 + \left(L_{sat_i}\right)^2}$$

$$U = \begin{pmatrix} 38.078 \\ 26.312 \\ 16.652 \\ 9.143 \\ 3.837 \end{pmatrix} \text{klf}$$

$$\Delta P_{1a_i} := \frac{\left[\left(W_i + V\right) \cdot \left(\tan\left(\phi_{d_i}\right) \cdot \cos\left(\alpha_i\right) + \sin\left(\alpha_i\right)\right) - U_i \cdot \tan\left(\phi_{d_i}\right) + \left(H_L - H_R\right) \cdot \left(\tan\left(\phi_{d_i}\right) \cdot \sin\left(\alpha_i\right) - \cos\left(\alpha_i\right)\right) + \frac{c}{FS_{2_i}} \cdot L_i\right]}{\left(\cos\left(\alpha_i\right) - \tan\left(\phi_{d_i}\right) \cdot \sin\left(\alpha_i\right)\right)}$$

Driving Wedge (#1b): $L_\beta = 0.0\,ft$

$\beta_w := \beta$ $\beta_w = 33.7\,deg$

$\alpha := \alpha_{1b}$ $\alpha = \begin{pmatrix} -33.7 \\ -33.7 \\ -33.7 \\ -33.7 \\ -33.7 \end{pmatrix} deg$

$\phi_d := \phi_{d\_1b}$ $\phi_d = \begin{pmatrix} 33.7 \\ 33.7 \\ 33.7 \\ 33.7 \\ 33.7 \end{pmatrix} deg$

$h = \begin{pmatrix} 32.0 \\ 32.0 \\ 32.0 \\ 32.0 \\ 32.0 \end{pmatrix} ft$

$L_h := L_\beta$ $L_h = 0.0\,ft$

$L_i := \dfrac{L_\beta}{\cos(\alpha_i)}$ $L = \begin{pmatrix} 0.0 \\ 0.0 \\ 0.0 \\ 0.0 \\ 0.0 \end{pmatrix} ft$

$h_{satr_i} := \max\left[\begin{bmatrix} E_{wheel_i} - (E_{ftg} - t_{base} - h_{key}) \\ 0 \cdot ft \end{bmatrix}\right]$ $h_{satr} = \begin{pmatrix} 32.0 \\ 26.5 \\ 21.0 \\ 15.5 \\ 10.0 \end{pmatrix} ft$

$h_{satl_i} := \max\left[\begin{bmatrix} E_{wheel_i} - (E_{ftg} - t_{base} - h_{key}) - \dfrac{L_\beta}{\cos(\alpha_i)} \\ 0 \cdot ft \end{bmatrix}\right]$ $h_{satl} = \begin{pmatrix} 32.0 \\ 26.5 \\ 21.0 \\ 15.5 \\ 10.0 \end{pmatrix} ft$

$L_{sat_i} := \min\left[\begin{bmatrix} L_\beta \\ \dfrac{h_{satr_i}}{\tan\left[(-\alpha)_i\right]} \end{bmatrix}\right]$ $L_{sat} = \begin{pmatrix} 0.0 \\ 0.0 \\ 0.0 \\ 0.0 \\ 0.0 \end{pmatrix} ft$

$h_{left_i} := h_{1a_i}$ $h_{left} = \begin{pmatrix} 32.0 \\ 32.0 \\ 32.0 \\ 32.0 \\ 32.0 \end{pmatrix} ft$

$h_{right} := h_{1b}$ $h_{right} = 32.0\,ft$

$W_i := \gamma_{fill} \cdot \left(L_h \cdot \dfrac{h_{left_i} + h_{right}}{2}\right) + (\gamma_{sat} - \gamma_{fill}) \cdot L_{sat_i} \cdot \left(\dfrac{h_{satr_i} + h_{satl_i}}{2}\right)$

$W_i =$

0.0
0.0
0.0
0.0
0.0

klf

$V := 0 \cdot klf$

$H_L := 0 \cdot klf$

$H_R := 0 \cdot klf$

$U_i := \gamma_w \cdot \left(\dfrac{h_{satr_i} + h_{satl_i}}{2}\right) \cdot \sqrt{\left(h_{satr_i} - h_{satl_i}\right)^2 + (L_h)^2}$

$$\Delta P_{1b_i} := \frac{\left[(W_i + V) \cdot \left(\tan(\phi_{d_i}) \cdot \cos(\alpha_i) + \sin(\alpha_i)\right) - U_i \cdot \tan(\phi_{d_i}) + (H_L - H_R) \cdot \left(\tan(\phi_{d_i}) \cdot \sin(\alpha_i) - \cos(\alpha_i)\right) + \dfrac{c}{FS_{2_i}} \cdot L_i\right]}{\left(\cos(\alpha_i) - \tan(\phi_{d_i}) \cdot \sin(\alpha_i)\right)}$$

Structure Wedge (#2)

$U_i =$

0.0
0.0
0.0
0.0
0.0

klf

$\beta_w := 0 \cdot deg$

$\phi := \phi_{fill}$ $\phi = 32.0\,deg$

$c := 0 \cdot ksf$

$\phi_{d_i} := atan\left(\frac{tan(\phi)}{FS_{2_i}}\right)$ $\phi_{d_i} = \begin{pmatrix} 24.4 \\ 23.0 \\ 21.7 \\ 20.4 \\ 19.0 \end{pmatrix} deg$

$\alpha := 0 \cdot deg$ $\alpha = 0.0\,deg$

$L := \frac{L_{ftg}}{cos(\alpha)}$ $L = 32.0\,ft$

$h_{S1} := h_{key}$ $h_{S1} = 0.0\,ft$

$L_{S1} := x_{key} - \frac{L_{key}}{2}$ $L_{S1} = 9.3\,ft$

$x_{S1} := \frac{1}{2} \cdot L_{S1}$ $x_{S1} = 4.6\,ft$

$S1 := \gamma_{sat} \cdot h_{S1} \cdot L_{S1}$ $S1 = 0.0\,klf$

$h_{S2} := h_{key}$ $h_{S2} = 0.0\,ft$

$L_{S2} := L_{ftg} - x_{key} - \frac{L_{key}}{2}$ $L_{S2} = 18.8\,ft$

$x_{S2} := L_{ftg} - \frac{L_{S2}}{2}$ $x_{S2} = 22.6\,ft$

$S2 := \gamma_{sat} \cdot h_{S2} \cdot L_{S2}$ $S2 = 0.0\,klf$

$$W_i := \sum_{i=1}^{4} W_{C_i} + W_{W1_i} + W_{WS1_i} + W_{WS2_i} + W_{WS3_i} + W_{WS4_i} + W_{WS5} + W_{WS6} + S1 + S2 + S_{\beta_i}$$

Uplift below structural wedge:

$u_{toe_i} := \gamma_w \cdot \left\lfloor E_{wtoe_i} - \left(E_{bftg} - h_{key}\right)\right\rfloor$

$u_{heel_i} := \gamma_w \cdot \left\lfloor E_{wheel_i} - \left(E_{bftg} - h_{key}\right)\right\rfloor$

$\delta_{u_i} := \frac{\gamma_w \cdot \left(E_{wheel_i} - E_{wtoe_i}\right)}{L_{ftg} - L_{t2_i}}$

$u1_i := u_{toe_i} \cdot \left(L_{ftg} - L_{t2_i}\right)$

$x_{u1_i} := \dfrac{L_{ftg} - L_{t2_i}}{2}$ $\qquad x_{u1} = \begin{pmatrix} 15.8 \\ 16.0 \\ 16.0 \\ 16.0 \\ 16.0 \end{pmatrix} ft$

$u2_i := \left(u_{heel_i} - u_{toe_i}\right) \cdot \dfrac{\left(L_{ftg} - L_{t2_i}\right)}{2}$

$x_{u2_i} := \dfrac{2}{3} \cdot \left(L_{ftg} - L_{t2_i}\right)$ $\qquad x_{u2} = \begin{pmatrix} 21.0 \\ 21.3 \\ 21.3 \\ 21.3 \\ 21.3 \end{pmatrix} ft$

$u3_i := u_{heel_i} \cdot \left(L_{t2_i}\right)$

$x_{u3_i} := L_{ftg} - \dfrac{L_{t2_i}}{2}$

$U_i := u1_i + u2_i + u3_i$

$x_{U_i} := \dfrac{u1_i \cdot x_{u1_i} + u2_i \cdot x_{u2_i} + u3_i \cdot x_{u3_i}}{U_i}$ $\qquad x_U = \begin{pmatrix} 17.0 \\ 17.2 \\ 17.7 \\ 18.5 \\ 17.8 \end{pmatrix} ft$

$$\Sigma M_{grav_i} := \left(\sum_{i=1}^{4} W_{C_i} \cdot x_{C_i} + W_{W1_i} \cdot x_{W1} + W_{WS1_i} \cdot x_{WS1} + W_{WS2_i} \cdot x_{WS2_i} + W_{WS3_i} \cdot x_{WS3_i}\right) \ldots$$
$$+ W_{WS4_i} \cdot x_{WS4_i} + W_{WS5} \cdot x_{WS5} + W_{WS6} \cdot x_{WS6} + S1 \cdot x_{S1} + S2 \cdot x_{S2} + S_{\beta_i} \cdot x_{S\beta} - \left(U_i \cdot x_{U_i}\right)$$

$h_{H1_i} := E_{wtoe_i} - \left(E_{bftg} - h_{key}\right)$

$y_{H1_i} := \dfrac{h_{H1_i}}{3} - h_{key}$

$H1_i := \gamma_w \cdot \dfrac{\left(h_{H1_i}\right)^2}{2}$

h_{H1_i} = (ft)	y_{H1_i} = (ft)	$H1_i$ = (klf)
22.00	7.33	15.1
16.50	5.50	8.5
11.00	3.67	3.8
5.50	1.83	0.9
5.00	1.67	0.8

$K1_i := 0 \cdot klf$

$K2_i := 0 \cdot klf$

$$\Sigma M_{lat_i} := -H1_i \cdot \left(y_{H1_i}\right) - K1_i \cdot \left(y_{K1}\right) - K2_i \cdot \left(y_{K2}\right) + H2_i \cdot \left(y_{H2_i}\right) + H3_i \cdot \left(y_{H3}\right) \ldots$$
$$+ A1_i \cdot \left(y_{A1_i}\right) + A2_i \cdot \left(y_{A2_i}\right) + A3_i \cdot \left(y_{A3_i}\right) - R_{key_i} \cdot \left(y_{Rkey}\right)$$

$$x_{R_i} := \frac{\Sigma M_{grav_i} - \Sigma M_{lat_i}}{W_i - U_i} \qquad L_{brg_i} := \min\left(3 \cdot x_{R_i}, L_{ftg}\right)$$

$ok_{u_i} :=$ if$\left[\left|L_{brg_i} - \left(L_{ftg} - L_{t2_i}\right)\right| > 0.001 \cdot ft\right.$, "Uplift assumptions wrong in sliding analysis.", "Matched."$\left.\right]$

$W_i =$ (klf)	$u_{toe_i} =$ (ksf)	$u_{heel_i} =$ (ksf)	$\delta_{u_i} =$ (psf/ft)	$u1_i =$ (klf)	$u2_i =$ (klf)	$u3_i =$ (klf)
118.0	1.375	2.000	19.8	43.370	9.857	0.916
115.6	1.031	1.656	19.5	33.000	10.000	0.000
113.1	0.688	1.313	19.5	22.000	10.000	0.000
110.7	0.344	0.969	19.5	11.000	10.000	0.000
110.7	0.313	0.625	9.8	10.000	5.000	0.000

$x_{u3_i} =$ (ft)	$h_{H2_i} =$ (ft)	$y_{H2_i} =$ (ft)	$H2_i =$ (klf)
31.8	32.0	10.7	32.0
32.0	26.5	8.8	21.9
32.0	21.0	7.0	13.8
32.0	15.5	5.2	7.5
32.0	10.0	3.3	3.1

$U_i =$ (klf)	$x_{U_i} =$ (ft)	$\Sigma M_{grav_i} =$ (kip)	$\Sigma M_{lat_i} =$ (kip)	$x_{R_i} =$ (ft)	$L_{brg_i} =$ (ft)
54.1	17.0	1178	506	10.5	31.5
43.0	17.2	1353	542	11.2	32.0
32.0	17.7	1524	557	11.9	32.0
21.0	18.5	1695	558	12.7	32.0
15.0	17.8	1823	553	13.3	32.0

$H_{L_i} := 0 \cdot klf$

$$H_{R_i} := \gamma_w \cdot \frac{\left(E_{wtoe_i} - E_{ftg}\right)^2}{2}$$

$$\Delta P_{2_i} := \frac{\left[\left(W_i + V\right) \cdot \left(\tan\left(\phi_{d_i}\right) \cdot \cos(\alpha) + \sin(\alpha)\right) - U_i \cdot \tan\left(\phi_{d_i}\right) + \left(H_{L_i} - H_{R_i}\right) \cdot \left(\tan\left(\phi_{d_i}\right) \cdot \sin(\alpha) - \cos(\alpha)\right) + \frac{c}{FS_{2_i}} \; L\right]}{\left(\cos(\alpha) - \tan\left(\phi_{d_i}\right) \cdot \sin(\alpha)\right)}$$

H_{L_i} =		H_{R_i} =	
0.0	klf	9.0	klf
0.0		4.1	
0.0		1.1	
0.0		$7.8 \cdot 10^{-3}$	
0.0		0.0	

ok_{u_i} = ("Matched." "Matched." "Matched." "Matched." "Matched.")

$L_{ftg} - L_{brg_i}$ =

0.458	ft
0.000	
0.000	
0.000	
0.000	

$$L_{t2} \equiv \begin{pmatrix} 0.458 \\ 0 \\ 0 \\ 0 \\ 0 \end{pmatrix} \cdot ft$$

$ok := if\left[\max\left(\left|L_{brg} - \left(L_{ftg} - L_{t2}\right)\right|\right) < 0.001 \; ft, ok, \text{"Uplift area does not match."}\right]$

$ok := if\left(\min\left(L_{brg}\right) < x_{key} + \frac{L_{key}}{2}, \text{"Uplift assumptions incorrect."}, ok\right)$ $\quad ok = \text{"Ok"}$

Resisting Wedge (#3)

$\beta_w := 0 \cdot deg$

$\phi := \phi_{fill}$ $\phi = 32.0\,deg$

$c := 0 \cdot ksf$

$\phi_{d_i} := atan\left(\frac{\tan(\phi)}{FS_{2_i}}\right)$

$\alpha_i := 45 \cdot deg - \frac{\phi_{d_i}}{2}$

$L_i := \frac{t_{base} + h_{key}}{\sin(\alpha_i)}$

$\phi_{d_i} = \begin{pmatrix} 24.4 \\ 23.0 \\ 21.7 \\ 20.4 \\ 19.0 \end{pmatrix} deg$ $\alpha_i = \begin{pmatrix} 32.8 \\ 33.5 \\ 34.1 \\ 34.8 \\ 35.5 \end{pmatrix} deg$ $L = \begin{pmatrix} 9.225 \\ 9.063 \\ 8.907 \\ 8.761 \\ 8.615 \end{pmatrix} ft$

$W_i := \gamma_{sat} \cdot \frac{L_i \cdot \cos(\alpha_i) \cdot (t_{base} + h_{key})}{2} + \gamma_w \cdot (E_{wtoe_i} - E_{ftg}) \cdot L_i \cdot \cos(\alpha_i)$

$U_i := \gamma_w \cdot \left(E_{wtoe_i} - E_{ftg} + \frac{t_{base} + h_{key}}{2}\right) \cdot L_i$

$H_L := 0 \cdot klf$

$H_R := 0 \cdot klf$

$V := 0 \cdot klf$

$$\Delta P_{3_i} := \frac{\left[(W_i + V)\cdot(\tan(\phi_{d_i})\cdot\cos(\alpha_i) + \sin(\alpha_i)) - U_i \cdot \tan(\phi_{d_i}) + (H_L - H_R)\cdot(\tan(\phi_{d_i})\cdot\sin(\alpha_i) - \cos(\alpha_i)) + \frac{c}{FS_{2_i}} \cdot L_i\right]}{(\cos(\alpha_i) - \tan(\phi_{d_i}) \cdot \sin(\alpha_i))}$$

$\Sigma P_i := \Delta P_{1a_i} + \Delta P_{1b_i} + \Delta P_{2_i} + \Delta P_{3_i}$

$W_i =$ (klf)	$U_i =$ (klf)	$\Delta P_{1a_i} =$ (klf)	$\Delta P_{1b_i} =$ (klf)	$\Delta P_{2_i} =$ (klf)	$\Delta P_{3_i} =$ (klf)	$\Sigma P_i =$ (klf)
10.7	11.2	-45.8	0.0	38.0	8.0	0.2
7.8	7.9	-41.1	0.0	35.0	6.2	0.1
5.1	4.7	-37.8	0.0	33.4	4.4	0.0
2.5	1.6	-35.9	0.0	33.4	2.6	0.1
2.2	1.3	-35.3	0.0	33.0	2.4	0.1

$FS_2 \equiv \begin{pmatrix} 1.38 \\ 1.47 \\ 1.57 \\ 1.68 \\ 1.81 \end{pmatrix}$

$L_{heel} \equiv 24 \cdot ft$

$h_{key} \equiv 0 \cdot ft$

$L_{ftg} = 32.0\,ft$

$L_{toe} \equiv 8 \cdot ft$

$L_{ftg} - x_{key} - \frac{L_{key}}{2} = 18.8\,ft$

ok := if$(FS_{2_1} \geq 1.33$, ok, "Sliding instability: LC#1")

ok := if$(FS_{2_n} \geq 1.50$, ok, "Sliding instability: LC#n")

ok = "Ok"

Section 4
Headwall

Headwall at Ramp Level (right side):

Reference:T:\ST\CALCS\Common geometry.mcd(R)

Geometry:

$\Delta_w := 10 \cdot ft$ (maximum height of retained water above water in basin)

$E_{wall} := 530 \ ft$

$E_{grade} := 527 \cdot ft$

$E_{ftg} := E_{ramp}$ $E_{ftg} = 503.5\,ft$

$t_{w\_top} := 18 \cdot in$

$t_{w\_bot} := \dfrac{(E_{wall} - E_{ftg})}{8} + t_{w\_top}$ $t_{w\_bot} = 4.8125\,ft$

$E_{rot} := E_{ftg} - 3 \cdot ft$

$n := floor\left(\dfrac{E_{grade} - E_{ftg}}{2ft}\right) + 1$ $n = 12.0$

$i := 1..n$

$E_{wheel_i} := E_{ftg} + (n - i) \cdot \dfrac{(E_{grade} - E_{ftg})}{n - 1}$

$E_{wtoe_i} := max\left(\begin{pmatrix} E_{wheel_i} - \Delta_w \\ E_{ftg} \end{pmatrix}\right)$

$t_{ftg} := 6 \cdot ft$

$L_{heel} := ceil\left(\dfrac{t_{w\_bot}}{ft}\right) \cdot ft + 14 \cdot ft$ $L_{heel} = 19.0\,ft$

$L_{toe} := 15 \cdot ft$

$L_{ftg} := L_{toe} + L_{heel}$ $L_{ftg} = 34.0\,ft$

Material:

$\gamma_{fill\_eff} := 65 \cdot pcf$

$\gamma_{fill} := 130 \cdot pcf$

$k_{0\_fill} := 0.5$

$\phi_{fill} := 28 \cdot deg$

Constants:

$\gamma_w = 62.5\,pcf$

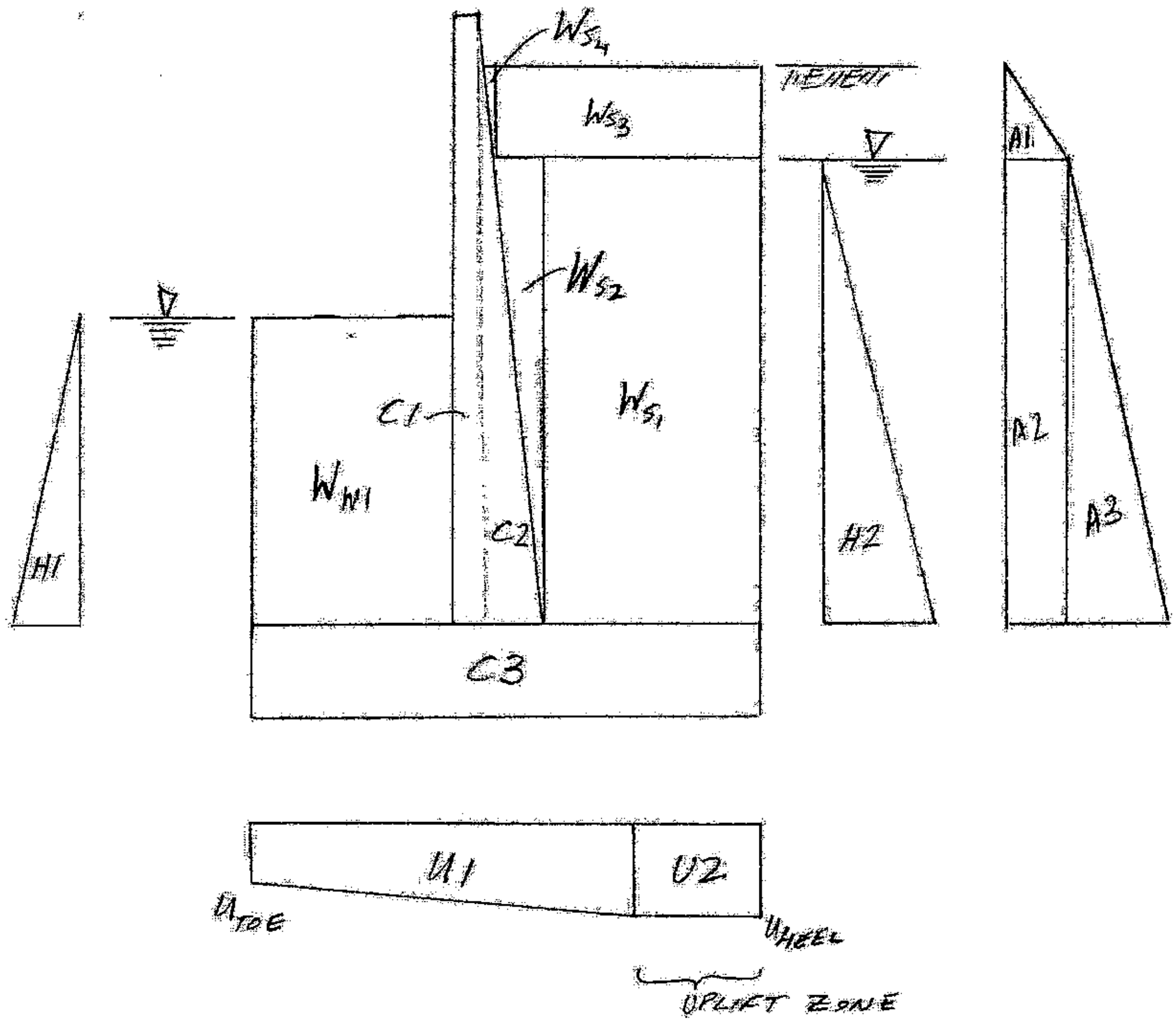
$\gamma_c = 150.0\,pcf$

Pre-Definitions:

$kip \equiv 1000 \cdot lbf$ $\quad ksi \equiv 1000 \cdot psi$ $\quad ok \equiv "Ok"$

$psf \equiv \dfrac{lbf}{ft^2}$ $\quad plf \equiv \dfrac{lbf}{ft}$ $\quad ORIGIN = 1.0$

$pcf \equiv \dfrac{lbf}{ft^3}$ $\quad klf \equiv 1000 \cdot plf$ $\quad ksf := \dfrac{1000 \cdot lbf}{ft^2}$


Ws4
Ws3
Ws2
Ws1
C1
C2
C3
Ww1
H1
H2
A1
A2
A3
U1
U2
Utoe
Uheel
UPLIFT ZONE

Analysis:

Gravity Loads:

$h_{C_1} := E_{wall} - E_{ftg}$ $\quad h_{C_1} = 26.5\,ft$

$L_{C_1} := t_{w\_top}$ $\quad L_{C_1} = 1.5\,ft$

$x_{C_1} := L_{toe} + \frac{L_{C_1}}{2}$ $\quad x_{C_1} = 15.8\,ft$

$W_{C_1} := \gamma_c \cdot h_{C_1} \cdot L_{C_1}$ $\quad W_{C_1} = 6.0\,klf$

$h_{C_2} := h_{C_1}$ $\quad h_{C_2} = 26.5\,ft$

$L_{C_2} := t_{w\_bot} - t_{w\_top}$ $\quad L_{C_2} = 3.3\,ft$

$x_{C_2} := L_{toe} + L_{C_1} + \frac{L_{C_2}}{3}$ $\quad x_{C_2} = 17.6\,ft$

$W_{C_2} := \gamma_c \cdot \frac{h_{C_2} \cdot L_{C_2}}{2}$ $\quad W_{C_2} = 6.6\,klf$

$h_{C_3} := t_{ftg}$ $\quad h_{C_3} = 6.0\,ft$

$L_{C_3} := L_{ftg}$ $\quad L_{C_3} = 34.0\,ft$

$x_{C_3} := \frac{L_{C_3}}{2}$ $\quad x_{C_3} = 17.0\,ft$

$W_{C_3} := \gamma_c \cdot h_{C_3} \cdot L_{C_3}$ $\quad W_{C_3} = 30.6\,klf$

$h_{W1_i} := E_{wheel_i} - E_{ftg}$

$L_{W1} := L_{toe}$ $\quad L_{W1} = 15.0\,ft$

$x_{W1} := \frac{L_{W1}}{2}$ $\quad x_{W1} = 7.5\,ft$

$W_{W1_i} := \gamma_w \cdot h_{W1_i} \cdot L_{W1}$

$h_{WS1_i} := E_{wtoe_i} - E_{ftg}$

$L_{WS1} := L_{heel} - t_{w\_bot}$ $\qquad L_{WS1} = 14.2\,ft$

$x_{WS1} := L_{ftg} - \frac{L_{WS1}}{2}$ $\qquad x_{WS1} = 26.9\,ft$

$W_{S1_i} := (\gamma_{fill\_eff} + \gamma_w) \cdot h_{WS1_i} \cdot L_{WS1}$

$h_{WS2_i} := h_{WS1_i}$

$L_{WS2_i} := (t_{w\_bot} - t_{w\_top}) \cdot \frac{h_{WS2_i}}{E_{wall} - E_{ftg}}$

$x_{WS2_i} := L_{ftg} - L_{heel} + t_{w\_bot} - \frac{L_{WS2_i}}{3}$

$W_{S2_i} := (\gamma_{fill\_eff} + \gamma_w) \cdot \frac{h_{WS2_i} \cdot L_{WS2_i}}{2}$

$h_{WS3_i} := \max(E_{grade} - E_{wheel_i}, 0\ ft)$

$L_{WS3_i} := L_{WS1} + L_{WS2_i}$

$x_{WS3_i} := L_{ftg} - \frac{L_{WS3_i}}{2}$

$W_{S3_i} := \gamma_{fill} \cdot h_{WS3_i} \cdot L_{WS3_i}$

$h_{WS4_i} := h_{WS3_i}$

$L_{WS4_i} := (t_{w\_bot} - t_{w\_top}) \cdot \frac{h_{WS4_i}}{E_{wall} - E_{ftg}}$

$x_{WS4_i} := L_{ftg} - L_{WS3_i} - \frac{L_{WS4_i}}{3}$

$W_{S4_i} := \gamma_{fill} \cdot \frac{h_{WS4_i} \cdot L_{WS4_i}}{2}$

E_{wtoe_i} = (ft)	E_{wheel_i} = (ft)	h_{WS1_i} = (ft)	h_{WS2_i} = (ft)	h_{WS3_i} = (ft)	h_{WS4_i} = (ft)	L_{WS2_i} = (ft)	L_{WS3_i} = (ft)	L_{WS4_i} = (ft)
517.0	527.0	13.5	13.5	0.0	0.0	1.7	15.9	0.0
514.9	524.9	11.4	11.4	2.1	2.1	1.4	15.6	0.3
512.7	522.7	9.2	9.2	4.3	4.3	1.2	15.3	0.5
510.6	520.6	7.1	7.1	6.4	6.4	0.9	15.1	0.8
508.5	518.5	5.0	5.0	8.5	8.5	0.6	14.8	1.1
506.3	516.3	2.8	2.8	10.7	10.7	0.4	14.5	1.3
504.2	514.2	0.7	0.7	12.8	12.8	0.1	14.3	1.6
503.5	512.0	0.0	0.0	15.0	15.0	0.0	14.2	1.9
503.5	509.9	0.0	0.0	17.1	17.1	0.0	14.2	2.1
503.5	507.8	0.0	0.0	19.2	19.2	0.0	14.2	2.4
503.5	505.6	0.0	0.0	21.4	21.4	0.0	14.2	2.7
503.5	503.5	0.0	0.0	23.5	23.5	0.0	14.2	2.9

x_{WS2_i} = (ft)	x_{WS3_i} = (ft)	x_{WS4_i} = (ft)	W_{W1_i} = (klf)	W_{S1_i} = (klf)	W_{S2_i} = (klf)	W_{S3_i} = (klf)	W_{S4_i} = (klf)
19.3	26.1	18.1	22.0	24.4	1.5	0.0	0.0
19.3	26.2	18.3	20.0	20.6	1.0	4.3	0.0
19.4	26.3	18.5	18.0	16.7	0.7	8.5	0.1
19.5	26.5	18.7	16.0	12.8	0.4	12.6	0.3
19.6	26.6	18.8	14.0	9.0	0.2	16.4	0.6
19.7	26.7	19.0	12.0	5.1	0.1	20.2	0.9
19.8	26.9	19.2	10.0	1.2	0.0	23.8	1.3
19.8	26.9	19.2	8.0	0.0	0.0	27.6	1.8
19.8	26.9	19.1	6.0	0.0	0.0	31.5	2.4
19.8	26.9	19.0	4.0	0.0	0.0	35.5	3.0
19.8	26.9	18.9	2.0	0.0	0.0	39.4	3.7
19.8	26.9	18.8	0.0	0.0	0.0	43.3	4.5

Lateral loads:

$$h_{H1_i} := E_{wtoe_i} - E_{ftg}$$

$$y_{H1_i} := \frac{h_{H1_i}}{3} + \left(E_{ftg} - E_{rot}\right)$$

$$H1_i := \gamma_w \cdot \frac{\left(h_{H1_i}\right)^2}{2}$$

$$h_{H2_i} := E_{wheel_i} - E_{ftg}$$

$$y_{H2_i} := \frac{h_{H2_i}}{3} + \left(E_{ftg} - E_{rot}\right)$$

$$H2_i := \gamma_w \cdot \frac{\left(h_{H2_i}\right)^2}{2}$$

$$h_{A1_i} := h_{WS4_i}$$

$$y_{A1_i} := E_{grade} - E_{rot} - \frac{2}{3} h_{A1_i}$$

$$H_{A1_i} := k_{0\_fill} \ \gamma_{fill} \ \frac{\left(h_{A1_i}\right)^2}{2}$$

$$h_{A2_i} := h_{H2_i}$$

$$y_{A2_i} := \frac{h_{H2_i}}{2} + E_{ftg} - E_{rot}$$

$$H_{A2_i} := k_{0\_fill} \ \gamma_{fill} \ h_{A1_i} \cdot h_{A2_i}$$

$$h_{A3_i} := h_{A2_i}$$

$$y_{A3_i} := \frac{h_{A3_i}}{3} + E_{ftg} - E_{rot}$$

$$H_{A3_i} := k_{0\_fill} \cdot \gamma_{fill\_eff} \cdot \frac{\left(h_{A3_i}\right)^2}{2}$$

$hH1_i$ = (ft)	$yH1_i$ = (ft)	$H1_i$ = (klf)	$hH2_i$ = (ft)	$yH2_i$ = (ft)	$H2_i$ = (klf)
13.5	7.5	5.7	23.5	10.8	17.3
11.4	6.8	4.0	21.4	10.1	14.3
9.2	6.1	2.7	19.2	9.4	11.6
7.1	5.4	1.6	17.1	8.7	9.1
5.0	4.7	0.8	15.0	8.0	7.0
2.8	3.9	0.2	12.8	7.3	5.1
0.7	3.2	0.0	10.7	6.6	3.6
0.0	3.0	0.0	8.5	5.8	2.3
0.0	3.0	0.0	6.4	5.1	1.3
0.0	3.0	0.0	4.3	4.4	0.6
0.0	3.0	0.0	2.1	3.7	0.1
0.0	3.0	0.0	0.0	3.0	0.0

$hA1_i$ = (ft)	$yA1_i$ = (ft)	$HA1_i$ = (klf)	$hA2_i$ = (ft)	$yA2_i$ = (ft)	$HA2_i$ = (klf)	$hA3_i$ = (ft)	$yA3_i$ = (ft)	$HA3_i$ = (klf)
0.0	26.5	0.0	23.5	14.8	0.0	23.5	10.8	9.0
2.1	25.1	0.1	21.4	13.7	3.0	21.4	10.1	7.4
4.3	23.7	0.6	19.2	12.6	5.3	19.2	9.4	6.0
6.4	22.2	1.3	17.1	11.5	7.1	17.1	8.7	4.7
8.5	20.8	2.4	15.0	10.5	8.3	15.0	8.0	3.6
10.7	19.4	3.7	12.8	9.4	8.9	12.8	7.3	2.7
12.8	18.0	5.3	10.7	8.3	8.9	10.7	6.6	1.9
15.0	16.5	7.3	8.5	7.3	8.3	8.5	5.8	1.2
17.1	15.1	9.5	6.4	6.2	7.1	6.4	5.1	0.7
19.2	13.7	12.0	4.3	5.1	5.3	4.3	4.4	0.3
21.4	12.3	14.8	2.1	4.1	3.0	2.1	3.7	0.1
23.5	10.8	17.9	0.0	3.0	0.0	0.0	3.0	0.0

Uplift:

$$u_{heel_i} := \gamma_w \cdot \left\lfloor E_{wheel_i} - \left(E_{ftg} - t_{ftg}\right)\right\rfloor$$

$$u_{toe_i} := \gamma_w \cdot \left\lfloor \left(E_{gate} + 2\ ft\right) - \left(E_{ftg} - t_{ftg}\right)\right\rfloor$$

(Base uplift pressure at toe on gates closed with two feet of flow over the top.)

$$u_{rect_i} := \min\left(u_{heel_i}, u_{toe_i}\right)$$

$$u_{tri_i} := \left|u_{heel_i} - u_{toe_i}\right|$$

$$L_{U1_i} := \text{if}\left[u_{toe_i} < u_{heel_i}, \min\left(\begin{pmatrix} 3 \cdot frac_{u_i} \cdot L_{ftg} \\ L_{ftg} \end{pmatrix}\right), L_{ftg}\right]$$

$$U_{rect_i} := u_{rect_i} \cdot L_{U1_i}$$

$$U_{tri_i} := \frac{u_{tri_i} \cdot L_{U1_i}}{2}$$

$$x_{rect_i} := \frac{L_{U1_i}}{2}$$

$$x_{tri_i} := \frac{L_{U1_i}}{2} + \frac{L_{U1_i}}{6} \cdot \text{if}\left(u_{heel_i} > u_{toe_i}, 1, -1\right)$$

$$U1_i := U_{rect_i} + U_{tri_i}$$

$$x_{U1_i} := \frac{U_{rect_i} \cdot x_{rect_i} + U_{tri_i} \cdot x_{tri_i}}{U1_i}$$

$$L_{U2_i} := L_{ftg} - L_{U1_i}$$

$$U2_i := u_{heel_i} \cdot L_{U2_i}$$

$$x_{U2_i} := L_{U1_i} + \frac{L_{U2_i}}{2}$$

u_{heel_i} = (ksf)	u_{toe_i} = (ksf)	u_{rect_i} = (ksf)	u_{tri_i} = (ksf)	L_{U1_i} = (ft)	L_{U2_i} = (ft)	$U1_i$ = (klf)	$U2_i$ = (klf)
1.844	1.906	1.844	0.063	34.00	0.00	63.8	0.0
1.710	1.906	1.710	0.196	34.00	0.00	61.5	0.0
1.577	1.906	1.577	0.330	34.00	0.00	59.2	0.0
1.443	1.906	1.443	0.463	34.00	0.00	56.9	0.0
1.310	1.906	1.310	0.597	34.00	0.00	54.7	0.0
1.176	1.906	1.176	0.730	34.00	0.00	52.4	0.0
1.043	1.906	1.043	0.864	34.00	0.00	50.1	0.0
0.909	1.906	0.909	0.997	34.00	0.00	47.9	0.0
0.776	1.906	0.776	1.131	34.00	0.00	45.6	0.0
0.642	1.906	0.642	1.264	34.00	0.00	43.3	0.0
0.509	1.906	0.509	1.398	34.00	0.00	41.1	0.0
0.375	1.906	0.375	1.531	34.00	0.00	38.8	0.0

U_{rect_i} = (klf)	U_{tri_i} = (klf)	x_{rect_i} = (ft)	x_{tri_i} = (ft)	x_{U1_i} = (ft)	x_{U2_i} = (ft)	$U2_i$ = (klf)
62.7	1.1	17.0	11.3	16.9	34.0	0.0
58.1	3.3	17.0	11.3	16.7	34.0	0.0
53.6	5.6	17.0	11.3	16.5	34.0	0.0
49.1	7.9	17.0	11.3	16.2	34.0	0.0
44.5	10.1	17.0	11.3	15.9	34.0	0.0
40.0	12.4	17.0	11.3	15.7	34.0	0.0
35.4	14.7	17.0	11.3	15.3	34.0	0.0
30.9	17.0	17.0	11.3	15.0	34.0	0.0
26.4	19.2	17.0	11.3	14.6	34.0	0.0
21.8	21.5	17.0	11.3	14.2	34.0	0.0
17.3	23.8	17.0	11.3	13.7	34.0	0.0
12.7	26.0	17.0	11.3	13.2	34.0	0.0

$$\Sigma V_i := \sum_{i=1}^{3} W_{C_i} + W_{W1_i} + W_{S1_i} + W_{S2_i} + W_{S3_i} + W_{S4_i} - U1_i - U2_i$$

$$\Sigma M_{grav_i} := \sum_{i=1}^{3} W_{C_i} \cdot x_{C_i} + W_{W1_i} \cdot x_{W1} + W_{S1_i} \cdot x_{WS1} + W_{S2_i} \cdot x_{WS2_i} + W_{S3_i} \cdot x_{WS3_i} \cdots + W_{S4_i} \cdot x_{WS4_i} - U1_i \cdot x_{U1_i} - U2_i \cdot x_{U2_i}$$

$$\Sigma H_i := -H1_i + H2_i + H_{A1_i} + H_{A2_i} + H_{A3_i}$$

$$\Sigma M_{lat_i} := -H1_i \cdot y_{H1_i} + H2_i \cdot y_{H2_i} + H_{A1_i} \cdot y_{A1_i} + H_{A2_i} \cdot y_{A2_i} + H_{A3_i} \cdot y_{A3_i}$$

$$\Sigma M_i := \Sigma M_{grav_i} - \Sigma M_{lat_i}$$

$$x_{res_i} := \frac{\Sigma M_i}{\Sigma V_i} \qquad frac_i := \frac{x_{res_i}}{L_{ftg}}$$

$frac\_text_i := if\left(frac_i > \frac{2}{3}, \text{"Over stable"}, \text{""}\right)$

$frac\_text_i := if\left(frac_i < \frac{2}{3} \wedge frac_i \geq \frac{1}{3}, \text{"Resultant in middle third. Okay normal case."}, frac\_text_i\right)$

$frac\_text_i := if\left(frac_i < \frac{1}{3} \wedge frac_i \geq \frac{1}{4}, \text{"Resultant in middle half. Unusual case only."}, frac\_text_i\right)$

$frac\_text_i := if\left(frac_i < \frac{1}{4} \wedge frac_i \geq 0, \text{"Resultant within base. Extreme case only."}, frac\_text_i\right)$

$frac\_text_i := if\left(frac_i < 0, \text{"Unstable"}, frac\_text_i\right)$

$L_{contact_i} := \min\left(3 \cdot x_{res_i}, L_{ftg}\right)$

ΣV_i = (klf)	ΣM_{grav_i} = (kip)	ΣH_i = (klf)	ΣM_{lat_i} = (kip)	ΣM_i = (kip)	x_{res_i} = (ft)	$L_{contact_i}$ = (ft)
27.3	503	20.5	241.5	261.1	9.6	28.7
27.7	541	20.8	236.3	304.8	11.0	33.1
28.0	580	20.8	230.4	349.3	12.5	34.0
28.3	618	20.8	224.1	394.2	13.9	34.0
28.7	657	20.5	217.7	439.2	15.3	34.0
29.0	695	20.2	211.4	484.0	16.7	34.0
29.4	734	19.6	205.6	528.3	18.0	34.0
32.7	850	19.0	200.8	648.7	19.8	34.0
37.5	1002	18.6	197.6	804.8	21.5	34.0
42.3	1157	18.2	195.6	961.0	22.7	34.0
47.2	1312	18.0	194.7	$1.1 \cdot 10^3$	23.7	34.0
52.2	1469	17.9	194.4	$1.3 \cdot 10^3$	24.4	34.0

$frac_i =$

	1
1	0.281
2	0.324
3	0.367
4	0.409
5	0.450
6	0.490
7	0.529
8	0.584
9	0.632
10	0.668
11	0.696
12	0.718
13	
14	
15	
16	
17	

$frac\_text_i =$

	1
1	"Resultant in middle half. Unusual case only."
2	"Resultant in middle half. Unusual case only."
3	"Resultant in middle third. Okay normal case."
4	"Resultant in middle third. Okay normal case."
5	"Resultant in middle third. Okay normal case."
6	"Resultant in middle third. Okay normal case."
7	"Resultant in middle third. Okay normal case."
8	"Resultant in middle third. Okay normal case."
9	"Resultant in middle third. Okay normal case."
10	"Over stable"
11	"Over stable"
12	"Over stable"
13	
14	
15	
16	
17	

$E_{wheel_i} =$ (ft)

527.0
524.9
522.7
520.6
518.5
516.3
514.2
512.0
509.9
507.8
505.6
503.5

$error_i := \left| frac_i - frac_{u_i} \right|$ $\quad error_{max} := max(error)$ $\quad error_{max} = 0.00004$

$$frac_u \equiv \begin{pmatrix} .2813 \\ .3242 \\ .3669 \\ .4090 \\ .4502 \\ .4902 \\ .5287 \\ .5835 \\ .6319 \\ .6682 \\ .6962 \\ .7182 \\ 1 \\ 1 \\ 1 \\ 1 \\ 1 \end{pmatrix}$$

	$frac_i =$ 1	$frac_{u_i} =$ 1	$error_i =$ 1
1	0.2813	0.2813	0.0000
2	0.3242	0.3242	0.0000
3	0.3669	0.3669	0.0000
4	0.4090	0.4090	0.0000
5	0.4502	0.4502	0.0000
6	0.4902	0.4902	0.0000
7	0.5287	0.5287	0.0000
8	0.5835	0.5835	0.0000
9	0.6319	0.6319	0.0000
10	0.6682	0.6682	0.0000
11	0.6962	0.6962	0.0000
12	0.7182	0.7182	0.0000
13			
14			
15			
16			
17			

$ok := if(error_{max} > 0.00005, \text{"Uplift does not match compression area."}, ok)$ $\quad ok = \text{"Ok"}$

Evaluate Overturning Stability as Retaining Wall:

$$rwfrac_i := \frac{L_{contact_i}}{L_{ftg}}$$

brg := "rock"

$rw\_text_i := if\left[\left(rwfrac_i \geq 1.0\right), \text{"Overstable."}, \text{""}\right]$

$rw\_text_i := if\left(brg = \text{"rock"} \wedge rwfrac_i \geq 0.75, \text{"Okay Usual case."}, rw\_text_i\right)$

$rw\_text_i := if\left[\left(brg = \text{"rock"} \wedge rwfrac_i < 0.75 \wedge rwfrac_i \geq 0.50\right), \text{"Unusual case only."}, rw\_text_i\right]$

$rw\_text_i := if\left[\left(\left(brg = \text{"rock"} \wedge rwfrac_i < 0.50\right)\right), \text{"Unstable."}, rw\_text_i\right]$

$rw\_text_i := if\left(brg = \text{"soil"} \wedge rwfrac_i = 1.0, \text{"Okay Usual case."}, rw\_text_i\right)$

$rw\_text_i := if\left[\left(brg = \text{"soil"} \wedge rwfrac_i < 1.0 \wedge rwfrac_i \geq 0.75\right), \text{"Unusual case only."}, rw\_text_i\right]$

$rw\_text_i := if\left[\left(\left(brg = \text{"soil"} \wedge rwfrac_i < 0.75\right)\right), \text{"Unstable."}, rw\_text_i\right]$

$rwfrac_i =$ (%)

	1
1	84.4
2	97.3
3	100.0
4	100.0
5	100.0
6	100.0
7	100.0
8	100.0
9	100.0
10	100.0
11	100.0
12	100.0
13	
14	
15	
16	
17	

$rw\_text_i =$

	1
1	"Okay Usual case."
2	"Okay Usual case."
3	"Okay Usual case."
4	"Okay Usual case."
5	"Okay Usual case."
6	"Okay Usual case."
7	"Okay Usual case."
8	"Okay Usual case."
9	"Okay Usual case."
10	"Okay Usual case."
11	"Okay Usual case."
12	"Okay Usual case."
13	
14	
15	
16	
17	

Base Pressures:

$$e_{ftg_i} := \frac{L_{ftg}}{2} - x_{res_i}$$ (eccentricity with respect to the footing centroid)

$$e_i := \frac{L_{contact_i}}{2} - x_{res_i}$$ (eccentricity with respect to the compression area)

$$\sigma_{toe_i} := \frac{\Sigma V_i}{L_{contact_i}} + \frac{\Sigma V_i \cdot e_i}{\frac{\left(L_{contact_i}\right)^2}{6}}$$

$$\sigma_{heel_i} := \frac{\Sigma V_i}{L_{contact_i}} - \frac{\Sigma V_i \cdot e_i}{\frac{\left(L_{contact_i}\right)^2}{6}}$$

ΣH_i = (klf)	ΣV_i = (klf)	e_i = (ft)	e_{ftg_i} = (ft)	σ_{heel_i} = (ksf)	σ_{toe_i} = (ksf)
20.5	27.3	4.78	7.44	0.000	1.903
20.8	27.7	5.51	5.98	0.000	1.672
20.8	28.0	4.53	4.53	0.166	1.481
20.8	28.3	3.09	3.09	0.378	1.289
20.5	28.7	1.69	1.69	0.592	1.096
20.2	29.0	0.33	0.33	0.804	0.904
19.6	29.4	-0.98	-0.98	1.013	0.715
19.0	32.7	-2.84	-2.84	1.444	0.480
18.6	37.5	-4.49	-4.49	1.974	0.230
18.2	42.3	-5.72	-5.72	2.500	-0.012
18.0	47.2	-6.67	-6.67	3.023	-0.246
17.9	52.2	-7.42	-7.42	3.545	-0.474

$L_{contact_1} = 28.69\,\text{ft}$ $\quad \Sigma H_1 = 20.5\,\text{klf}$ $\quad \frac{L_{contact_1}}{L_{ftg}} = 84.4\,\%$

$x_{res_1} = 9.56\,\text{ft}$ $\quad \Sigma V_1 = 27.3\,\text{klf}$

$k_{0\_fill} \ \gamma_{fill} = 65\ 0\ pcf$

$k_{0\_fill} \ \gamma_{fill\_eff} = 32.5\ pcf$

Head wall at Basin (right side):

Reference:T:\ST\CALCS\Common geometry.mcd(R)

Geometry:

$\Delta_w := 10 \cdot ft$ (maximum height of retained water above water in basin)

$E_{wall} := 530 \cdot ft$

$E_{grade} := 527 \cdot ft$

$E_{ftg} := E_{basin}$ $E_{ftg} = 491.0\,ft$

$t_{w\_top} := 18 \cdot in$

$t_{w\_bot} := \frac{(E_{wall} - E_{ftg})}{8} + t_{w\_top}$ $t_{w\_bot} = 6.3750\,ft$

$E_{rot} := E_{ftg} - 3 \cdot ft$

$n := floor\left(\frac{E_{grade} - E_{sill}}{2ft}\right) + 1$ $n = 17.0$

$i := 1 .. n$

$E_{wheel_i} := E_{sill} + (n - i) \cdot 2ft$

$E_{wtoe_i} := max\left(\begin{pmatrix} E_{wheel_i} - \Delta_w \\ E_{sill} \end{pmatrix}\right)$

$t_{ftg} := 6 \cdot ft$

$L_{heel} := ceil\left(\frac{t_{w\_bot}}{ft}\right) \cdot ft + 18 \cdot ft$ $L_{heel} = 25.0\,ft$

$L_{toe} := 17 \cdot ft$

$L_{ftg} := L_{toe} + L_{heel}$ $L_{ftg} = 42.0\,ft$

Material:

$\gamma_{fill\_eff} = 65.0\,pcf$

$\gamma_{fill} = 130.0\,pcf$

$k_{0\_fill} = 0\ 5$

$\phi_{fill} = 32.0\,deg$

Constants:

$\gamma_w = 62.5\,pcf$

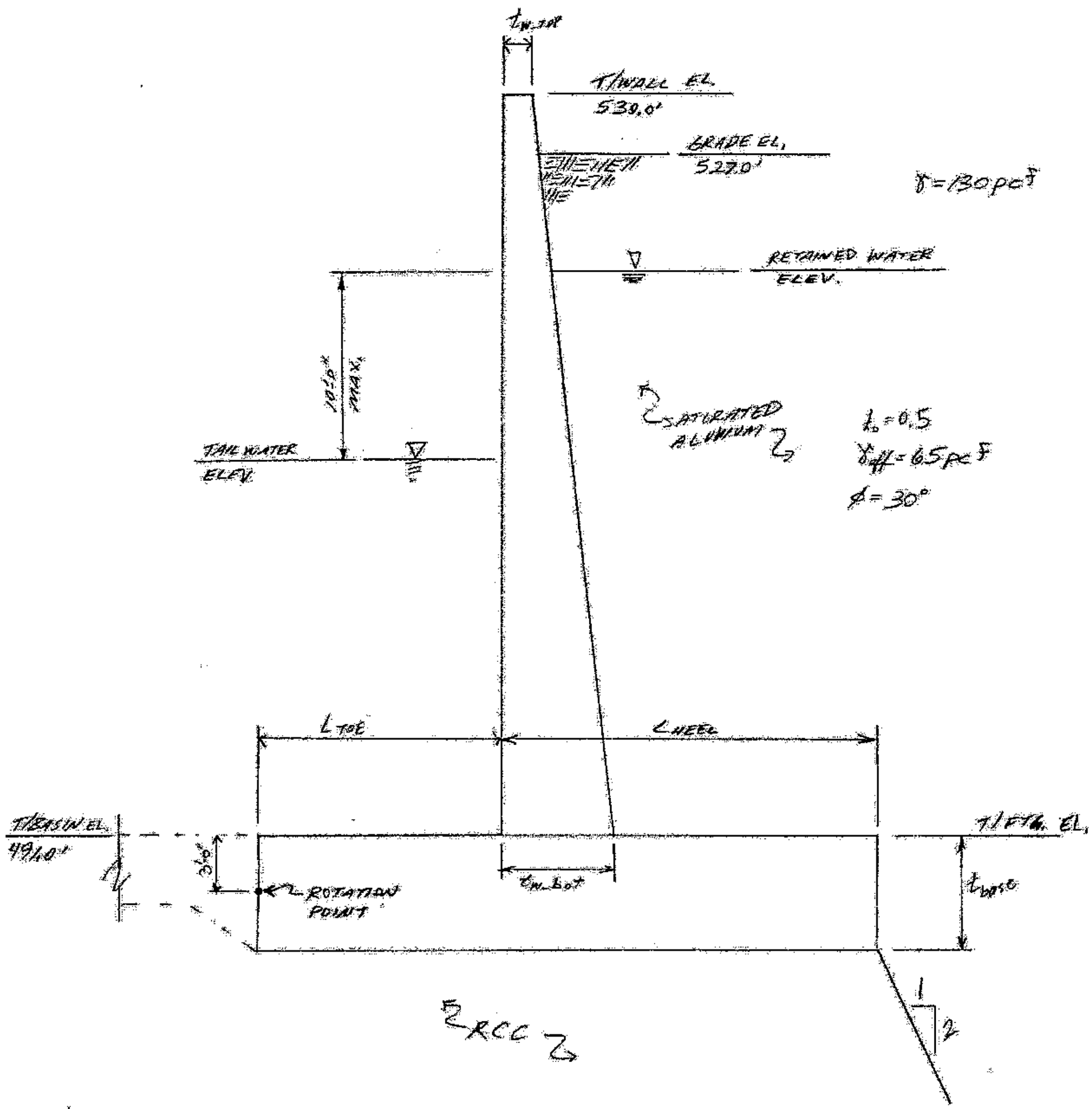
$\gamma_c = 150\ 0\,pcf$

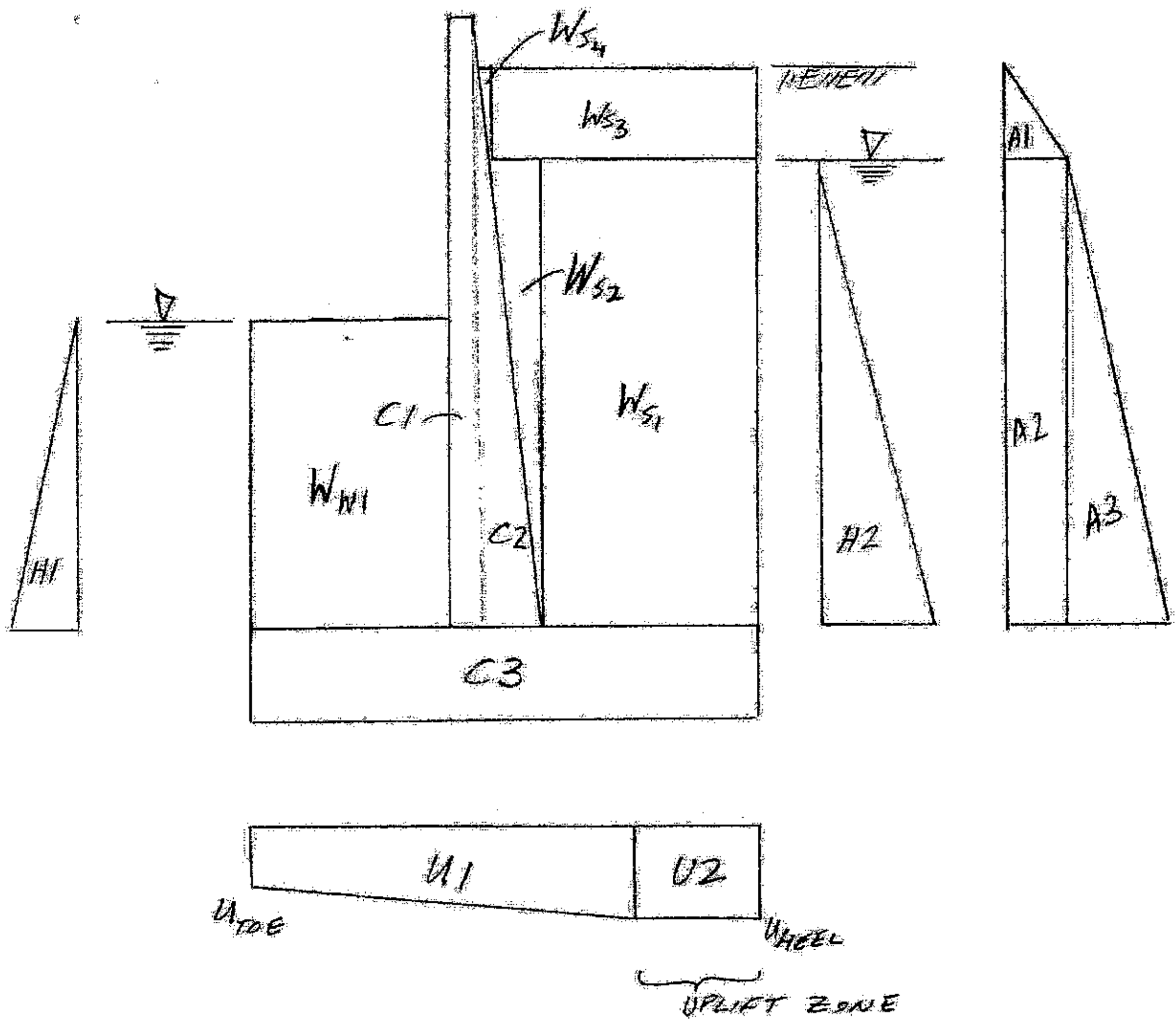
Pre-Definitions:

$kip \equiv 1000 \cdot lbf$ $\quad$ $ksi \equiv 1000 \cdot psi$ $\quad$ $ok \equiv$ "Ok"

$psf \equiv \dfrac{lbf}{ft^2}$ $\quad$ $plf \equiv \dfrac{lbf}{ft}$ $\quad$ $ORIGIN = 1.0$

$pcf \equiv \dfrac{lbf}{ft^3}$ $\quad$ $klf \equiv 1000 \cdot plf$ $\quad$ $ksf := \dfrac{1000 \cdot lbf}{ft^2}$


t_{w_top}
T/WALL EL.
539.0'
GRADE EL.
527.0'
γ=130pcf
RETAINED WATER
ELEV.
10'-0" MAX.
TAIL WATER
ELEV.
SATURATED ALLUVIUM
k_o=0.5
γ_{eff}=65pcf
φ=30°
L_{TOE}
L_{HEEL}
T/BASIN EL.
494.0'
3'-0"
ROTATION POINT
t_{w_bot}
T/FTG. EL.
t_{base}
RCC
1
2


W_{S4}
W_{S3}
W_{S2}
W_{S1}
W_{N1}
C1
C2
C3
H1
H2
A1
A2
A3
U1
U2
U_{TOE}
U_{HEEL}
UPLIFT ZONE

Analysis:

Gravity Loads:

$h_{C_1} := E_{wall} - E_{ftg}$ $\qquad h_{C_1} = 39.0\,ft$

$L_{C_1} := t_{w\_top}$ $\qquad L_{C_1} = 1.5\,ft$

$x_{C_1} := L_{toe} + \frac{L_{C_1}}{2}$ $\qquad x_{C_1} = 17.8\,ft$

$W_{C_1} := \gamma_c \cdot h_{C_1} \cdot L_{C_1}$ $\qquad W_{C_1} = 8.8\,klf$

$h_{C_2} := h_{C_1}$ $\qquad h_{C_2} = 39.0\,ft$

$L_{C_2} := t_{w\_bot} - t_{w\_top}$ $\qquad L_{C_2} = 4.9\,ft$

$x_{C_2} := L_{toe} + L_{C_1} + \frac{L_{C_2}}{3}$ $\qquad x_{C_2} = 20.1\,ft$

$W_{C_2} := \gamma_c \cdot \frac{h_{C_2} \cdot L_{C_2}}{2}$ $\qquad W_{C_2} = 14.3\,klf$

$h_{C_3} := t_{ftg}$ $\qquad h_{C_3} = 6.0\,ft$

$L_{C_3} := L_{ftg}$ $\qquad L_{C_3} = 42.0\,ft$

$x_{C_3} := \frac{L_{C_3}}{2}$ $\qquad x_{C_3} = 21.0\,ft$

$W_{C_3} := \gamma_c \cdot h_{C_3} \cdot L_{C_3}$ $\qquad W_{C_3} = 37.8\,klf$

$h_{W1_i} := E_{wheel_i} - E_{ftg}$

$L_{W1} := L_{toe}$ $\qquad L_{W1} = 17.0\,ft$

$x_{W1} := \frac{L_{W1}}{2}$ $\qquad x_{W1} = 8.5\,ft$

$W_{W1_i} := \gamma_w \cdot h_{W1_i} \cdot L_{W1}$

$h_{WS1_i} := E_{wtoe_i} - E_{ftg}$

$L_{WS1} := L_{heel} - t_{w\_bot}$ $\quad\quad L_{WS1} = 18.6\,ft$

$x_{WS1} := L_{ftg} - \frac{L_{WS1}}{2}$ $\quad\quad x_{WS1} = 32\ 7\,ft$

$W_{S1_i} := (\gamma_{fill\_eff} + \gamma_w) \cdot h_{WS1_i} \cdot L_{WS1}$

$h_{WS2_i} := h_{WS1_i}$

$L_{WS2_i} := (t_{w\_bot} - t_{w\_top}) \cdot \frac{h_{WS2_i}}{E_{wall} - E_{ftg}}$

$x_{WS2_i} := L_{ftg} - L_{heel} + t_{w\_bot} - \frac{L_{WS2_i}}{3}$

$W_{S2_i} := (\gamma_{fill\_eff} + \gamma_w) \cdot \frac{h_{WS2_i} \cdot L_{WS2_i}}{2}$

$h_{WS3_i} := \max(E_{grade} - E_{wheel_i}, 0\ ft)$

$L_{WS3_i} := L_{WS1} + L_{WS2_i}$

$x_{WS3_i} := L_{ftg} - \frac{L_{WS3_i}}{2}$

$W_{S3_i} := \gamma_{fill} \cdot h_{WS3_i} \cdot L_{WS3_i}$

$h_{WS4_i} := h_{WS3_i}$

$L_{WS4_i} := (t_{w\_bot} - t_{w\_top}) \cdot \frac{h_{WS4_i}}{E_{wall} - E_{ftg}}$

$x_{WS4_i} := L_{ftg} - L_{WS3_i} - \frac{L_{WS4_i}}{3}$

$W_{S4_i} := \gamma_{fill} \cdot \frac{h_{WS4_i} \cdot L_{WS4_i}}{2}$

E_{wtoe_i} = (ft)	E_{wheel_i} = (ft)	h_{WS1_i} = (ft)	h_{WS2_i} = (ft)	h_{WS3_i} = (ft)	h_{WS4_i} = (ft)	L_{WS2_i} = (ft)	L_{WS3_i} = (ft)	L_{WS4_i} = (ft)
517.0	527.0	26.0	26.0	0.0	0.0	3.3	21.9	0.0
515.0	525.0	24.0	24.0	2.0	2.0	3.0	21.6	0.3
513.0	523.0	22.0	22.0	4.0	4.0	2.8	21.4	0.5
511.0	521.0	20.0	20.0	6.0	6.0	2.5	21.1	0.8
509.0	519.0	18.0	18.0	8.0	8.0	2.3	20.9	1.0
507.0	517.0	16.0	16.0	10.0	10.0	2.0	20.6	1.3
505.0	515.0	14.0	14.0	12.0	12.0	1.8	20.4	1.5
503.0	513.0	12.0	12.0	14.0	14.0	1.5	20.1	1.8
501.0	511.0	10.0	10.0	16.0	16.0	1.3	19.9	2.0
499.0	509.0	8.0	8.0	18.0	18.0	1.0	19.6	2.3
497.0	507.0	6.0	6.0	20.0	20.0	0.8	19.4	2.5
495.0	505.0	4.0	4.0	22.0	22.0	0.5	19.1	2.8
495.0	503.0	4.0	4.0	24.0	24.0	0.5	19.1	3.0
495.0	501.0	4.0	4.0	26.0	26.0	0.5	19.1	3.3
495.0	499.0	4.0	4.0	28.0	28.0	0.5	19.1	3.5
495.0	497.0	4.0	4.0	30.0	30.0	0.5	19.1	3.8
495.0	495.0	4.0	4.0	32.0	32.0	0.5	19.1	4.0

x_{WS2_i} = (ft)	x_{WS3_i} = (ft)	x_{WS4_i} = (ft)	W_{W1_i} = (klf)	W_{S1_i} = (klf)	W_{S2_i} = (klf)	W_{S3_i} = (klf)	W_{S4_i} = (klf)
22.3	31.1	20.1	38.3	61.7	5.4	0.0	0.0
22.4	31.2	20.3	36.1	57.0	4.6	5.6	0.0
22.5	31.3	20.5	34.0	52.2	3.9	11.1	0.1
22.5	31.4	20.6	31.9	47.5	3.2	16.5	0.3
22.6	31.6	20.8	29.8	42.7	2.6	21.7	0.5
22.7	31.7	21.0	27.6	38.0	2.0	26.8	0.8
22.8	31.8	21.1	25.5	33.2	1.6	31.8	1.2
22.9	31.9	21.3	23.4	28.5	1.1	36.6	1.6
23.0	32.1	21.5	21.3	23.7	0.8	41.3	2.1
23.0	32.2	21.6	19.1	19.0	0.5	45.9	2.6
23.1	32.3	21.8	17.0	14.2	0.3	50.4	3.3
23.2	32.4	22.0	14.9	9.5	0.1	54.7	3.9
23.2	32.4	21.9	12.7	9.5	0.1	59.7	4.7
23.2	32.4	21.8	10.6	9.5	0.1	64.6	5.5
23.2	32.4	21.7	8.5	9.5	0.1	69.6	6.4
23.2	32.4	21.6	6.4	9.5	0.1	74.6	7.3
23.2	32.4	21.5	4.3	9.5	0.1	79.6	8.3

Lateral loads:

$$h_{H1_i} := E_{wtoe_i} - E_{ftg}$$

$$y_{H1_i} := \frac{h_{H1_i}}{3} + (E_{ftg} - E_{rot})$$

$$H1_i := \gamma_w \cdot \frac{(h_{H1_i})^2}{2}$$

$$h_{H2_i} := E_{wheel_i} - E_{ftg}$$

$$y_{H2_i} := \frac{h_{H2_i}}{3} + (E_{ftg} - E_{rot})$$

$$H2_i := \gamma_w \cdot \frac{(h_{H2_i})^2}{2}$$

$$h_{A1_i} := h_{WS4_i}$$

$$y_{A1_i} := E_{grade} - E_{rot} - \frac{2}{3} h_{A1_i}$$

$$H_{A1_i} := k_{0\_fill} \cdot \gamma_{fill} \cdot \frac{(h_{A1_i})^2}{2}$$

$$h_{A2_i} := h_{H2_i}$$

$$y_{A2_i} := \frac{h_{H2_i}}{2} + E_{ftg} - E_{rot}$$

$$H_{A2_i} := k_{0\_fill} \cdot \gamma_{fill} \cdot h_{A1_i} \cdot h_{A2_i}$$

$$h_{A3_i} := h_{A2_i}$$

$$y_{A3_i} := \frac{h_{A3_i}}{3} + E_{ftg} - E_{rot}$$

$$H_{A3_i} := k_{0\_fill} \cdot \gamma_{fill\_eff} \cdot \frac{(h_{A3_i})^2}{2}$$

h_{H1_i} = (ft)	y_{H1_i} = (ft)	$H1_i$ = (klf)	h_{H2_i} = (ft)	y_{H2_i} = (ft)	$H2_i$ = (klf)
26.0	11.7	21.1	36.0	15.0	40.5
24.0	11.0	18.0	34.0	14.3	36.1
22.0	10.3	15.1	32.0	13.7	32.0
20.0	9.7	12.5	30.0	13.0	28.1
18.0	9.0	10.1	28.0	12.3	24.5
16.0	8.3	8.0	26.0	11.7	21.1
14.0	7.7	6.1	24.0	11.0	18.0
12.0	7.0	4.5	22.0	10.3	15.1
10.0	6.3	3.1	20.0	9.7	12.5
8.0	5.7	2.0	18.0	9.0	10.1
6.0	5.0	1.1	16.0	8.3	8.0
4.0	4.3	0.5	14.0	7.7	6.1
4.0	4.3	0.5	12.0	7.0	4.5
4.0	4.3	0.5	10.0	6.3	3.1
4.0	4.3	0.5	8.0	5.7	2.0
4.0	4.3	0.5	6.0	5.0	1.1
4.0	4.3	0.5	4.0	4.3	0.5

h_{A1_i} = (ft)	y_{A1_i} = (ft)	H_{A1_i} = (klf)	h_{A2_i} = (ft)	y_{A2_i} = (ft)	H_{A2_i} = (klf)	h_{A3_i} = (ft)	y_{A3_i} = (ft)	H_{A3_i} = (klf)
0.0	39.0	0.0	36.0	21.0	0.0	36.0	15.0	21.1
2.0	37.7	0.1	34.0	20.0	4.4	34.0	14.3	18.8
4.0	36.3	0.5	32.0	19.0	8.3	32.0	13.7	16.6
6.0	35.0	1.2	30.0	18.0	11.7	30.0	13.0	14.6
8.0	33.7	2.1	28.0	17.0	14.6	28.0	12.3	12.7
10.0	32.3	3.3	26.0	16.0	16.9	26.0	11.7	11.0
12.0	31.0	4.7	24.0	15.0	18.7	24.0	11.0	9.4
14.0	29.7	6.4	22.0	14.0	20.0	22.0	10.3	7.9
16.0	28.3	8.3	20.0	13.0	20.8	20.0	9.7	6.5
18.0	27.0	10.5	18.0	12.0	21.1	18.0	9.0	5.3
20.0	25.7	13.0	16.0	11.0	20.8	16.0	8.3	4.2
22.0	24.3	15.7	14.0	10.0	20.0	14.0	7.7	3.2
24.0	23.0	18.7	12.0	9.0	18.7	12.0	7.0	2.3
26.0	21.7	22.0	10.0	8.0	16.9	10.0	6.3	1.6
28.0	20.3	25.5	8.0	7.0	14.6	8.0	5.7	1.0
30.0	19.0	29.3	6.0	6.0	11.7	6.0	5.0	0.6
32.0	17.7	33.3	4.0	5.0	8.3	4.0	4.3	0.3

Uplift:

$$u_{heel_i} := \gamma_w \cdot \left[E_{wheel_i} - \left(E_{ftg} - t_{ftg}\right)\right]$$

$$u_{toe\_dam} := 1.868 \cdot ksf$$

(from dam analysis)

$$u_{toe_i} := \max\left[\begin{bmatrix} u_{toe\_dam} - \gamma_w \cdot \left(20 \cdot ft - t_{ftg}\right) \\ \gamma_w \cdot \left[E_{wtoe_i} - \left(E_{ftg} - t_{ftg}\right)\right] \end{bmatrix}\right]$$

$$u_{rect_i} := \min\left(u_{heel_i}, u_{toe_i}\right)$$

$$u_{tri_i} := \left|u_{heel_i} - u_{toe_i}\right|$$

$$L_{U1_i} := \min\left(\begin{pmatrix} 3 \cdot frac_{u_i} \cdot L_{ftg} \\ L_{ftg} \end{pmatrix}\right)$$

$$U_{rect_i} := u_{rect_i} \cdot L_{U1_i}$$

$$U_{tri_i} := \frac{u_{tri_i} \cdot L_{U1_i}}{2}$$

$$x_{rect_i} := \frac{L_{U1_i}}{2}$$

$$x_{tri_i} := \frac{L_{U1_i}}{2} + \frac{L_{U1_i}}{6} \cdot \text{if}\left(u_{heel_i} > u_{toe_i}, 1, -1\right)$$

$$U1_i := U_{rect_i} + U_{tri_i}$$

$$x_{U1_i} := \frac{U_{rect_i} \cdot x_{rect_i} + U_{tri_i} \cdot x_{tri_i}}{U1_i}$$

$$L_{U2_i} := L_{ftg} - L_{U1_i}$$

$$U2_i := u_{heel_i} \cdot L_{U2_i}$$

$$x_{U2_i} := L_{U1_i} + \frac{L_{U2_i}}{2}$$

$$L_{ftg} = 42.0\,ft$$

$uheel_i$ (ksf)	$utoe_i$ (ksf)	$urect_i$ (ksf)	$utri_i$ (ksf)	L_{U1_i} (ft)	L_{U2_i} (ft)	$U1_i$ (klf)	$U2_i$ (klf)
2.625	2.000	2.000	0.625	37.94	4.06	87.7	10.7
2.500	1.875	1.875	0.625	40.43	1.57	88.4	3.9
2.375	1.750	1.750	0.625	42.00	0.00	86.6	0.0
2.250	1.625	1.625	0.625	42.00	0.00	81.4	0.0
2.125	1.500	1.500	0.625	42.00	0.00	76.1	0.0
2.000	1.375	1.375	0.625	42.00	0.00	70.9	0.0
1.875	1.250	1.250	0.625	42.00	0.00	65.6	0.0
1.750	1.125	1.125	0.625	42.00	0.00	60.4	0.0
1.625	1.000	1.000	0.625	42.00	0.00	55.1	0.0
1.500	0.993	0.993	0.507	42.00	0.00	52.4	0.0
1.375	0.993	0.993	0.382	42.00	0.00	49.7	0.0
1.250	0.993	0.993	0.257	42.00	0.00	47.1	0.0
1.125	0.993	0.993	0.132	42.00	0.00	44.5	0.0
1.000	0.993	0.993	0.007	42.00	0.00	41.9	0.0
0.875	0.993	0.875	0.118	42.00	0.00	39.2	0.0
0.750	0.993	0.750	0.243	42.00	0.00	36.6	0.0
0.625	0.993	0.625	0.368	42.00	0.00	34.0	0.0

U_{rect_i} (klf)	U_{tri_i} (klf)	x_{rect_i} (ft)	x_{tri_i} (ft)	x_{U1_i} (ft)	x_{U2_i} (ft)	$U2_i$ (klf)
75.9	11.9	19.0	25.3	19.8	40.0	10.7
75.8	12.6	20.2	27.0	21.2	41.2	3.9
73.5	13.1	21.0	28.0	22.1	42.0	0.0
68.3	13.1	21.0	28.0	22.1	42.0	0.0
63.0	13.1	21.0	28.0	22.2	42.0	0.0
57.8	13.1	21.0	28.0	22.3	42.0	0.0
52.5	13.1	21.0	28.0	22.4	42.0	0.0
47.3	13.1	21.0	28.0	22.5	42.0	0.0
42.0	13.1	21.0	28.0	22.7	42.0	0.0
41.7	10.6	21.0	28.0	22.4	42.0	0.0
41.7	8.0	21.0	28.0	22.1	42.0	0.0
41.7	5.4	21.0	28.0	21.8	42.0	0.0
41.7	2.8	21.0	28.0	21.4	42.0	0.0
41.7	0.1	21.0	28.0	21.0	42.0	0.0
36.8	2.5	21.0	14.0	20.6	42.0	0.0
31.5	5.1	21.0	14.0	20.0	42.0	0.0
26.3	7.7	21.0	14.0	19.4	42.0	0.0

$$\Sigma V_i := \sum_{i=1}^{3} W_{C_i} + W_{W1_i} + W_{S1_i} + W_{S2_i} + W_{S3_i} + W_{S4_i} - U1_i - U2_i$$

$$\Sigma M_{grav_i} := \sum_{i=1}^{3} W_{C_i} \cdot x_{C_i} + W_{W1_i} \cdot x_{W1} + W_{S1_i} \cdot x_{WS1} + W_{S2_i} \cdot x_{WS2_i} + W_{S3_i} \cdot x_{WS3_i} \ldots + W_{S4_i} \cdot x_{WS4_i} - U1_i \cdot x_{U1_i} - U2_i \cdot x_{U2_i}$$

$$\Sigma H_i := -H1_i + H2_i + H_{A1_i} + H_{A2_i} + H_{A3_i}$$

$$\Sigma M_{lat_i} := -H1_i \cdot y_{H1_i} + H2_i \cdot y_{H2_i} + H_{A1_i} \cdot y_{A1_i} + H_{A2_i} \cdot y_{A2_i} + H_{A3_i} \cdot y_{A3_i}$$

$$\Sigma M_i := \Sigma M_{grav_i} - \Sigma M_{lat_i}$$

$$x_{res_i} := \frac{\Sigma M_i}{\Sigma V_i} \qquad frac_i := \frac{x_{res_i}}{L_{ftg}}$$

$$frac\_text_i := if\left(frac_i > \frac{2}{3}, \text{"Over stable"}, \text{""}\right)$$

$$frac\_text_i := if\left(frac_i < \frac{2}{3} \wedge frac_i \ge \frac{1}{3}, \text{"Resultant in middle third. Okay normal case."}, frac\_text_i\right)$$

$$frac\_text_i := if\left(frac_i < \frac{1}{3} \wedge frac_i \ge \frac{1}{4}, \text{"Resultant in middle half. Unusual case only."}, frac\_text_i\right)$$

$$frac\_text_i := if\left(frac_i < \frac{1}{4} \wedge frac_i \ge 0, \text{"Resultant within base. Extreme case only."}, frac\_text_i\right)$$

$$frac\_text_i := if\left(frac_i < 0, \text{"Unstable"}, frac\_text_i\right)$$

$$L_{contact_i} := \min\left(3 \cdot x_{res_i}, L_{ftg}\right)$$

$\Sigma V_i =$ (klf)	$\Sigma M_{grav_i} =$ (kip)	$\Sigma H_i =$ (klf)	$\Sigma M_{lat_i} =$ (kip)	$\Sigma M_i =$ (kip)	$x_{res_i} =$ (ft)	$L_{contact_i} =$ (ft)
67.8	1535	40.4	676.9	857.7	12.6	37.9
71.8	1651	41.5	682.3	968.2	13.5	40.4
75.6	1760	42.4	685.4	$1.1 \cdot 10^3$	14.2	42.0
78.8	1855	43.1	686.5	$1.2 \cdot 10^3$	14.8	42.0
82.0	1951	43.8	685.7	$1.3 \cdot 10^3$	15.4	42.0
85.2	2046	44.3	683.4	$1.4 \cdot 10^3$	16.0	42.0
88.5	2141	44.6	679.9	$1.5 \cdot 10^3$	16.5	42.0
91.7	2237	44.9	675.3	$1.6 \cdot 10^3$	17.0	42.0
94.9	2332	45.0	670.0	$1.7 \cdot 10^3$	17.5	42.0
95.7	2393	45.0	664.2	$1.7 \cdot 10^3$	18.1	42.0
96.3	2452	44.8	658.2	$1.8 \cdot 10^3$	18.6	42.0
96.9	2510	44.6	652.2	$1.9 \cdot 10^3$	19.2	42.0

$frac_i =$

	1
1	0.301
2	0.321
3	0.338
4	0.353
5	0.367
6	0.381
7	0.393
8	0.405
9	0.417
10	0.430
11	0.444
12	0.457
13	0.485
14	0.509
15	0.530
16	0.549
17	0.566

$frac\_text_i =$

	1
1	"Resultant in middle half. Unusual case only."
2	"Resultant in middle half. Unusual case only."
3	"Resultant in middle third. Okay normal case."
4	"Resultant in middle third. Okay normal case."
5	"Resultant in middle third. Okay normal case."
6	"Resultant in middle third. Okay normal case."
7	"Resultant in middle third. Okay normal case."
8	"Resultant in middle third. Okay normal case."
9	"Resultant in middle third. Okay normal case."
10	"Resultant in middle third. Okay normal case."
11	"Resultant in middle third. Okay normal case."
12	"Resultant in middle third. Okay normal case."
13	"Resultant in middle third. Okay normal case."
14	"Resultant in middle third. Okay normal case."
15	"Resultant in middle third. Okay normal case."
16	"Resultant in middle third. Okay normal case."
17	"Resultant in middle third. Okay normal case."

$E_{wheel_i} =$ (ft)

527.0
525.0
523.0
521.0
519.0
517.0
515.0
513.0
511.0
509.0
507.0
505.0
503.0
501.0
499.0
497.0
495.0

$error_i := \left| frac_i - frac_{u_i} \right|$ $\quad error_{max} := \max(error)$ $\quad error_{max} = 0.00005$

$$frac_u \equiv \begin{pmatrix} .3011 \\ .3209 \\ .3385 \\ .3532 \\ .3672 \\ .3806 \\ .3933 \\ .4055 \\ .4169 \\ .4302 \\ .4435 \\ .4567 \\ .4846 \\ .5089 \\ .5303 \\ .5491 \\ .5657 \end{pmatrix}$$

$frac_i =$

	1
1	0.3011
2	0.3209
3	0.3385
4	0.3532
5	0.3672
6	0.3806
7	0.3933
8	0.4055
9	0.4169
10	0.4302
11	0.4435
12	0.4567
13	0.4846
14	0.5089
15	0.5303
16	0.5491
17	0.5657

$ic_{u_i} =$

	1
1	0.3011
2	0.3209
3	0.3385
4	0.3532
5	0.3672
6	0.3806
7	0.3933
8	0.4055
9	0.4169
10	0.4302
11	0.4435
12	0.4567
13	0.4846
14	0.5089
15	0.5303
16	0.5491
17	0.5657

$error_i =$

	1
1	0.0000
2	0.0000
3	0.0000
4	0.0000
5	0.0000
6	0.0000
7	0.0000
8	0.0000
9	0.0000
10	0.0000
11	0.0000
12	0.0000
13	0.0000
14	0.0000
15	0.0000
16	0.0000
17	0.0000

ok := if($error_{max} > 0.00005$, "Uplift does not match compression area." , ok) ok = "Ok"

Evaluate Overturning Stability as Retaining Wall

$$rwfrac_i := \frac{L_{contact_i}}{L_{ftg}}$$

brg := "rock"

$rw\_text_i :=$ if[(rwfrac$_i \geq 1.0$), "Overstable.", ""]

$rw\_text_i :=$ if(brg = "rock" $\wedge$ rwfrac$_i \geq 0.75$, "Okay Usual case.", rw_text$_i$)

$rw\_text_i :=$ if[(brg = "rock" $\wedge$ rwfrac$_i < 0.75 \wedge$ rwfrac$_i \geq 0.50$), "Unusual case only ", rw_text$_i$]

$rw\_text_i :=$ if[((brg = "rock" $\wedge$ rwfrac$_i < 0.50$)), "Unstable.", rw_text$_i$]

$rw\_text_i :=$ if(brg = "soil" $\wedge$ rwfrac$_i = 1.0$, "Okay Usual case.", rw_text$_i$)

$rw\_text_i :=$ if[(brg = "soil" $\wedge$ rwfrac$_i < 1.0 \wedge$ rwfrac$_i \geq 0.75$), "Unusual case only.", rw_text$_i$]

$rw\_text_i :=$ if[((brg = "soil" $\wedge$ rwfrac$_i < 0.75$)), "Unstable.", rw_text$_i$]

$rwfrac_i =$ (%)

	1
1	90.3
2	96.3
3	100.0
4	100.0
5	100.0
6	100.0
7	100.0
8	100.0
9	100.0
10	100.0
11	100.0
12	100.0
13	100.0
14	100.0
15	100.0
16	100.0
17	100.0

$rw\_text_i =$

	1
1	"Okay Usual case."
2	"Okay Usual case."
3	"Okay Usual case."
4	"Okay Usual case."
5	"Okay Usual case."
6	"Okay Usual case."
7	"Okay Usual case."
8	"Okay Usual case."
9	"Okay Usual case."
10	"Okay Usual case."
11	"Okay Usual case."
12	"Okay Usual case."
13	"Okay Usual case."
14	"Okay Usual case."
15	"Okay Usual case."
16	"Okay Usual case."

Base Pressures:

$$e_{ftg_i} := \frac{L_{ftg}}{2} - x_{res_i}$$ (eccentricity with respect to the footing centroid)

$$e_i := \frac{L_{contact_i}}{2} - x_{res_i}$$ (eccentricity with respect to the compression area)

$$\sigma_{toe_i} := \frac{\Sigma V_i}{L_{contact_i}} + \frac{\Sigma V_i \cdot e_i}{\frac{\left(L_{contact_i}\right)^2}{6}}$$

$$\sigma_{heel_i} := \frac{\Sigma V_i}{L_{contact_i}} - \frac{\Sigma V_i \cdot e_i}{\frac{\left(L_{contact_i}\right)^2}{6}}$$

ΣH_i = (klf)	ΣV_i = (klf)	e_i = (ft)	e_{ftg_i} = (ft)	σ_{heel_i} = (ksf)	σ_{toe_i} = (ksf)
40.4	67.8	6.32	8.35	0.000	3.575
41.5	71.8	6.74	7.52	0.000	3.553
42.4	75.6	6.78	6.78	0.056	3.542
43.1	78.8	6.17	6.17	0.223	3.529
43.8	82.0	5.58	5.58	0.397	3.509
44.3	85.2	5.02	5.02	0.575	3.484
44.6	88.5	4.48	4.48	0.758	3.455
44.9	91.7	3.97	3.97	0.945	3.422
45.0	94.9	3.49	3.49	1.134	3.386
45.0	95.7	2.93	2.93	1.324	3.231
44.8	96.3	2.37	2.37	1.516	3.068
44.6	96.9	1.82	1.82	1.707	2.906
43.8	103.1	0.65	0.65	2.228	2.681
43.1	109.4	-0.38	-0.38	2.744	2.464
42.6	115.7	-1.27	-1.27	3.255	2.255
42.2	122.1	-2.06	-2.06	3.764	2.052
41.9	128.6	-2.76	-2.76	4.270	1.854

$L_{contact_1} = 37.94\,ft$ $\Sigma H_1 = 40.4\,klf$ $\frac{L_{contact_1}}{L_{ftg}} = 90.3\,\%$

$x_{res_1} = 12.65\,ft$ $\Sigma V_1 = 67.8\,klf$

Section 5
Dam Stability Analysis

Dam Stability Analysis: (right end at deep rock)

Reference:T:\ST\CALCS\Common geometry.mcd(R)

Geometry:

$E_{rock\_base} := 468.2 \cdot ft$

$E_{RCC} := 498 \cdot ft$

$slope_{RCCd} \equiv 1.0$ (run per unit rise, downstream)

$slope_{RCCu} \equiv 2.0$ (run per unit rise, upstream)

$E_{RCCd} := 485 \cdot ft$ (top of downstream RCC)

Constants:

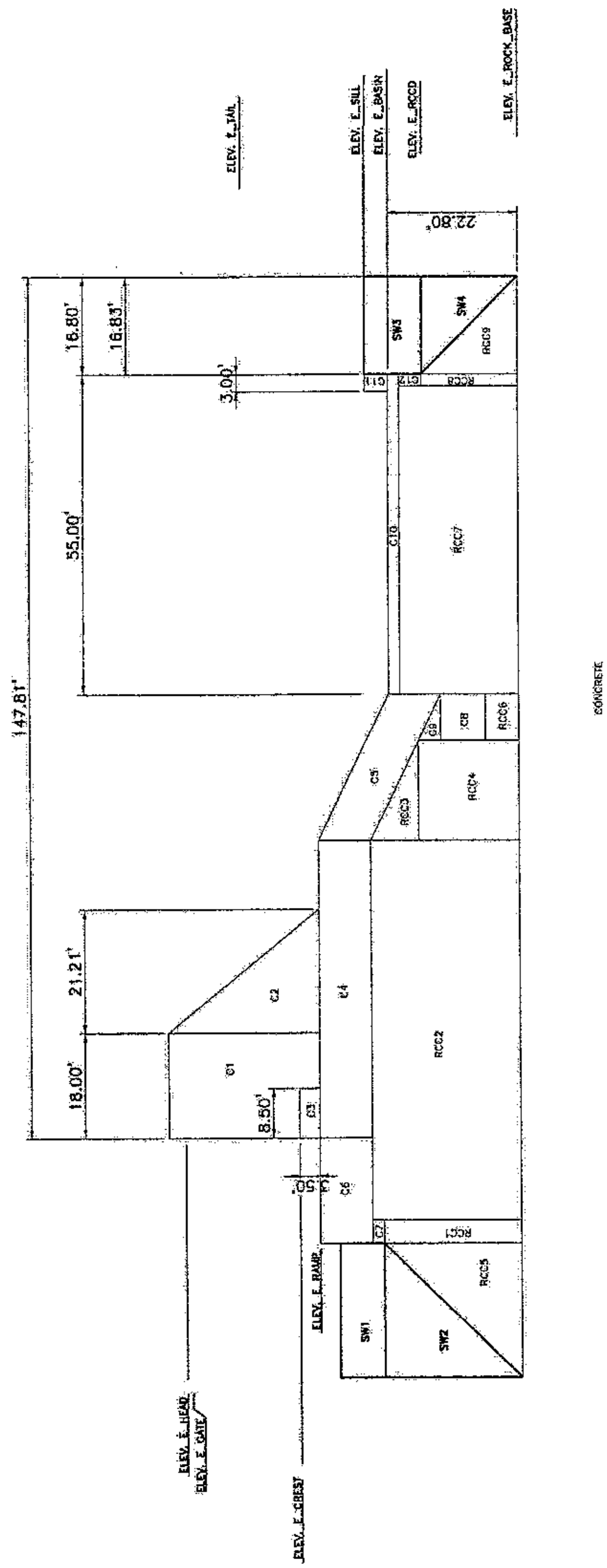
Pre-Definitions:

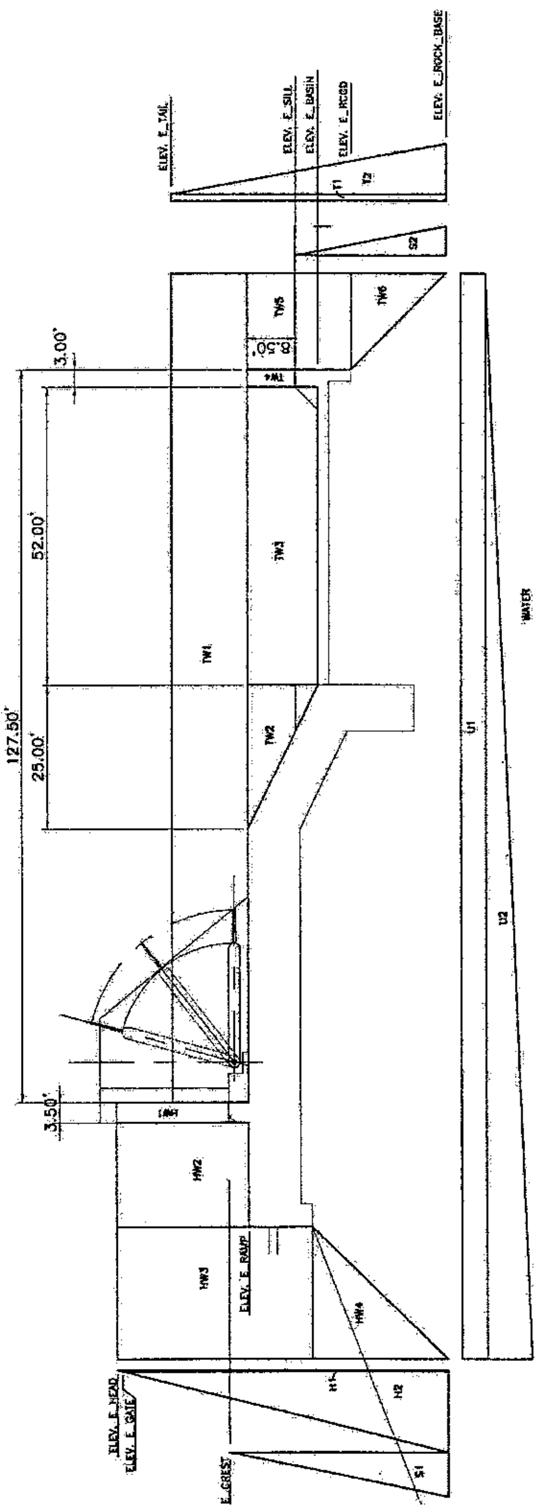
$kip \equiv 1000 \cdot lbf$ $ksi \equiv 1000 \cdot psi$ $ok \equiv$ "Ok"

$psf \equiv \frac{lbf}{ft^2}$ $plf \equiv \frac{lbf}{ft}$ $ORIGIN \equiv 1.0$

$pcf \equiv \frac{lbf}{ft^3}$ $klf \equiv 1000 \cdot plf$ $ksf := \frac{1000 \cdot lbf}{ft^2}$

Freese and Nichols




ELEV. E_TAIL
ELEV. E_SILL
ELEV. E_BASIN
ELEV. E_RCGD
ELEV. E_ROCK_BASE
3.00'
6.50'
52.00'
127.50'
25.00'
3.50'
ELEV. E_RAMP
ELEV. E_HEAD
ELEV. E_GATE
E_CREST
WATER

Analysis:

Self-weight of stucture:

$h_{C_5} := \frac{25 \cdot ft}{slope_{basin}}$ $h_{C_5} = 12.5\,ft$

$L_{C_5} := h_{C_5} \cdot slope_{basin}$ $L_{C_5} = 25.0\,ft$

$x_{C_5} := \frac{L_{C_5}}{2}$ $x_{C_5} = 12.5\,ft$

$W_{C_5} := \gamma_c \cdot \left\lfloor \left(h_{C_5} + t_c\right) \cdot L_{C_5} - h_{C_5} \cdot L_{C_5} \right\rfloor$ $W_{C_5} = 22.5\,klf$

$h_{C_4} := t_c$ $h_{C_4} = 6.00\,ft$

$L_{C_4} := 51 \cdot ft$

$x_{C_4} := L_{C_5} + \frac{L_{C_4}}{2}$ $x_{C_4} = 50.5\,ft$

$W_{C_4} := \gamma_c \cdot h_{C_4} \cdot L_{C_4}$ $W_{C_4} = 45.9\,klf$

$h_{C_1} := E_{pier} - E_{ramp}$ $h_{C_1} = 26.5\,ft$

$L_{C_1} := 18 \cdot ft$

$x_{C_1} := L_{C_4} + L_{C_5} - \frac{L_{C_1}}{2}$ $x_{C_1} = 67.0\,ft$

$W_{C_1} := \gamma_c \cdot h_{C_1} \cdot L_{C_1} \cdot \frac{w_{pier}}{s_{pier}}$ $W_{C_1} = 10.2\,klf$

$h_{C_2} := h_{C_1}$ $h_{C_2} = 26.5\,ft$

$L_{C_2} := h_{C_2} \cdot \frac{1.00}{1.25}$ $L_{C_2} = 21.2\,ft$

$x_{C_2} := L_{C_4} + L_{C_5} - L_{C_1} - \frac{L_{C_2}}{3}$ $x_{C_2} = 50.9\,ft$

$W_{C_2} := \gamma_c \cdot \frac{h_{C_2} \cdot L_{C_2}}{2} \cdot \frac{w_{pier}}{s_{pier}}$ $W_{C_2} = 6.0\,klf$

$h_{C_3} := E_{crest} - E_{ramp}$ $h_{C_3} = 3.5\,ft$

$L_{C_3} := 8.5 \cdot ft$

$x_{C_3} := L_{C_4} + L_{C_5} - \frac{L_{C_3}}{2}$ $\quad x_{C_3} = 71.8\,ft$

$W_{C_3} := \gamma_c \cdot h_{C_3} \cdot L_{C_3} \cdot \frac{(s_{pier} - w_{pier})}{s_{pier}}$ $\quad W_{C_3} = 3.8\,klf$

$h_{C_6} := h_{C_4}$ $\quad h_{C_6} = 6.0\,ft$

$L_{C_6} := 18 \cdot ft$ $\quad L_{C_6} = 18.0\,ft$

$x_{C_6} := L_{C_4} + L_{C_5} + \frac{L_{C_6}}{2}$ $\quad x_{C_6} = 85.0\,ft$

$W_{C_6} := \gamma_c \cdot h_{C_6} \cdot L_{C_6}$ $\quad W_{C_6} = 16.2\,klf$

$h_{C_7} := E_{ramp} - t_c - E_{ukey}$ $\quad h_{C_7} = 9.5\,ft$

$L_{C_7} := L_{ukey}$ $\quad L_{C_7} = 6.0\,ft$

$x_{C_7} := L_{C_4} + L_{C_5} + L_{C_6} - \frac{L_{C_7}}{2}$ $\quad x_{C_7} = 91.0\,ft$

$W_{C_7} := \gamma_c \cdot h_{C_7} \cdot L_{C_7}$ $\quad W_{C_7} = 8.55\,klf$

$h_{C_8} := E_{ramp} - t_c - h_{C_5} - E_{dkey}$ $\quad h_{C_8} = 14.00\,ft$

$L_{C_8} := L_{dkey}$ $\quad L_{C_8} = 6.00\,ft$

$x_{C_8} := \frac{L_{C_8}}{2}$ $\quad x_{C_8} = 3.00\,ft$

$W_{C_8} := \gamma_c \cdot h_{C_8} \cdot L_{C_8}$ $\quad W_{C_8} = 12.6\,klf$

$h_{C_9} := \frac{L_{C_8}}{slope_{basin}}$ $\quad h_{C_9} = 3.00\,ft$

$L_{C_9} := L_{C_8}$ $\quad L_{C_9} = 6.0\,ft$

$x_{C_9} := \frac{2}{3} \cdot L_{C_9}$ $\qquad x_{C_9} = 4.0\,ft$

$W_{C_9} := \gamma_c \cdot \frac{h_{C_9} \cdot L_{C_9}}{2}$ $\qquad W_{C_9} = 1.4\,klf$

$h_{C_{10}} := t_{basin}$ $\qquad h_{C_{10}} = 6.0\,ft$

$L_{C_{10}} := L_{basin}$ $\qquad L_{C_{10}} = 55.0\,ft$

$x_{C_{10}} := \frac{-L_{C_{10}}}{2}$ $\qquad x_{C_{10}} = -27.5\,ft$

$W_{C_{10}} := \gamma_c \cdot h_{C_{10}} \cdot L_{C_{10}}$ $\qquad W_{C_{10}} = 49.5\,klf$

$h_{C_{11}} := E_{sill} - E_{basin}$ $\qquad h_{C_{11}} = 4.0\,ft$

$L_{C_{11}} := 3 \cdot ft$ $\qquad L_{C_{11}} = 3.0\,ft$

$x_{C_{11}} := -L_{C_{10}} + \frac{L_{C_{11}}}{2}$ $\qquad x_{C_{11}} = -53.5\,ft$

$W_{C_{11}} := \gamma_c \cdot h_{C_{11}} \cdot L_{C_{11}}$ $\qquad W_{C_{11}} = 1.8\,klf$

$h_{C_{12}} := E_{basin} - t_{basin} - E_{RCCd}$ $\qquad h_{C_{12}} = 0.0\,ft$

$L_{C_{12}} := 2 \cdot ft$ $\qquad L_{C_{12}} = 2.0\,ft$

$x_{C_{12}} := -L_{C_{10}} + \frac{L_{C_{12}}}{2}$ $\qquad x_{C_{12}} = -54.0\,ft$

$W_{C_{12}} := \gamma_c \cdot h_{C_{12}} \cdot L_{C_{12}}$ $\qquad W_{C_{12}} = 0.0\,klf$

Self weight of RCC·

$h_{RCC_1} := E_{ramp} - t_c - h_{C_7} - E_{rock\_base}$ $\quad h_{RCC_1} = 19.8\ ft$

$L_{RCC_1} := L_{C_7}$ $\quad L_{RCC_1} = 6.0\ ft$

$x_{RCC_1} := L_{C_4} + L_{C_5} + L_{C_6} - \frac{L_{RCC_1}}{2}$ $\quad x_{RCC_1} = 91\ 0\ ft$

$W_{RCC_1} := \gamma_{RCC}\ h_{RCC_1} \cdot L_{RCC_1}$ $\quad W_{RCC_1} = 15.4\ klf$

$h_{RCC_2} := E_{ramp} - t_c - E_{rock\_base}$ $\quad h_{RCC_2} = 29.3\ ft$

$L_{RCC_2} := L_{C_4} + L_{C_6} - L_{RCC_1}$ $\quad L_{RCC_2} = 63.0\ ft$

$x_{RCC_2} := L_{C_5} + \frac{L_{RCC_2}}{2}$ $\quad x_{RCC_2} = 56.5\ ft$

$W_{RCC_2} := \gamma_{RCC}\ h_{RCC_2}\ L_{RCC_2}$ $\quad W_{RCC_2} = 240.0\ klf$

$h_{RCC_3} := \frac{L_{C_5} - L_{C_9}}{slope_{basin}}$ $\quad h_{RCC_3} = 9.5\ ft$

$L_{RCC_3} := L_{C_5} - L_{C_9}$ $\quad L_{RCC_3} = 19.0\ ft$

$x_{RCC_3} := L_{C_9} + \frac{2}{3} L_{RCC_3}$ $\quad x_{RCC_3} = 18\ 7\ ft$

$W_{RCC_3} := \gamma_{RCC} \cdot \frac{h_{RCC_3}\ L_{RCC_3}}{2}$ $\quad W_{RCC_3} = 11.7\ klf$

$h_{RCC_4} := E_{ramp} - t_c - h_{RCC_3} - E_{dkey}$ $\quad h_{RCC_4} = 17.0\ ft$

$L_{RCC_4} := L_{RCC_3}$ $\quad L_{RCC_3} = 19.0\ ft$

$x_{RCC_4} := L_{C_9} + \frac{L_{RCC_4}}{2}$ $\quad x_{RCC_4} = 15.5\ ft$

$W_{RCC_4} := \gamma_{RCC} \cdot h_{RCC_4} \cdot L_{RCC_4}$ $\quad W_{RCC_4} = 42\ 0\ klf$

$h_{RCC_5} := h_{RCC_1}$ $\quad h_{RCC_5} = 19.800\ ft$

$L_{RCC_5} := h_{RCC_5} \cdot slope_{RCCu}$ $\quad L_{RCC_5} = 39.6\,ft$

$x_{RCC_5} := L_{C_4} + L_{C_5} + L_{C_6} + \frac{L_{RCC_5}}{3}$ $\quad x_{RCC_5} = 107.2\,ft$

$W_{RCC_5} := \gamma_{RCC} \cdot \frac{h_{RCC_5} \cdot L_{RCC_5}}{2}$ $\quad W_{RCC_5} = 51.0\,klf$

$h_{RCC_6} := \max(E_{dkey} - E_{rock\_base}, 0 \cdot ft)$ $\quad h_{RCC_6} = 2.8\,ft$

$L_{RCC_6} := L_{C_8}$ $\quad L_{RCC_6} = 6.0\,ft$

$x_{RCC_6} := \frac{L_{RCC_6}}{2}$ $\quad x_{RCC_6} = 3.0\,ft$

$W_{RCC_6} := \gamma_{RCC} \cdot h_{RCC_6} \cdot L_{RCC_6}$ $\quad W_{RCC_6} = 2.2\,klf$

$h_{RCC_7} := E_{basin} - t_{basin} - E_{rock\_base}$ $\quad h_{RCC_7} = 16.8\,ft$

$L_{RCC_7} := L_{basin} - L_{C_{12}}$ $\quad L_{RCC_7} = 53.0\,ft$

$x_{RCC_7} := -\frac{L_{RCC_7}}{2}$ $\quad x_{RCC_7} = -26.5\,ft$

$W_{RCC_7} := \gamma_{RCC} \cdot h_{RCC_7} \cdot L_{RCC_7}$ $\quad W_{RCC_7} = 115.8\,klf$

$h_{RCC_8} := E_{RCCd} - E_{rock\_base}$ $\quad h_{RCC_8} = 16.8\,ft$

$L_{RCC_8} := L_{C_{12}}$ $\quad L_{RCC_8} = 2.0\,ft$

$x_{RCC_8} := -L_{basin} + \frac{L_{RCC_8}}{2}$ $\quad x_{RCC_8} = -54.0\,ft$

$W_{RCC_8} := \gamma_{RCC} \cdot h_{RCC_8} \cdot L_{RCC_8}$ $\quad W_{RCC_8} = 4.4\,klf$

$h_{RCC_9} := E_{RCCd} - E_{rock\_base}$ $\quad h_{RCC_9} = 16.8\,ft$

$L_{RCC_9} := h_{RCC_9} \cdot slope_{RCCd}$ $\quad L_{RCC_9} = 16.8\,ft$

$x_{RCC_9} := -L_{RCC_7} - L_{RCC_8} - \frac{L_{RCC_9}}{3}$ $\quad x_{RCC_9} = -60.6\,ft$

$W_{RCC_9} := \gamma_{RCC} \cdot \frac{h_{RCC_9} \cdot L_{RCC_9}}{2}$ $\quad W_{RCC_9} = 18.3\,klf$

Gravity loads on structure:

$h_{HW_1} := E_{head} - E_{crest}$ $\quad h_{HW_1} = 18.0\,ft$

$L_{HW_1} := 3.5 \cdot ft$ $\quad L_{HW_1} = 3.5\,ft$

$x_{HW_1} := L_{C_5} + L_{C_4} - \frac{L_{HW_1}}{2}$ $\quad x_{HW_1} = 74.3\,ft$

$W_{HW_1} := \gamma_w \cdot h_{HW_1} \cdot L_{HW_1} \cdot \frac{(s_{pier} - w_{pier})}{s_{pier}}$ $\quad W_{HW_1} = 3.4\,klf$

$h_{HW_2} := E_{head} - E_{ramp}$ $\quad h_{HW_2} = 21.5\,ft$

$L_{HW_2} := L_{C_6}$ $\quad L_{HW_2} = 18.0\,ft$

$x_{HW_2} := x_{C_6}$ $\quad x_{HW_2} = 85.0\,ft$

$W_{HW_2} := \gamma_w \cdot h_{HW_2} \cdot L_{HW_2}$ $\quad W_{HW_2} = 24.2\,klf$

$h_{HW_3} := E_{head} - E_{ukey}$ $\quad h_{HW_3} = 37.0\,ft$

$L_{HW_3} := L_{RCC_5}$ $\quad L_{HW_3} = 39.6\,ft$

$x_{HW_3} := L_{C_4} + L_{C_5} + L_{C_6} + \frac{L_{HW_3}}{2}$ $\quad x_{HW_3} = 113.8\,ft$

$W_{HW_3} := \gamma_w \cdot h_{HW_3} \cdot L_{HW_3}$ $\quad W_{HW_3} = 91.6\,klf$

$h_{HW_4} := E_{ukey} - E_{rock\_base}$ $\quad h_{HW_4} = 19.8\,ft$

$L_{HW_4} := h_{HW_4} \cdot slope_{RCCu}$ $\quad L_{HW_4} = 39.6\,ft$

$x_{HW_4} := L_{C_4} + L_{C_5} + L_{C_6} + \frac{2}{3} \cdot L_{HW_4}$ $\quad x_{HW_4} = 120.4\,ft$

$W_{HW_4} := \gamma_w \cdot \frac{h_{HW_4} \cdot L_{HW_4}}{2}$ $\quad W_{HW_4} = 24.5\,klf$

$h_{TW_1} := \max\left(\begin{pmatrix} E_{tail\_redux} - E_{ramp} \\ 0 \cdot ft \end{pmatrix}\right)$ $\quad h_{TW_1} = 0.0\,ft$

$L_{TW_1} := L_{RCC_9} + L_{basin} + L_{C_4} + L_{C_5} - L_{HW_1}$ $\quad L_{TW_1} = 144.3\,ft$

$x_{TW_1} := L_{C_4} + L_{C_5} - L_{HW_1} - \frac{L_{TW_1}}{2}$ $\quad x_{TW_1} = 0.3\,ft$

$W_{TW_1} := \gamma_w \cdot h_{TW_1} \cdot L_{TW_1}$ $\quad W_{TW_1} = 0.0\,klf$

$h_{TW_2} := \max\left[\min\left(\begin{pmatrix} E_{tail\_redux} - E_{basin} \\ E_{ramp} - E_{basin} \end{pmatrix}\right), 0 \cdot ft\right]$ $\quad h_{TW_2} = 4.0\,ft$

$L_{TW_2} := h_{TW_2} \cdot slope_{basin}$ $\quad L_{TW_2} = 8.0\,ft$

$x_{TW_2} := \frac{L_{TW_2}}{3}$ $\quad x_{TW_2} = 2.7\,ft$

$W_{TW_2} := \gamma_w \cdot \frac{h_{TW_2} \cdot L_{TW_2}}{2}$ $\quad W_{TW_2} = 1.0\,klf$

$h_{TW_3} := h_{TW_2}$ $\quad h_{TW_3} = 4.0\,ft$

$L_{TW_3} := L_{basin} - L_{C_{11}}$ $\quad L_{TW_3} = 52.0\,ft$

$x_{TW_3} := -\frac{L_{basin} - L_{C_{11}}}{2}$ $\quad x_{TW_3} = -26.0\,ft$

$W_{TW_3} := \gamma_w \cdot h_{TW_3} \cdot L_{TW_3}$ $\quad W_{TW_3} = 13.0\,klf$

$h_{TW_4} := \max\left[\min\left(\begin{pmatrix} E_{tail\_redux} - E_{sill} \\ E_{ramp} - E_{sill} \end{pmatrix}\right), 0 \cdot ft\right]$ $\quad h_{TW_4} = 0.0\,ft$

$L_{TW_4} := L_{C_{11}}$ $\quad L_{TW_4} = 3.0\,ft$

$x_{TW_4} := -L_{basin} + \frac{L_{TW_4}}{2}$ $\quad x_{TW_4} = -53.5\,ft$

$W_{TW_4} := \gamma_w \cdot h_{TW_4} \cdot L_{TW_4}$ $\quad W_{TW_4} = 0.0\,klf$

$h_{TW_5} := \max(E_{tail\_redux} - E_{RCCd}, 0 \cdot ft)$ $\quad h_{TW_5} = 10.0\,ft$

$L_{TW_5} := L_{RCC_9}$ $\quad L_{TW_5} = 16.8\,ft$

$x_{TW_5} := -L_{basin} - \frac{L_{TW_5}}{2}$ $x_{TW_5} = -63.4\ ft$

$W_{TW_5} := \gamma_w \cdot h_{TW_5} \cdot L_{TW_5}$ $W_{TW_5} = 10.5\ klf$

$h_{TW_6} := E_{RCCd} - E_{rock\_base}$ $h_{TW_6} = 16.8\ ft$

$L_{TW_6} := slope_{RCCd} \cdot h_{TW_6}$ $L_{TW_6} = 16.8\ ft$

$x_{TW_6} := -L_{basin} - \frac{2}{3} \cdot L_{TW_6}$ $x_{TW_6} = -66.2\ ft$

$W_{TW_6} := \gamma_w \cdot \frac{h_{TW_6} \cdot L_{TW_6}}{2}$ $W_{TW_6} = 8.8\ klf$

$h_{SW_1} := E_{approach} - E_{ukey}$ $h_{SW_1} = 12.0\ ft$

$L_{SW_1} := L_{RCC_5}$ $L_{SW_1} = 39.6\ ft$

$x_{SW_1} := L_{C_4} + L_{C_5} + L_{C_6} + \frac{L_{SW_1}}{2}$ $x_{SW_1} = 113.8\ ft$

$W_{SW_1} := \gamma_{Su} \cdot h_{SW_1} \cdot L_{SW_1}$ $W_{SW_1} = 28.5\ klf$

$h_{SW_2} := E_{ukey} - E_{rock\_base}$ $h_{SW_2} = 19.8\ ft$

$L_{SW_2} := L_{SW_1}$ $L_{SW_2} = 39.6\ ft$

$x_{SW_2} := x_{SW_1} + \frac{L_{SW_2}}{6}$ $x_{SW_2} = 120.4\ ft$

$W_{SW_2} := \gamma_{Su} \cdot \frac{h_{SW_2} \cdot L_{SW_2}}{2}$ $W_{SW_2} = 23.5\ klf$

$h_{SW_3} := E_{sill} - E_{RCCd}$ $h_{SW_3} = 10.0\ ft$

$L_{SW_3} := L_{RCC_9}$ $L_{SW_3} = 16.8\ ft$

$x_{SW_3} := -L_{basin} - \frac{L_{SW_3}}{2}$ $x_{SW_3} = -63.4\ ft$

$W_{SW_3} := \gamma_{Sd} \cdot h_{SW_3} \cdot L_{SW_3}$ $\quad W_{SW_3} = 10.1\,\text{klf}$

$h_{SW_4} := E_{RCCd} - E_{rock\_base}$ $\quad h_{SW_4} = 16.8\,\text{ft}$

$L_{SW_4} := L_{SW_3}$ $\quad L_{SW_4} = 16.8\,\text{ft}$

$x_{SW_4} := -L_{basin} - \frac{2}{3} \cdot L_{SW_4}$ $\quad x_{SW_4} = -66.2\,\text{ft}$

$W_{SW_4} := \gamma_{Sd} \cdot \frac{h_{SW_4} \cdot L_{SW_4}}{2}$ $\quad W_{SW_4} = 8.5\,\text{klf}$

Uplift at base:

$u_{head} := \gamma_w \cdot (E_{head} - E_{rock\_base})$ $\quad u_{head} = 3.550\,\text{ksf}$

$u_{tail} := \gamma_w \cdot (E_{tail} - E_{rock\_base})$ $\quad u_{tail} = 1.675\,\text{ksf}$

$L_{U_1} := L_{RCC_9} + L_{basin} + L_{C_4} + L_{C_5} + L_{C_6} + L_{RCC_5}$ $\quad L_{U_1} = 205.4\,\text{ft}$

$x_{U_1} := -L_{basin} - L_{RCC_9} + \frac{L_{U_1}}{2}$ $\quad x_{U_1} = 30.9\,\text{ft}$

$U_1 := u_{tail} \cdot L_{U_1}$ $\quad U_1 = 344.0\,\text{klf}$

$L_{U_2} := L_{U_1}$ $\quad L_{U_2} = 205.4\,\text{ft}$

$x_{U_2} := -L_{basin} - L_{RCC_9} + \frac{2}{3} \cdot L_{U_2}$ $\quad x_{U_2} = 65.1\,\text{ft}$

$U_2 := (u_{head} - u_{tail}) \cdot \frac{L_{U_2}}{2}$ $\quad U_2 = 192.6\,\text{klf}$

Lateral loads on dam:

$h_{H_1} := \min\left(\begin{pmatrix} E_{gate} - E_{rock\_base} \\ E_{head} - E_{rock\_base} \end{pmatrix}\right)$ $\quad h_{H_1} = 56.8\,\text{ft}$

$H_{H_1} := \gamma_w \cdot \max\left(\begin{pmatrix} E_{head} - E_{gate} \\ 0 \cdot \text{ft} \end{pmatrix}\right) \cdot h_{H_1}$ $\quad H_{H_1} = 0.0\,\text{klf}$

$y_{H_1} := \frac{h_{H_1}}{2}$ $\quad y_{H_1} = 28.4\,\text{ft}$

$h_{H_2} := h_{H_1}$ $\qquad h_{H_2} = 56.8\,\text{ft}$

$H_{H_2} := \gamma_w \cdot \frac{(h_{H_2})^2}{2}$ $\qquad H_{H_2} = 100.8\,\text{klf}$

$y_{H_2} := \frac{h_{H_2}}{3}$ $\qquad y_{H_2} = 18.9\,\text{ft}$

$h_{S_1} := E_{crest} - E_{rock\_base}$ $\qquad h_{S_1} = 38.8\,\text{ft}$

$H_{S_1} := k_{Su} \cdot \gamma_{Su} \cdot \frac{(h_{S_1})^2}{2}$ $\qquad H_{S_1} = 22.6\,\text{klf}$

$y_{S_1} := \frac{h_{S_1}}{3}$ $\qquad y_{S_1} = 12.9\,\text{ft}$

$h_{S_2} := E_{sill} - E_{rock\_base}$ $\qquad h_{S_2} = 26.8\,\text{ft}$

$H_{S_2} := -k_{Sd} \cdot \gamma_{Sd} \cdot \frac{(h_{S_2})^2}{2}$ $\qquad H_{S_2} = -10.8\,\text{klf}$

$y_{S_2} := \frac{h_{S_2}}{3}$ $\qquad y_{S_2} = 8.9\,\text{ft}$

$h_{T_1} := \max\left[\min\left(\begin{pmatrix} E_{tail\_redux} - E_{rock\_base} \\ E_{gate} - E_{rock\_base} \end{pmatrix}\right), 0 \cdot \text{ft}\right]$ $\qquad h_{T_1} = 26.8\,\text{ft}$

$H_{T_1} := \gamma_w \cdot \max\left(\begin{pmatrix} E_{tail\_redux} - E_{gate} \\ 0 \cdot \text{ft} \end{pmatrix}\right) \cdot h_{T_1}$ $\qquad H_{T_1} = 0.0\,\text{klf}$

$y_{T_1} := \frac{h_{T_1}}{2}$ $\qquad y_{T_1} = 13.4\,\text{ft}$

$h_{T_2} := h_{T_1}$ $\qquad h_{T_2} = 26.8\,\text{ft}$

$H_{T_2} := \gamma_w \cdot \frac{(h_{T_2})^2}{2}$ $\qquad H_{T_2} = 22.4\,\text{klf}$

$y_{T_2} := \frac{h_{T_2}}{3}$ $\qquad y_{T_2} = 8.9\,\text{ft}$

Sum vertical forces

$$\Sigma V := \sum_{i=1}^{12} W_{C_i} + \sum_{i=1}^{9} W_{RCC_i} + \sum_{i=1}^{4} W_{HW_i} + \sum_{i=1}^{6} W_{TW_i} + \sum_{i=1}^{4} W_{SW_i} - \sum_{i=1}^{2} U_i \qquad \Sigma V = 390.1\,\text{klf}$$

$$\Sigma H := \sum_{i=1}^{2} H_{H_i} + \sum_{i=1}^{2} H_{S_i} - \sum_{i=1}^{2} H_{T_i} \qquad \Sigma H = 90.2\,\text{klf}$$

$$M_{grav} := \sum_{i=1}^{12} W_{C_i} \cdot x_{C_i} + \sum_{i=1}^{9} W_{RCC_i} \cdot x_{RCC_i} + \sum_{i=1}^{4} W_{HW_i} \cdot x_{HW_i} \cdots + \sum_{i=1}^{6} W_{TW_i} \cdot x_{TW_i} + \sum_{i=1}^{4} W_{SW_i} \cdot x_{SW_i} - \sum_{i=1}^{2} U_i \cdot x_{U_i} \qquad M_{grav} = 17291\,\text{kip}$$

$$M_{lat} := \sum_{i=1}^{2} H_{H_i} \cdot y_{H_i} + \sum_{i=1}^{2} H_{S_i} \cdot y_{S_i} - \sum_{i=1}^{2} H_{T_i} \cdot y_{T_i} \qquad M_{lat} = 1904\,\text{kip}$$

$$\Sigma M := \left\lfloor M_{grav} + \Sigma V \cdot \left(L_{basin} + L_{RCC_9}\right)\right\rfloor - M_{lat} \qquad \Sigma M = 43399\,\frac{\text{ft}\cdot\text{kip}}{\text{ft}}$$

$$x_{res} := \frac{\Sigma M}{\Sigma V} \qquad x_{res} = 111.2\,\text{ft}$$

$$L_{rock} := L_{RCC_5} + L_{C_4} + L_{C_5} + L_{C_6} + L_{basin} + L_{RCC_9} \qquad L_{rock} = 205.4\,\text{ft}$$

$$frac := \frac{x_{res}}{L_{rock}} \qquad frac = 0.542$$

frac_text := if(frac > $\frac{2}{3}$, "Over stable", "")

frac_text := if(frac < $\frac{2}{3}$ ∧ frac ≥ $\frac{1}{3}$, "Resultant in middle third. Okay normal case.", frac_text)

frac_text := if(frac < $\frac{1}{3}$ ∧ frac ≥ $\frac{1}{4}$, "Resultant in middle half. Okay unusual case.", frac_text)

frac_text := if(frac < $\frac{1}{4}$ ∧ frac ≥ 0, "Resultant within base. Okay extreme case.", frac_text)

frac_text := if(frac < 0, "Unstable", frac_text) frac_text = "Resultant in middle third. Okay normal case."

$$L_{contact} := \min\left(3 \cdot x_{res}, L_{rock}\right) \qquad L_{contact} = 205.4\,\text{ft}$$

$\nu_{ult} := \Sigma V \cdot \tan(\phi_{RCC\_Rock})$ $\nu_{ult} = 181.9\,klf$ $\phi_{RCC\_Rock} = 25.0\,deg$

$FS_{sliding} := \frac{\nu_{ult}}{\Sigma H}$ $FS_{sliding} = 2.02$

$FS_{sliding\_reqd} := 2.0$

$ok := if(FS_{sliding} < FS_{sliding\_reqd}, \text{"Sliding instability "}, ok)$ $ok = \text{"Ok"}$

Base Pressures:

$e_{dam} := \frac{L_{rock}}{2} - x_{res}$ $e_{dam} = -8.54\,ft$ (eccentricity with respect to dam block centroid)

$e := \frac{L_{contact}}{2} - x_{res}$ $e = -8.54\,ft$ (eccentricity with respect to the compression area centroid)

$\sigma_{toe} := \frac{\Sigma V}{L_{contact}} + \frac{\Sigma V \cdot e}{\frac{L_{contact}^2}{6}}$ $\sigma_{toe} = 1.426\,ksf$

$\sigma_{heel} := \frac{\Sigma V}{L_{contact}} - \frac{\Sigma V \cdot e}{\frac{L_{contact}^2}{6}}$ $\sigma_{heel} = 2.373\,ksf$

$\frac{L_{contact}}{L_{rock}} = 100.0\%$

Dam Stability Analysis: (left end at shallow rock)

Reference:T:\ST\CALCS\Common geometry.mcd(R)

$k_{Su} = 0.5$ $E_{ramp} = 503.5\,ft$

$\gamma_{Su} = 60.0\,pcf$ $\phi_{conc\_rock} = 20.0\,deg$

$\phi_{shale} = 20.0\,deg$ $\phi_{limestone} = 40.0\,deg$

$\phi_{ls\_inc} = 50.0\,deg$ $eff_{drain} = 50\,\%$

$E_{ukey} = 488.0\,ft$ $E_{dkey} = 471.0\,ft$

$t_c = 6.0\,ft$

Geometry:

$E_{rock} := 503.5 \cdot ft - t_c$ $E_{rock} = 497.50\,ft$

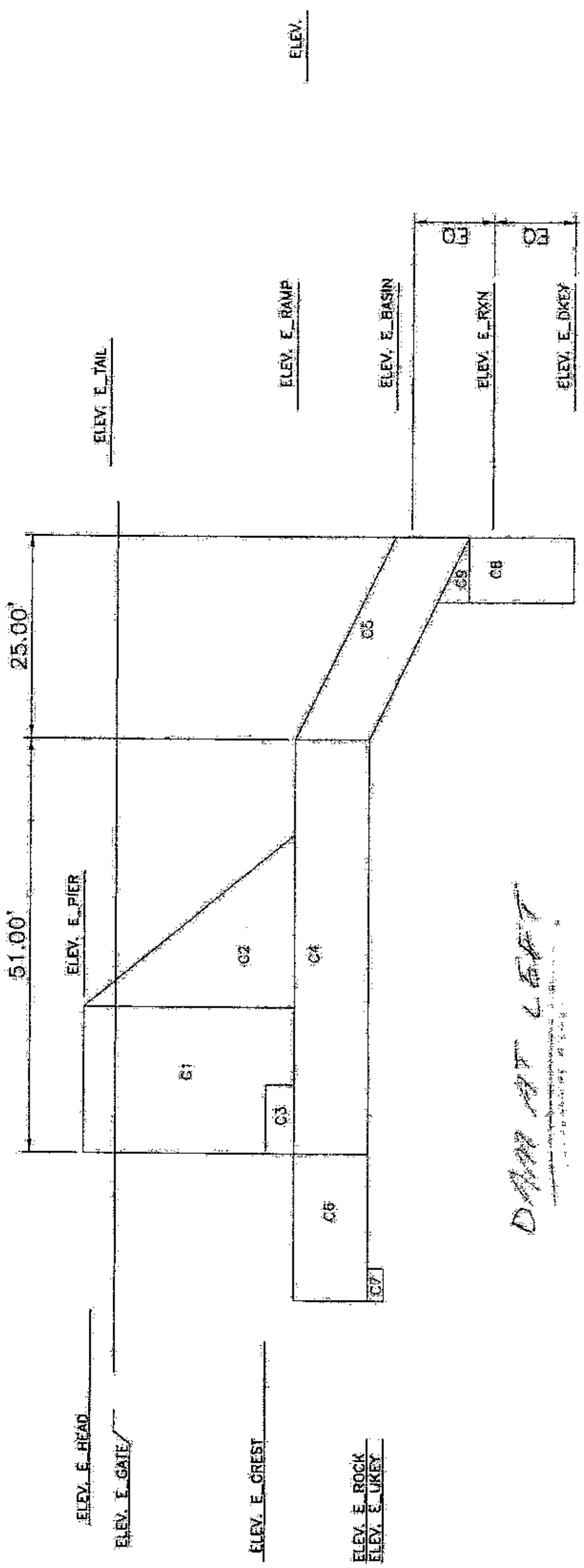
Constants:

Pre-Definitions:

$kip \equiv 1000 \cdot lbf$ $ksi \equiv 1000 \cdot psi$ $ok \equiv$ "Ok"

$psf \equiv \frac{lbf}{ft^2}$ $plf \equiv \frac{lbf}{ft}$ $ORIGIN = 1.0$

$pcf \equiv \frac{lbf}{ft^3}$ $klf \equiv 1000 \cdot plf$ $ksf := \frac{1000 \cdot lbf}{ft^2}$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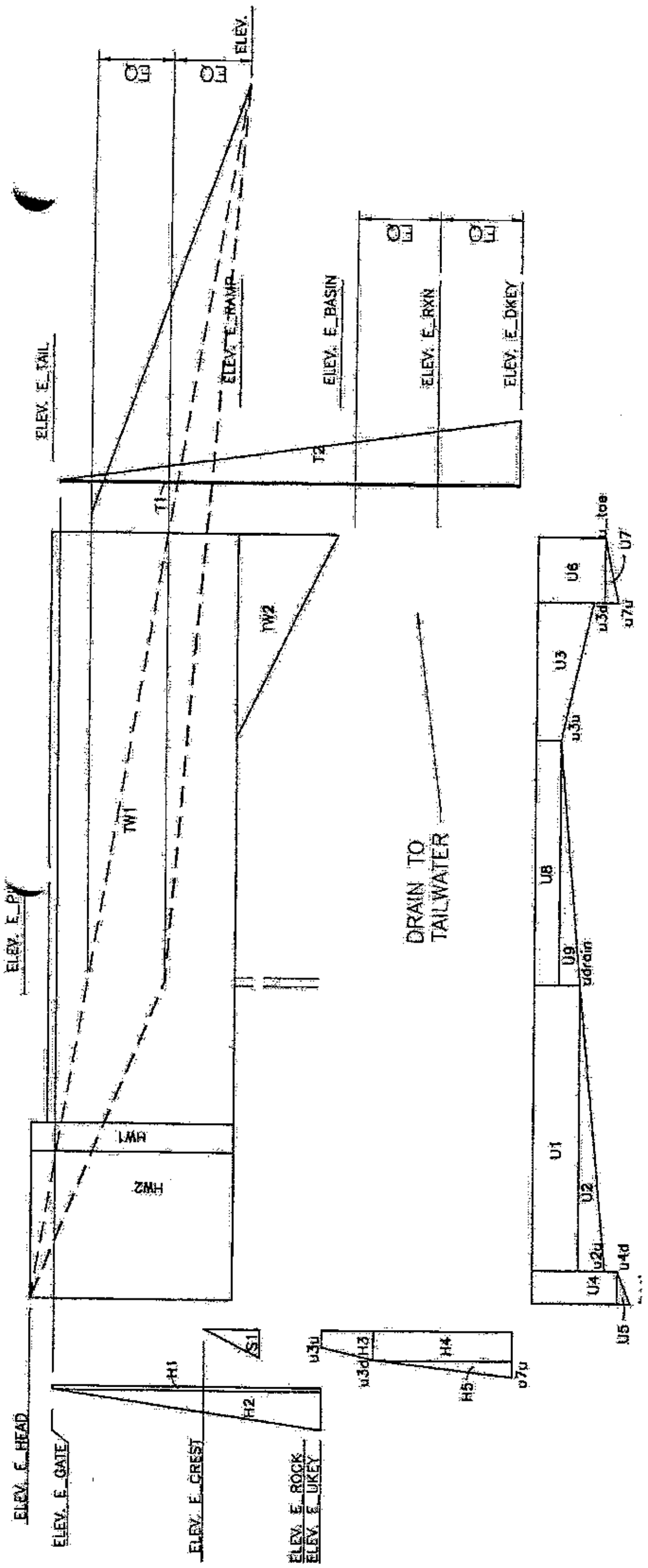
ELEV. E_TAIL
ELEV. E_RAMP
ELEV. E_BASIN
ELEV. E_RXN
ELEV. E_DKEY
D3
D3
25.00'
51.00'
ELEV. E_PIER
C1
C2
C3
C4
C5
C6
C7
C8
C9
ELEV. E_HEAD
ELEV. E_GATE
ELEV. E_CREST
ELEV. E_ROCK
ELEV. E_UKEY


ELEV.
EQ
EQ
ELEV. E_TAIL
ELEV. E_RAMP
ELEV. E_BASIN
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ELEV. E_DKEY
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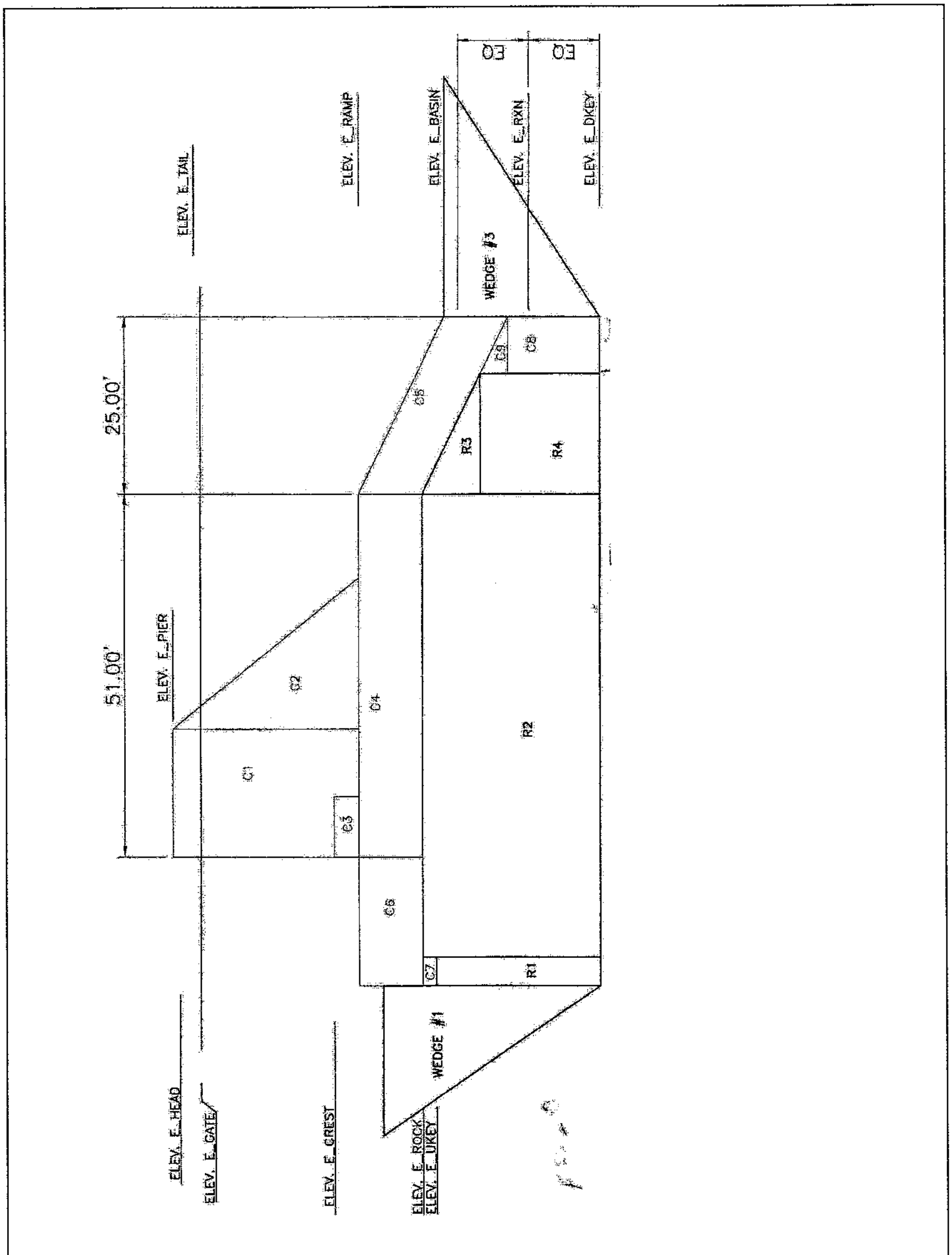
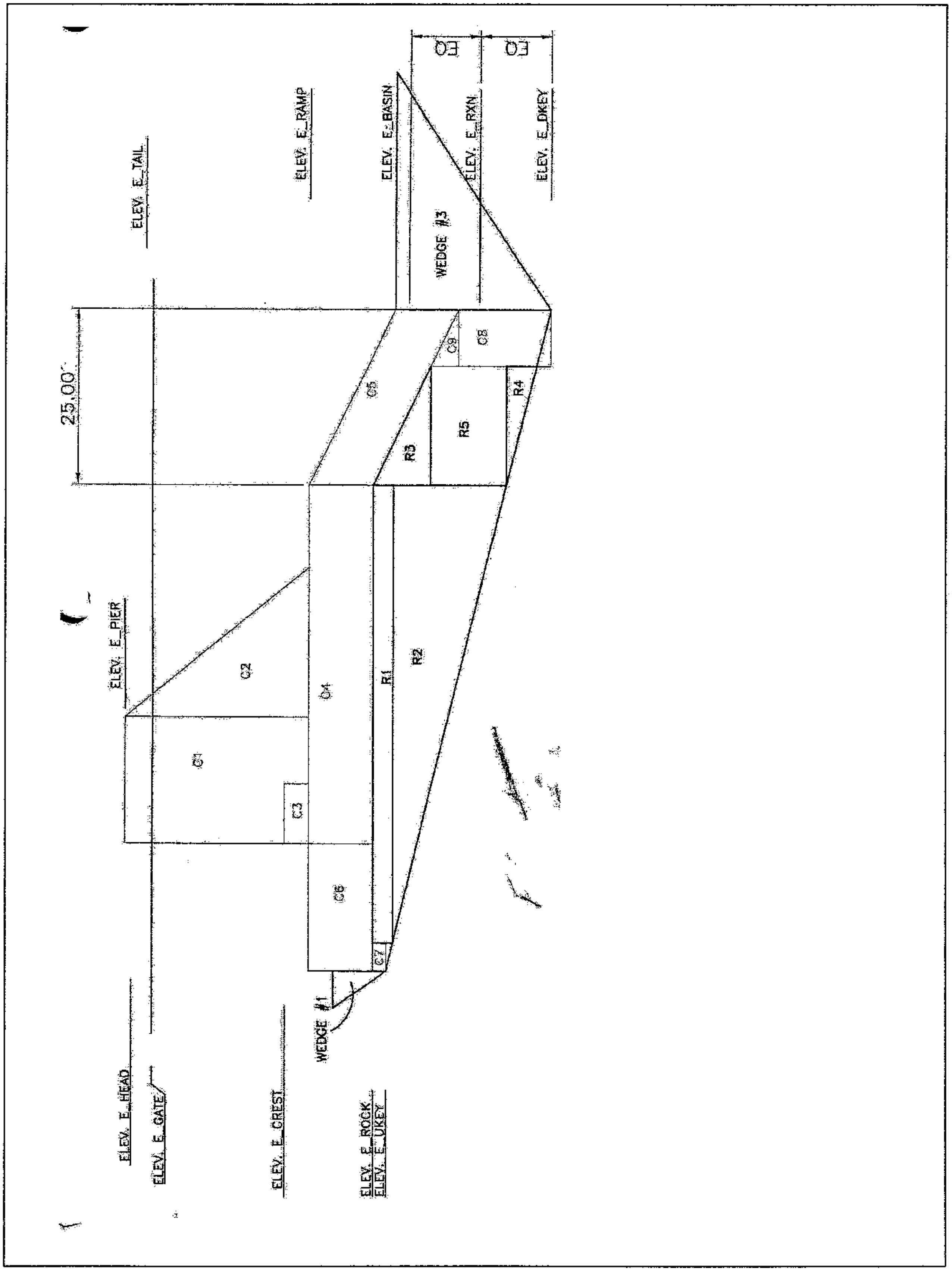
T1
T2
TW1
TW2
HW1
HW2
ELEV. E_PI
DRAIN TO TAILWATER
U1
U2
U3
U4
U5
U6
U7
U8
U9
u_toe
u3d
u7u
u3u
udrain
u2u
u4d
H1
H2
H3
H4
H5
S1
u3u
u3d
u7u
ELEV. E_HEAD
ELEV. E_GATE
ELEV. E_CREST
ELEV. E_ROCK
ELEV. E_UKEY


E0
E0
ELEV. E_TAIL
ELEV. E_RAMP
ELEV. E_BASIN
ELEV. E_RXN
ELEV. E_DKEY
WEDGE #3
25.00'
51.00'
ELEV. E_PIER
C1
C2
C3
C4
C5
C6
C7
C8
C9
R1
R2
R3
R4
WEDGE #1
ELEV. E_HEAD
ELEV. E_GATE
ELEV. E_CREST
ELEV. E_ROCK
ELEV. E_UKEY


ELEV. E_TAIL
ELEV. E_RAMP
ELEV. E_BASIN
ELEV. E_RXN
ELEV. E_DKEY
EQ
EQ
WEDGE #3
25.00'
C1
C2
C3
C4
C5
C6
C7
C8
C9
R1
R2
R3
R4
R5
ELEV. E_PIER
WEDGE #1
ELEV. E_HEAD
ELEV. E_GATE
ELEV. E_CREST
ELEV. E_ROCK
ELEV. E_UKEY

Analysis:

Self-weight of stucture:

$h_{C_5} := \frac{25 \cdot ft}{slope_{basin}}$ $h_{C_5} = 12.5\,ft$

$L_{C_5} := h_{C_5} \cdot slope_{basin}$ $L_{C_5} = 25.0\,ft$

$x_{C_5} := \frac{L_{C_5}}{2}$ $x_{C_5} = 12.5\,ft$

$W_{C_5} := \gamma_c \cdot \left[\left[h_{C_5} + (E_{ramp} - E_{rock})\right] \cdot L_{C_5} - h_{C_5} \cdot L_{C_5}\right]$ $W_{C_5} = 22.5\,klf$

$h_{C_4} := E_{ramp} - E_{rock}$ $h_{C_4} = 6.0\,ft$

$L_{C_4} := 51 \cdot ft$

$x_{C_4} := L_{C_5} + \frac{L_{C_4}}{2}$ $x_{C_4} = 50.5\,ft$

$W_{C_4} := \gamma_c \cdot h_{C_4} \cdot L_{C_4}$ $W_{C_4} = 45.9\,klf$

$h_{C_1} := E_{pier} - E_{ramp}$ $h_{C_1} = 26.5\,ft$

$L_{C_1} := 18 \cdot ft$

$x_{C_1} := L_{C_4} + L_{C_5} - \frac{L_{C_1}}{2}$ $x_{C_1} = 67.0\,ft$

$W_{C_1} := \gamma_c \cdot h_{C_1} \cdot L_{C_1} \cdot \frac{w_{pier}}{s_{pier}}$ $W_{C_1} = 10.2\,klf$

$h_{C_2} := h_{C_1}$ $h_{C_2} = 26.5\,ft$

$L_{C_2} := h_{C_2} \cdot \frac{1.00}{1.25}$ $L_{C_2} = 21.2\,ft$

$x_{C_2} := L_{C_4} + L_{C_5} - L_{C_1} - \frac{L_{C_2}}{3}$ $x_{C_2} = 50.9\,ft$

$W_{C_2} := \gamma_c \cdot \frac{h_{C_2} \cdot L_{C_2}}{2} \cdot \frac{w_{pier}}{s_{pier}}$ $W_{C_2} = 6.0\,klf$

$h_{C_3} := E_{crest} - E_{ramp}$ $\qquad h_{C_3} = 3.5\,ft$

$L_{C_3} := 8.5 \cdot ft$

$x_{C_3} := L_{C_4} + L_{C_5} - \frac{L_{C_3}}{2}$ $\qquad x_{C_3} = 71.8\,ft$

$W_{C_3} := \gamma_c \cdot h_{C_3} \cdot L_{C_3} \cdot \frac{(s_{pier} - w_{pier})}{s_{pier}}$ $\qquad W_{C_3} = 3.8\,klf$

$h_{C_6} := h_{C_4}$ $\qquad h_{C_6} = 6.0\,ft$

$L_{C_6} = 18.0\,ft$

$x_{C_6} := L_{C_4} + L_{C_5} + \frac{L_{C_6}}{2}$ $\qquad x_{C_6} = 85.0\,ft$

$W_{C_6} := \gamma_c \cdot h_{C_6} \cdot L_{C_6}$ $\qquad W_{C_6} = 16.2\,klf$

$L_{dam} := L_{C_4} + L_{C_5} + L_{C_6}$ $\qquad L_{dam} = 94.0\,ft$

$h_{C_7} := E_{rock} - E_{ukey}$ $\qquad h_{C_7} = 9.5\,ft$

$L_{C_7} := L_{ukey}$ $\qquad L_{C_7} = 6.0\,ft$

$x_{C_7} := L_{dam} - \frac{L_{C_7}}{2}$ $\qquad x_{C_7} = 91.0\,ft$

$W_{C_7} := \gamma_c \cdot h_{C_7} \cdot L_{C_7}$ $\qquad W_{C_7} = 8.6\,klf$

$h_{C_8} := E_{rock} - h_{C_5} - E_{dkey}$ $\qquad h_{C_8} = 14.0\,ft$

$L_{C_8} := L_{dkey}$ $\qquad L_{C_8} = 6.0\,ft$

$x_{C_8} := \frac{L_{C_8}}{2}$ $\qquad x_{C_8} = 3.0\,ft$

$W_{C_8} := \gamma_c \cdot h_{C_8} \cdot L_{C_8}$ $\qquad W_{C_8} = 12.6\,klf$

$$h_{C_9} := \frac{L_{C_8}}{slope_{basin}}$$ $h_{C_9} = 3.0\,ft$

$$L_{C_9} := L_{C_8}$$ $L_{C_9} = 6.0\,ft$

$$x_{C_9} := \frac{2}{3} \cdot L_{C_9}$$ $x_{C_9} = 4.0\,ft$

$$W_{C_9} := \gamma_c \cdot \frac{h_{C_9} \cdot L_{C_9}}{2}$$ $W_{C_9} = 1.4\,klf$

Gravity loads on structure

$h_{HW_1} := E_{head} - E_{crest}$ $\quad h_{HW_1} = 18.0\ ft$

$L_{HW_1} := 3.5 \cdot ft$ $\quad L_{HW_1} = 3.5\ ft$

$x_{HW_1} := L_{dam} - L_{C_6} - \dfrac{L_{HW_1}}{2}$ $\quad x_{HW_1} = 74.3\ ft$

$W_{HW_1} := \gamma_w \cdot h_{HW_1} \cdot L_{HW_1} \cdot \dfrac{(s_{pier} - w_{pier})}{s_{pier}}$ $\quad W_{HW_1} = 3.4\ klf$

$h_{HW_2} := E_{head} - E_{crest}$ $\quad h_{HW_2} = 18.0\ ft$

$L_{HW_2} := L_{C_6}$ $\quad L_{C_6} = 18.0\ ft$

$x_{HW_2} := x_{C_6}$ $\quad x_{HW_2} = 85.0\ ft$

$W_{HW_2} := \gamma_w \cdot h_{HW_2} \cdot L_{HW_2}$ $\quad W_{HW_2} = 20.3\ klf$

$h_{TW_1} := \max\left(\begin{pmatrix} E_{tail\_redux} - E_{ramp} \\ 0 \cdot ft \end{pmatrix}\right)$ $\quad h_{TW_1} = 0.0\ ft$

$L_{TW_1} := L_{dam} - L_{HW_1}$ $\quad L_{TW_1} = 90.5\ ft$

$x_{TW_1} := \dfrac{L_{TW_1}}{2}$ $\quad x_{TW_1} = 45.3\ ft$

$W_{TW_1} := \gamma_w \cdot h_{TW_1} \cdot L_{TW_1}$ $\quad W_{TW_1} = 0.0\ klf$

$h_{TW_2} := \max\left[\min\left(\begin{pmatrix} E_{tail\_redux} - E_{basin} \\ E_{ramp} - E_{basin} \end{pmatrix}\right), 0 \cdot ft\right]$ $\quad h_{TW_2} = 4.0\ ft$

$L_{TW_2} := h_{TW_2} \cdot slope_{basin}$ $\quad L_{TW_2} = 8.0\ ft$

$x_{TW_2} := \dfrac{L_{TW_2}}{3}$ $\quad x_{TW_2} = 2.7\ ft$

$W_{TW_2} := \gamma_w \cdot \dfrac{h_{TW_2} \cdot L_{TW_2}}{2}$ $\quad W_{TW_2} = 1.0\ klf$

Uplift at base (no tailwater reduction taken for turbulence and aeration)

$u_{heel} := \gamma_w \cdot (E_{head} - E_{ukey})$ $u_{heel} = 2.313\,ksf$

$E_{drain} := E_{tail} + \dfrac{(E_{head} - E_{tail}) \cdot (L_{basin} + x_{drain})}{L_{dam} + L_{basin}}$ $E_{drain} = 517.1\,ft$ (assumed uplift driving head at drain w/out drain active)

$\delta E_{drain} := eff_{drain} \cdot (E_{drain} - E_{tail})$ $\delta E_{drain} = 11.074\,ft$ (assumed head drop at upstream drain)

$u_{drain} := \gamma_w \cdot \max\left[\begin{bmatrix} E_{drain} - \delta E_{drain} - (E_{ramp} - t_c) \\ 0 \cdot ft \end{bmatrix}\right]$ $u_{drain} = 0.536\,ksf$

$\delta u_u := \dfrac{\gamma_w \cdot \lfloor E_{head} - (E_{drain} - \delta E_{drain}) \rfloor}{L_{dam} - x_{drain}}$ $\delta u_u = 0.03033041 \dfrac{ksf}{ft}$

$\delta u_d := \dfrac{\gamma_w \cdot \lfloor (E_{drain} - \delta E_{drain}) - E_{tail} \rfloor}{L_{basin} + x_{drain}}$ $\delta u_d = 0.00629195 \dfrac{ksf}{ft}$

$u2u := u_{drain} + \delta u_u \cdot (L_{dam} - x_{drain} - L_{ukey})$ $u2u = 1.537\,ksf$

$u4d := u2u + \gamma_w \cdot (h_{C_7})$ $u4d = 2.131\,ksf$

$u_{heel} := u4d + \delta u_u \cdot L_{ukey}$ $u_{heel} = 2.313\,ksf$

$\dfrac{u_{heel}}{\gamma_w} + E_{ukey} = 525.0\,ft$

$ok := if\left[\left(\dfrac{u_{heel}}{\gamma_w} + E_{ukey} = E_{head}\right), ok, \text{"Uplift pressures do not close."}\right]$ $ok = \text{"Ok"}$

$u3u := u_{drain} - \delta u_d \cdot (x_{drain} - L_{C_5})$ $u3u = 0.347\,ksf$

$u3d := u3u + \gamma_w \cdot (h_{C_5} - h_{C_9}) - \delta u_d \cdot (L_{C_5} - L_{C_9})$ $u3d = 0.821\,ksf$

$u7u := u3d + \gamma_w \cdot (h_{C_8} + h_{C_9})$ $u7u = 1.884\,ksf$

$u_{toe} := u7u - \delta u_d \cdot L_{dkey}$ $u_{toe} = 1.846\,ksf$

$\dfrac{u_{toe} - \delta u_d \cdot L_{basin}}{\gamma_w} + E_{dkey} = 495.0\,ft$

$ok := if\left[\left(\dfrac{u_{toe} - \delta u_d \cdot L_{basin}}{\gamma_w} + E_{dkey} = E_{tail}\right), ok, \text{"Uplift pressures do not close."}\right]$ $ok = \text{"Ok"}$

$L_{U_1} := L_{dam} - x_{drain} - L_{ukey}$ $\quad L_{U_1} = 33.0\,ft$

$x_{U_1} := x_{drain} + \frac{L_{U_1}}{2}$ $\quad x_{U_1} = 71.5\,ft$

$U_1 := u_{drain} \cdot L_{U_1}$ $\quad U_1 = 17.7\,klf$

$L_{U_2} := L_{U_1}$ $\quad L_{U_2} = 33.0\,ft$

$x_{U_2} := x_{drain} + \frac{2}{3} \cdot L_{U_2}$ $\quad x_{U_2} = 77.0\,ft$

$U_2 := (u2u - u_{drain}) \cdot \frac{L_{U_2}}{2}$ $\quad U_2 = 16.5\,klf$

$L_{U_3} := L_{C_5} - L_{dkey}$ $\quad L_{U_3} = 19.0\,ft$

$U_{rect} := L_{U_3} \cdot \min(u3d, u3u)$ $\quad U_{rect} = 6.595\,klf$

$U_{tri} := \frac{L_{U_3} \cdot |u3d - u3u|}{2}$ $\quad U_{tri} = 4.505\,klf$

$x_{U_3} := \frac{\frac{L_{U_3}}{2} \cdot U_{rect} + \frac{L_{U_3}}{3} \cdot U_{tri} \cdot \text{if}(u3d > u2u, 2, 1)}{U_{rect} + U_{tri}} + L_{C_9}$ $\quad x_{U_3} = 14.2\,ft$

$U_3 := U_{rect} + U_{tri}$ $\quad U_3 = 11.100\,klf$

$L_{U_4} := L_{ukey}$ $\quad L_{U_4} = 6.0\,ft$

$x_{U_4} := L_{dam} - \frac{L_{U_4}}{2}$ $\quad x_{U_4} = 91.0\,ft$

$U_4 := u4d \cdot L_{U_4}$ $\quad U_4 = 12.783\,klf$

$L_{U_5} := L_{U_4}$ $\quad L_{U_5} = 6.0\,ft$

$x_{U_5} := L_{dam} - \frac{L_{U_5}}{3}$ $\quad x_{U_5} = 92.0\,ft$

$U_5 := \frac{(u_{heel} - u4d) \cdot L_{U_5}}{2}$ $\quad U_5 = 0.546\,klf$

$L_{U_6} := L_{dkey}$ $\quad L_{U_6} = 6.0\,ft$

$x_{U_6} := \frac{L_{U_6}}{2}$ $\quad x_{U_6} = 3.0\,ft$

$U_6 := u_{toe} \cdot L_{U_6}$ $\quad U_6 = 11.076\,klf$

$L_{U_7} := L_{dkey}$ $\quad L_{U_7} = 6.0\,ft$

$x_{U_7} := \frac{2}{3} \cdot L_{U_7}$ $\quad x_{U_7} = 4.0\,ft$

$U_7 := \frac{(u7u - u_{toe}) \cdot L_{U_7}}{2}$ $\quad U_7 = 0.113\,klf$

$L_{U_8} := x_{drain} - L_{C_5}$ $\quad L_{U_8} = 30.0\,ft$

$x_{U_8} := L_{C_5} + \frac{L_{U_8}}{2}$ $\quad x_{U_8} = 40.0\,ft$

$U_8 := u3u \cdot L_{U_8}$ $\quad U_8 = 10.4\,klf$

$L_{U_9} := L_{U_8}$ $\quad L_{U_9} = 30.0\,ft$

$x_{U_9} := L_{C_5} + \frac{2}{3} \cdot L_{U_9}$ $\quad x_{U_9} = 45.0\,ft$

$U_9 := \frac{(u_{drain} - u3u) \cdot L_{C_9}}{2}$ $\quad U_9 = 0.566\,klf$

Lateral loads on dam:

$E_{rxn} := \frac{E_{basin} - 2 \cdot ft + E_{dkey}}{2}$ $E_{rxn} = 480.0\,ft$ <--- Verify

$h_{H_1} := \min\left(\begin{pmatrix} E_{gate} - E_{ukey} \\ E_{head} - E_{ukey} \end{pmatrix}\right)$ $h_{H_1} = 37.0\,ft$

$H_{H_1} := \gamma_w \cdot \max\left(\begin{pmatrix} E_{head} - E_{gate} \\ 0 \cdot ft \end{pmatrix}\right) \cdot h_{H_1}$ $H_{H_1} = 0.0\,klf$

$y_{H_1} := \frac{h_{H_1}}{2} + (E_{rock} - E_{rxn})$ $y_{H_1} = 36.0\,ft$

$h_{H_2} := h_{H_1}$ $h_{H_2} = 37.0\,ft$

$H_{H_2} := \gamma_w \cdot \frac{(h_{H_2})^2}{2}$ $H_{H_2} = 42.8\,klf$

$y_{H_2} := \frac{h_{H_2}}{3} + (E_{rock} - E_{rxn})$ $y_{H_2} = 29.8\,ft$

$h_{H_3} := E_{ukey} - (E_{dkey} + h_{C_8} + h_{C_9})$ $h_{H_3} = 0.00\,ft$

$H_{rect} := h_{H_3} \cdot \min(u3d, u3u)$ $H_{rect} = 0.00\,klf$

$H_{tri} := \frac{h_{H_3} \cdot |u3d - u3u|}{2}$ $H_{tri} = 0.00\,klf$

$H_{H_3} := H_{rect} + H_{tri}$ $H_{H_3} = 0.00\,klf$

$y_{H_3} := \frac{H_{rect} \cdot \frac{h_{H_3}}{2} + H_{tri} \cdot \frac{h_{H_3}}{3} \cdot \text{if}(u3d > u3u, 1, 2)}{H_{H_3}} + h_{C_8} + E_{dkey} - E_{rxn}$ $y_{H_3} = 5.00\,ft$

$h_{H_4} := h_{C_8} + h_{C_9}$ $h_{H_4} = 17.0\,ft$

$H_{H_4} := u3d \cdot h_{H_4}$ $H_{H_4} = 14.0\,klf$

$y_{H_4} := \frac{h_{H_4}}{2} - (E_{rxn} - E_{dkey})$ $y_{H_4} = -0.5\,ft$

$h_{H_5} := h_{H_4}$ $h_{H_5} = 17.0\,ft$

$$H_{H_5} := \frac{(u7u - u3d) \cdot h_{H_5}}{2} \qquad H_{H_5} = 9.0\,\text{klf}$$

$$y_{H_5} := \frac{h_{H_5}}{3} + (E_{dkey} - E_{rxn}) \qquad y_{H_5} = -3.3\,\text{ft}$$

$$h_{S1} := E_{crest} - E_{approach} \qquad h_{S1} = 7.0\,\text{ft}$$

$$H_{S1} := k_{Su} \cdot \gamma_{Su} \cdot \frac{h_{S1}^{\,2}}{2} \qquad H_{S1} = 0.7\,\text{klf}$$

$$y_{S1} := \frac{h_{S1}}{3} + (E_{approach} - E_{rxn}) \qquad y_{S1} = 22.3\,\text{ft}$$

$$h_{T_1} := \max\left[\min\left(\begin{pmatrix} E_{tail\_redux} - E_{dkey} \\ E_{gate} - E_{dkey} \end{pmatrix}\right), 0 \cdot \text{ft}\right] \qquad h_{T_1} = 24.0\,\text{ft}$$

$$H_{T_1} := \gamma_w \cdot \max\left(\begin{pmatrix} E_{tail\_redux} - E_{gate} \\ 0 \cdot \text{ft} \end{pmatrix}\right) \cdot h_{T_1} \qquad H_{T_1} = 0.0\,\text{klf}$$

$$y_{T_1} := \frac{h_{T_1}}{2} + (E_{dkey} - E_{rxn}) \qquad y_{T_1} = 3.0\,\text{ft}$$

$$h_{T_2} := h_{T_1} \qquad h_{T_2} = 24.0\,\text{ft}$$

$$H_{T_2} := \gamma_w \cdot \frac{\left(h_{T_2}\right)^2}{2} \qquad H_{T_2} = 18.0\,\text{klf}$$

$$y_{T_2} := \frac{h_{T_2}}{3} + (E_{dkey} - E_{rxn}) \qquad y_{T_2} = -1.0\,\text{ft}$$

Sum vertical forces:

$$\Sigma V := \sum_{i=1}^{9} W_{C_i} + \sum_{i=1}^{2} W_{HW_i} + \sum_{i=1}^{2} W_{TW_i} - \sum_{i=1}^{9} U_i \qquad \Sigma V = 71.0\,klf$$

$$M_{grav} := \sum_{i=1}^{9} W_{C_i} \cdot x_{C_i} + \sum_{i=1}^{2} W_{HW_i} \; x_{HW_i} + \sum_{i=1}^{2} W_{TW_i} \cdot x_{TW_i} - \sum_{i=1}^{9} U_i \cdot x_{U_i} \qquad M_{grav} = 3654.8\,kip$$

$$\Sigma H := \sum_{i=1}^{5} H_{H_i} + H_{S1} - \sum_{i=1}^{2} H_{T_i} \qquad \Sigma H = 48.5\,klf$$

$$M_{lat} := \sum_{i=1}^{5} H_{H_i} \cdot y_{H_i} + H_{S1} \cdot y_{S1} - \sum_{i=1}^{2} H_{T_i} \cdot y_{T_i} \qquad M_{lat} = 1273.6\,kip$$

$$\Sigma M := M_{grav} - M_{lat} \qquad \Sigma M = 2381.2 \frac{ft \cdot kip}{ft}$$

$$x_{res} := \frac{\Sigma M}{\Sigma V} \qquad x_{res} = 33.5\,ft$$

$$frac := \frac{x_{res}}{L_{dam}} \qquad frac = 0.357$$

$$frac\_text := if\left(frac > \frac{2}{3}, \text{"Over stable"}, \text{""}\right)$$

$$frac\_text := if\left(frac < \frac{2}{3} \wedge frac \ge \frac{1}{3}, \text{"Resultant in middle third. Okay normal case."}, frac\_text\right)$$

$$frac\_text := if\left(frac < \frac{1}{3} \wedge frac \ge \frac{1}{4}, \text{"Resultant in middle half. Unusual case only."}, frac\_text\right)$$

$$frac\_text := if\left(frac < \frac{1}{4} \wedge frac \ge 0, \text{"Resultant within base. Extreme case only."}, frac\_text\right)$$

$$frac\_text := if(frac < 0, \text{"Unstable"}, frac\_text) \qquad frac\_text = \text{"Resultant in middle third. Okay normal case."}$$

$$L_{contact} := \min(3 \cdot x_{res}, L_{dam}) \qquad L_{contact} = 94.0\,ft$$

$$\sum_{i=1}^{9} W_{C_i} = 127.2\,klf \qquad frac = 0.357$$

frac_text = "Resultant in middle third. Okay normal case."

Base Pressures:

$$e_{dam} := \frac{L_{dam}}{2} - x_{res}$$ $e_{dam} = 13.46\,ft$ (eccentricity with respect to dam centroid)

$$e := \frac{L_{contact}}{2} - x_{res}$$ $e = 13.46\,ft$ (eccentricity with respect to compression area centroid)

$$\sigma_{toe} := \frac{\Sigma V}{L_{contact}} + \frac{\Sigma V \cdot e}{\frac{L_{contact}^{2}}{6}}$$ $\sigma_{toe} = 1.404\,ksf$

$$\sigma_{heel} := \frac{\Sigma V}{L_{contact}} - \frac{\Sigma V \cdot e}{\frac{L_{contact}^{2}}{6}}$$ $\sigma_{heel} = 0.106\,ksf$

$$\frac{L_{contact}}{L_{dam}} = 100.0\%$$

$x_{res} = 33.5\,ft$

$\Sigma V = 71.0\,klf$

$\Sigma H = 48.5\,klf$

Sliding Stability Analysis: Failure plane from key-to-key.

Compute driving wedge properties: (1st wedge)

$\phi_1 := \phi_{ls\_inc}$ $\qquad \phi_1 = 50.0\,deg$

$c_1 := 0 \cdot ksf$

$\phi_{d_1} := atan\left(\frac{tan(\phi_1)}{FS_1}\right)$ $\qquad \phi_{d_1} = 29.4\,deg$

$\alpha_1 := -\left(45 \cdot deg + \frac{\phi_{d_1}}{2}\right)$ $\qquad \alpha_1 = -59.7\,deg$

$L_{v_1} := E_{approach} - E_{ukey}$ $\qquad L_{v_1} = 12.0\,ft$

$L_{h_1} := \frac{L_{v_1}}{tan(-\alpha_1)}$ $\qquad L_{h_1} = 7.0\,ft$

$L_1 := \sqrt{(L_{v_1})^2 + (L_{h_1})^2}$ $\qquad L_1 = 13.9\,ft$

$W_1 := \gamma_{rock} \cdot \frac{L_{h_1} \cdot L_{v_1}}{2}$ $\qquad W_1 = 5.5\,klf$

$V_1 := \gamma_w \cdot (E_{head} - E_{approach}) \cdot L_{h_1}$ $\qquad V_1 = 11.0\,klf$

$HL_1 := 0 \cdot klf$

$HR_1 := 0 \cdot klf$

$U_1 := \gamma_w \cdot \left(E_{head} - \frac{E_{approach} + E_{ukey}}{2}\right) \cdot L_1$ $\qquad U_1 = 26.9\,klf$

Compute structural wedge properties: (2nd wedge)

$\phi_2 := \phi_{ls\_inc}$ $\phi_2 = 50.0\,deg$

$c_2 := 0\ ksf$

$\alpha_2 := -atan\left(\frac{E_{ukey} - E_{dkey}}{L_{dam}}\right)$ $\alpha_2 = -10.25\,deg$

$L_{R_1} := L_{C_4} + L_{C_6} - L_{C_7}$ $L_{R_1} = 63.0\,ft$

$h_{R_1} := L_{C_7} \cdot tan(\alpha_2) + h_{C_7}$ $h_{R_1} = 8.41\,ft$

$x_{R_1} := L_{C_5} + \frac{L_{R_1}}{2}$ $x_{R_1} = 56.5\,ft$

$R_1 := \gamma_{rock} \cdot h_{R_1} \cdot L_{R_1}$ $R_1 = 68.9\,klf$

$L_{R_2} := L_{R_1}$ $L_{R_2} = 63.0\,ft$

$h_{R_2} := L_{R_2} \cdot tan(|\alpha_2|)$ $h_{R_2} = 11.39\,ft$

$x_{R_2} := L_{C_5} + \frac{L_{R_2}}{3}$ $x_{R_2} = 46.00\,ft$

$R_2 := \gamma_{rock} \cdot \frac{h_{R_2} \cdot L_{R_2}}{2}$ $R_2 = 46.7\,klf$

$L_{R_3} := (h_{C_5} - h_{C_9}) \cdot slope_{basin}$ $L_{R_3} = 19.0\,ft$

$h_{R_3} := h_{C_5} - h_{C_9}$ $h_{R_3} = 9.5\,ft$

$x_{R_3} := L_{C_5} - \frac{L_{R_3}}{3}$ $x_{R_3} = 18.7\,ft$

$R_3 := \gamma_{rock} \cdot \frac{h_{R_3} \cdot L_{R_3}}{2}$ $R_3 = 11.7\,klf$

$L_{R_4} := L_{C_5} - L_{C_9}$ $L_{R_4} = 19.0\,ft$

$h_{R_4} := L_{R_4} \cdot tan(|\alpha_2|)$ $h_{R_4} = 3.4\,ft$

$x_{R_4} := L_{C_9} + \frac{L_{R_4}}{3}$ $x_{R_4} = 12.3\,ft$

$R_4 := \gamma_{rock} \cdot \frac{h_{R_4} \cdot L_{R_4}}{2}$ $R_4 = 4.2\,klf$

$L_{R_5} := L_{R_4}$ $L_{R_5} = 19.0\,ft$

$h_{R_5} := h_{C_8} + h_{C_9} - L_{C_5} \cdot \tan(\alpha_2)$ $h_{R_5} = 21.52\,ft$

$R_5 := \gamma_{rock} \cdot h_{R_5} \cdot L_{R_5}$ $R_5 = 53.2\,klf$

$x_{R_5} := L_{C_9} + \frac{L_{R_5}}{2}$ $x_{R_5} = 15.5\,ft$

$W_2 := \sum_{i=1}^{9} W_{C_i} + \sum_{i=1}^{2} W_{HW_i} + \sum_{i=1}^{2} W_{TW_i} + \sum_{i=1}^{5} R_i$ $W_2 = 336.5\,klf$

$L_2 := \frac{L_{dam}}{\cos(\alpha_2)}$ $L_2 = 95.5\,ft$

$HL_2 := \gamma_w \cdot \frac{(E_{head} - E_{approach})^2}{2}$ $HL_2 = 19.5\,klf$

$HR_2 := \gamma_w \cdot \frac{\left[\max\left(\begin{pmatrix} E_{tail\_redux} - E_{basin} \\ 0 \cdot ft \end{pmatrix}\right)\right]^2}{2}$ $HR_2 = 0.5\,klf$

$V_2 := 0 \cdot klf$

$U_2 := \gamma_w \cdot \frac{\left[(E_{head} - E_{ukey}) + (E_{tail\_redux} - E_{dkey})\right]}{2} \cdot L_2$ $U_2 = 182.1\,klf$

Note: This assumes full compression. <--- Verify

Compute resisting wedge properties:

$\phi_3 := \phi_{ls\_inc}$ $\phi_3 = 50.0\,deg$

$c_3 := 0 \cdot ksf$

$\phi_{d_3} := atan\left(\frac{tan(\phi_3)}{FS_1}\right)$ $\phi_{d_3} = 29.4\,deg$

$\alpha_3 := 45 \cdot deg - \frac{\phi_{d_3}}{2}$ $\alpha_3 = 30.3\,deg$

$L_{v_3} := E_{basin} - E_{dkey}$ $L_{v_3} = 20.0\,ft$

$L_{h_3} := \frac{L_{v_3}}{tan(\alpha_3)}$ $L_{h_3} = 34.2\,ft$

$L_3 := \sqrt{(L_{v_3})^2 + (L_{h_3})^2}$ $L_3 = 39.6\,ft$

$W_3 := \gamma_{rock} \cdot \frac{L_{h_3} \cdot L_{v_3}}{2}$ $W_3 = 44.5\,klf$

$V_3 := \gamma_w \cdot (E_{tail} - E_{basin}) \cdot L_{h_3}$ $V_3 = 8.6\,klf$

$HL_3 := 0 \quad klf$ $HR_3 := 0 \cdot klf$

$U_3 := \gamma_w \cdot \left(E_{tail} - \frac{E_{basin} + E_{dkey}}{2}\right) \cdot L_3$ $U_3 = 34.7\,klf$

$i := 1 .. 3$

$$\Delta P_i := \frac{\left\lfloor (W_i + V_i) \cdot cos(\alpha_i) - U_i + (HL_i - HR_i) \cdot sin(\alpha_i) \right\rfloor \cdot \frac{tan(\phi_i)}{FS_1} \ldots + -(HL_i - HR_i) \cdot cos(\alpha_i) + (W_i + V_i) \cdot sin(\alpha_i) + \frac{c_i}{FS_1} \cdot L_i}{\left(cos(\alpha_i) - sin(\alpha_i) \cdot \frac{tan(\phi_i)}{FS_1}\right)}$$

$\Delta P = \begin{pmatrix} -24.9 \\ 3.2 \\ 57.1 \end{pmatrix} klf$ $\Sigma P := \sum_i \Delta P_i$ $\Sigma P = 35.376\,klf$ $FS_1 \equiv 2.11386$

Sliding Stability Analysis: Failure plane level with downstream key.

Compute driving wedge properties: (1st wedge)

$\phi_1 := \phi_{ls\_inc}$ $\qquad \phi_1 = 50.0\,\text{deg}$

$c_1 := 0 \cdot \text{ksf}$

$\phi_{d_1} := \text{atan}\left(\frac{\tan(\phi_1)}{FS_2}\right)$ $\qquad \phi_{d_1} = 29.2\,\text{deg}$

$\alpha_1 := -\left(45 \cdot \text{deg} + \frac{\phi_{d_1}}{2}\right)$ $\qquad \alpha_1 = -59.6\,\text{deg}$

$Lv_1 := E_{approach} - E_{dkey}$ $\qquad Lv_1 = 29.0\,\text{ft}$

$Lh_1 := \frac{Lv_1}{\tan(-\alpha_1)}$ $\qquad Lh_1 = 17.0\,\text{ft}$

$L_1 := \sqrt{(Lv_1)^2 + (Lh_1)^2}$ $\qquad L_1 = 33.6\,\text{ft}$

$W_1 := \gamma_{rock} \cdot \frac{Lh_1 \cdot Lv_1}{2}$ $\qquad W_1 = 32.1\,\text{klf}$

$V_1 := \gamma_w \cdot (E_{head} - E_{approach}) \cdot Lh_1$ $\qquad V_1 = 26.6\,\text{klf}$

$HL_1 := 0 \cdot \text{klf}$

$HR_1 := 0 \cdot \text{klf}$

$U_1 := \gamma_w \cdot \left(E_{head} - \frac{E_{approach} + E_{dkey}}{2}\right) \cdot L_1$ $\qquad U_1 = 83.0\,\text{klf}$

Compute structural wedge properties: (2nd wedge)

$\phi_2 := \phi_{shale}$ $\phi_2 = 20.0\,deg$

$c_2 := 0\ \ ksf$

$\alpha_2 := atan\left(\frac{E_{dkey} - E_{dkey}}{L_{dam}}\right)$ $\alpha_2 = 0.00\,deg$

$L_{R_1} := L_{C_7}$ $L_{R_1} = 6.0\,ft$

$h_{R_1} := E_{ukey} - E_{dkey}$ $h_{R_1} = 17.00\,ft$

$x_{R_1} := L_{dam} - \frac{L_{C_7}}{2}$ $x_{R_1} = 91.00\,ft$

$R_1 := \gamma_{rock} \cdot h_{R_1} \cdot L_{R_1}$ $R_1 = 13.3\,klf$

$L_{R_2} := L_{C_4} + L_{C_6} - L_{C_7}$ $L_{R_2} = 63.00\,ft$

$h_{R_2} := E_{rock} - E_{dkey}$ $h_{R_2} = 26.50\,ft$

$x_{R_2} := L_{C_5} + \frac{L_{R_2}}{2}$ $x_{R_2} = 56.50\,ft$

$R_2 := \gamma_{rock} \cdot h_{R_2} \cdot L_{R_2}$ $R_2 = 217.0\,klf$

$L_{R_3} := L_{C_5} - L_{C_9}$ $L_{R_3} = 19.00\,ft$

$h_{R_3} := h_{R_2} - \left(h_{C_8} + h_{C_9}\right)$ $h_{R_3} = 9.50\,ft$

$x_{R_3} := L_{C_5} - \frac{L_{R_3}}{3}$ $x_{R_3} = 18.7\,ft$

$R_3 := \gamma_{rock} \cdot \frac{h_{R_3} \cdot L_{R_3}}{2}$ $R_3 = 11.7\,klf$

$L_{R_4} := L_{C_5} - L_{C_9}$ $L_{R_4} = 19.00\,ft$

$h_{R_4} := h_{C_8} + h_{C_9}$ $h_{R_4} = 17.00\,ft$

$x_{R_4} := L_{C_9} + \frac{L_{R_4}}{2}$ $x_{R_4} = 15.50\,ft$

$R_4 := \gamma_{rock} \cdot h_{R_4} \cdot L_{R_4}$ $R_4 = 42.0\,klf$

$$W_2 := \sum_{i=1}^{9} W_{C_i} + \sum_{i=1}^{2} W_{HW_i} + \sum_{i=1}^{2} W_{TW_i} + \sum_{i=1}^{4} R_i \qquad W_2 = 435.8\,\text{klf}$$

$$L_2 := \frac{L_{dam}}{\cos(\alpha_2)} \qquad L_2 = 94.0\,\text{ft}$$

$$HL_2 := \gamma_w \cdot \frac{\left(E_{head} - E_{approach}\right)^2}{2} \qquad HL_2 = 19.5\,\text{klf}$$

$$HR_2 := \gamma_w \cdot \frac{\left[\max\left(\begin{pmatrix} E_{tail\_redux} - E_{basin} \\ 0 \cdot \text{ft} \end{pmatrix}\right)\right]^2}{2} \qquad HR_2 = 0.5\,\text{klf}$$

$$V_2 := 0 \cdot \text{klf}$$

$$U_2 := \gamma_w \cdot \frac{\left\lfloor \left(E_{head} - E_{ukey}\right) + \left(E_{tail} - E_{dkey}\right) \right\rfloor}{2} \; L_2 \qquad U_2 = 179.2\,\text{klf}$$

Note: This assumes full compression <--- Verify

Compute resisting wedge properties:

$\phi_3 := \phi_{ls\_inc}$ $\phi_3 = 50.0\ deg$

$c_3 := 0 \cdot ksf$

$\phi_{d_3} := atan\left(\frac{tan(\phi_3)}{FS_2}\right)$ $\phi_{d_3} = 29.2\ deg$

$\alpha_3 := 45\ deg - \frac{\phi_{d_3}}{2}$ $\alpha_3 = 30.4\ deg$

$L_{v_3} := E_{basin} - E_{dkey}$ $L_{v_3} = 20.0\ ft$

$L_{h_3} := \frac{L_{v_3}}{tan(\alpha_3)}$ $L_{h_3} = 34.1\ ft$

$L_3 := \sqrt{(L_{v_3})^2 + (L_{h_3})^2}$ $L_3 = 39.5\ ft$

$W_3 := \gamma_{rock} \cdot \frac{L_{h_3} \cdot L_{v_3}}{2}$ $W_3 = 44.3\ klf$

$V_3 := \gamma_w\ (E_{tail} - E_{basin}) \cdot L_{h_3}$ $V_3 = 8.5\ klf$

$HL_3 := 0 \cdot klf$

$HR_3 := 0 \cdot klf$

$U_3 := \gamma_w \cdot \left(E_{tail} - \frac{E_{basin} + E_{dkey}}{2}\right) \cdot L_3$ $U_3 = 34.6\ klf$

$i := 1..3$

$$\Delta P_i := \frac{\left\lfloor (W_i + V_i)\ cos(\alpha_i) - U_i + (HL_i - HR_i) \cdot sin(\alpha_i) \right\rfloor \cdot \frac{tan(\phi_i)}{FS_2} \ldots + -(HL_i - HR_i) \cdot cos(\alpha_i) + (W_i + V_i) \cdot sin(\alpha_i) + \frac{c_i}{FS_2} \cdot L_i}{\left(cos(\alpha_i) - sin(\alpha_i) \cdot \frac{tan(\phi_i)}{FS_2}\right)}$$

$\Delta P = \begin{pmatrix} -81.38 \\ 24.71 \\ 56.67 \end{pmatrix} klf$ $\Sigma P := \sum_i \Delta P_i$ $\Sigma P = 0.000\ klf$ $FS_2 \equiv 2.13534$

$LC_6 \equiv 18\ ft$