ANCHORED SOLDIER PILE DESIGN

ANCHORED SOLDIER PILE retaining wall;
Refer to California Trenching and Shoring Design Manual ’90 (Nomenclature has been changed slightly in calculation);

Geometry and soil parameters:
Exposed wall height: $H=7.0\text{ft}$
Distance to anchor from top of wall: $a=1.5\text{ft}$
Angle of anchor from horizontal: $\theta=15\degree$
Spacing of piles: $S=4\text{ft}$
Width of piles: $b=3.5\text{in}$
Soil weight: $\gamma=120\text{pcf}$
Frictional angle: $\phi_i=28\degree$
Interface friction angle (at back of wall): $\delta_i=0\degree$
Live load: $q_{LL}=320\text{psf}$
Wall batter: $\omega=0\degree$
Backslope: $\beta=0\degree$
Distance to broken back: $d_b=8\text{ft}$
Toe slope (use negative): $\beta'=-12\degree$
Horizontal distance to flat ground at toe: $d_b'=20\text{ft}$

Equivalent backslope:
$\beta_{eq}=\text{if}(d_b<2*H,\text{atan}(d_b\tan(\beta)/(2*H)),\beta)$; $\beta_{eq}=0.000\degree$

Equivalent toe slope (approx)
$\beta_{eq}'=\text{if}(d_b'<2*H,\text{atan}(d_b'\tan(\beta')/(2*H)),\beta')$; $\beta_{eq}'=-12.000\degree$

Arching adjustment factor: $f_{arch}=\text{min}(3,0.08*\phi_i)$; $f_{arch}=2.240$

Soldier pile spacing factor: $f=\text{Min}(1, f_{arch}^*b/S)$; $f=0.163$

Active pressure coefficient:
$K_a=\cos(\phi_i+\omega)^2/[(\cos(\omega)^2)*\cos(\omega-\delta_i)\{1+[(\sin(\delta_i+\phi_{eq})\sin(\phi+\beta_{eq})]/(\cos(\omega-\delta_i)*\cos(\omega+\beta_{eq}))\}^{0.5}]^2$;
$K_a=0.361$

$K_{ah}=K_{a}\cos(\delta_i-\omega)$; $K_{ah}=0.361$

$K_{av}=K_{a}\sin(\delta_i-\omega)$; $K_{av}=0.000$

Internal failure plane:
$\alpha_a=\text{atan}((-1*\tan(\phi_{eq})+(\tan(\phi_{eq})+\cot(\phi_{eq}))*((1+\tan(\delta_i-\omega)\cot(\phi_{eq}))^{0.5})/(1+\tan(\delta_i-\omega)*\tan(\phi_{eq})+\cot(\phi_{eq})))+\phi_{eq})=59.000\degree$

Passive pressure coefficient:
$K_p=\cos(\phi_i-\omega)^2/[(\cos(\omega)^2)*\cos(\omega+\delta_i)\{1-[(\sin(\delta_i+\phi_{eq})\sin(\phi+\beta_{eq})]/(\cos(\omega+\delta_i)*\cos(\omega+\beta_{eq}))\}^{0.5}]^2$;
$K_p=1.926$

$K_{ph}=K_{p}\cos(\delta_i-\omega)$; $K_{ph}=1.926$

$K_{pv}=K_{p}\sin(\delta_i-\omega)$; $K_{pv}=0.000$

Internal failure plane:
$\alpha_p=\text{atan}((-1*\tan(\phi_{eq})-(\tan(\phi_{eq})+\cot(\phi_{eq}))*((1+\tan(\delta_i-\omega)\cot(\phi_{eq}))^{0.5})/(1+\tan(\delta_i-\omega)*\tan(\phi_{eq})+\cot(\phi_{eq})))+\phi_{eq})=-19.073\degree$
Soil Pressures / Toe Embedment:

Depth of embedded toe; \( D = 7.4 \text{ ft} \);
Increase embedded toe depth by 30% or use FS on \( P_p \);
\( D' = 1.3 \times D = 9.620 \text{ ft} \);

Active soil pressures:
Active soil pressure per foot of depth on lagging; \( Q_s = K_a \gamma = 43.324 \) pcf;
Active soil pressure at depth of excavation on lagging; \( P_s = Q_s \frac{H}{2} = 303.268 \) psf;
Active surcharge pressure on lagging; \( P_q = K_a q_L L = 115.531 \) psf;
Total Active pressure on lagging at depth of exc; \( P_a = P_s + P_q = 418.799 \) psf;
Force of soil pressure on lagging; \( F_s = P_s \frac{H}{2} = 1061.438 \) plf;
Force of surcharge pressure on lagging; \( F_q = P_q H = 808.715 \) plf;
Force of active soil pressure on soldier pile below exc; \( F' = P_s' \frac{H}{2} = 55.244 \) plf;
Force of active soil pressure on soldier pile below exc; \( F'q = P_q' Y = 42.091 \) plf;

Passive soil pressures:
Passive pressure per foot of depth on soldier pile; \( Q_p = f K_p \gamma = 37.743 \) pcf;
Depth of net passive pressure; \( d = D - Y = 5.169 \) ft;
Passive pressure at toe of pile; \( P_p = Q_p d = 195.109 \) psf;
Force of passive pressure on pile; \( F_p = P_p d / 2 = 504.301 \) plf;

Sum moments about anchor (equal to zero):
\[
M = F_s \left( \frac{2}{3} H - a \right) + F_q \left( H - a \right) + F's \left( H - a + \frac{Y}{3} \right) + F'q \left( H - a + \frac{Y}{2} \right) - F_p \left( H - a + \frac{Y}{2} + \frac{2}{3} d \right) = -0.034 \text{ kip-ft/ft};
\]

Anchor Forces;
Horizontal comp anchor tension; \( T = F_s + F_q + F's + F'q - F_p = 1463.187 \) plf;
Total Horiz comp anchor tension; \( T_{tot} = T' S = 5.853 \) kip;
Actual Tension; \( F_T = T_{tot} / \cos(\theta) = 6.059 \) kip;
Vertical load on pile; \( F_V = F_T \sin(\theta) = 1.568 \) kip;

Maximum moment on pile;
Locate point of zero shear (max moment); \( \text{"Ps}/(2'H) x^2 + Pq x - T = 0\text{plf}"; \( a_1 = \text{Ps}/(2'H) = 21.662 \) pcf; \( b_1 = P_q = 115.531 \) psf; \( c_1 = -1 \times T = -1463.187 \) plf;
Quadratic; \( \frac{d_t = b_1^2}{4} a_1 c_1; \) \( d_t = 140129.636 \)
Determinate; \( x_p = \left( -1 \times b_1 + \sqrt{b_1^2 - 4 \times a_1 c_1} \right) / (2 \times a_1); \) \( x_p = 5.974 \)
Add determinate; \( x_n = \left( -1 \times b_1 - \sqrt{b_1^2 - 4 \times a_1 c_1} \right) / (2 \times a_1); \) \( x_n = -11.307 \)
Subtract determinate; \( x = \max(x_p, x_n) = 5.974 \) ft;
Distance to equivalent amount of shear; \( x = \max(x_p, x_n) = 5.974 \) ft;
Check shear equals zero; \( \text{Ps}/(2'H)x^2 + Pq x - T = 0.000 \) plf;
Max moment btwn exc and anchor; \( M_1 = \text{-Ps}/(2'H) x^3 / (3) - Pq x (x/2) + T (x-a) = 2.945 \) kip-ft/ft;
Max moment above anchor; \( M_2 = \text{Ps'}/a/H' a/2 a/3 + Pq' a/2 = 0.154 \) kip-ft/ft;
Max moment; \( M_{max} = \max(M_1, M_2) = 2.945 \) kip-ft/ft;
Design moment; \( M_r = M_{max} S = 11.781 \) kip-ft;
Lagging:
UDL per foot of height at bottom of excavation; \[ W_{lag} = Pa + Pq = 534.330 \text{ plf/ft}; \]
Moment on lagging; \[ M_{lag} = (W_{lag}) \times \frac{S^2}{8} = 1.069 \text{ kip-ft/ft}; \]

Summary:
Embedment of toe; \[ D' = 9.620 \text{ ft}; \]
Tension on anchor; \[ FT = 6.059 \text{ kip}; \]
Shear on pile; \[ Vr = T_{tot} = 5.853 \text{ kip}; \]
Axial load on pile; \[ Pr = 1.568 \text{ kip}; \]
Moment on pile; \[ Mr = 11.781 \text{ kip-ft}; \]
Moment on lagging (per foot height of lagging); \[ M_{lag} = 1.069 \text{ kip-ft/ft}; \]