Pile Foundation

Materials

Rebar Yield Strength $f_y := 420MPa$

Concrete Strength $f'_c := 25MPa$

Concrete Density $\rho_{soil} := 20\frac{kN}{m^3}$

Soil Density $\rho_{conc} := 25\frac{kN}{m^3}$

Footing Dimensions

Width (longitudinal) $w_{ftg} := 10m$

Length (transverse) $l_{ftg} := 10m$

Depth $d_{ftg} := 2.5m$

Piles

Number of Piles $n := 8$

Y Offset $y_{offset} := \frac{1}{2}\cdot w_{ftg} - 700mm$ $y_{offset} = 4.3\,m$

X Offset $x_{offset} := \frac{1}{2}\cdot l_{ftg} - 700mm$ $x_{offset} = 4.3\,m$

Column Dimensions

Width (longitudinal) $w_{col} := 1000mm$

Length (transverse) $l_{col} := 2000mm$

Area $area_{col} := w_{col}\cdot l_{col}$

Soil Cover

Depth $d_{soil} := 150mm$

Reinforcement Clearances

Top Clearance $clr_{top} := 75mm$

Bottom Clearance $clr_{bot} := 150mm$

Loads

$Axial := 100000kN$

$M_{xx} := 100000kN \cdot m$

$M_{yy} := 100000kN \cdot m$

Calculations

$I_{xx} := y_{offset}^{2} \cdot n$ $I_{xx} = 1.479 \times 10^{8}\, mm^{2}$

$I_{yy} := x_{offset}^{2} \cdot n$ $I_{yy} = 1.479 \times 10^{8}\, mm^{2}$

Axial Load Due to Column Load + Soil + Footing

$P := Axial + \left(l_{ftg} \cdot w_{ftg} \cdot d_{ftg}\right) \cdot \rho_{conc} + \left(l_{ftg} \cdot w_{ftg} - area_{col}\right) \cdot d_{soil} \cdot \rho_{soil}$

$P = 106544\, kN$

Maximum and Minimum Pile Reactions

$$\frac{P}{n} + \frac{M_{yy} \cdot x_{offset}}{I_{yy}} + \frac{M_{xx} \cdot y_{offset}}{I_{xx}} = 19132\, kN$$

$$\frac{P}{n} - \frac{M_{yy} \cdot x_{offset}}{I_{yy}} - \frac{M_{xx} \cdot y_{offset}}{I_{xx}} = 7504\, kN$$

Effective Column Dimensions

$$w_{coleff} := \sqrt{area_{col} \cdot \frac{l_{col}}{w_{col}}} \cdot \frac{w_{col}}{l_{col}} \qquad w_{coleff} = 1\, m$$

$$l_{coleff} := \sqrt{area_{col} \cdot \frac{l_{col}}{w_{col}}} \qquad l_{coleff} = 2\, m$$

Cap Reinforcement

Bottom Reinforcement X-X

$Pile_c := \frac{P}{n} + \frac{M_{xx} \cdot y_{offset}}{I_{xx}}$ $Pile_c = 16225\,kN$ $M_{xx} = 100000000\,N \cdot m$

Critical Section

$cs := \frac{1}{2} w_{coleff}$ $cs = 0.5\,m$

$y_{cs} := \frac{1}{2} w_{ftg} - cs$

$M_{ftg} := -\frac{1}{2} y_{cs}^2 \cdot l_{ftg} \cdot d_{ftg} \cdot \rho_{conc}$ $M_{ftg} = -6328\,kN \cdot m$

$M_{soil} := -\frac{1}{2} y_{cs}^2 \cdot l_{ftg} \cdot d_{soil} \cdot \rho_{soil}$ $M_{soil} = -304\,kN \cdot m$

$M_{pile} := 3 \cdot Pile_c \cdot (y_{offset} - cs)$ $M_{pile} = 184965\,kN \cdot m$

$M_u := M_{pile} + M_{ftg} + M_{soil}$ $M_u = 178333\,kN \cdot m$

$\phi := 0.90$

Solver Initial Guess

$A_s := 10000 \cdot mm^2$

$a := 1000mm$

$b := l_{ftg}$

$d := d_{ftg} - clr_{bot}$ $d = 2.35\,m$ Effective Depth

Given

$a = \frac{A_s \cdot f_y}{0.85 \cdot f'_c \cdot b}$

$M_u = \left[A_s \cdot f_y \cdot \left(d - \frac{a}{2} \right) \right] \cdot \phi$

$result := Find(A_s, a)$

$A_s := result_0$ $A_s = 221364\,mm^2$ <~~~~~ Controls

$a := result_1$ $a = 437.52\,mm$

Temperature Requirements

$\frac{1}{8}\cdot in^2\cdot\frac{l_{ftg}}{ft} = 2646\,mm^2$

Minimum Reinforcement - 1.2 Mcr

$S := \frac{l_{ftg}\cdot d_{ftg}^2}{12}$

$f_r := 7.5\cdot\sqrt{f'_c\cdot psi}$

$M_u := 1.2\cdot S\cdot f_r$ $M_u = 1.946\times 10^4\,kN\cdot m$

Given

$a = \frac{A_s\cdot f_y}{0.85\cdot f'_c\cdot b}$

$M_u = \left[A_s\cdot f_y\cdot\left(d-\frac{a}{2}\right)\right]\cdot\phi$

$result := Find(A_s, a)$ <~~~~~~~~~~ Solve for Area of Steel, and dimension a

$A_s := result_0$ $A_s = 22114\,mm^2$

$a := result_1$ $a = 43.708\,mm$

Top Reinforcement X-X

$Pile_t := \frac{P}{n} - \frac{M_{xx}\cdot y_{offset}}{I_{xx}}$ $Pile_t = 10411\,kN$ Compression Not Tension

$cs := \frac{1}{2}w_{coleff}$ $cs = 0.5\,m$

$y_{cs} := \frac{1}{2} w_{ftg} - cs$

$M_{ftg} := -\frac{1}{2} y_{cs}^{2} \cdot l_{ftg} \cdot d_{ftg} \cdot \rho_{conc}$ $M_{ftg} = -6328\,kN \cdot m$

$M_{soil} := -\frac{1}{2} y_{cs}^{2} \cdot l_{ftg} \cdot d_{soil} \cdot \rho_{soil}$ $M_{soil} = -304\,kN \cdot m$

$M_{pile} := 3 \cdot Pile_t \cdot (y_{offset} - cs)$ $M_{pile} = 118686\,kN \cdot m$

$M_u := M_{pile} + M_{ftg} + M_{soil}$ $M_u = 112054\,kN \cdot m$

$M_u := if(M_u > 0.0 \cdot kN \cdot m, 0.0 \cdot kN \cdot m, M_u)$

$\phi := 0.9$

Solver Initial Guess

$A_s := 10000 \cdot mm^2$

$a := 1000mm$

$b := w_{ftg}$

$d := d_{ftg} - clr_{top}$

Given

$a = \frac{A_s \cdot f_y}{0.85 \cdot f'_c \cdot b}$

$M_u = \left[A_s \cdot f_y \cdot \left(d - \frac{a}{2} \right) \right] \cdot \phi$

$result := Find(A_s, a)$ <~~~~~~~~~~ Solve for Area of Steel, and dimension a

$A_s := result_0$ $A_s = 0\,mm^2$

$a := result_1$ $a = -9.802 \times 10^{-4}\,mm$

Temperature Requirements

$$\frac{1}{8}\cdot in^2\cdot\frac{w_{ftg}}{ft} = 2646\,mm^2$$

Minimum Reinforcement - 1.2 Mcr

$A_s := 1000mm^2$ Guess

$$S := \frac{w_{ftg}\cdot d_{ftg}^2}{12}$$

$$f_r := 7.5\cdot\sqrt{f'_c\cdot psi}$$

$M_u := 1.2\cdot S\cdot f_r$ $M_u = 1.946\times 10^4\,kN\cdot m$

Given

$$a = \frac{A_s\cdot f_y}{0.85\cdot f'_c\cdot b}$$

$$M_u = \left[A_s\cdot f_y\cdot\left(d-\frac{a}{2}\right)\right]\cdot\phi$$

result := Find(A_s, a) <~~~~~~~~~ Solve for Area of Steel, and dimension a

$A_s := result_0$ $A_s = 21418\,mm^2$ <~~~ Controls

$a := result_1$ $a = 42.332\,mm$

Bottom Reinforcement Y-Y

$$Pile_c := \frac{P}{n} + \frac{M_{yy}\cdot x_{offset}}{I_{yy}}$$ $Pile_c = 16225\,kN$ $M_{yy} = 100000000\,N\cdot m$

$cs := \frac{1}{2}l_{coleff}$ $cs = 1\,m$ $l_{col} = 2\,m$

$$x_{cs} := \frac{1}{2}l_{ftg} - cs$$

$M_{ftg} := -\frac{1}{2} x_{cs}^2 \cdot w_{ftg} \cdot d_{ftg} \cdot \rho_{conc}$ $M_{ftg} = -5000\,kN \cdot m$

$M_{soil} := -\frac{1}{2} x_{cs}^2 \cdot w_{ftg} \cdot d_{soil} \cdot \rho_{soil}$ $M_{soil} = -240\,kN \cdot m$

$M_{pile} := 3 \cdot Pile_c \cdot (x_{offset} - cs)$ $M_{pile} = 160627\,kN \cdot m$

$M_u := M_{pile} + M_{ftg} + M_{soil}$ $M_u = 155387\,kN \cdot m$

$\phi := 0.9$

Solver Initial Guess

$A_s := 10000 \cdot mm^2$

$a := 1000mm$

$b := w_{ftg}$

$d := d_{ftg} - clr_{bot}$

Given

$a = \frac{A_s \cdot f_y}{0.85 \cdot f'_c \cdot b}$

$M_u = \left[A_s \cdot f_y \cdot \left(d - \frac{a}{2}\right)\right] \cdot \phi$

$result := Find(A_s, a)$

$A_s := result_0$ $A_s = 190128\,mm^2$ <~~~~~ Controls

$a := result_1$ $a = 375.782\,mm$

Temperature Requirements

$\frac{1}{8} \cdot in^2 \cdot \frac{w_{ftg}}{ft} = 2646\,mm^2$

Minimum Reinforcement - 1.2 Mcr

$$S := \frac{w_{ftg} \cdot d_{ftg}^{2}}{12}$$

$$f_r := 7.5 \cdot \sqrt{f'_c \cdot psi}$$

$M_u := 1.2 \cdot S \cdot f_r$ $\quad M_u = 1.946 \times 10^{4}\,kN \cdot m$

Given

$$a = \frac{A_s \cdot f_y}{0.85 \cdot f'_c \cdot b}$$

$$M_u = \left[A_s \cdot f_y \cdot \left(d - \frac{a}{2} \right) \right] \cdot \phi$$

$result := Find(A_s, a)$ $\quad$ <~~~~~~~~~~ Solve for Area of Steel, and dimension a

$A_s := result_0$ $\quad A_s = 22114\,mm^2$

$a := result_1$ $\quad a = 43.708\,mm$

Top Reinforcement Y-Y

$$Pile_t := \frac{P}{n} - \frac{M_{yy} \cdot x_{offset}}{I_{yy}} \qquad Pile_t = 10411\,kN$$

$cs := \frac{1}{2} l_{coleff}$ $\quad cs = 1\,m$

$x_{cs} := \frac{1}{2} l_{ftg} - cs$ $\quad x_{cs} = 4\,m$

$M_{ftg} := -\frac{1}{2} x_{cs}^{2} \cdot w_{ftg} \cdot d_{ftg} \cdot \rho_{conc}$ $\quad M_{ftg} = -5000\,kN \cdot m$

$M_{soil} := -\frac{1}{2} x_{cs}^{2} \cdot w_{ftg} \cdot d_{soil} \cdot \rho_{soil}$ $\quad M_{soil} = -240\,kN \cdot m$

$M_{pile} := 3 \cdot Pile_t \cdot (x_{offset} - cs)$ $\quad M_{pile} = 103069\,kN \cdot m$

$M_u := (M_{pile} + M_{ftg} + M_{soil})$ $M_u = 97829\,kN\cdot m$

$M_u := if(M_u > 0.0\cdot kN\cdot m, 0.0\cdot kN\cdot m, M_u)$ $M_u = 0\,kN\cdot m$

$\phi = 0.9$

Solver Initial Guess

$A_s := 10000\cdot mm^2$

$a := 1000mm$

$b := w_{ftg}$

$d := d_{ftg} - clr_{top}$

Given

$$a = \frac{A_s\cdot f_y}{0.85\cdot f'_c\cdot b}$$

$$M_u = \left[A_s\cdot f_y\cdot\left(d - \frac{a}{2}\right)\right]\cdot\phi$$

$result := Find(A_s, a)$ <~~~~~~~~~~ Solve for Area of Steel, and dimension a

$A_s := result_0$ $A_s = 0\,mm^2$

$a := result_1$ $a = -9.802\times 10^{-4}\,mm$

Temperature Requirements

$$\frac{1}{8}\cdot in^2\cdot\frac{w_{ftg}}{ft} = 2646\,mm^2$$

Minimum Reinforcement - 1.2 Mcr

$A_s := 1000mm^2$ Guess

$d := d_{ftg} - clr_{top}$ $d = 2.425\,m$

$S := \frac{w_{ftg} \cdot d_{ftg}^2}{12}$ $S = 5.208\,m^3$

$f_r := 7.5 \cdot \sqrt{f'_c \cdot psi}$

$M_u := 1.2 \cdot S \cdot f_r$ $M_u = 1.946 \times 10^4\,kN \cdot m$

Given

$a = \frac{A_s \cdot f_y}{0.85 \cdot f'_c \cdot b}$

$M_u = \left[A_s \cdot f_y \cdot \left(d - \frac{a}{2} \right) \right] \cdot \phi$

$result := Find(A_s, a)$ <~~~~~~~~~~ Solve for Area of Steel, and dimension a

$A_s := result_0$ $A_s = 21418\,mm^2$ <~~~~~ Controls

$a := result_1$ $a = 42.332\,mm$

One Way Shear

$\phi := 0.85$

X-X

$C := \frac{P}{n} + \frac{M_{xx} \cdot y_{offset}}{I_{xx}}$ $C = 16225\,kN$

$T := \frac{P}{n} - \frac{M_{xx} \cdot y_{offset}}{I_{xx}}$ $T = 10411\,kN$

Critical Section

$cs := \frac{1}{2} \cdot w_{coleff} + d_{ftg}$ $cs = 3\,m$

$y_{cs} := \frac{1}{2} \cdot w_{ftg} - cs$ $y_{cs} = 2\,m$

$V_u := 3 \cdot piles \cdot C - y_{cs} \cdot l_{ftg} \cdot (d_{ftg} \cdot \rho_{conc} + d_{soil} \cdot \rho_{soil})$ $V_u = 47365\,kN$

$V_c := 2 \cdot \sqrt{f'_c \cdot psi} \cdot l_{ftg} \cdot (d_{ftg} - clr_{bot})$ $V_c = 19513\,kN$

$V_s := \frac{V_u}{\phi} - V_c$ $V_s = 36210\,kN$

$s := 300mm$ Assumed

$A_v := \frac{V_s \cdot s}{(d_{ftg} - clr_{bot}) \cdot f_y}$ $A_v = 11006\,mm^2$ <~~~Controls

$V_u := 3 \cdot piles \cdot T + y_{cs} \cdot l_{ftg} \cdot (d_{ftg} \cdot \rho_{conc} + d_{soil} \cdot \rho_{soil})$ $V_u = 3.254 \times 10^4\,kN$

$V_c := 2 \cdot \sqrt{f'_c \cdot psi} \cdot l_{ftg} \cdot (d_{ftg} - clr_{bot})$ $V_c = 19513\,kN$

$V_s := \frac{V_u}{\phi} - V_c$ $V_s = 18773\,kN$

$A_v := \frac{V_s \cdot s}{(d_{ftg} - clr_{bot}) \cdot f_y}$ $A_v = 5706\,mm^2$

Y-Y

$C := \frac{P}{n} + \frac{M_{yy} \cdot x_{offset}}{I_{yy}}$ $C = 16225\,kN$

$T := \frac{P}{n} - \frac{M_{yy} \cdot x_{offset}}{I_{yy}}$ $T = 10411\,kN$

Critical Section

$cs := \frac{1}{2} \cdot l_{coleff} + d_{ftg}$ $cs = 3.5\,m$

$x_{cs} := \frac{1}{2} l_{ftg} - cs$ $x_{cs} = 1.5\,m$

Pile Compression Case

$V_u := 3 \cdot piles \cdot C - x_{cs} \cdot l_{ftg} \cdot (d_{ftg} \cdot \rho_{conc} + d_{soil} \cdot \rho_{soil})$ $V_u = 4.769 \times 10^4\,kN$

$V_c := 2 \cdot \sqrt{f'_c \cdot psi} \cdot l_{ftg} \cdot (d_{ftg} - clr_{bot})$ $V_c = 19513\,kN$

$V_s := \frac{V_u}{\phi} - V_c$ $V_s = 36596\,kN$

$s := 300mm$ Assumed

$A_v := \frac{V_s \cdot s}{(d_{ftg} - clr_{bot}) \cdot f_y}$ $A_v = 11123\,mm^2$ <~~~Controls

Pile Tension Case

$V_u := 3 \cdot piles \cdot T + x_{cs} \cdot l_{ftg} \cdot (d_{ftg} \cdot \rho_{conc} + d_{soil} \cdot \rho_{soil})$ $V_u = 3.222 \times 10^4\,kN$

$V_c := 2 \cdot \sqrt{f'_c \cdot psi} \cdot l_{ftg} \cdot (d_{ftg} - clr_{top})$ $V_c = 20136\,kN$

$V_s := \frac{V_u}{\phi} - V_c$ $V_s = 17765\,kN$

$A_v := \frac{V_s \cdot s}{(d_{ftg} - clr_{top}) \cdot f_y}$ $A_v = 5233\,mm^2$

Punching Shear

$\phi = 0.85$

$P = 106544\,kN$ Column Axial + Soil + Footing

$csy := \frac{1}{2} \cdot (d_{ftg} + l_{coleff})$ $csy = 2.25\,m$

$csx := \frac{1}{2}(d_{ftg} + w_{coleff})$ $csx = 1.75\,m$

$b_o := 2 \cdot (csx + csy)$ $b_o = 8\,m$

$area := (w_{ftg} \cdot l_{ftg}) - 2 \cdot csx \cdot csy$

$V_u := [P - area \cdot (d_{soil} \cdot \rho_{soil} + d_{ftg} \cdot \rho_{conc})] \cdot \frac{1}{\phi}$ $V_u = 118247\,kN$

$$\beta_c := \frac{\min(w_{ftg}, l_{ftg})}{\max(w_{ftg}, l_{ftg})}$$

$$\text{factor} := \min\left[\left(2 + \frac{4}{\beta_c}\right), 4\right] \qquad \text{factor} = 4$$

$$V_c := \text{factor} \cdot \sqrt{f'_c \cdot \text{psi}} \cdot b_o \cdot (d_{ftg} - clr_{bot}) \qquad V_c = 31221\,\text{kN}$$

$$V_s := V_u - V_c \qquad V_s = 87026\,\text{kN}$$

$s := 300\text{mm}$ Assumed

$$A_v := \frac{V_s \cdot s}{(d_{ftg} - clr_{bot}) \cdot f_y} \qquad A_v = 26452\,\text{mm}^2$$