Appendix D Example 29 – Short Poured-In-Place Concrete Piles

The following section presents sample calculations for specific items discussed in the subsections of Section 5-6, *Short Poured-In-Place Concrete Piles*. For a full example problem see Appendix D, Example 30 – *Short Poured-In-Place Concrete Piles.*

Pile Uplift in Cohesionless Soil:

Refer to Section 5-6.02A, *Pile Uplift in Cohesionless Soil*.

Given Information

Soil internal friction:
angle ϕ = 30°

Unit weight of concrete:
$\gamma_c = 145$ pcf

Unit weight of soil:
γ_s = 100 pcf

Water table:
4 feet from pile tip at anticipated time of load application

Pile:
L_p = Length of the pile = 12 ft
d = Pile diameter = 18 in = 1.5 ft
z = Depth below ground = 10 ft

Single use loading (FS = 2)

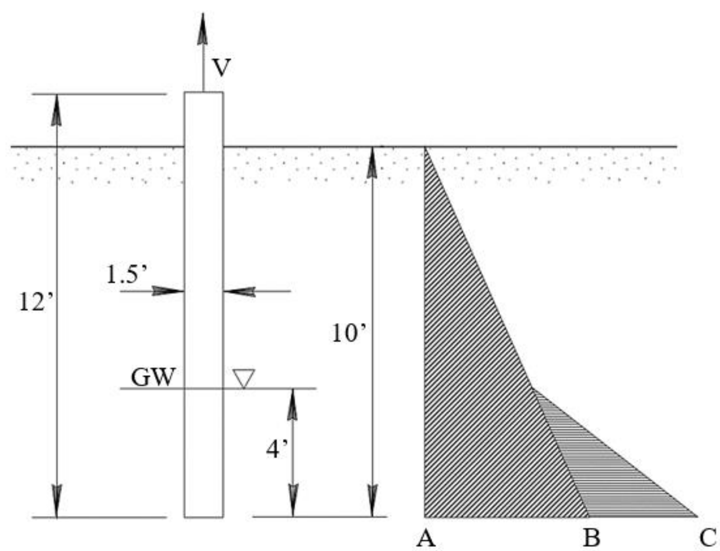

Figure D-29-1. Short Concrete Pile in Cohesionless Soil

Determine vertical load capacity for the poured-in-place concrete pile in Cohesionless Soil

$$R = \pi dzS + W \quad (5\text{-}6.02\text{-}1)$$

$$S = \beta\sigma_z \le 4{,}000 \text{ psf} \quad (5\text{-}6.02A\text{-}1)$$

$$\beta = 1.5 - 0.315\, z^{1/2} \text{ but } 0.25 \le \beta \le 1.2 \quad (5\text{-}6.02A\text{-}2)$$

Where:

R = Resistance to pile uplift (lb)

S = Unit shearing resistance on the soil-pile interface (psf)

W = Pile weight (lbs)

β = Reduction factor for cohesionless soils

σ_z = Effective overburden soil weight (psf). Below the water table the weight of water is subtracted from the soil unit weight so that only the submerged soil weight is used

AB = The pressure due to the weight of the soil

BC = The pressure due to the weight of the water

Unit shearing resistance

$\beta = 1.5 - 0.315\, z^{1/2} = 1.5 - 0.315(10)^{1/2} = 0.5 \quad 0.25 \le \beta \le 1.2$ **<u>OK</u>**

$z = 10$ ft (z_{dry} = 6 ft; $z_{submerged}$ = 4 ft)

$\sigma_z = 6(100) + 4(100 - 62.4) = 750$ pcf

$S = \beta\sigma_z = 0.5(750) = 375 \text{ psf} < 4000 \text{ psf}$ **<u>OK</u>**

Net pile shearing resistance

R_s = (Pile surface area) S= $\pi dzS = \pi(1.5)(10)(375)$ = 17,671 lbs

Pile weight

$W = \pi\left(\frac{d}{2}\right)^2 L_p\, \gamma_c = \pi\left(\frac{1.5}{2}\right)^2 (12)(145) = 3075$ lbs

Resistance to pile uplift

R = Net pile shearing resistance (R_s) + Pile weight (W) = $\pi dzS + W$

= 17,671 + 3,075 = 20,746 lbs

Working load

$$(V) = \frac{\text{Ultimate Load}}{\text{FS}} = \frac{(20{,}746)}{2} = 10{,}373 \text{ lbs}$$

Pile Uplift in Cohesive Soil:

Refer to Section 5-6.02B, *Pile Uplift in Cohesive Soil*.

Given Information

Unit weight of concrete:
$\gamma_c = 145$ pcf

Soil cohesion:
C = undrained shear strength = 910 psf

Unit weight of soil:
γ_s = 110 pcf

Pile:
L_p = Length of the pile = 12 ft
d = Pile diameter = 18 in = 1.5 ft
z = Depth below ground = 10 ft

Single use loading (FS = 2)

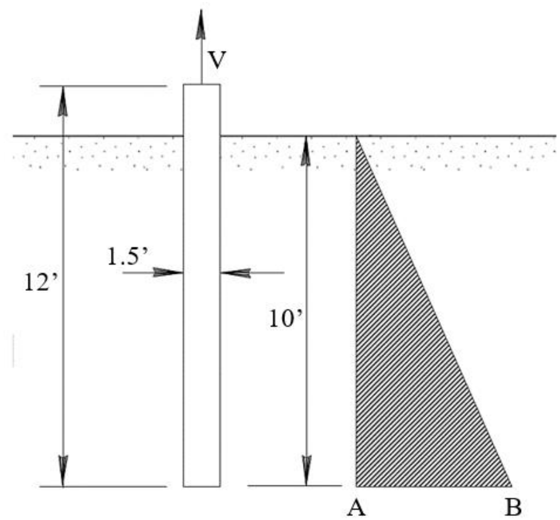

Figure D-29-2. Short Concrete Pile in Cohesive Soil

Determine vertical load capacity for the poured-in-place concrete pile in Cohesive Soil

$$R_s = \pi d z S \qquad (5\text{-}6.02B\text{-}1)$$

Where:

R_s = Shearing resistance (lbs)
S = Unit shearing resistance (psf)
a_z = An empirical unitless reduction factor which accounts for clay shrinkage and lateral pile loadings
AB = The pressure due to the weight of the soil

Unit shearing resistance

$$S = a_z C \leq 5{,}500 \text{ psf} \qquad (5\text{-}6.02B\text{-}2)$$

Use reduction factor for pile diameter d ≤ 18", pile length with more than 5 feet embedment

For $0 \leq z \leq 5$ feet

$$a_{z(0-5)} = (0.055)z \qquad (5\text{-}6.02B\text{-}6)$$

$$= (0.055)5 = 0.275$$

$$S_{(0-5)} = a_{z(0-5)}C = 0.275(910) = 250 \text{ psf} \leq 5500 \text{ psf}$$ **OK**

For z > 5 feet:

$$a_{z(>5)} = 0.55 \qquad (5\text{-}6.02B\text{-}8)$$

$$S_{(>5)} = a_{z(>5)} C = 0.55(910) = 500 \text{ psf} \leq 5{,}500 \text{ psf}$$ **OK**

Net pile shearing resistance

$$R_s = \pi d[(5)S_{(0-5)} + (z-5)\,S_{(>5)}]$$

$$= \pi\,(1.5)[(5)(250) + (10-5)(500)]$$

$$= \pi\,(1.5)(3750) = 17{,}671 \text{ lbs}$$

Pile weight

$$W = \pi\left(\frac{d}{2}\right)^2 L_p\, \gamma_c = \pi\left(\frac{1.5}{2}\right)^2 (12)(145) = 3075 \text{ lbs}$$

Resistance to pile uplift

R = Net pile shearing resistance (R_s) + Pile weight (W)

= 17,671 + 3,075 = 20,746 Lbs

Working load

$$V = \frac{\text{Ultimate Load}}{\text{FS}} = \frac{20{,}746}{2} = 10{,}373 \text{ lbs}$$

Lateral Loading in Cohesionless Soil:

Refer to Section 5-6.03A, *Lateral Loading in Cohesionless Soil*.

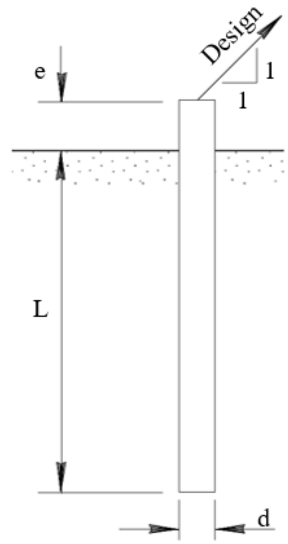

Figure D-29-3. Pile Lateral Loading in Cohesionless Soil

Given Information

Soil internal friction:
angle ϕ = 30°

Unit weight of concrete:
$\gamma_c = 145 \text{ pcf}$

Unit weight of soil:
γ_s = 110 pcf

Pile:
L = Depth below ground = 8 ft
e = Length from ground surface to ultimate lateral load = 2 ft
d = Pile diameter = 18 in = 1.5 ft

Single use loading (FS = 2)

Determine allowable loading for the poured-in-place concrete pile in Cohesionless Soil

Working load value for lateral load H

$K_p = \tan^2\left(45° + \frac{\phi}{2}\right) = \tan^2\left(45° + \frac{30°}{2}\right)$ = 3.00 (for level ground surface)

L/d = 8/1.5 = 5.33 e/d = 2/1.5 = 1.33

Use Figure 5-23 to find $\frac{H_{ULT}}{K_p \gamma_s d^3}$

$\frac{H_{ULT}}{K_p \gamma_s d^3} \approx 5$ when e = 2'- 0"

$H_{ULT} = 5 \times K_p \gamma_s d^3 = 5 \times (3.0)(110)(1.5)^3 = 5569$ lbs

Working Load Value for H = $\frac{H_{ULT}}{FS} = \frac{5569}{2}$ = 2784 lbs

Working load value for moment M

$$(f_g)^2 = \frac{H_{ULT}}{1.5\ \gamma_s\ dK_p} \qquad (5\text{-}6.03A\text{-}1)$$

$$f_g = \left(\frac{H_{ULT}}{1.5\ \gamma_s\ dK_p}\right)^{\frac{1}{2}} = \left(\frac{5569}{1.5\ (110)(1.5)(3.0)}\right)^{\frac{1}{2}} = 2.74 \text{ ft}$$

$$M_{ULT} = H_{ULT}\left(e + \frac{2f_g}{3}\right) \qquad (5\text{-}6.03A\text{-}2)$$

$$= 5569\left(2 + \frac{(2)(2.74)}{3}\right) = 21{,}311 \text{ ft-lb}$$

Working Load Value for M = $\frac{M_{ULT}}{FS} = \frac{21{,}311}{2}$ = 10,656 ft-lb

Lateral Loading in Cohesive Soil:

Refer to Section 5-6.03B, *Lateral Loading in Cohesive Soil*.

Given Information

Unit weight of concrete:
$\gamma_c = 145$ pcf

Unit weight of soil:
$\gamma_s = 110$ pcf

Pile:
L = Depth below ground = 8 ft
e = Length from ground surface to ultimate lateral load = 2 ft
d = Pile diameter = 18 in = 1.5 ft

Undrained shear strength:
$C_u = 1000$ psf

Single use loading (FS = 2)

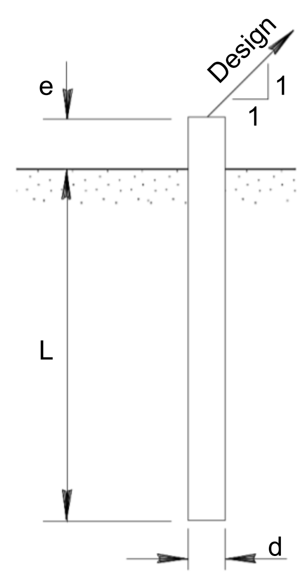

Figure D-29-4. Pile Lateral Loading in Cohesive Soil

Determine allowable loading for poured-in-place concrete pile in Cohesive Soil

Working load value for lateral load H

L/d = 8/1.5 = 5.33 e/d = 2/1.5 = 1.33

Use Figure 5-24 to find $\frac{H_{ULT}}{C_u d^2}$

$\frac{H_{ULT}}{C_u\, d^2} \approx 5.5$ when e = 2'–0″

$H_{ULT} = 5.5 \times C_u d^2 = 5.5 \times (1{,}000)\,(1.5)^2 = 12{,}375$ lbs

Working Load Value for H = $\frac{H_{ULT}}{FS} = \frac{12{,}375}{2} = 6188$ lbs

Working load value for moment M

$$f_c = \frac{H_{ULT}}{9C_u d} \qquad (5\text{-}6.03B\text{-}1)$$

$$= \frac{12{,}375}{9\,(1{,}000)(1.5)} = 0.917 \text{ ft}$$

$$M_{ULT} = H_{ULT}(e + 1.5d + 0.5f_c) \qquad (5\text{-}6.03B\text{-}2)$$

$$= (12{,}375)\,[2 + 2.25 + 0.46] = 58{,}266 \text{ ft-lb}$$

Working Load Value for M = $\frac{M_{ULT}}{FS} = \frac{58{,}266}{2} = 29{,}133$ ft-lb

Concrete Stress:

Refer to Section 5-6.04, *Concrete Stresses,*

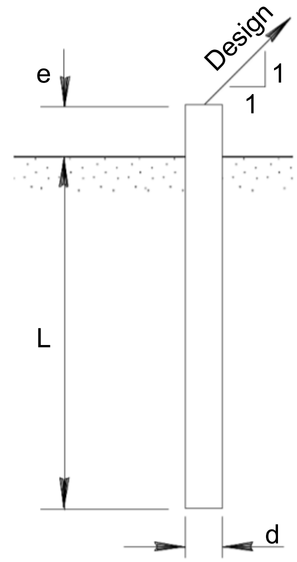

Figure D-29-5. Pile Lateral Loading for Concrete Stress

Given Information

Pile:
L = Depth below ground = 8 ft
e = Length from ground surface to ultimate lateral load = 2 ft
d = Pile diameter = 18 in = 1.5 ft

Unit weight of concrete:
$\gamma_c = 145 \text{ pcf}$

Concrete compressive strength:
f'_c = 3250 psi

Design loads:
V_{MAX} = 6188 lbs
H_{MAX} = 6188 lbs
M_{MAX} = 29,133 ft-lb

Single use loading (FS = 2)

Determine the concrete stress for this poured-in-place pile

With forces acting through the center of the pile consider one half of pile in compression.

Use the simplified equation:

$$f_c = \frac{Md}{2I_g} - \frac{V'}{A_g} \leq \frac{f'c}{2} \quad (5\text{-}6.04\text{-}1)$$

where V' = 6188 lbs minus the pile weight above the plane of zero shear.

Distance to plane of zero shear $\approx \frac{M_{ULT}}{H_{ULT}} \approx \frac{M_{MAX}}{H_{MAX}} \approx \frac{29{,}133}{6188}$ = 4.7 ft

$$\text{Pile Weight} = \pi\left(\frac{d}{2}\right)^2 (4.7 + 2)\,\gamma_c$$

$$= \pi\left(\frac{1.5}{2}\right)^2 (6.7)(145) = 1717 \text{ lbs}$$

V' = 6188 – 1717 = 4471 lbs

$$I_g = \frac{\pi}{4}\left(\frac{d}{2}\right)^4 = \frac{\pi}{4}\left(\frac{18}{2}\right)^4 = 5153 \text{ in}^4$$

$$A_g = \pi\left(\frac{d}{2}\right)^2 = \pi\left(\frac{18}{2}\right)^2 = 254.5 \text{ in}^2$$

$$f_c = \frac{(29{,}133 \text{ x } 12)(18)}{2\,(5153.0)} - \frac{4{,}471}{254.5} = 593 \text{ psi} \le 1625 \text{ psi} = \frac{f'c}{2}$$

Bar Reinforcing Stress:

Refer to Section 5-6.05, *Bar Reinforcing Stresses*.

Given Information

Pile:
- L = Depth below ground = 8 ft
- e = Length from ground surface to ultimate lateral load = 2 ft
- d = Pile diameter = 18 in = 1.5 ft

Bar Reinforcing Steel:
- 2-#8 Grade 60 bars, full length, 2" clear

Placed symmetrically along the pile axis

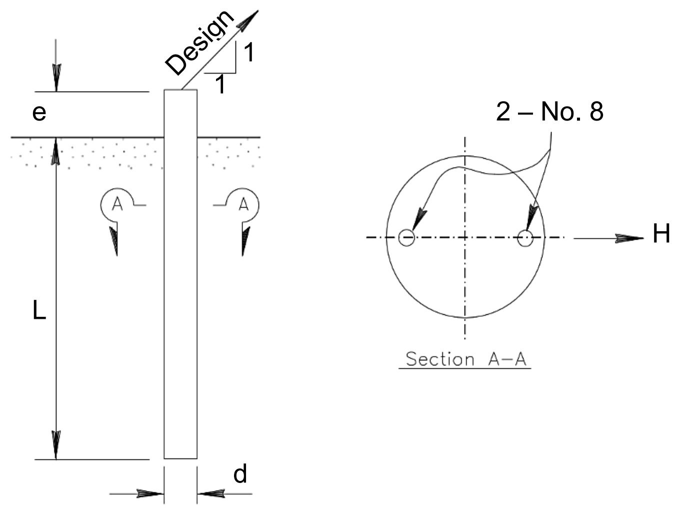

Figure D-29-6. Laterally Loaded Pile with Reinforcement

Design loads:
- V_{MAX} = 6188 lbs
- H_{MAX} = 6188 lbs
- M_{MAX} = 29,133 ft-lb

Single use loading (FS = 2)

Determine the bar reinforcing stress in this pile

$d_s = d_{pile} - 2[2'' \text{ clear}] - 2(d_{bar}/2) = 18 - 2(2) - 2(1.0/2) = 13$ in

$A_s = 0.79 \text{ in}^2$
$\Sigma A_s = 2(0.79 \text{ in}^2) = 1.58 \text{ in}^2$

$V' = V_{MAX}$ – pile weight = 6188 – 1717 = 4471 lbs

$$f_s = \frac{M}{A_s d_s} + \frac{V'}{\Sigma A_s} \qquad (5\text{-}6.05\text{-}3)$$

$$= \frac{29{,}133\ (12)}{(0.79)\ (13)} + \frac{4{,}471}{1.58} = 36{,}870 \text{ psi}$$

$$F_s \leq 0.70\ F_y = 0.7\ (60{,}000) = 42{,}000 \text{ psi} \qquad (5\text{-}6.05\text{-}4)$$

36,870 psi < 42,000 psi allowable **OK**

Combined Uplift and Horizontal Load:

Refer to Section 5-6.06, *Resistance to Combined Uplift and Horizontal Load*.

Given Information

Load capacities:
V_{ULT} = 15,800 lbs
H_{ULT} = 11,900 lbs

Single use loading (FS = 2)

Determine the load that the following pile types would be designed to resist:

a. For a plumb pile with load 30º from horizontal?
b. For a pile that is battered 15º towards the load with load 45º from H?

a. Plumb Pile

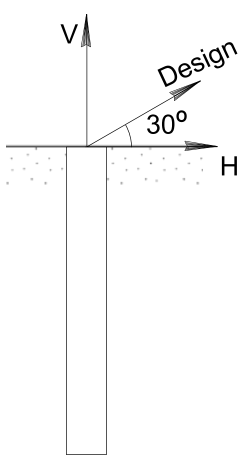

Figure D-29-7. Combined Loading for Plumb Pile

$$\text{Design}_1 = \frac{15{,}800}{\sin(30°)} = 31{,}600 \text{ lbs}$$

$$\text{Design}_2 = \frac{11{,}900}{\cos(30°)} = 13{,}741 \text{ lbs}$$

The design loading of 13,741 lbs governs

$$\text{Design working load} = \frac{13{,}741}{2} = 6871 \text{ lbs}$$

b. Battered Pile

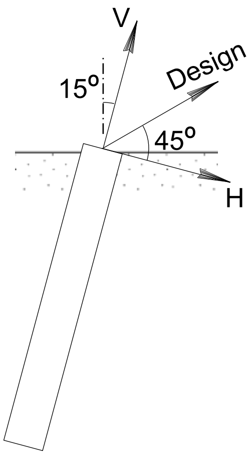

Figure D-29-8. Combined Loading for Battered Pile

$$\text{Design}_1 = \frac{15{,}800}{\sin(45°)} = 22{,}345 \text{ lbs}$$

$$\text{Design}_2 = \frac{11{,}900}{\cos(45°)} = 16{,}829 \text{ lbs}$$

The design loading of 16,829 lbs governs

$$\text{Design working load} = \frac{16{,}829}{2} = 8415 \text{ lbs}$$

The forgoing equations may be used when the horizontal force H is to be less than the computed ultimate lateral force H_{ULT}.