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CHAPTER 23

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* Indicates 11 x 17 sheet; all others are 8½ x 11.

This chapter is under development and will be revised at a later date.

Data in this chapter is provided for use until revisions are complete.

Notes to designer:

This guide is for analyzing steel H-pile and prestressed square concrete piles subject to scour. The guide provides information on how to determine the point of fixity below the ground surface for the pile, the effective length factor K, and how to check the allowable stress in the pile.

For the 100 year storm, the allowable stress is checked against the AASHTO group loading factors. This provides a factor of safety of greater than two. For the 500 year storm, the allowable stress is checked against twice the group loading factors. This provides a factor of safety greater than one.

This guide does not indicate how to determine the axial loads and moments to be used in the formulas. Because the piles are not laterally restrained, sidesway is not prevented; therefore, it is recommended that the STAAD-III/ISDS finite element program be used to determine the axial loads and moments.

Definitions:

$\bar{b}$ = Pile width in direction of bending (ft)

c = 0.125N ksf

D = Pile embedment length into ground (ft)

$\bar{D}$ = Depth of assumed point of fixity (ft)

E = Modulus of elasticity ksf

E_c = 580,388 ksf for f'c = 5000 psi

= 635,790 ksf for f'c = 6000 psi

E_s = 4,176,000 ksf

I = Moment of interia of pile (ft^4)

k = Coefficient of horizontal subgrade reaction for fine grained soil ksf

L = Unsupported length of pile (ft)

$\bar{m}$ = 0.32 for c < 1 ksf
= 0.34 for c = 1 ksf
= 0.36 for 1 < c < 4 ksf
= 0.38 for c = 4 ksf
= 0.40 for c > 4 ksf

N = Blow count

n_h = Coefficient of horizontal subgrade reaction for coarse grained soil kips/ft^3 (Use n_{hs} for saturated soil)

$\bar{D} = 1.8 \sqrt[5]{EI/n_h}$ for coarse grained soils

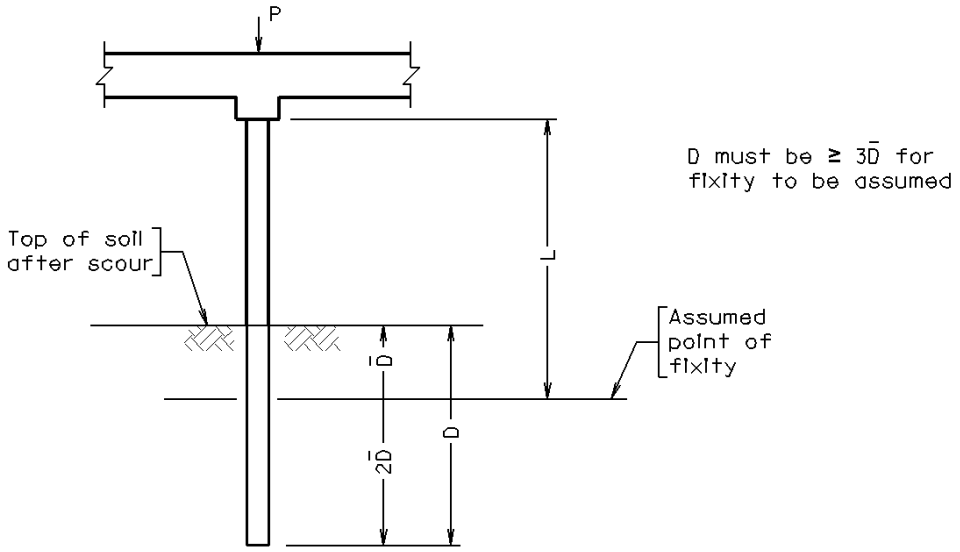
$\delta = \sqrt[5]{n_h/EI}$ if $\delta D < 4$, then pinned end; otherwise fixed end

$\bar{D} = 1.4 \sqrt[4]{EI/k}$ for cohesive soils

$\beta = \sqrt[4]{k\bar{b}/EI}$ if $\beta D < 2.25$, then pinned ends; otherwise fixed end

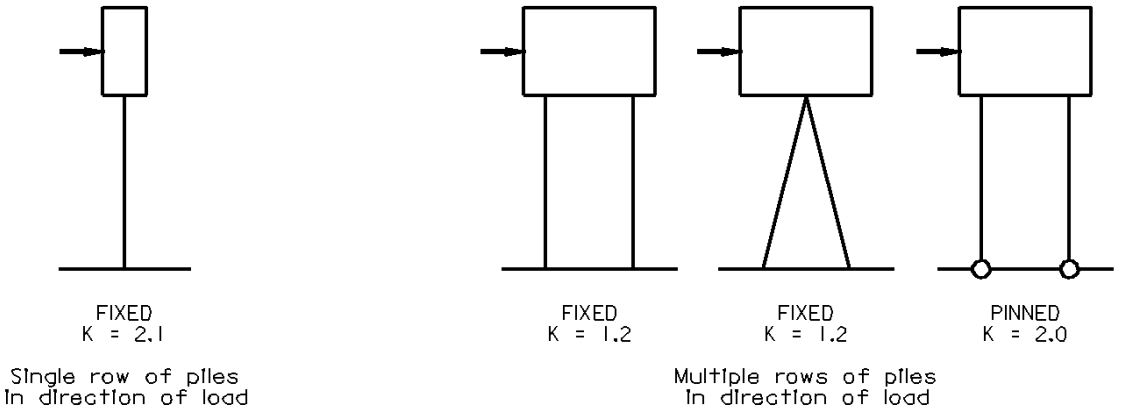
$k = 160\ \bar{m}c/\bar{b}$

POINT OF FIXITY FOR FREE STANDING PILE
DESIGN CRITERIA



EFFECTIVE LENGTH FACTOR - K

SIDESWAY PERMITTED



PILES **DESIGN GUIDE FOR LATERALLY UNSUPPORTED PILES** **DESIGN CRITERIA**	VOL. V - PART 2 DATE: 01Apr2005 SHEET 2 of 11 FILE NO. 23.100-2

COEFFICIENT OF HORIZONTAL SUBGRADE REACTION FOR COARSE GRAINED SOIL		
Blow Count N	Above Ground Water n_h	Below Ground Water n_{hs}
5	14	8
10	18	10
15	23	13
20	29	17
25	37	21
30	48	28
35	61	35
40	78	45
45	100	58
50	126	73

SHEAR STRENGTH OF COHESIVE SOILS						
Consistency	Very Soft	Soft	Medium	Stiff	Very Stiff	Hard
q_u = unconfined compression strength lb/ft^2	0 500	1000	2000	4000	8000	
Standard penetration resistance, N = no. of blows per ft.	0 2	4	8	16	32	
Unit weight, pcf (saturated)	100-120		110-130	120-140		130+

Cohesive (c) = ½ unconfined compression strength (q_u)

POINT OF FIXITY FOR FREE STANDING PILE
COARSE GRAIN SOIL EXAMPLE

Coarse grain soil, medium relative density (N = 27), above ground water.

HP12X53 subject to biaxial bending.

Pile Length = 60 ft. Scour Depth = 10 ft. D = 50 ft.

$\bar{D}_x = 1.8 \sqrt[5]{EI_x/n_h} = 8.14$ ft.

$n_h = 42$ k/ft^3

$EI_x = 29{,}000(393)/144 = 79{,}145.8$ ksf

$\bar{D}_y = 1.8 \sqrt[5]{EI_y/n_h} = 6.49$ ft.

$EI_y = 29{,}000(127)/144 = 25{,}576.4$ ksf

$\delta_x = \sqrt[5]{n_h/EI_x} = 0.22$ $\delta_x D = 11.06 > 4$ therefore fixed end

$\delta_y = \sqrt[5]{n_h/EI_y} = 0.28$ $\delta_y D = 13.87 > 4$ therefore fixed end

$D/\bar{D}_x = 50/8.14 = 6.14 > 3$ therefore fixed end

$D/\bar{D}_y = 50/6.49 = 7.70 > 3$ therefore fixed end

$L_x = 10 + 8.14 = 18.14$ ft.

$L_y = 10 + 6.49 = 16.49$ ft.

Single row of piles with fixed ends in x-direction, $K_x = 2.1$

$K_xL_x/r_x = 2.1(18.14)(12)/5.03 = 90.88$

Multiple rows of piles with fixed ends in y-direction, $K_y = 1.2$

$K_yL_y/r_y = 1.2(16.49)(12)/2.86 = 83.03$

where: L = Unsupported length of pile

K = Effective length factor

r = Radius of gyration

POINT OF FIXITY FOR FREE STANDING PILE
COHESIVE SOIL EXAMPLE

Cohesive soil, blow count = 12.

HP12x53 subject to biaxial bending.

Pile Length = 60 ft. Scour Depth = 10 ft. D = 50 ft.

$c = 0.125N = 1.5$ ksf

$k_x = 160\ \bar{m}c/\bar{b}_x = 160(0.36)(1.5)/(12.045/12) = 86.08$ ksf

$k_y = 160\ \bar{m}c/\bar{b}_y = 160(0.36)(1.5)/(11.78/12) = 88.01$ ksf

$\bar{D}_x = 1.4\sqrt[4]{EI_x/k_x} = 7.71$ ft

$EI_x = 29{,}000(393)/144 = 79{,}145.8$ ksf

$\bar{D}_y = 1.4\sqrt[4]{EI_y/k_y} = 5.78$ ft

$EI_y = 29{,}000(127)/144 = 25{,}576.4$ ksf

$\beta_x = \sqrt[4]{k_x\bar{b}_x/EI_x} = 0.18$ $\beta_x D = 0.18(50) = 9.09 > 2.25$ therefore fixed end

$\beta_y = \sqrt[4]{k_y\bar{b}_y/EI_y} = 0.24$ $\beta_y D = 0.24(50) = 12.05 > 2.25$ therefore fixed end

$D/\bar{D}_x = 50/7.71 = 6.48 > 3$ therefore fixed end

$D/\bar{D}_y = 50/5.78 = 8.65 > 3$ therefore fixed end

$L_x = 10 + 7.71 = 17.71$ ft.

$L_y = 10 + 5.78 = 15.78$ ft.

Single row of piles with fixed ends in x-direction, $K_x = 2.1$

$K_xL_x/r_x = 2.1(17.71)(12)/5.03 = 88.73$

Multiple row of piles with fixed ends in y-direction, $K_y = 1.2$

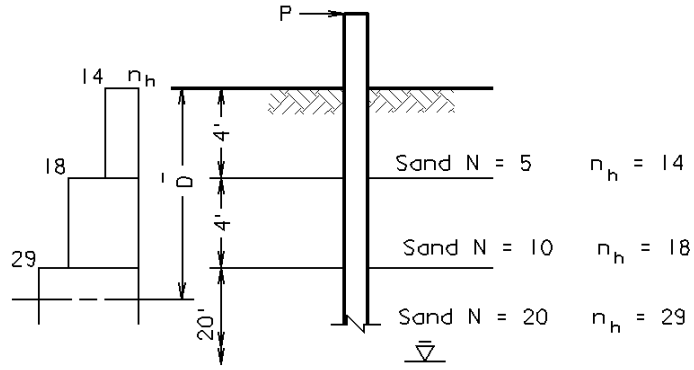
$K_yL_y/r_y = 1.2(15.78)(12)/2.86 = 79.45$

where: L = Unsupported length of pile

K = Effective legth factor

r = Radius of gyration

POINT OF FIXITY FOR FREE STANDING PILE
LAYERED SOIL EXAMPLE



Assume an average n_h = 15 as first guess.

Pile EI = 79,146

$$\bar{D} = 1.8\sqrt[5]{\frac{79,146}{15}} = 9.994 \text{ ft}$$

$$n_h = \frac{3}{\bar{D}^3}\Sigma\left(\frac{n_{hi}d_i^3}{3} + n_{hi}d_i y_i^2\right)$$

Second moment of area of n_h diagram

taken about line at assumed $\bar{D}$

$$n_h = \frac{3}{9.994^3}\left[\frac{14(4)^3}{3} + 14(4)(2 + 5.994)^2 + \frac{18(4)^3}{3} 18(4)(2 + 1.994)^2 + \frac{29(1.994)^3}{3}\right]$$

n_h = 16.489

Use new n_h to calculate a new $\bar{D}$

$$\bar{D} = 1.8\sqrt[5]{\frac{79,146}{16.489}} = 9.807 \text{ ft}$$

$$n_h = \frac{3}{9.807^3}\left[\frac{14(4)^3}{3} + 14(4)(2 + 5.807)^2 + \frac{18(4)^3}{3} + 18(4)(2 + 1.807)^2 \frac{29(1.807)^3}{3}\right]$$

n_h = 16.528

$$\bar{D} = 1.8\sqrt[5]{\frac{79,146}{16.489}} = 9.802 \text{ ft} \longleftarrow \text{Use this value as convergence}$$

where: d_i = depth of a layer

y_i = distance from assumed $\bar{D}$ to center of a layer

STEEL H-PILE DESIGN CRITERIA

$C_c = \sqrt{2\pi^2 E/F_y}$ For $F_y = 36{,}000$, $C_c = 126.1$

For $F_y = 50{,}000$, $C_c = 107.0$

AASHTO limits KL/r not to exceed 120 for main compression members

$KL/r < C_c$ use $F_a = \frac{F_y}{2.12}\left[1 - \frac{(KL/r)^2}{2C_c}\right]$ $F_y = 36{,}000$, $F_a = 16{,}980 - 0.53\,(KL/r)^2$
$F_y = 50{,}000$, $F_a = 23{,}580 - 1.03\,(KL/r)^2$

$\frac{KL}{r} > C_c$ use $F_a = \frac{\pi^2 E}{2.12(KL/r)^2} = \frac{135{,}000{,}740}{(KL/r)^2}$

$F_{bx} = 0.55F_y\left[1 - \frac{(L/r')^2 F_y}{4\pi^2 E}\right]$ $F_y = 36{,}000$ and $L/b \leq 36$, $Fbx = 20{,}000 - 7.5\,(L/b)^2$
$F_y = 50{,}000$ and $L/b \leq 30$, $Fbx = 27{,}000 - 14.4(L/b)^2$
$r' = \sqrt{b^2/12}$ b = flange width

$F_{by} = F_{bx}$

$f_a = \frac{P}{A}$ $f_{bx} = \frac{M_x}{S_x}$ $f_{by} = \frac{M_y}{S_y}$

Z = Group Loading Factor for 100 Year Storm

Z = 2 × Group Loading Factor for 500 Year Storm

$\frac{f_a}{F_a} \leq 0.15$ use $\frac{f_a}{F_a} + \frac{f_{bx}}{F_{bx}} + \frac{f_{by}}{F_{by}} \leq Z$

$\frac{f_a}{F_a} > 0.15$ use $\frac{f_a}{F_a} + \left[\frac{C_{mx}}{1 - (f_a/F'_{ex})}\right]\frac{f_{bx}}{F_{bx}} + \left[\frac{C_{my}}{1 - (f_a/F'_{ey})}\right]\frac{f_{by}}{F_{by}} \leq Z$

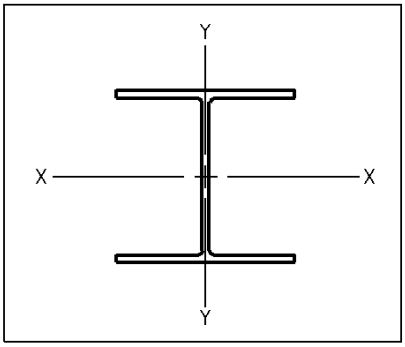
and, in addition, at points of support when $\frac{f_a}{F_a} > 0.15$

$$\frac{f_a}{0.472F_y} + \frac{f_{bx}}{F_{bx}} + \frac{f_{by}}{F_{by}} \leq Z$$

where $F'_e = \frac{\pi^2 E}{2.12(KL/r)^2} = \frac{135{,}000{,}740}{(KL/r)^2}$

and $C_{mx} = C_{my} = 0.85$

For definition of terms, see AASHTO Standard Specifications for Highway Bridges, Section 10.1.1



HP
H-Piles
Properties for Designing

Designation and Nominal Size	Weight Per Foot	Area	Depth	Flange Width	Flange Thickness	Web Thickness	Axis X-X I	Axis X-X S	Axis X-X r	Axis Y-Y I	Axis Y-Y S	Axis Y-Y r
In.	Lbs.	In.^{2}	In.	In.	In.	In.	In.^{4}	In.^{3}	In.	In.^{4}	In.^{3}	In.
HP14 14×14½	117	34.4	14.21	14.885	.805	.805	1220	172	5.96	443	59.5	3.59
	102	30.0	14.01	14.785	.705	.705	1050	150	5.92	380	51.4	3.56
	89	26.1	13.83	14.695	.615	.615	904	131	5.88	326	44.3	3.53
	73	21.4	13.61	14.585	.505	.505	729	107	5.84	261	35.8	3.49
HP12 12×12	74	21.8	12.13	12.215	.610	.605	569	93.8	5.11	186	30.4	2.92
	53	15.5	11.78	12.045	.435	.435	393	66.8	5.03	127	21.1	2.86
HP10 10×10	57	16.8	9.99	10.225	.565	.565	294	58.8	4.18	101	19.7	2.45
	42	12.4	9.70	10.075	.420	.415	210	43.4	4.13	71.7	14.2	2.41
HPS10 10×8	57	16.8	10.16	8.320	.650	.650	287	56.4	4.13	62.6	15.1	1.93
	42	12.3	9.82	8.150	.480	.480	203	41.3	4.06	43.4	10.7	1.88
HP8 8×8	36	10.6	8.02	8.155	.445	.445	119	29.8	3.36	40.3	9.88	1.95

Note:

The axes given in the table do not conform to the member axis in the STAAD-III/ISDS program.

STEEL H-PILE DESIGN EXAMPLE

Coarse grain soil, medium relative density, above ground water.

HP12x53 F_y = 36,000 psi. Group III loading 100 Year Storm

Pile Length = 60 ft. Scour death = 10 ft. D = 50 ft

$K_xL_x/r_x = 90.88$ $K_yL_y/r_y = 83.03$ (See previous example)

P = 124,000 lb M_x = 250,000 in-ld M_y = 50,000 in-lb

$C_c = 126.1$

$K_xL_x/r_x < C_c$ $K_yL_y/r_y < C_c$

$F_a = 16{,}980 - 0.53(KL/r)^2 = 16{,}980 - 053(90.88)^2 = 12{,}603$ psi

$$f_a = \frac{P}{A} = \frac{124{,}000}{15.5} = 8{,}000 \text{ psi}$$

$F_{bx} = 20{,}000 - 7.5((18.14)(12)/12.045)^2 = 17{,}551$ psi

$L/b = (18.14)(12)/12.045 = 18.07 < 36$ therefore o.k.

$F_{by} = 17{,}551$ psi

$f_{bx} = 250{,}000/66.8 = 3{,}743$ psi

$f_{by} = 50{,}000/21.1 = 2{,}370$ psi

$$\frac{f_a}{F_a} = \frac{8{,}000}{12{,}603} = 0.64 > 0.15 \quad \text{Therefore, use}$$

$$\frac{f_a}{F_a} + \left[\frac{C_{mx}}{1 - f_a/F'_{ex}}\right]\frac{f_{bx}}{F_{bx}} + \left[\frac{C_{my}}{1 - f_a/F'_{ey}}\right]\frac{f_{by}}{F_{by}} \leq 1.25 \text{ (Group III)}$$

$$\text{and } \frac{f_a}{0.472F_y} + \frac{f_{bx}}{F_{bx}} + \frac{f_{by}}{F_{by}} \leq 1.25$$

$$F'_{ex} = \frac{135{,}000{,}740}{(K_xL_x/r_x)^2} = \frac{135{,}000{,}740}{90.88^2} = 16.346 \text{ psi}$$

$$F'_{ey} = \frac{135{,}000{,}740}{(K_yL_y/r_y)^2} = \frac{135{,}000{,}740}{83.03^2} = 19.583 \text{ psi}$$

$$\frac{8000}{12{,}603} + \left[\frac{0.85}{1 - 8000/16{,}346}\right]\frac{3743}{17{,}551} + \left[\frac{0.85}{1 - 8000/19{,}583}\right]\frac{2370}{17{,}551} = 1.18 < 1.25 \quad \text{therefore o.k.}$$

$$\frac{8000}{0.472(36{,}000)} + \frac{3743}{17{,}551} + \frac{2370}{17{,}551} = 0.82 < 1.25 \quad \text{therefore o.k.}$$

PRESTRESS SQUARE CONCRETE PILE DESIGN CRITERIA

The stresses at serviceability limit shall be such that:

a) $(f_{pc} + P/A_g \pm Mc/I) \leq$ zero for no tension or

$> -4\sqrt{f'_c}$ if tension allowed

$\leq 0.45f'_c$ for compression

b) $(P/P_a + M/M_a) \leq Z$

where: $P_a = (0.33f'_c - 0.27f_{pc})A_g$ for laterally-supported piles

$P_a = R(0.33f'_c - 0.27\ f_{pc})A_g$ for laterally-unsupported piles with $KL/r \leq 120$

P = Axial load

$M_a = f_{pc}\ (I/c)$ or $(f_{pc} + 4\sqrt{f'_c})\ (I/c)$

$M = M_x + M_y$

f_{pc} = Prestress compression after losses

$r = 0.2887b$

A_g = Cross-sectional area of pile

$R = (1.23 - 0.008KL/r) \leq 1.0$

Z = Group Loading Factor for 100 Year Storm

Z = 2 x Group Loading Factor for 500 Year Storm

PRESTRESS SQUARE CONCRETE PILES					
Size in	A_g in^2	I in^4	c in	f_{pc} psi	r in
10	100	833	5	772	2.887
12	144	1728	6	723	3.464
14	196	3201	7	817	4.042
16	256	5461	8	829	4.619
18	324	8748	9	750	5.200
20	400	13333	10	809	5.774
22	484	19521	11	765	6.351
24	576	27648	12	803	6.929

PRESTRESS SQUARE CONCRETE PILE DESIGN EXAMPLE

12" prestress pile, mulitple rows, tension allowed in pile

f'_c = 5,000 psi Group I Loading 1000 Year Storm

Pile Length = 10 ft K = 1.2

P = 72,000 lb M_x = 120,000 in-lb M_y = 12,000 in-lb

KL/r = 1.2(10)(12)/3.464 = 41.6 < 120 o.k.

R = (1.23 - 0.0008(41.6))= 0.897 < 1 o.k.

P_a = 0.897(0.33(5000) - 0.27(723))144 = 187,912 lb

M_a = (723 + $4\sqrt{5000}$)288 = 289,683 in-lb

$$\frac{72{,}000}{187{,}912} + \frac{120{,}000 + 12{,}000}{289{,}683} = 0.839 < 1 \quad \text{therefore o.k.} \quad \text{(Group I Loading)}$$

$$723 + \frac{72{,}000}{144} \pm \frac{132{,}000(6)}{1728} = \begin{array}{l} +765 \text{ psi} > -283 \quad \text{therefore o.k.} \\ +1681 \text{ psi} < 2250 \quad \text{therefore o.k.} \end{array}$$

References:

AISC Marketing, Highway Structures Design Handbook, Vol. II Part 2 and Vol. I Part 10.

AASHTO Standard Specifications for Highway Bridges, Sections 10.32.1 and 10.36 and Appendix C.

ACI Journal, August 1973.

PCI Journal, March-April 1977.

Ontario Highway Bridge Design Code, 1983, Section 9-27.6.

Bayshore Concrete Products, Engineering Design Data.