Example 2 – hand calculations – solid fencing for wind loading – no ice loading

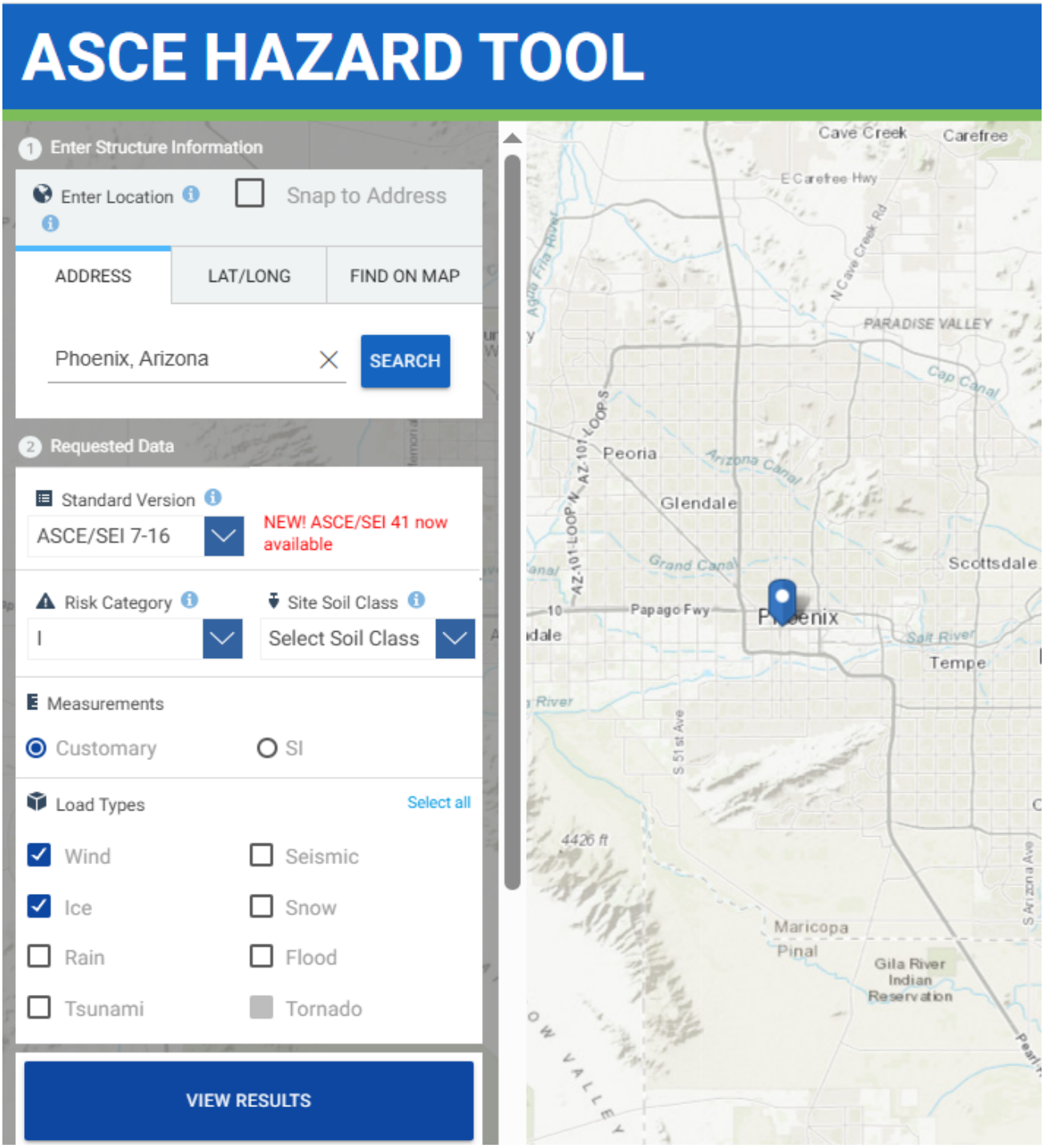
6’ mostly solid wooden fence no gap at the bottom 96’ long 8’ post spacing Elevation - 1,086 ft

5-1/4” wooden pickets w/ ¼” gaps 5-1/2” picket spacing Solidity Ratio, $\varepsilon = 5.5 / 5.25 = 0.95$

Site Location – Phoenix, AZ Exposure B (residential) Risk Category I Flat ground

ARIZONA
2018 International Building Code with amendments (at the time of this writing) For IBC 2018 & 2021 use ASCE 7-16

https://ascehazardtool.org/



Standard:	ASCE/SEI 7-16
Risk Category:	I
Soil Class:	

Wind

95 Vmph

Ice

0 in.

q_w Values	
V_w (mph)	q_w (psf)
85	8.02
90	8.99
95	10.02
100	11.10
105	12.24
110	13.43
115	14.68
120	15.98
125	17.34
130	18.75
135	20.23
140	21.75

K_z Values for ASCE 7-10 & 7-16			
Fence Height, h (ft)	Exposure Class		
	B	C	D
0-15	0.57	0.85	1.03
16	0.59	0.86	1.04
17	0.60	0.87	1.05
18	0.61	0.88	1.06
19	0.61	0.89	1.07
20	0.62	0.90	1.08

K_e Values		
Site Elevation	ASCE	
	7-16 & 7-22	7-10
z_e (ft)	K_e	K_e = 1.0
0	1.00	1.00
500	0.98	1.00
1,000	0.96	1.00
1,500	0.95	1.00
2,000	0.93	1.00
2,500	0.91	1.00
3,000	0.90	1.00
3,500	0.88	1.00
4,000	0.87	1.00
4,500	0.85	1.00
5,000	0.84	1.00

Inverted Fence Opening Reduction Factor, R_1

ε or ε'	R_1
0.71	1.19
0.72	1.17
0.73	1.16
0.74	1.15
0.75	1.14
0.76	1.13
0.77	1.12
0.78	1.12
0.79	1.11
0.80	1.10
0.81	1.09
0.82	1.08
0.83	1.08
0.84	1.07
0.85	1.06

ε or ε'	R_1
0.86	1.06
0.87	1.05
0.88	1.04
0.89	1.04
0.90	1.03
0.91	1.03
0.92	1.02
0.93	1.02
0.94	1.01
0.95	1.01
0.96	1.01
0.97	1.01
0.98	1.00
0.99	1.00
1.00	1.00

$R_{1w} = 1 / (1 - (1 - \varepsilon)^{1.5})$

$R_{1i} = 1 / (1 - (1 - \varepsilon')^{1.5})$

K_{zt} = 1.0 for flat ground

See ASEC 7 Fig. 26.8-1 to calculate K_{zt} values for site locations on hills or escarpments

h = 6’ g = 0’ s = 6’ ε = 0.95 (5.25 / 5.5 = 0.95) C_{fw} = value determined on following pages D_w = 1.5 psf

R_{1w} = 1.01

Case C Reduction Factor R_{2w} = 0.8 Return Corner Reduction Factor, F_{3w} = 1.0 as there is no return corner

F_{hw} = 1.1

Case C Reduction Factor, R_2	
s/h	R_2
1.000	0.80
0.975	0.83
0.950	0.85
0.925	0.88
0.900	0.90
0.875	0.93
0.850	0.95
0.825	0.98
≥ 0.800	1.00
$R_2 = (1.8 - s/h) \leq 1.0$	

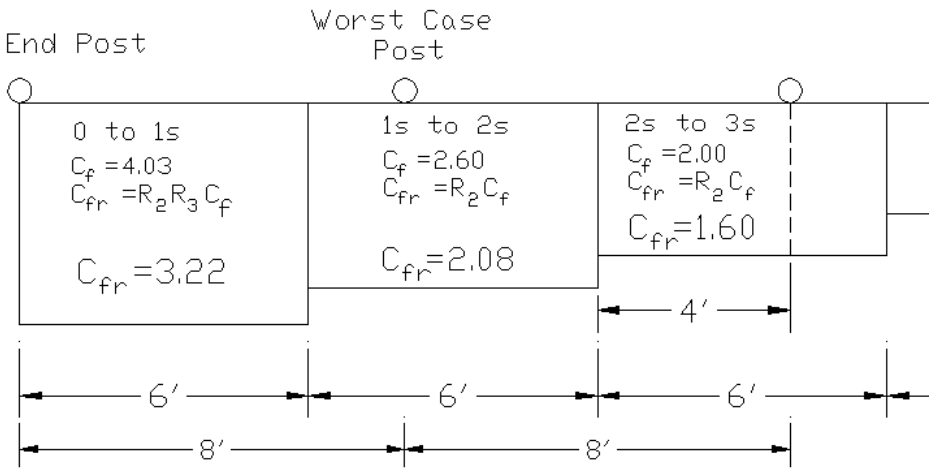
Force Height Adjustment Factor, F_h		
s/h	F_h	Notes
1.000	1.100	Per Solid Wall Table, Note 3
0.975	1.025	$F_h = 2 - s/h$
0.950	1.050	
0.925	1.075	
0.900	1.100	
0.875	1.125	
0.850	1.150	
0.825	1.175	
0.800	1.200	

Fence Length, B = 96 ft Fencing Height, s = 6' Aspect Ratio B/s = 16 Case C controls wost case post

C_f values - Solid / Mostly Solid Fencing - Case C - Posts near ends and corners											
Wind Region	Aspect Ratio, B/s										
	13	16	19	22	25	28	31	34	37	40	≥45
0 to s	4.00*	4.03*	4.06*	4.09*	4.12*	4.15*	4.18*	4.21*	4.24*	4.27*	4.30*
s to 2s	2.60	2.60	2.59	2.59	2.58	2.58	2.57	2.57	2.56	2.56	2.55
2s to 3s	2.00	2.00	1.99	1.99	1.98	1.98	1.97	1.97	1.96	1.96	1.95
3s to 4s	1.50	1.54	1.57	1.61	1.64	1.68	1.71	1.75	1.78	1.82	1.85
4s to 5s	1.35	1.40	1.45	1.50	1.55	1.60	1.65	1.70	1.75	1.80	1.85
5s to 10s	0.90	0.92	0.94	0.96	0.98	1.00	1.02	1.04	1.06	1.08	1.10
>10s	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55

For solid / mostly solid fencing, the post with the highest wind loading is typically the 1st post in from the end of the longest fence run. Return corners reduce the forces so for complicated fencing, multiple checks may need to be done to find the worst case post. In this case, a straight fence with no corners, the posts next to the end posts have the highest loading. End posts get higer wind pressures, but only half the wind area.

L = 8' R_2 = 0.8 Worst case post
B = 96' R_3 = 1.0 weighted average method
s = 6'
B/s = 16
C_f = 1.07(6 × 3.22 + 6 × 2.08 + 4 × 1.60) / (2 × 8) = 2.55



C_{fw} for the worst case post = 2.55

Site Location: Phoenix, AZ

Customer:

Site and Geometrical Variables

IBC 2018 ASCE 7-16 Risk Category I Frost Depth 1.0 ft

Basic Wind Speed, V_w = 95 mph

Wind Pressure, q_w = 10.02 psf

Exposure Category B Topographical Factor, K_{zt} = 1.0

Site Elevation, Z_e = 1,086 ft Elevation Factor, K_e = 0.96

Height of fence, h = 6 ft Gap at bottom of fence, g = 0 ft (zero if no gap)

Height of fencing material, s = h - g = 6 ft

Velocity Pressure Exposure Coefficient, K_z = 0.57

Wind & Axial Loading

Fence Run # 1 Length of Fence, B = 96 ft Post spacing, L = 8 ft

Post Type: Line Posts ( ) Post near end or corner (X)

Solidity Ratio, ε = 0.95 Inverted Fence Opening Reduction Factor, R_{1w} = 1.01

Case C Reduction Factor, R_{2w} = 0.8 Return Corner Reduction Factor, R_{3w} = 1.0

Force Height Adjustment Factor, F_{hw} = 1.1 Wind Force Coefficient, C_{fw} = 2.55

Wind area tributary to the post, $A_w = \varepsilon\ s\ L$ = 0.95 (ε) × 6 ft (s) × 8 ft (L) = 45.6 (A_w) ft^2

Dead Load of fencing materials, D_m 2.2 psf weight of pickets and assuming two 2 x 4 rails

Lateral and Axial Forces for Wind Loading

Minimum wind force to the post, $f_{min} = (0.6)\ 16.0\ A_w = 9.6 \times$ 45.6 (A_w) = 438 (f_{min}) lbs

Calculated Wind Force to the post, $f_w = q_w\ K_z\ K_{zt}\ K_e\ R_{1w}\ F_{hw}\ C_{fw}\ A_w$

f_w = 10.02 (q_w) × 0.57 (K_z) × 1.0 (K_{zt}) × 0.96 (K_e) × 1.01 (R_{1w}) × 1.1 (F_{hw}) × 2.55 (C_{fw}) × 45.6 (A_w) = 708 (f_w) lbs

Maximum wind force to the post, f_w' = maximum value of either f_{min} or f_w = 708 (f_w') lbs

The Axial Force supported by the post, $p_w = D_m\ s\ L$

P_w = 2.2 psf (D_m) × 6 ft (s) × 8 ft (L) = 106 (p_w) lbs

5 × p_w = 530 lbs (used for stability check)

f_w = 708 lbs p_w = 106 lbs 5 x p_i = 530 lbs

Lightest wood post that looks possible is 6 x 6 – checking #2 southern pine pressure treated

Maximum Allowable Wind Force at Mid-height, F_a (lbs) & Maximum Axial Force, P_a (lbs)											
Post Size	Weight D_p (plf)		Fence Height, h (ft)								
			3	4	5	6	7	8	9	10	11
#2 Southern Pine - Pressure Treated											
4 x 4	6.2	F_a	699	524	419	349	299	-	-	-	-
		P_a	7,640	4,948	3,332	2,369	1,763	-	-	-	-
6 x 4	9.8	F_a	1,439	1,053	823	670	561	479	416	366	325
		P_a	16,797	14,108	10,978	8,349	6,425	5,050	4,057	3,322	2,767
6 x 6	15.3	F_a	2,465	1,849	1,479	1,232	1,056	924	822	739	672
		P_a	26,395	22,169	17,251	13,120	10,096	7,936	6,375	5,221	4,348
#2 Western Red Cedar											
4 x 4	2.0	F_a	445	333	267	222	191	-	-	-	-
		P_a	4,959	3,419	2,356	1,692	1,266	-	-	-	-
6 x 4	3.5	F_a	1,010	740	579	472	395	338	294	258	230
		P_a	10,111	8,915	7,320	5,764	4,517	3,587	2,898	2,382	1,989
6 x 6	4.8	F_a	1,725	1,294	1,035	863	739	647	575	518	471
		P_a	15,889	14,009	11,503	9,057	7,099	5,636	4,554	3,743	3,126
Post Size	D_p (plf) Weight		3	4	5	6	7	8	9	10	11
			Fence Height, h (ft)								

For steel pipes

Allowable Wind Force at Mid-height, F_a (lbs) & Allowable Axial Force, P_a (lbs) - Group IA and IC Posts																		
Post Size	Weight, D_p lbs / ft		Fence Height, H (ft)															
			5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Schedule 40 / ASTM F1043 / Group 1A / 30 ksi																		
1-5/8"	2.3	F_a	182	152	130	114	-	-	-	-	-	-	-	-	-	-	-	-
		P_a	1,745*	1,212*	890*	681*	-	-	-	-	-	-	-	-	-	-	-	-
1-7/8"	2.7	F_a	252	210	180	157	140	-	-	-	-	-	-	-	-	-	-	-
		P_a	2,773*	1,926*	1,415*	1,083*	856*	-	-	-	-	-	-	-	-	-	-	-
2-3/8"	3.7	F_a	427	356	305	267	237	213	194	178	-	-	-	-	-	-	-	-
		P_a	5,943	4,127	3,032*	2,321*	1,834*	1,485*	1,227*	1,031*	-	-	-	-	-	-	-	-
2-7/8"	5.8	F_a	817	680	583	510	453	408	371	340	314	291	272	-	-	-	-	-
		P_a	13,272	9,494	6,975	5,340*	4,219*	3,418*	2,824*	2,373*	2,022*	1,743*	1,519*	-	-	-	-	-
3-1/2"	7.6	F_a	1,310	1,092	936	819	728	655	595	546	504	468	436	409	385	364	-	-
		P_a	22,458	17,944	13,733	10,514	8,307	6,729*	5,561*	4,673*	3,981*	3,433*	2,990*	2,628*	2,328*	2,076*	-	-
4"	9.1	F_a	1,809	1,507	1,292	1,130	1,005	904	822	753	695	646	603	565	532	502	476	452
		P_a	30,535	25,757	21,064	16,666	13,168	10,666	8,815*	7,407*	6,311*	5,442*	4,740*	4,166*	3,690*	3,292*	2,954*	2,666*
4-1/2"	10.8	F_a	2,419	2,016	1,728	1,512	1,344	1,209	1,099	1,008	930	864	806	756	711	672	636	604
		P_a	39,301	34,390	29,370	24,481	19,876	16,100	13,305	11,180	9,526*	8,214*	7,155*	6,289*	5,570*	4,969*	4,459*	4,025*
5-9/16"	14.6	F_a	4,069	3,391	2,906	2,543	2,260	2,034	1,849	1,695	1,565	1,453	1,356	1,271	1,196	1,130	1,070	1,017
		P_a	59,190	54,288	49,016	43,565	38,117	32,830	27,809	23,367	19,910	17,167	14,955*	13,144*	11,643*	10,385*	9,321*	8,412*
6-5/8"	19.0	F_a	6,319	5,266	4,514	3,949	3,511	3,159	2,872	2,633	2,430	2,257	2,106	1,974	1,858	1,755	1,663	1,579
		P_a	81,532	76,751	71,462	65,810	59,943	54,002	48,119	42,408	36,967	31,890	27,780	24,416	21,628	19,291*	17,314*	15,626*
8-5/8"	28.6	F_a	12,434	10,362	8,881	7,771	6,908	6,217	5,652	5,181	4,782	4,440	4,144	3,885	3,657	3,454	3,272	3,108
		P_a	129,849	125,342	120,217	114,564	108,477	102,056	95,401	88,609	81,773	74,982	68,314	61,841	55,623	49,640	44,552	40,208
40 Weight / ASTM F1043 / Group 1C / 50 ksi																		
1-5/8"	1.8	F_a	244	203	174	152	-	-	-	-	-	-	-	-	-	-	-	-
		P_a	1,455*	1,010*	742*	568*	-	-	-	-	-	-	-	-	-	-	-	-
1-7/8"	2.3	F_a	350	292	250	219	194	175	-	-	-	-	-	-	-	-	-	-
		P_a	2,385	1,656*	1,217*	931*	736*	596*	-	-	-	-	-	-	-	-	-	-
2-3/8"	3.1	F_a	608	507	434	380	338	304	276	253	-	-	-	-	-	-	-	-
		P_a	5,178	3,596	2,642*	2,022*	1,598*	1,294*	1,069*	899*	-	-	-	-	-	-	-	-
2-7/8"	4.6	F_a	1,095	912	782	684	608	547	497	456	421	391	365	-	-	-	-	-
		P_a	11,274	7,829	5,752	4,404*	3,479*	2,818*	2,329*	1,957*	1,667*	1,438*	1,252*	-	-	-	-	-
4"	6.6	F_a	2,222	1,852	1,587	1,389	1,234	1,111	1,010	926	854	793	740	694	653	617	584	555
		P_a	28,899	22,018	16,247	12,439	9,828	7,961	6,579*	5,528*	4,710*	4,061*	3,538*	3,109*	2,754*	2,457*	2,205*	1,990*
4-1/2"	7.4	F_a	2,851	2,376	2,036	1,782	1,584	1,425	1,296	1,188	1,096	1,018	950	891	838	792	750	712
		P_a	37,346	30,183	23,447	17,951	14,184	11,489	9,495	7,978	6,798*	5,861*	5,106*	4,487*	3,975*	3,546*	3,182*	2,872*

Post Selection

Using the diameter of the desired post size, O.D., and the Fence Height, h, look through the post charts for post types that have F_a values larger than the f_w' value, and P_a values larger than the p_w value. If the post has an * next to the P_a value, only use it if the P_a value is ≥ 5 × p_w due to stability requirements.

Put in the O.D, post type, weight per foot, D_p and fence height, h and calculate p_w' to include the weight of the post. Add any additional weight if needed.

f_w' / F_a is the bending strength ratio for Wind. p_w' / P_a is the axial strength ratio for Wind

If the sum of the bending strength and axial strength ratios for both Wind and Wind & Ice loading are ≤ 1.0, the post is acceptable.

O.D.	Post Type	D_p (lb/f)	h (ft)	$p_w' = p_w + (D_p \times h)$	
6 x 6	#2 pine PT	15.3	6	p_w' = 198 lbs	
Wind					
$f_w' = \frac{708}{1{,}232} = 0.57$			$p_w' = \frac{198}{13{,}120} = 0.2$		$\frac{f_w'}{F_a} + \frac{p_w'}{P_a} = 0.59$

O.D.	Post Type	D_p (lb/f)	h (ft)	$p_w' = p_w + (D_p \times h)$	
3-1/2"	Sched 40 / 30 ksi	7.6	6	p_w' = 152 lbs	
Wind					
$f_w' = \frac{708}{1{,}092} = 0.65$			$p_w' = \frac{152}{17{,}944} = 0.01$		$\frac{f_w'}{F_a} + \frac{p_w'}{P_a} = 0.66$

O.D.	Post Type	D_p (lb/f)	h (ft)	$p_w' = p_w + (D_p \times h)$	
2-7/8"	40 qr / 50 ksi	4.6	6	p_w' = 134 lbs	
Wind					
$f_w' = \frac{708}{912} = 0.78$			$p_w' = \frac{134}{7{,}829} = 0.02$		$\frac{f_w'}{F_a} + \frac{p_w'}{P_a} = 0.80$

Next, size post footing assuming 2-7/8" dia post - 6-7/8" minium footing diameter - start with 9" (common auger)

With a 9" dia footing, the depth had to be over 6'. Trying again with a 12" diameter footing.

Footing Sizing (non-constrained footings)

Design Footing Depth, D = 5.5 ft Footing Diameter, b = 1.0 ft

Assumes soil class 4

Lateral Bearing Pressure per foot of depth, S = 150 psf / ft per geotechnical analysis or table 1806.2

Maximum Wind Force, P = f_w' = 708 lbs Post Height, h = 6 ft

Modifier for Isolated Posts, M = 2.0 per IBC §1086.3.4

Allowable Lateral Soil Bearing Pressure for non-constrained footings, S_1 = ⅓ D S M

$S_1 = ⅓ \times \frac{5.5}{D} \times \frac{150}{S} \times 2.0 = \frac{550}{S_1}$ psf per IBC §1807.3.2.1

Soil Bearing Factor, A = 2.34 P / (S_1 b) per IBC §1807.3.2.1

$A = 2.34 \times \frac{708}{P} \div \left(\frac{550}{S_1} \times \frac{1.0}{b} \right) = \frac{3.012}{A}$

Minimum Depth, $d = ½ A \left(1 + \sqrt{1 + \frac{4.36 \times ½ h}{A}}\right)$ per Eq. 18-1, modified for fencing

$d = ½ \times \frac{3.012}{A} \times \left(1 + \sqrt{1 + \left(4.36 \times ½ \times \frac{5.5}{h} \div \frac{3.012}{A}\right)}\right) = \frac{5.0}{d}$ ft

D > d - OK

If you run the numbers again, you can get down to 5' 3" depth in this case

Area of the bottom of the footing, $A_f = \pi (½ b)^2 = 3.14 \times \left(½ \times \frac{1.0}{b}\right)^2 = \frac{0.785}{A_f}$ ft²

Footing Volume, $V = A_f D = \frac{0.785}{A_f} \times \frac{5.5}{D} = \frac{4.32}{V}$ ft³

Weight of footing, $D_f = 150 V = 150 \times \frac{4.32}{V} = \frac{648}{D_f}$ lbs (Typical Concrete weight is 150 lbs / ft³)

Axial Dead Load, $D_{max} = D_f + p_w$'

$D_{max} = \frac{648}{D_f} + \frac{134}{p_w'} = \frac{782}{D_{max}}$ lbs

assumes soil class 4

Maximum Vertical Foundation Pressure, S_y = 2,000 psf per geotechnical analysis or table 1806.2

Maximum Axial Pressure on the soil, $s_y = D_{max} / A_f = \frac{728}{D_{max}} \div \frac{0.785}{A_f} = \frac{996}{s_y}$ psf

Actual to Allowable Soil Strength Ratio, $s_y / S_y = \frac{996}{s_y} \div \frac{2,000}{S_y} = \frac{0.50}{}$ ≤ 1.0 is OK

s_y / S_y must be less than 1.0. If not, start over with a larger footing diameter, b