DESIGN CALCULATIONS – INSTA-FOOTING LOAD BEARING CAPACITIES ON CONCRETE SLAB

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Rev -

Projection Name: Insta-Footing Design Calculations

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REPORT DESCRIPTION

This report documents the structural design of Insta-footing steel bearing plates and determines and certifies their load bearing capacity along with the load bearing capacity of the concrete slab that the plates are mounted to.

INSTA-FOOTING STEEL PLATE DESCRIPTION

The Insta-Footing plates are manufactured from ½-inch thick A36 carbon steel with a minimum yield strength of 36 KSI. The plates have an 18-guage, u-shaped connector that is welded to the center of the Insta-Footing steel plate. The Insta-footing plates have two 5/8" diameter holes drilled in opposite corners and two 3/16" diameter holes drilled in opposite corners used to secure the plates to the concrete floor slab with either ½" diameter concrete expansion anchors or powder driven nails or concrete screws. The plates are galvanized for rust protection required by the 2015 International Residential Code and powder coated in safety yellow for added corrosion protection.

R407.2 Steel column protection. All surfaces (inside and outside) of steel columns shall be given a shop coat of rust inhibitive paint, except for corrosion-resistant steel and steel treated with coatings to provide corrosion resistance.

R301.1.1 Alternative provisions. As an alternative to the requirements in Section R301.1, the following standards are permitted subject to the limitations of this code and the limitations therein. Where engineered design is used in conjunction with these standards, the design shall comply with the *International Building Code*.

R301.1.3 Engineered design. Where a building of otherwise conventional construction contains structural elements exceeding the limits of Section R301 or otherwise not conforming to this code, these elements shall be designed in accordance with accepted engineering practice. The extent of such design need only demonstrate compliance of nonconventional elements with other applicable provisions and shall be compatible with the performance of the conventional framed system. Engineered design in accordance with the *International Building Code* is permitted for buildings and structures, and parts thereof, included in the scope of this code.

DESIGN METHODOLOGY

ASD- Allowable Stress Design for the steel plate

LRFD – Load and Resistance Factored Design for concrete

DESIGN CODE REFERENCES

American Institute of Steel Construction (AISC) – Thirteenth Edition, Part 14, page 14-4, reference (a)

American Institute of Steel Construction (AISC) – Thirteenth Edition, Chapter F, page 16.1-46, reference (b)

American Institute of Steel Construction (AISC) – Thirteenth Edition, Chapter G, page 16.1-64, reference (c)

2015 International Building Code (IBC) with 2016 NYS Supplement

2015 International Residential Code (IRC) with 2016 NYS Supplement

ASCE 7, Minimum Design Loads for Buildings and Other Structures

Building Code Requirements for Structural Concrete (ACI-318) and Commentary, Fourth Printing January 2011

DESIGN ASSUMPTIONS

- Minimum concrete compressive strength is 2500 psi concrete – this is the minimum concrete compressive strength permitted per the 2015 International Residential Code with 2016 NYS supplement.
- 2000 psf soil bearing – this is fair assumptions for most soils except the most undesirable
- level slab, condition of slab is fair
- tight contact of soil/stone beneath slab, soil/stone beneath slab is compacted – normal practice during construction
- Insta-Footing plate placement is 7 inches away from any slab edge – this requirement is in the product instructions

DESIGN PROCEDURE

The baseplate itself is checked to determine the maximum load carry capacity to ensure that it does not fail in shear or beading under the column load. Then the concrete under the baseplate is checked to ensure that it does not fail under the baseplate load in compression, shear or bending. The limiting load carry capacity of the baseplate or concrete is used to determine the design capacity of the Insta-Footing plate.

STEEL BASEPLATE ANALYSIS

The steel plate is checked to determine the maximum load it can sustain in bending and in shear stress. Per reference (a), the column baseplate is assumed to distribute the column axial force to the concrete as a uniform bearing pressure by cantilevered bending of the plate.

Steel Plate Bending Stress

The baseplate is loaded by a square or rectangular shaped column. It was determined that a 12” x 12” baseplate can sustain a 14,300# load. For this load the uniform pressure on the bottom of the baseplate is defined as P_{12} and is solved below.

P_{12} = 14,300#/ (12” x 12”) = 99.3 PSI.

The column width is 3.5” for a 4” by 4” post. This leaves a cantilevered extension on both sides of the post that is defined as “L” and is solved below.

L= (12” – 3.5”) / 2 = 4.25”

The bending moment on a one-inch strip is determined. The total force on the cantilevered section of the one-inch strip is the strip area times the strip pressure:

F = 1in x 4.25in x 99.3 PSI = 422#

The moment arm is one-half the cantilevered strip length = 4.25in / 2 = 2.125in

Therefore, the bending moment is the product of the force on the strip and the moment arm:

M = 422# x 2.125in = 897 in #

The moment of inertia on the one-inch strip is calculated below:

I = (1/12) x b x h^3 = (1/12) x 1in x 0.5^3 = 0.01042 in^4

Half the plate thickness is, c = 0.5in / 2 = 0.25in.

The bending stress in the one-inch strip is calculated below:

S = Mc / I = ((897 in #) x (0.25 in)) / (0.0104 in^4) = 21,521 psi

Minimum yield stress of steel plate: 36,000 psi.

Safety Factor, SF = 1.67per reference (b)

Allowed bending stress:

Sa = S / SF = 36,000 psi / 1.67 = 21,557 psi

S<Sa therefore acceptable for a maximum load of 14,300#.

Steel Plate Shear Stress

The shear area is the perimeter around the 4”x4” posts (actual post dimensions 3.5”x3.5”) times the thickness of the plate:

As = 4x 3.5in x 0.5in = 7in^2

Minimum yield stress of steel plate: 36,000 psi.

Safety Factor, SF = 1.67per reference (c)

Allowed shear stress:

Sa = S / SF = 36,000 psi / 1.67 = 21,557 psi

The shear load is the product of the shear area and the allowed shear stress:

Fs = 7in^2 x 21,557 psi = 150,899#

Figure 1 and Figure 2 below show the calculations above performed using the spreadsheet program Microsoft Excel. Figure 1 is for the 12” x 12” plate and Figure 2 is for the 16” x 16” plate. The calculations show that the 12” x 12” plate is capable of 9,150 # and the 16” x 16” plate is capable of supporting 16,650 #.

Steel Thickness Calculation for 12”x12” plate w/4”x4” post

Thickness of plate	0.5	in
Baseplate length, W1	12	in
Baseplate Width, W2	12	in
Baseplate Area	144	in^2
Load	14300	#
Factor of safety	1.67	
Pressure	99.3	psi
post width 1	3.5	in
post width 2	3.5	in
cantilevered part of plate, w1	4.25	in
cantilevered part of plate, w2	4.25	in
Maximum cantilever length	4.25	in
Bending moment, 1” strip	897	in #
Moment of Inertia	0.01042	in^4
Bending Stress	21524	psi
Yield	36000	psi
Allowed stress	21557	psi
ratio	0.998	
max deflection	0.013	in
L/D	317	
shear area	7	in^2
allowable shear stress	21557	psi
max allowed load in shear	150898	#

Figure 1 – 12” x 12” plate calculation for shear and bending

Steel Thickness Calculation for 16"x16" plate w/6"x6"post		
Thickness of plate	0.5	in
Baseplate length, W1	16	in
Baseplate Width, W2	16	in
Baseplate Area	256	in^2
Load	16650	#
Factor of safety	1.67	
Pressure	65.0	psi
post width 1	5.5	in
post width 2	5.5	in
cantilevered part of plate, w1	5.25	in
cantilevered part of plate, w2	5.25	in
Maximum cantilever length	5.25	in
Bending moment, 1" strip	896	in #
Moment of Inertia	0.01042	in^4
Bending Stress	21512	psi
Yield	36000	psi
Allowed stress	21557	psi
ratio	0.998	
max deflection	0.020	in
L/D	257	
shear area	11	in^2
allowable shear stress(.66)	23760	psi
max allowed load in shear	261360	#

Figure 1 – 16" x 16" plate calculation for shear and bending

CONCRETE SHEAR STRENGTH

Per ACI 318-08, 9.3.5, the strength reduction factor for compression, shear and bearing for structural plainconcrete shall be $\phi = 0.60$.

ACI 318-08 11.11, provisions for slabs and footings.

11.11.1.2 – For two-way action, the slab or footing shall be designed in accordance with 11.11.2 through 11.11.6.

11.11.2 – The design of the slab or footing for two-way action is based on eq.(11-1) and eq.(11-2). V_c shall be computed in accordance with 11.11.2.1, 11.11.2.2 or 11.11.3.1. VS shall be computed in accordance with 11.11.3.

Per section 11.11.2.1, V_c shall be the smallest of the following:

$$V_C = \left(2 + \frac{4}{\beta}\right)\lambda\sqrt{f_C'}b_0 d \qquad \text{(11-31)}$$

$$V_C = \left(\frac{\alpha_S d}{b_0} + 2\right)\lambda\sqrt{f_C'}b_0 d \qquad \text{(11-32)}$$

$$V_C = 4\lambda\sqrt{f_C'}b_0 d \qquad \text{(11-33)}$$

Where β is the ratio of the long side to the short side of the plate. Since the plate is square in shape, β is unity. λ is unity for normal weight concrete (ACI 8.6.1). f_C^1 is the compressive strength of the concrete and is assumed to be 2500 psi since this is the minimum compressive strength required in the building code. The perimeter of the punching section (b_0) of the concrete that is calculate to be the width of the plate plus thickness of the slab. α_S is 40 for interior columns, 30 for edge columns and 20 for corner columns.

$$b_0 = 4 * (l + d)$$

$$b_0 = 4 * (12 + 3.5) = 62in$$

Where "l" is the length of one side of the plate and "d" is the thickness of the slab. Assuming a slab thickness of 3.5 inches, equations 11-31 through 11-33 reduce to:

$$V_C = 6\sqrt{2500}b_0 3.5 \qquad \text{(11-31)}$$

$$V_C = \left(\frac{\alpha_s d}{b_0} + 2\right)\sqrt{2500}b_0 3.5 \qquad \text{(11-32)}$$

$$V_C = 4\sqrt{2500}b_0 3.5 \qquad \text{(11-33)}$$

For the 12” x 12” plate, b_0 is 4(12+3.5) = 62 inches. For interior columns, equations 11-31 through 11-33 result in:

$$V_c = 65{,}100\ \#\ (11\text{-}31)$$

$$V_c = 46{,}200\ \#\ (11\text{-}32)$$

$$V_c = 43{,}400\ \#\ (11\text{-}33)$$

$$\phi V_N \geq V_U\ (11\text{-}1)$$

V_U is the factored shear force at the section considered (the actual plate force on the concrete) and V_n is the nominal shear strength computed by equation 11-2 below.

The smallest, limiting load is 43,400#. Applying the strength reduction factor yields the following concrete strength for punching shear strength:

$$V_C = 0.6 * 43{,}400 = 26{,}040\#$$

$$V_n = V_c + V_s\ (11\text{-}2)$$

Where V_C is the nominal shear strength provided by the concrete calculated in accordance with 11.2, 11.3 or 11.11, and Vs is the nominal shear strength provided by shear reinforcement. No shear reinforcement is provided in plan concrete so $V_s = 0$.

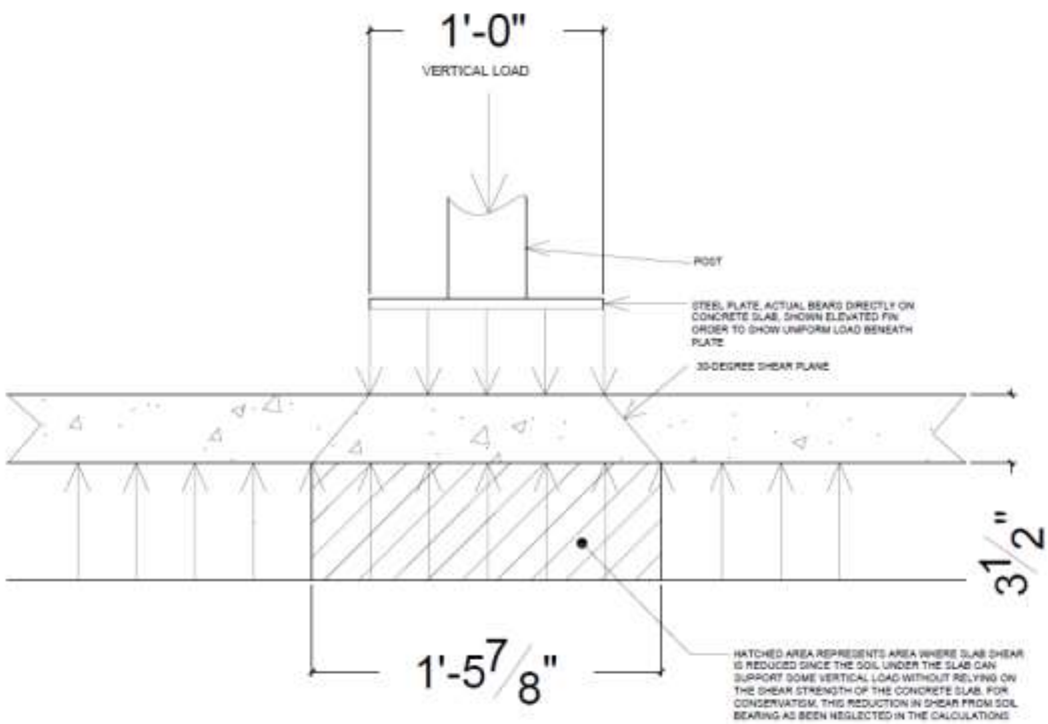

Figure 1 – Schematic of load transfer through concrete slab

Figure 3 & 4 below show the same shear calculation performed above for the 12" x 12" and 16 x 16" plate carried out in an Microsoft Excel spreadsheet. The limiting concrete shear for the 12" x 12" plate is 26,040# and the limiting shear for the 16" x 16" plate is 31,080#.

12" x 12" plate				
ACI 318-08, 9.3.5 Punching Shear				
Strength Reduction Factor	0.6			
Beta	1	plate dimensions ration		
lambda	1	normal weight concrete		
fc	2500	psi		
alphas	40			
plate width 1	12	in		
plate width 2	12	in		
slab thickness	3.5	in		
shear perimeter	62	in		
Vc_1	65100	lbs	eq. 11-31	
Vc_2	46200	lbs	eq. 11-32	
Vc_3	43400	lbs	eq. 11-33	
Minimum from (1-3 above)	43400	lbs		
Adjusted for strength reduction	26040	lbs		

Figure 3 – concrete punching shear calculation for 12" x 12" plate

16" x 16" plate				
ACI 318-08, 9.3.5 Punching Shear				
Strength Reduction Factor	0.6			
Beta	1	plate dimensions ration		
lambda	1	normal weight concrete		
fc	2500	psi		
alphas	40			
plate width 1	16	in		
plate width 2	16	in		
slab thickness	3.5	in		
shear perimeter	78	in		
Vc_1	81900	lbs	eq. 11-31	
Vc_2	51800	lbs	eq. 11-32	
Vc_3	54600	lbs	eq. 11-33	
Minimum from (1-3 above)	51800	lbs		
Adjusted for strength reduction	31080	lbs		

Figure 4 – concrete punching shear calculation for 16" x 16" plate

CONCRETE BENDING STRENGTH

Per reference (d), the modulus of rupture, M_n, for plane concrete is:

$$M_n = 5\lambda\sqrt{f_c'}S_m$$

Where, λ is 1.0 for normal weight concrete, f'_c is the compressive strength of the concrete and S_m is the section modulus. The section modulus is based on the perimeter around the edge of the plate and the thickness of the concrete and is calculated below. The perimeter of the 12" x 12" plate is p = 4 x 12 = 48in. and the minimum concrete thickness is assumed to be 3.5 inches.

$$S_m = (1/6) \times 48 \text{ in} \times (3.5 \text{ in})^2 = 98 \text{ in}^3$$

Therefore, the modulus of rupture is:

$$M_n = 5\ x\ 1\sqrt{2500}\ x\ 98 \text{ in}^3 = 24{,}500 \text{ in \#}$$

The maximum load on the concrete before rupture occurs due to bending was calculated to be approximately 9,150#. At a soil bearing capacity of 2000PSF, this would require that the bearing area of the concrete be $4.58ft^2$ ($658.8in^2$). If the bearing area is assumed to be square, the length of one side of the bearing area would be:

$$L = \sqrt{4.58ft^2} = 2.14ft \text{ or } 25.67in$$

Since the plate is 12" long, the projection of the slab length required for bearing past the edge of the plate is:

$$P_r = (25.67in – 12in) / 2 = 6.8in$$

The moment arm of the slab portion that extends past the edge of the plate is one half the projection length = 6.8in/2 = 3.42in.

The pressure under the concrete slab in the required bearing area is calculated below:

$$\sigma = 9{,}150\# / 658.8in^2 = 13.9psi$$

The bearing area of the concrete that is not located underneath the 12" x 12" plate is calculated below:

$$A' = 658.8in^2 – (12in \times 12in) = 514.8in^2$$

The force under the portion of the cantilevered concrete that is not located directly under the plate is the pressure stress acting on the concrete times the area:

$$F = 13.9 \text{ psi} \times 514.8in^2 = 7150\#$$

The bending moment in the concrete slab is calculated below:

$$M = 7{,}150\# \times 3.42in = 24{,}453 \text{ in \#}$$

The bending moment of 24,450 in # is less than the modulus of rupture of 24,500 in #.

Figure 5 & 6 below show the same calculates performed in an Microsoft Excel spreadsheet for both the 12” x 12” plate and 16” x 16” plate. The calculations show that the concrete slab can support a bending load of 9,150# for the 12” x 12” plate and 12,700# for the 16” x 16” plate.

<u>Bending Calculations for 12"x12" plate</u>			
allowable soil bearing	2000	PSF	
Concrete strength	2500	psi	
plate length	12	in	
b'	48	in	
d	3.5	in	concrete thickness
c	1.75	in	
Load	9150	#	
A	4.575	ft^2	area under concrete needed for bearing
L	2.14	ft	length of side of concrete bearing area
L	25.67	in	length of side of concrete bearing area
Pr	6.8	in	Projection past side of plate
r	3.42	in	Moment arm, half of projection
A'	658.8	in^2	bearing area, in^2
Sigma	13.9	psi	stress underside of bearing area
A''	514.8	in^2	bearing area of section not under plate
F	7150	#	force under perimeter
M	24430	in #	bending moment in concrete beyond plate edge
I	171.50	in^4	modulus of inertial of leaf
Bending stress	249.3	psi	concrete bending stress
Sm	98.0	in^3	section modulus
Modulus of rupture	24500	in #	ACI318-08, 22-2
Modulus of rupture	424	psi	modulus of ruptur
LSF	0.6		
	254		factored bending stress

Figure 5 – concrete bending calculation for 12” x 12” plate

Bending Calculations for 16"x16" plate			
allowable soil bearing	2000	PSF	
Concrete strength	2500	psi	
plate length	16	in	
b'	64	in	
d	3.5	in	concrete thickness
c	1.75	in	
Modulus	12700	#	
A	6.35	ft^2	area under concrete needed for bearing
L	2.52	ft	length of side of concrete bearing area
L	30.24	in	length of side of concrete bearing area
Pr	7.1	in	Projection past side of plate
r	3.56	in	Moment arm, half of projection
A'	914.4	in^2	bearing area, in^2
Sigma	13.9	psi	stress underside of bearing area
A"	658.4	in^2	bearing area of section not under plate
F	9144	#	force under perimeter
M	32552	in #	bending moment in concrete beyond plate edge
I	228.67	in^4	modulus of inertial of leaf
Bending stress	249.1	psi	concrete bending stress
Sm	130.7	in^3	section modulus
Modulus of rupture	32667	in #	
Modulus of rupture	424	psi	modulus of ruptur
LSF	0.6		
	254		factored bending stress

Figure 6 – concrete bending calculation for 16” x 16” plate

Concrete Bearing Strength

The minimum concrete compressive bearing strength, f_C^1 required by the 2015 IRC building code is 2500 psi. The LFRD specification defines the concrete bearing limit state in Section J9 as

$$P_U \leq \emptyset_C P_P$$

Where:

$$P_P = 0.85 f_c' A_1$$

A_1 is the area of the plate bearing on the concrete:

$$A_1 = 12in \times 12in = 144in^2$$

$$P_P = 0.85(2500psi)(144in^2) = 306{,}000\#$$

The actual bearing plate load is 15,800# which is less than 306,000# and therefore the concrete is acceptable in compression.

$$A_1 = 16in \times 16in = 256in^2$$

$$P_P = 0.85(2500psi)(256in^2) = 544{,}000\#$$

SUMMARY

The summary table lists the strength checks of the various items, checked (ex. steel plate bending and shear and concrete shear, bearing and bending) and the last row is the limiting load.

Analsysis check	12"x12" lbs	16"x16" lbs
plate bending	14300	16650
plate shear	150898	261360
concrete shear	26040	31080
concrete bending	9150	12700
concrete bearing	30600	54400
limiting load	***9150***	***12700***

Figure 7