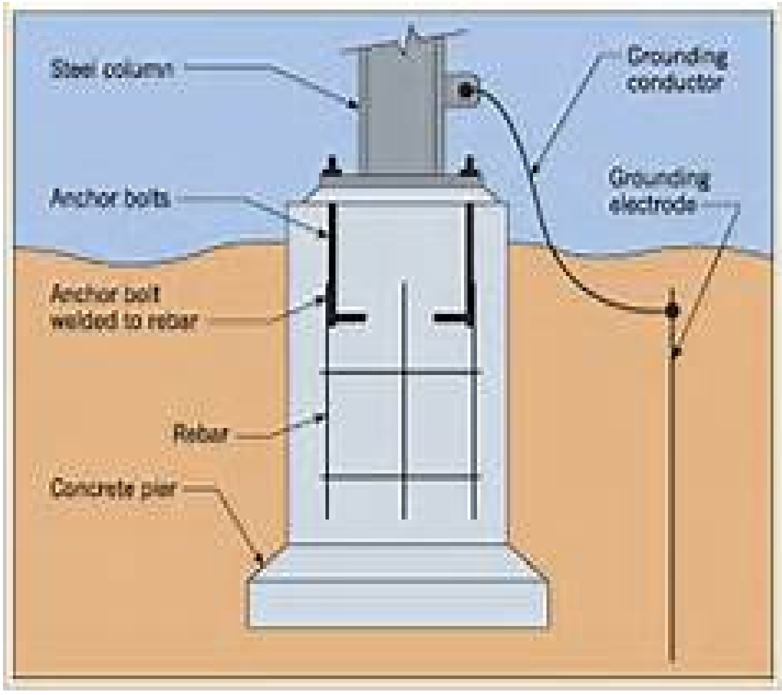
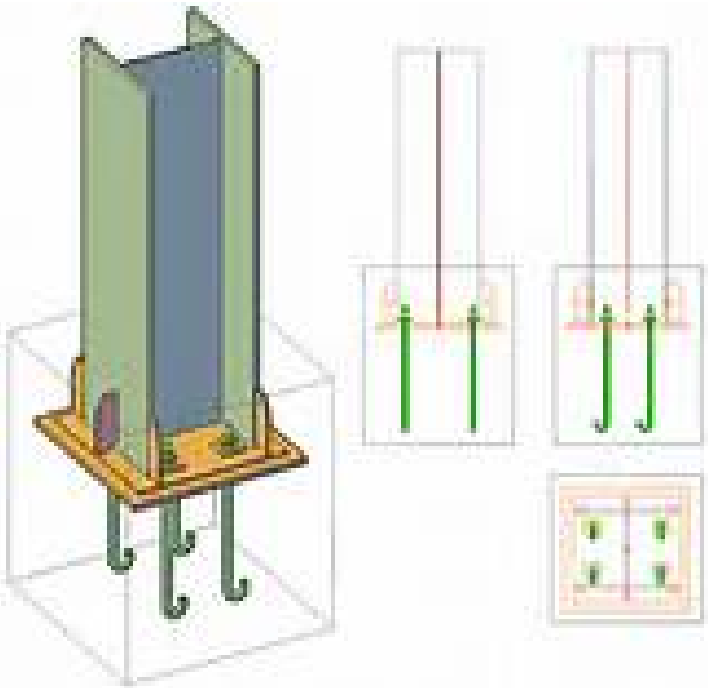
STRUCTURAL STEEL DESIGN





Column Base Plates

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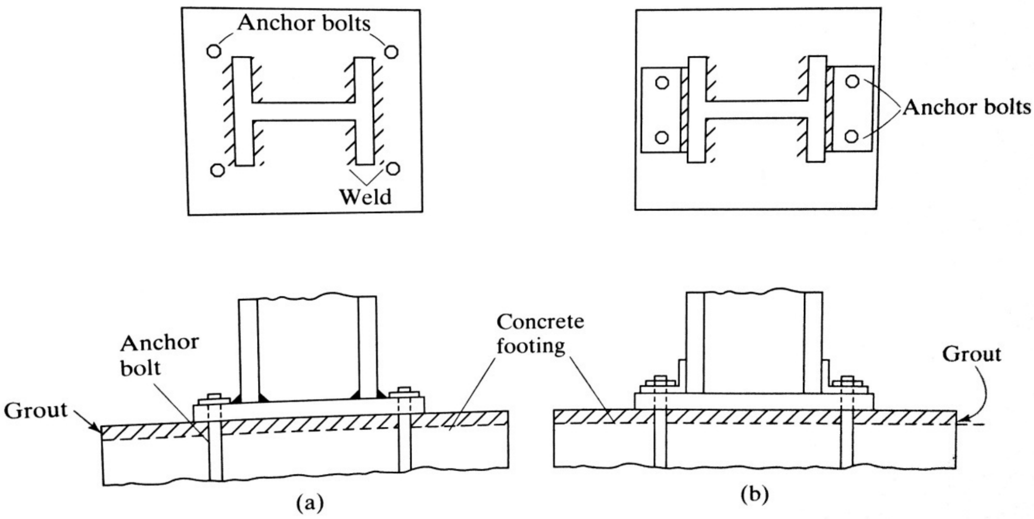
Base Plates For Concentrically Loaded Columns

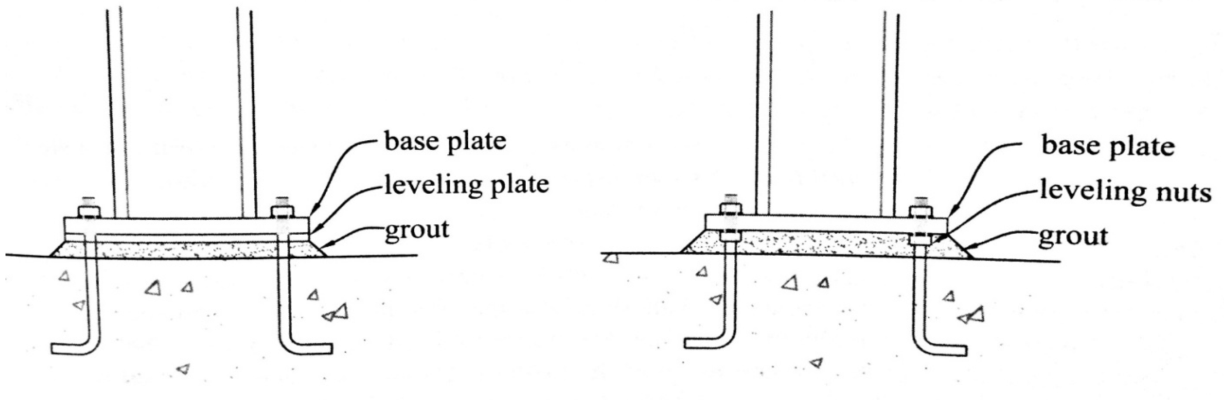
When a steel column is supported by a footing it is necessary for the column load to be spread over a sufficient area to keep the footing from being overstressed .Loads from steel columns are transferred through a steel base plate to large area of the footing .

The base plate can be welded directly to the columns ,or they can be fastened by means of some type of bolted or welded lug angles .These connection methods are illustrated below :



The base plate is usually larger than the column size by as much as 3 to 4 in ,all around to provide room for the placement of the anchor bolt holes outside of the column .

During steel erection 1/4-in, thick leveling plates ,which are slightly larger than the base plates or leveling nuts are used to plumb the column see fig. below :



a. leveling plate *b. leveling nuts*

In the design of the base plate , the bearing stress below the plate are assumed to be uniform and the base plate is assumed to bent in two directions into a bowl-shaped surface .

Plate Area

The nominal bearing strength, *Pu*, is determined as follows:

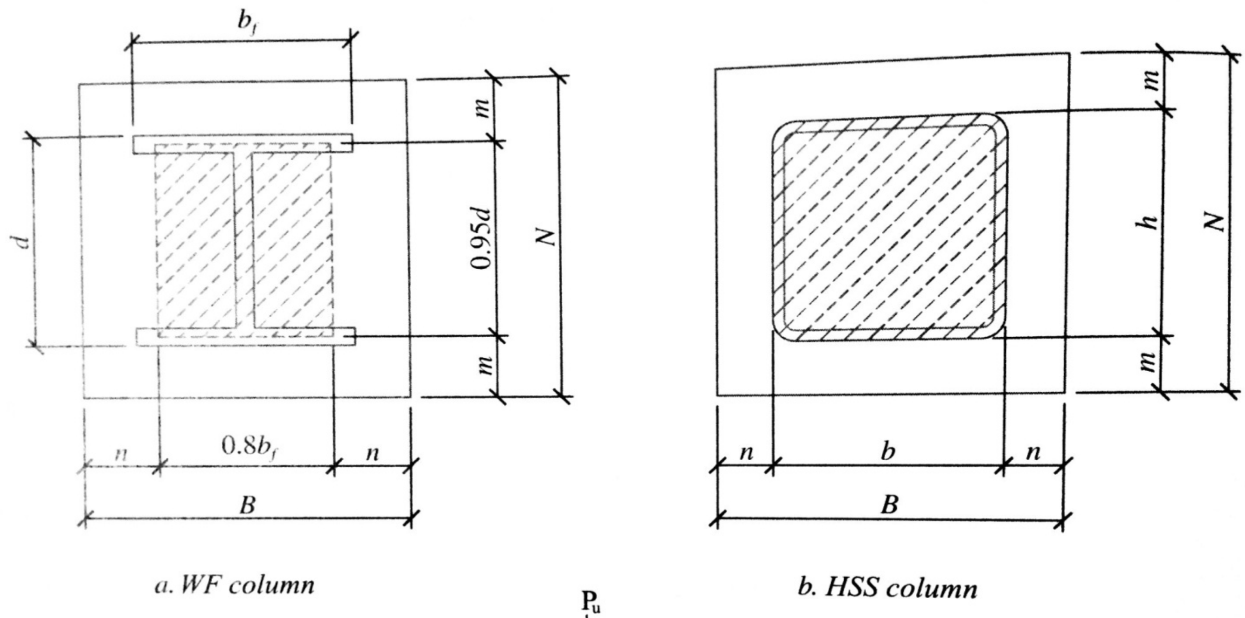
(a) On the full area of a concrete support:

$$Pu = 0.85\varphi_c \ fc.\ A1 \text{ ....(J8-1)}$$

(b) On less than the full area of a concrete support:

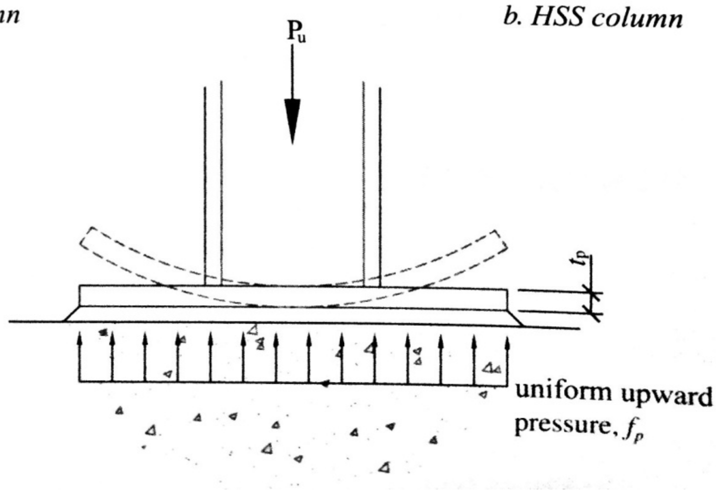
$$Pu = 0.85\varphi_c\, fc\, A1\sqrt{\frac{A_2}{A_1}} \leq 1.7\, fc\, A1 \text{ ....(J8-2)}$$

$$A_1 = \frac{P_u}{0.85\varphi_c\, fc\sqrt{\frac{A_2}{A_1}}}$$



a. WF column

b. HSS column



where

A_1 = Base plate area = $B \times N$,

B = Width of base plate,

N = Length of base plate,

A_2 = Area of concrete pier concentric with the base plate area, A_1, projected at the top of the concrete pier (or at the top of the concrete footing when the column base plate is supported directly by the footing) without extending beyond the edges of the pier or footing,

f_c' = Compressive strength of the concrete pier or footing, ksi, and

ϕ_c = Strength reduction factor for concrete in bearing = 0.65 (ACI 318).

$$1 \leq \sqrt{\frac{A_2}{A_1}} \leq 2$$

Plate Thickness

In determining the base plate thickness ,the base plate is assume to be rigid enough to ensure a uniform bearing pressure distribution at the base plate The requared plate thickness as :

$$t_p = \ell \sqrt{\frac{2P_u}{\varphi_b B.N.F_y}}$$

$$m = \frac{N - 0.95d}{2},$$

$$n = \frac{B - 0.80b_f}{2}, \text{ and}$$

$$n' = \frac{1}{4}\sqrt{db_f}.$$

The above equations are valid for W-shaped columns. For a **square HSS column,**

$$m = \frac{N - b}{2},$$

$$n = \frac{B - b}{2}, \text{ and}$$

$$n' = \frac{b}{4},$$

where

ϕ_b = 0.9 (strength reduction factor for plate bending),
F_y = Yield strength of the base plate,
d = Depth of column,
b_f = Flange width of column,
$m, n, \lambda n'$ = Cantilever lengths of the base plate beyond the edges of the critical area of the column,
ℓ = Maximum of $(m, n, \lambda n')$,
λ is conservatively taken as 1.0 [10] in this text, and
b = Width of square HSS column.

$$N \approx \sqrt{A_1} + \Delta$$

$$A_1 = \text{area of plate} = BN$$

$$\Delta = 0.5\,(0.95\,d - 0.80\,b_f)$$

$$N = \sqrt{A_1} + \Delta$$

$$B \approx \frac{A_1}{N}$$

Example (1)

Design a base plate of A36 steel ($F_y = 36$ ksi) for a W12 × 65 column ($F_y = 50$ ksi) that supports the loads $P_D = 200$ k and $P_L = 300$ k. The concrete has a compressive strength $f'_c = 3$ ksi, and the footing has the dimensions 9 ft × 9 ft.

Solution. Using a W12 × 65 column ($d = 12.1$ in, $b_f = 12.0$ in)

LRFD	ASD
$P_u = (1.2)(200) + (1.6)(300) = 720$ k	$P = 200 + 300 = 500$ k
A_2 = footing area = $(12 \times 9)(12 \times 9) = 11{,}664$ in^2	$A_2 = 11{,}664$ in^2

Determine required base plate area $A_1 = BN$. Note that the area of the supporting concrete is for greater than the base plate area, such that $\sqrt{\frac{A_2}{A_1}} > 2.0$.

LRFD ϕ_c = 0.65	ASD $\Omega_c = 2.50$
$A_1 = \frac{P_u}{\phi_c(0.85f'_c)\sqrt{\frac{A_2}{A_1}}}$ $= \frac{720}{0.65\,(0.85)(3)(2)} = 217.2 \text{ in}^2$	$A_1 = \frac{P_a\Omega_c}{0.85f'_c\sqrt{\frac{A_2}{A_1}}} = \frac{(500)(2.50)}{(0.85)(3)(2)}$ $= 245 \text{ in}^2$

The base plate must be at least as large as the column $b_f d = (12.0)(12.1)$ 145.2 in^2 < 217.2 optimize base plate dimensions to make m and n

LRFD	ASD
$\Delta = \frac{0.95d - 0.8b_f}{2}$ $= \frac{(0.95)(12.1) - (0.8)(12.0)}{2} = 0.947$ in	$\Delta = 0.947$ in
$N = \sqrt{A_1} + \Delta = \sqrt{217.2} + 0.947 = 15.7$ Say 16 in	$N = \sqrt{245} + 0.947 = 16.6$ in Say 17 in
$B = \frac{A_1}{N} = \frac{217.2}{16} = 13.6 \text{ in}^2$	$B = \frac{245}{17} = 14.41$

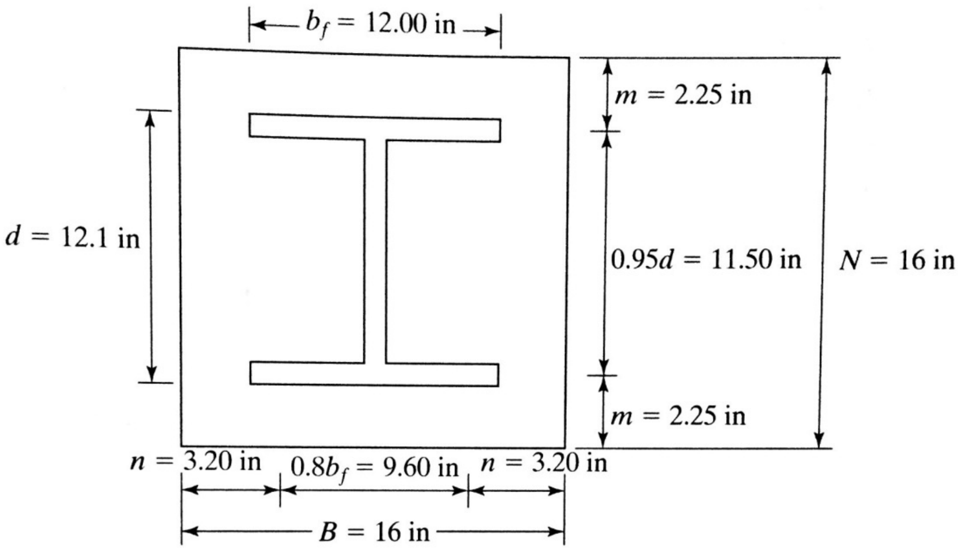


FIGURE 7.15

As previously mentioned, we might very well simplify the plates by making them square—say, 16 in × 16 in.

Check the bearing strength of the concrete.

LRFD $\phi_c = 0.65$	ASD $\Omega_c = 2.50$
$\phi_c P_p = \phi_c 0.85 f_c' A_1 \sqrt{\frac{A_2}{A_1}}$	$\frac{P_p}{\Omega_c} = \frac{0.85 f_c' A_1}{\Omega_c}\sqrt{\frac{A_2}{A_1}}$
$= 0.65 \quad 0.85)(3)(16 \times 16)(2)$	$= \frac{(0.85)(3)(16 \times 16)(2)}{2.50} = 522.2\text{ k} > 500\text{ k}$ **OK**
$= 848.6 > 720\text{ k}$ **OK**	

Computing required base plate thickness

$$m = \frac{N - 0.95d}{2} = \frac{16 - (0.95)(12.1)}{2} = 2.25\text{ in}$$

$$n = \frac{B - 0.8b_f}{2} = \frac{16 - (0.8)(12.0)}{2} = 3.20\text{ in}$$

$$n' = \frac{\sqrt{db_f}}{4} = \frac{\sqrt{(12.1)(12.0)}}{4} = 3.01\text{ in}$$

$$\ell = \text{largest of } m, n, \text{ or } n' = 3.20\text{ in}$$

LRFD	ASD
$t_{reqd} = \ell\sqrt{\frac{2P_u}{0.9F_yBN}}$	$t_{reqd} = \ell\sqrt{\frac{3.33P_a}{F_yBN}}$
$= 3.20\sqrt{\frac{(2)(720)}{(0.9)(36)(16 \times 16)}} = 1.33\text{ in}$	$= 3.20\sqrt{\frac{(3.33)(500)}{(36)(16)(16)}} = 1.36\text{ in}$
Use PL $1\frac{1}{2} \times 16 \times 1$ ft 4 in A36.	Use PL $1\frac{1}{2} \times 16 \times 1$ ft 4 in A36.

Example (2)

A base plate is to be designed for a W12 × 152 column ($F_y = 50$ ksi) that supports the loads $P_D = 200$ k and $P_L = 450$ k. Select an A36 plate ($F_y = 36$ ksi) to cover the entire area of the 3 ksi concrete pedestal underneath.

Solution. Using a W12 × 152 column ($d = 13.7$ in, $b_f = 12.5$ in)

LRFD	ASD
$P_u = (1.2)(200) + (1.6)(450) = 960$ k	$P_a = 200 + 450 = 650$ k

Determine the required base plate area, noting that the term $\sqrt{\frac{A_2}{A}}$ is equal to 1.0, since $A_1 = A_2$.

LRFD $\phi_c =$ 0.65	ASD $\Omega_c = 2.50$
$A_1 = \dfrac{P_u}{\phi_c(0.85f'_c)\sqrt{\frac{A_2}{A_1}}}$	$A_1 = \dfrac{P_a\Omega_c}{0.85f'_c\sqrt{\frac{A_2}{A_1}}}$
$= \dfrac{960}{0.65\,(0.85 \times 3)(1)}$	$= \dfrac{(650)(2.5)}{(0.85)(3)(1)}$
$=$ 579.2	$= 637.3\ \text{in}^2 \leftarrow$
$A_1 \min = db_f = (13.7)(12.5)$	$A_1 \min = db_f = (13.7)(12.5)$
$= 171.2\ \text{in}^2$	$= 171.2\ \text{in}^2$

Optimizing base plate dimensions n ~ m

LRFD	ASD
$\Delta = \dfrac{0.95d - 0.8b_f}{2}$	
$= \dfrac{(0.95)(13.7) - (0.8)(12.5)}{2} = 1.51$ in	$\Delta = 1.51$ in
$N = \sqrt{A_1} + \Delta =$	$N = \sqrt{637.3} + 1.51$
$=$ 25.6 Say 26	$= 26.75$ in. **Say 27 in**
$B = \dfrac{A_1}{N} = \dfrac{579.2}{27} =$ 22.3	$B = \dfrac{637.3}{27} = 23.60$ in
Say 23	**Say 24 in**

Check the bearing strength of the concrete.

LRFD ϕ_c = 0.65	ASD $\Omega_c = 2.50$
$\phi_c P_p = \phi_c 0.85 f'_c A_1 \sqrt{\frac{A_2}{A_1}}$ = 0.65 (0.85)(3) 23×26)(1) = 991.2 > 960 k **OK**	$\frac{P_p}{\Omega_c} = \frac{0.85 f'_c A_1}{\Omega_c} \sqrt{\frac{A_2}{A_1}}$ $= \frac{(0.85)(3)(24 \times 27)}{2.50}(1.0)$ = 661 k > 650 k **OK**

Computing required base plate thickness

$$m = \frac{N - 0.95d}{2} = \frac{27 - (0.95)(13.7)}{2} = 6.99 \text{ in}$$

$$n = \frac{B - 0.8b_f}{2} = \frac{24 - (0.8)(12.5)}{2} = 7.00 \text{ in}$$

$$n' = \frac{\sqrt{db_f}}{4} = \frac{\sqrt{(13.7)(12.5)}}{4} = 3.27 \text{ in}$$

$$\ell = \text{maximum of } m, n \text{ or } n' = 7.00 \text{ in}$$

LRFD	ASD
$t_{reqd} = \ell \sqrt{\frac{2P_u}{0.9F_y BN}}$ $= 7.00\sqrt{\frac{(2)(960)}{(0.9)(36)\ 23\times26}}$ = 2.05	$t_{reqd} = \ell \sqrt{\frac{3.33P_a}{F_y BN}}$ $= 7.00\sqrt{\frac{(3.33)(650)}{(36)(24 \times 27)}}$ = 2.13 in

Use $2\frac{1}{8}$ × 23 × 2 ft 2 in A 36 plate with 23×26 concrete pedestal (f_c = 3 ksi).

Example (3)

Repeat Example 2 if the column is to be supported by a concrete pedestal 2 in wider on each side than the base plate.

Solution. Using a W12 × 152 (d = 13.7 in, b_f = 12.5 in)

LRFD	ASD
$P_u = (1.2)(200) + (1.6)(450) = 960$ k A_1 required from Example 2 solution was 579.2	$P_a = 200 + 450 = 650$ k A_1 required from Example 7-6 solution was 637.3 in^2

If we try a plate 24×25 ($A_1 = 600\ \text{in}^2$), the pedestal area will equal $(24 + 4)(25 + 4) = 812\ \text{in}^2$, and $\sqrt{\frac{A_2}{A_1}}$ will equal $\sqrt{\frac{812}{600}} = 1.16$. Recalculating the A_1 values gives

LRFD $\phi_c = 0.65$	ASD $\Omega_c = 2.31$
$A_1 = \dfrac{P_u}{\phi_c(0.85f'_c)\sqrt{\frac{A_2}{A_1}}}$	$A_1 = \dfrac{P_a\Omega_c}{0.85f'_c\sqrt{\frac{A_2}{A_1}}}$
$= \dfrac{960}{(0.65)(0.85)(3)(1.16)} = 499.3\ \text{in}^2$	$= \dfrac{(650)(2.31)}{(0.85)(3)(1.16)} = 507.6\ \text{in}^2$

Optimizing base plate dimensions $n \sim m$

LRFD	ASD
$\Delta = \dfrac{0.95d - 0.8b_f}{2}$	
$= \dfrac{(0.95)(13.7) - (0.8)(12.5)}{2} = 1.51\ \text{in}$	$\Delta = 1.51\ \text{in}$
$N = \sqrt{A_1} + \Delta = \sqrt{490.8} + 1.51$	$N = \sqrt{A_1} + \Delta = \sqrt{499.0} + 1.51$
$= 23.66\ \text{in}$ **Say, 24 in**	$= 23.85\ \text{in.}$ **Say, 24 in**
$B = \dfrac{A_1}{N} = \dfrac{490.8}{24} = 20.45\ \text{in}$	$B = \dfrac{A_1}{N} = \dfrac{499}{24} = 20.79\ \text{in}$
Say, 21 in	**Say, 21 in**
Use pedestal 25 × 28	
$\sqrt{\dfrac{A_2}{A_1}} = \sqrt{\dfrac{(25)(28)}{(21)(24)}} = 1.18$	Same.

Check the bearing strength of the concrete

LRFD $\phi_c = 0.65$	ASD $\Omega_c = 2.31$
$\phi_c P_p = \phi_c 0.85 f'_c A_1 \sqrt{\dfrac{A_2}{A_1}}$	$\dfrac{P_p}{\Omega_c} = \dfrac{0.85f'_c A_1}{\Omega_c}\sqrt{\dfrac{A_2}{A_1}}$
$= (0.65)(0.85)(3)(21 \times 24)(1.18)$	$= \dfrac{(0.85)(3)(21 \times 24)}{2.31}(1.18)$
$= 985.7\ \text{k} > 960\ \text{k}$ **OK**	$= 656.5\ \text{k} > 650\ \text{k}$ **OK**

Computing required base plate thickness

$$m = \frac{N - 0.95d}{2} = \frac{24 - (0.95)(13.7)}{2} = 5.49 \text{ in}$$

$$n = \frac{B - 0.8b_f}{2} = \frac{21 - (0.8)(12.5)}{2} = 5.50 \text{ in}$$

$$n' = \frac{\sqrt{db_f}}{4} = \frac{\sqrt{(13.7)(12.5)}}{4} = 3.27 \text{ in}$$

$$\ell = \text{maximum of } m, n \text{ or } n' = 5.50 \text{ in}$$

LRFD	ASD
$t_{reqd} = \ell\sqrt{\frac{2P_u}{0.9F_yBN}}$	$t_{reqd} = \ell\sqrt{\frac{3.33P_a}{F_yBN}}$
$= 5.50\sqrt{\frac{(2)(960)}{(0.9)(36)(21)(24)}}$	$= 5.50\sqrt{\frac{(3.33)(650)}{(36)(21)(24)}}$
$= 1.89$ in	$= 1.90$ in

Use 2 × 21 × 2 ft 0 in A36 base plate with 25 × 28 concrete pedestal ($f'_c = 3$ ksi).

Example 4

A HSS 10 × 10 × $\frac{5}{16}$ with $F_y = 46$ ksi is used to support the service loads $P_D = 100$ k and $P_L = 150$ k. A spread footing underneath is 9 ft-0 in × 9 ft-0 in and consists of reinforced concrete with $f'_c = 4000$ psi. Design a base plate for this column with A36 steel ($F_y = 36$ ksi and $F_u = 58$ ksi).

Solution. Required strength

LRFD	ASD
$P_u = (1.2)(100) + (1.6)(150) = 360$ k	$P_a = 100 + 150 = 250$ k

Try a base plate extending 4 in from the face of the column in each direction—that is, an 18 in × 18 in plate.

Determine the available strength of the concrete footing.

$$A_1 = (18)(18) = 324 \text{ in}^2$$

$$A_2 = (12 \times 9)(12 \times 9) = 11{,}664 \text{ in}^2$$

$$P_p = 0.85f'_cA_1\sqrt{\frac{A_2}{A_1}} = (0.85)(4)(324)\sqrt{\frac{11{,}664}{324}} = 6609.6 \text{ K}$$

$$\text{since } \sqrt{\frac{11{,}664}{324}} = 6.0 > 2.0 \therefore P_p = 1.7f'_c A_1$$

$$P_p = 1.7f'_c A_1 = 1.7(4)(324) = 2203.2 \text{ k}$$

LRFD $\phi_c = 0.65$	ASD $\Omega_c = 2.31$
$\phi_c P_p = (0.65)(2203.2)$ $= 1432.1 \text{ k} > 360 \text{ k}$ **OK**	$\frac{P_p}{\Omega_c} = \frac{2203.2}{2.31}$ $= 953.8 \text{ k} > 250 \text{ k}$ **OK**

Determine plate thickness.

$$m = n = \frac{N - (0.95)(\text{outside dimension of HSS})}{2}$$

$$= \frac{18 - (0.95)(10)}{2} = 4.25 \text{ in}$$

Notice that these values for m and n are both less than the distance from the center of the base plate to the center of the HSS walls. However, the moment in the plate outside the walls is greater than the moment in the plate between the walls. You can verify this statement by drawing the moment diagrams for the situation shown in Fig. 7.16.

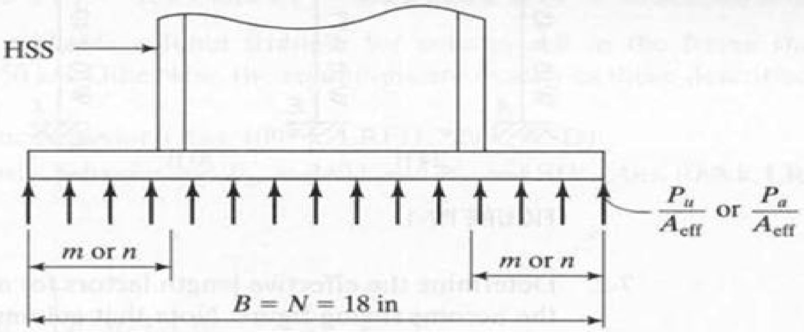


FIGURE 7.16

LRFD	ASD
$f_{pu} = \frac{P_u}{A_{eff}} = \frac{360}{(18)(18)} = 1.11 \text{ ksi}$	$f_{pa} = \frac{P_a}{A_{eff}} = \frac{250}{324} = 0.772 \text{ ksi}$
$t_{reqd} = \ell\sqrt{\frac{2P_u}{0.9F_yBN}}$	$t_{reqd} = \ell\sqrt{\frac{3.33P_a}{F_yBN}}$
$= 4.25\sqrt{\frac{(2)(360)}{(0.9)(36)(18)(18)}} = 1.11 \text{ in}$	$= 4.25\sqrt{\frac{(3.33)(250)}{(36)(18)(18)}} = 1.14 \text{ in}$

Use $1\frac{1}{4} \times 18 \times 1$ ft 6 in A36 base plate for both LRFD and ASD.