Design of Pipe Column Base Plates Under Gravity Load

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INTRODUCTION

Round pipe columns are often used in large, low buildings such as warehouses and department stores. No guidance regarding the design of the base plates for these columns is to be found in the Manual of Steel Construction,[1] and no definitive guidance may be found in the literature. In lieu of having a rational method for sizing the base plate, designers have often resorted to rules of thumb to determine the plate thickness. This paper provides a design procedure for determining the thickness of these base plates under gravity loads, applied to Allowable Stress Design criteria. This method is not applicable for uplift conditions where the column is in net tension nor does it consider erection criteria which is within the judgement of the detailer and erector.

EFFECTIVE PLATE AREA

For a square base plate under a round column, it is reasonable to assume the effective bearing area for this analysis to be within an inscribed circle of the same diameter as the plate dimensions as shown in Figure 1. Neglecting the area outside the inscribed circle will have little effect on the design. If a round base plate is used, the entire area may be considered effective in the design. In any case, the value of D should be limited to no greater than $2R$.

Therefore:

$$f_p = P / \pi D^2$$

BASE PLATE DESIGN

The base plate can be visualized as being overstressed in two areas, inside the column diameter and outside the column diameter. These areas may be designed by applying a yield line analysis to the base plate.

Yield line analysis of situations similar to this can be found in many references on yield lines and plastic plate analysis.[2] The simplest method of applying this analysis is that of virtual work.

Considering first the case of bending within the area enclosed by the column (Figure 2):

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W_i = Work of the perimeter yielding + work of the radial lines yielding

$= 2\pi M + 2\pi M = 4\pi M$

W_e = Bearing pressure × volume of cone shown in Figure 2

$= f_p(\tfrac{1}{3}\pi R^2)$

Setting internal work equal to external work:

$$4\pi M = f_p(\pi R^2 / 3)$$

Allowing M to be equal to the elastic moment capacity of a rectangle, to be consistent with the 9th Edition method:

$$M = t^2 F_b / 6$$

setting $F_b = 0.75F_y$ and solving for the plate thickness provides:

$$t = R(2f_p / 3F_y)^{1/2} \qquad (1)$$

Now consider the case of bending of the base plate outside the column as shown in Figure 3.

W_i = Work of the radial lines yielding + work of the perimeter yielding

$= 2\pi M[(D - R) / D] + 2\pi M(R / D)$

$= 2\pi M$

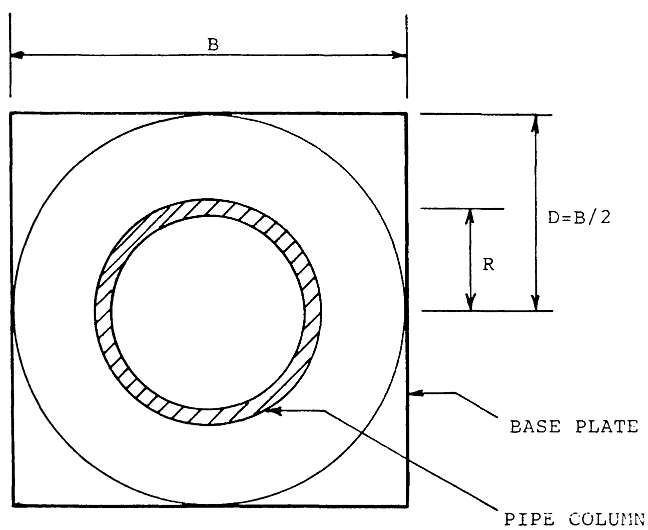

Figure 1

W_e = Bearing pressure × volume under the deflected area outside the column perimeter as shown in Figure 3.

$$= f_p[\pi D^2 - \pi D^2/3 - \pi(D^2 - R^2)(R/D) + (\pi R^3/3)(R/D)]$$

$$= f_p[2D^2/3 - RD + R^3/3D]$$

Setting internal work equal to external work and inserting $M = t^2F_b/6$ yields:

$$t = [4f_p/3F_y(2D^2 - 3RD + R^3/D)]^{1/2} \qquad (2)$$

LIGHTLY LOADED BASE PLATES

Reference 3 recommends that the loaded "H" section method described in the Manual of Steel Construction be applied to the design of these base plates. Referring to Figure 4, and again applying a yield line analysis to the plate:

$A = P/F_p = \pi(R_o^2 - R_c^2)$ therefore:

$R_c = [R_o^2 - (P/\pi F_p)]^{1/2}$

Applying a yield line analysis to the base plate,

$W_i = 2\pi M + 2\pi M = 4\pi M$, as for the first case

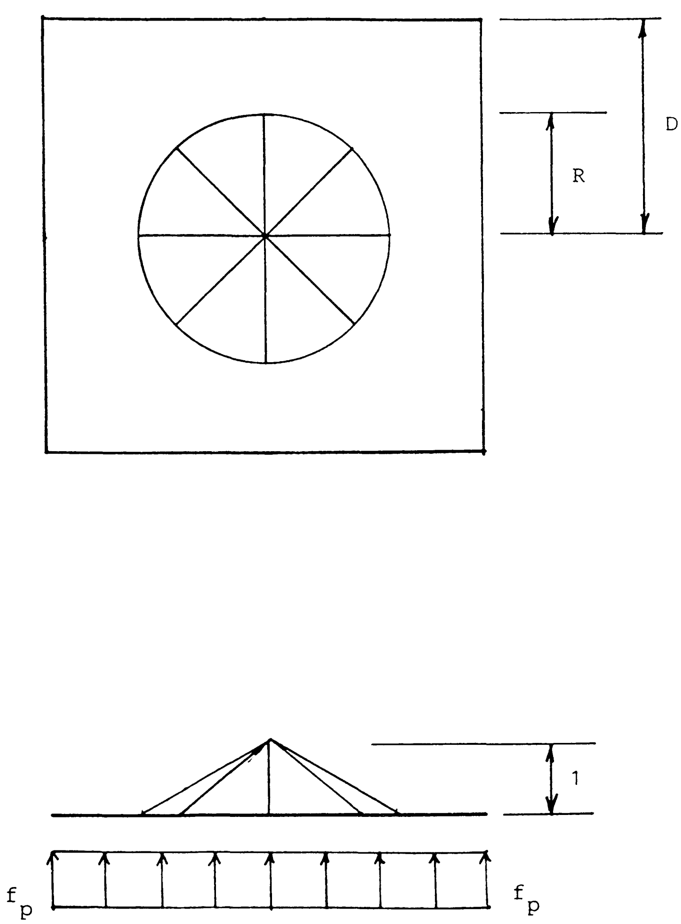

Figure 2

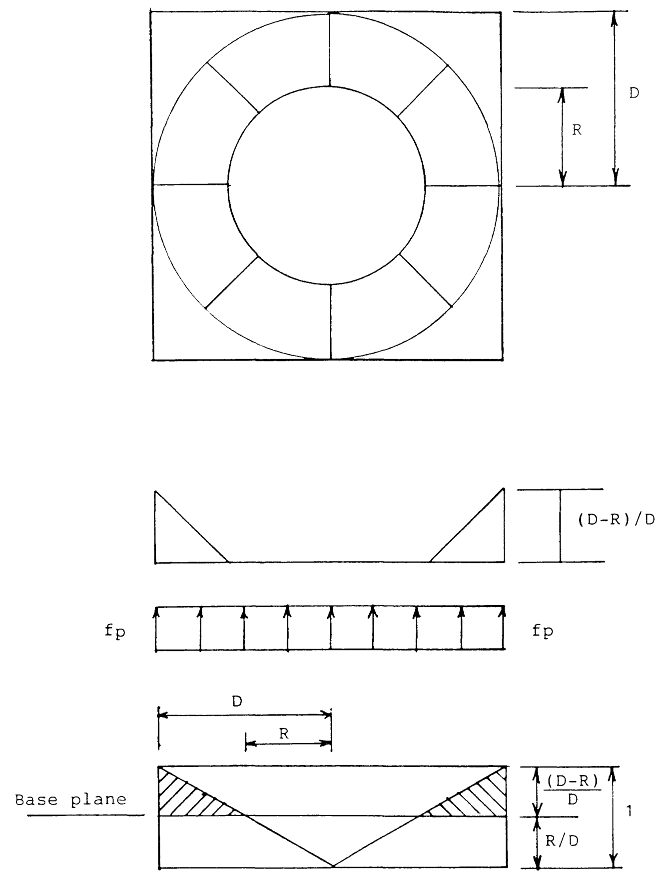

Figure 3

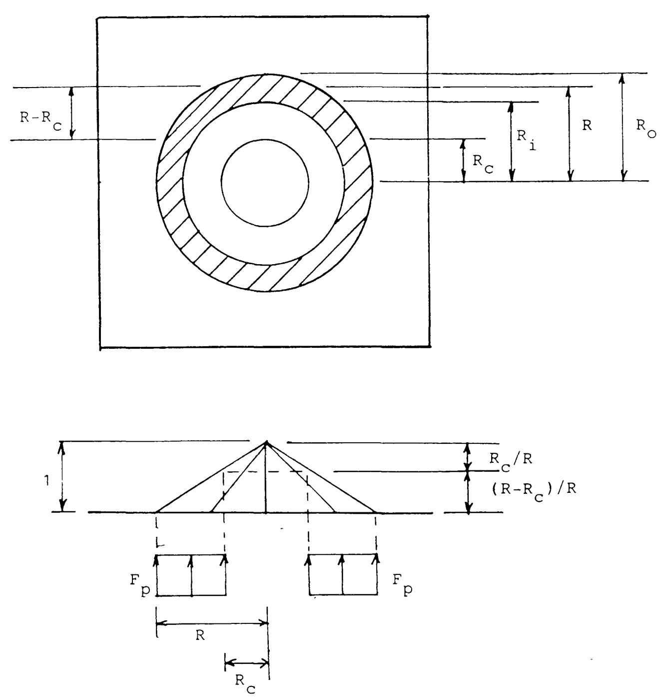

Figure 4

W_e = Bearing pressure under loaded portion of cone in Figure 4

$= F_p[\pi R^2/3 - \pi R_c^2((R - R_c)/R) - (\pi/3)R_c^2(R_c/R)]$

$= F_p \pi[R^2/3 - R_c^2 + 2R_c^2/3R]$

Setting internal work equal to external work, and substituting for the value of M and F_b:

$$t = [(2F_p/3F_y)(R^2 - 3R_c^2 + 2R_c^2/R)]^{1/2} \qquad (3)$$

It should be noted that if $F_p = f_p$ and $R_c = 0$, Equation 3 reduces to Equation 1.

If the result of Equation 3 is a plate thickness greater than that given by Equation 1, Equation 3 does not apply. The thickness of a lightly loaded base plate should not be greater than the thickness of one loaded over its entire area.[4]

The required base plate thickness is the greater of Equations 1 or 3 and 2.

EXAMPLE

Given:

Pipe Column, Standard Weight, 4 in. nominal diameter (OD = 4.500 in., ID = 4.026 in.)
Load = 12 kips
Base Plate = 7 in. × 7 in.
Steel = A36
Concrete = 3,000 psi

Solution:

$R = (4.500 + 4.026)/4 = 2.13$ in.

$D = 7.0/2 = 3.5$ in.

$f_p = 12 \text{ kips}/\pi(3.5)^2 = 0.31 \text{ ksi} < 0.35f_c'$

$t = (2.13)[2(0.31)/(3)(36)]^{1/2} = 0.161$ in. (1)

$t = [(4/3)(0.31/36)(2(3.5)^2 - 3(2.13)(3.5) + (2.13)^2/3.15] = 0.237$ in. (2)

$F_p = 0.35f_c' = 0\ 35(3) = 1.05$ ksi

$R_c = [2.25^2 - (12/\pi(1.05))]^{1/2} = 1.19$ in.

$t = \{[2(1.05)/3(36)][2.13^2 - 3(1.19)^2 + 2(1.19)^3/2.13]\}^{1/2} = 0.191$ in. (3)

This column requires a base plate 0.237 inches thick. Use a plate 7×7×¼-in.

REFERENCES

1. American Institute of Steel Construction, *Manual of Steel Construction,* 9th Edition, 1989, Chicago, Ill.
2. Save, M. A. and C. E. Massonnet, *Plastic Analysis and Design of Plates, Shells, and Disks,* 1967, Elsevier, New York.
3. DeWolf, John T., and David T. Ricker, *Column Base Plates,* 1990, AISC, Chicago, Ill.
4. Ahmed, Salahuddin, and Robert R. Kreps, "Inconsistencies in Column Base Plate Design in the New AISC ASD Manual," *Engineering Journal,* 3rd Qtr. 1990.

NOMENCLATURE

B = Base plate width
D = Radius of loaded area of base plate ($D \leq 2R$)
F_b = Allowable bending stress in base plate = $0.75F_y$
F_p = Allowable concrete bearing pressure as defined in manual
f_p = Actual bearing pressure as defined in manual
M = Base plate internal resisting moment per unit length
P = Total column load
R = Average radius of pipe column $= (R_i + R_o)/2$
R_c = Inside radius of loaded area for lightly loaded column
R_i = Pipe column outside radius
R_o = Pipe column inside radius
t = Thickness of base plate
W_e = External work done by bearing
W_i = Internal work done by plate bending