Graphical Aid for Design of Base Plate Subjected to Moment

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The purpose of the base plate is to distribute the column load to the concrete pedestal in such a way that the stress does not exceed the allowable bearing stress of the concrete. When the load is concentric, the distribution of pressure is uniform and is equal to P/A. (See nomenclature at the end of this paper.) If the load is eccentric, the pressure under the base plate is no longer uniform. The additional pressure will be $\pm Mc/I$, giving a net pressure equal to $P/A \pm Mc/I$, as shown in Fig. 1. So long as Mc/I is not greater than P/A, or in other words, so long as e is less than or equal to $L/6$, the above relationship is valid. When e is greater than $L/6$, a part of the base plate is under uplift and the stress block is as shown in Fig. 2. As tensile stress cannot be developed between the base plate and the pedestal, the uplift has to be wholly resisted by the anchor bolts. The situation is analogous to a reinforced concrete section under flexure, where the concrete above the neutral axis takes the compression and the reinforcing bars resist the tension.

Gray et al[1] have solved the base plate problem in the same way as a reinforced concrete beam is designed and have developed an equation to obtain the value of x (see Fig. 3). A modular ratio of 15 has been used in the worked out example in Ref. 1.

The solution offered by Blodgett[2] requires solving cubic equations to obtain the value of x. A modular ratio of 10 has been used by him in a worked out example (see Fig. 3).

An alternative shorter method, usually adopted by people on a construction site, is to assume that the centroid of the compression area is exactly at the center of the leeward anchor bolts, i.e., $\alpha d' = 2e'$, where $\alpha d'$ is as shown in Fig. 2 and $2e'$ is as shown in Fig. 4a, and tension in the bolt $= M/2e'$ (see Fig. 4a). Blodgett has outlined another approach. In this case the centroid of the pressure diagram is assumed to be exactly at the center of the leeward flange of the column, i.e., $\alpha d' = e' + (d - t_f)/2$ (see Fig. 4b).

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Although at a certain combination of P and M the above assumption may hold true, it cannot hold true for all load-moment combinations. Therefore, these two approximate methods are seldom used in design offices.

The solution outlined in Refs. 3 and 4 is exact and therefore preferable to the other methods described above. In this method load and moment compatibility equations are formed to obtain the values of T and x (see Fig. 2). For

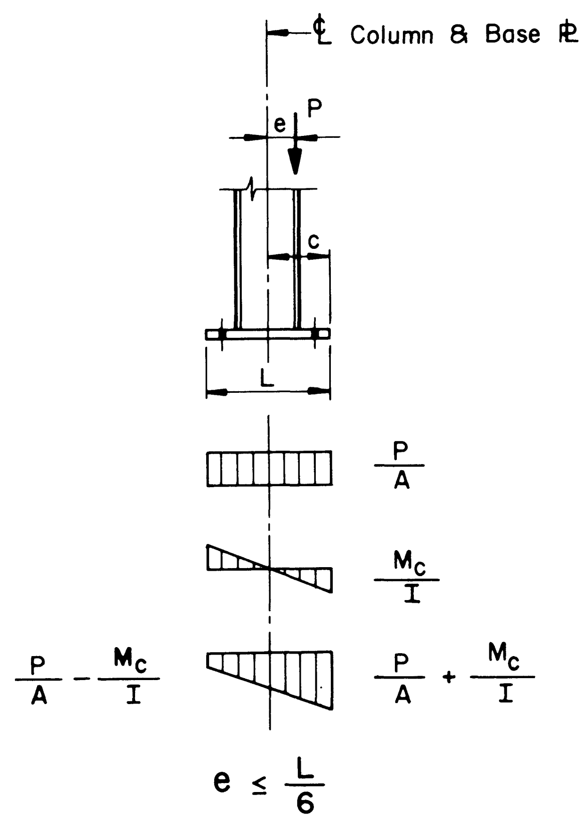


Figure 1

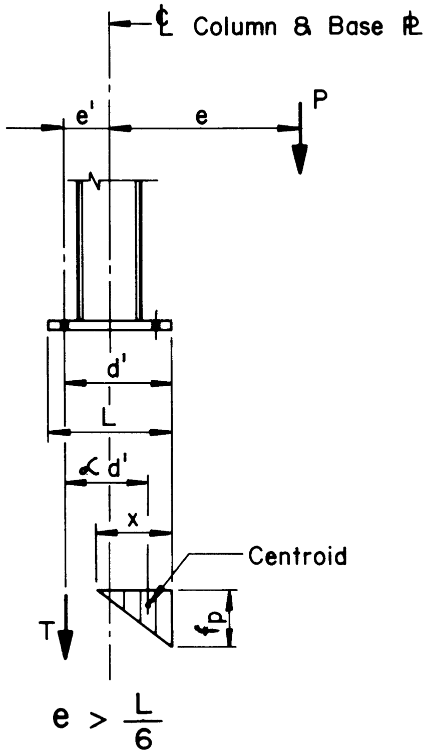
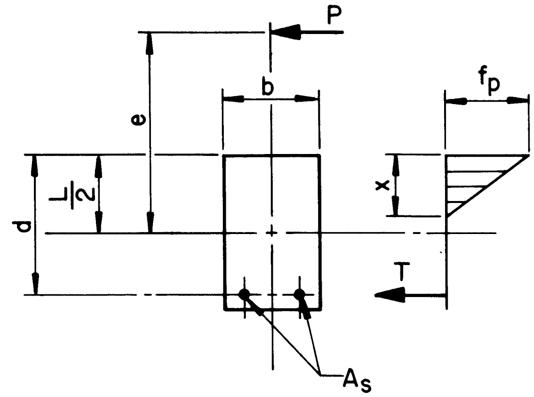


Figure 2



From Ref. 1:

$$x = \frac{(nf_p)\,d}{nf_p + f_t}$$

From Ref. 2:

$$x^3 + 3x^2\left(e - \frac{L}{2}\right) + \frac{6x\,A_s n}{b}(f_t + e) - \frac{6n A_s}{b}\left(\frac{L}{2} + f_t\right)(f_t + e) = 0$$

Figure 3

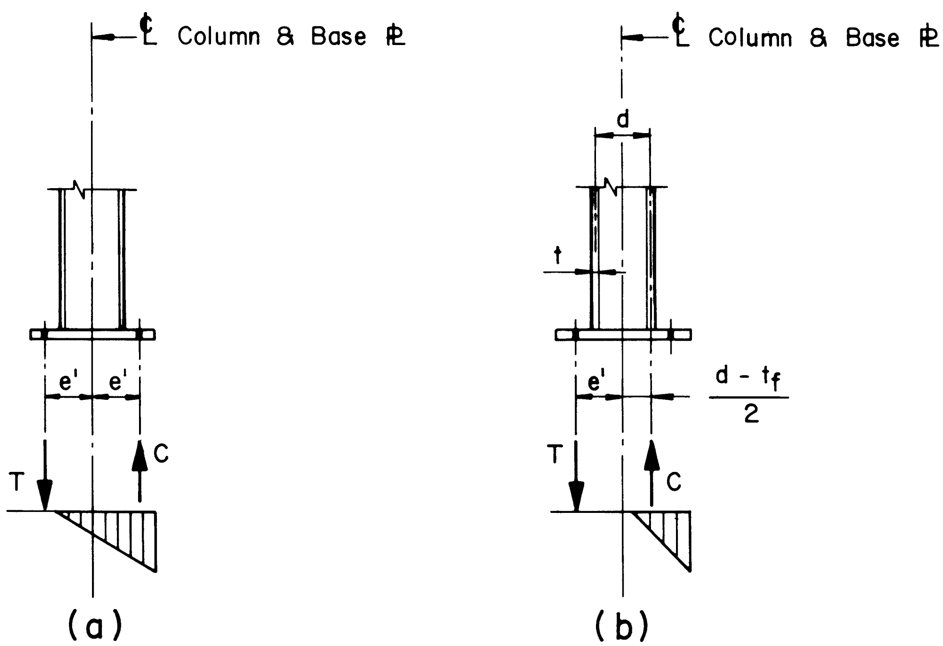


Figure 4

the triangular pressure diagram shown in Fig. 2, these equations are:

$$P + T = f_p \times b/2 \qquad (1)$$

$$M + Pe' = (\alpha d')(f_p \times b/2) \qquad (2)$$

This approach is not only independent of the value of n, the modular ratio, but also avoids any presumption regarding the location of the centroid of the pressure diagram.

Although solution of the base plate problem through the above two compatibility equations has no inherent flaw in assumptions and is exact, solving the equations simultaneously to obtain the value of x is time consuming, particularly when the number of such base plates is inordinately high, as usually is the case with process plants and refineries. A considerable amount of design office time could be saved if the task of forming the equations and then solving them simultaneously is altogether avoided. With this objective in view, the author presents herewith a graphical aid (see Fig. 5). In this chart the values of x and α have been tied to the known parameters and, therefore, should the designer choose to try another size of base plate or check for another load-moment combination, he can readily do so with the help of this graph, without getting involved in the mathematical side of the problem.

Once the values of x and T are known, the design of the base plate (i.e., its thickness, diameter of the anchor bolts, etc.) is routine procedure, well explained in the AISC *Manual of Steel Construction* and therefore not being repeated here.

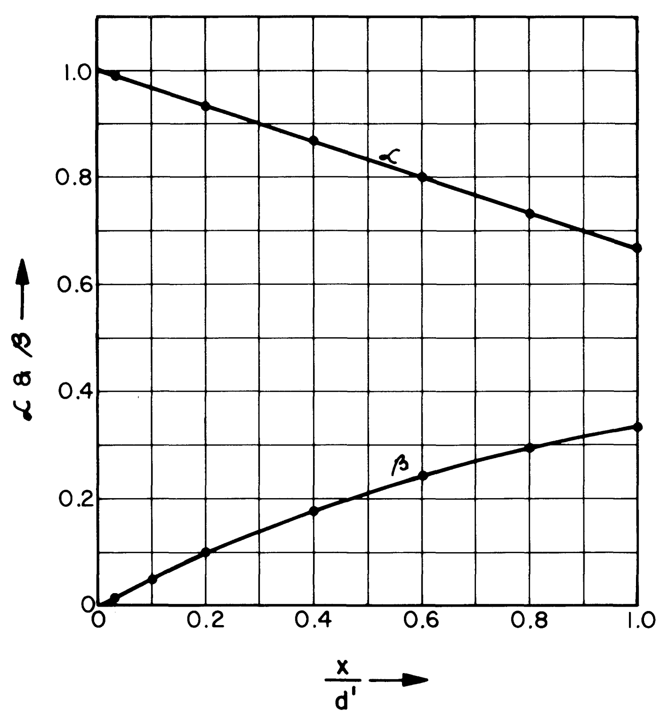


Figure 5

EXAMPLES

Example 1

Given:

$P = 15$ kips, $M = 200$ kip-ft $= 1.125$ ksi,

$b = 16$ in., $d' = 22.875$ in., $e' = 8.875$ in.

Solution:

$M + Pe' = (200 \times 12) + (15 \times 8.875) = 2533.1$ kip-in.

$f_p b(d')^2 = 1.125 \times 16 \times (22.875)^2 = 9418.8$ kip-in.

$\beta = 2533.1/9418.8 = 0.269$

From Fig. 5: $x/d' = 0.72$

$\alpha = 0.768$

$T = (M + Pe')/\alpha d' - P$
$= [2533.1/(0.768 \times 22.875)] - 15$
$= 129.1$ kips

$x = 0.72 \times 22.875 = 16.05$ in.

Note: This problem has been solved in Ref. 4, pg. 6.75, with identical results.

Example 2

Given:

$P = 20$ kips, $M = 130$ kip-ft, $f_p = 1$ ksi,

$b = 24$ in., $d' = 23$ in., $e' = 9.5$ in.

Solution:

$M + Pe' = (130 \times 12) + (20 \times 9.5) = 1750$ kip-in.

$f_p b(d')^2 = 1 \times 24 \times (23)^2 = 12{,}696$

$\beta = 1750/12696 = 0.1378$

From Fig. 5: $x/d' = 0.305$

$\alpha = 0.9$

$T = (M + Pe')/d' - P$
$= [1759/(0.9 \times 23)] - 20 = 64.5$ kips

$x = 0.305 \times 23 = 7.0$ in.

Note: This problem has been solved in Ref. 3, pg. 625, and the answers tally.

ACKNOWLEDGMENT

The chart in Fig. 5 was prepared for expediting design work. The encouragement and guidance received from Mr. B. Eyramya, Superviser, Civil/Structural Section, American Lurgi Corporation, is gratefully acknowledged.

NOMENCLATURE

A = Area of base plate
A_s = Area of steel in tension
b = Breadth of base plate
c = Maximum fiber distance from neutral axis
d = Depth of W section used as column
d' = Distance of leeward edge of base plate from center of tension bolts
e = Eccentricity of load from center of the base plate
e' = Distance of center of tension bolts from base plate center
f_p = Allowable bearing pressure on pedestal, per AISC *Manual of Steel Construction*
f_t = Tension stress on steel, ksi
I = Moment of inertia of base plate about axis about which M acts
L = Length of base plate
M = External moment = Pe
n = Modular ratio = (E of steel)/(E of concrete)
P = Load, kips
T = Total tension on windward bolts
t_f = Flange thickness of W section used as column
α = Coefficient for distance of tension bolts from centroid of compression (see Fig. 2)
β = Coefficient (see Fig. 2), equal to $(m + (Pe')/[f_p b(d')^2]$

REFERENCES

1. *Gray, Charles S. et al.* Steel Designer's Manual *Crosby Lockwood & Son Ltd, London, 1962, p. 614.*
2. *Blodgett, Omer W.* Design of Welded Structures *The James F. Lincoln Arc Welding Foundation, Cleveland, Ohio, 1972, p. 3.3-8—3.3-16.*
3. *Tall, Lambert, Ed.* Structural Steel Design *The Ronald Press Company, New York, 1964, p. 625.*
4. *Gaylord, Edwin H. and Charles N. Gaylord, Ed.* Structural Engineering Handbook *McGraw Hill Book Company, 1968, p. 6.75.*