

Discussion

Steel Column Base Plate Design

Paper presented by BALBIR S. SANDHU
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Discussion by **Gerard Dixon & William H. Mooseker**

MR. SANDHU is correct in his statement that the design of steel column base plates is a simple, but time consuming, process. In fact, for a large steel framed building with many columns of different sizes and loadings, the base plate design is indeed a chore.

Mr. Sandhu is to be commended on his efforts to speed up this base plate design process. However, the allowable bearing stresses, F_p , which he correctly quotes from the AISC Specification, Sect. 1.5.5, do not reflect the changes in allowable bearing pressures as specified in the 1971 A.C.I. Code for the Ultimate Strength Design of Concrete. Since these values have been liberalized, the required base plate area and thickness will be substantially smaller than heretofore with significant savings in steel weight. The liberalized bearing values in the 1971 A.C.I. Code, using the ultimate strength method, essentially renders the base plate design tables and the specified concrete bearing stresses in the AISC Manual obsolete.

The 1971 A.C.I. Code, Section 10.14—Bearing, allows ultimate bearing stresses up to $0.85 \phi f'_c$ except when the supporting surface is wider on all sides than the loaded area, in which case the permissible ultimate bearing stresses on the loaded area may be multiplied by $\sqrt{A_2/A_1}$ but not more than 2.0.

ϕ = capacity reduction factor, A.C.I. Section 9.2.1.4
= 0.70

f'_c = specified compressive strength of concrete

A_2 = total supporting area (in.²)

A_1 = loaded area (in.²)

Thus, $0.85 \phi f'_c = 0.595 f'_c$.

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The allowable ultimate bearing stress for various grades of concrete are therefore as listed in Table 1, and the multiplication factors for intermediate values of bearing area ratios can be graphed or listed as in Table 2.

With ultimate load factors of 1.4 dead load + 1.7 live load, as specified in the 1971 A.C.I. Code, the average ultimate factor for normal load ranges is $1.55 \pm$, while the ultimate bearing stress is 2.38 to 3.17 as great as the values of $0.25 f'_c$ and $0.375 f'_c$ listed in the AISC Manual. The net result is much smaller and thinner base plates.

A computer program, BASE, authored by Computer Analysis Services (C.A.S.)* and at present carried by Information Sciences, Inc. on their time sharing service, takes these ultimate bearing pressures into account and, in the documentation for the program use, lists Tables 1 and 2 as design aids for the selection of the allowable bearing pressure for use in the program input.

Table 1

| f'_c , psi | Allowable Ultimate Bearing Stress, psi |
|--------------|--|
| 3000 | 1785 |
| 3500 | 2082 |
| 4000 | 2380 |
| 4500 | 2677 |
| 5000 | 2975 |

Table 2

| A_1/A_2 | Multiplication Factor |
|-----------|-----------------------|
| 1.0 | 1.0 |
| 1.25 | 1.12 |
| 1.5 | 1.22 |
| 1.75 | 1.32 |
| 2.0 | 1.41 |
| 2.25 | 1.5 |
| 2.5 | 1.58 |
| 2.75 | 1.66 |
| 3.0 | 1.73 |
| 3.25 | 1.80 |
| 3.5 | 1.87 |
| 3.75 | 1.94 |
| 4.0 | 2.0 |

* Computer Analysis Services (C.A.S.) is a division of N. G. Jacobson & Associates, Inc., Seattle, Washington.

The two examples in Mr. Sandhu's paper were re-designed using this program and ultimate bearing with the assumption made that 25 percent of the load listed was live load. The resulting plates were:

- Example 1: 15.5" x 16.0" x 0.64";
 $f_{pu} = 1.427 < 1.785$ allowable
 Example 2: 15.7" x 16.6" x 0.75";
 $f_{pu} = 2.263 < 3.570$ allowable

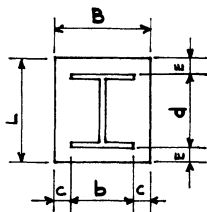
The reason for less than allowable pressures is that the program outputs a minimum size plate at least 1 in. greater than the column width, and 2 in. greater than the column depth. The resulting plates are smaller by 37 and 56 percent, respectively, than those sized by the nomograph.

Note that in Example 1 a base plate width of 14 in. is chosen using the nomograph. However, a W14X87 has a flange width of 14½ in., which is greater than the chosen base plate. In this case a minimum width of about 15½ to 16½ in. would be required (½- to 1-in. plate extension). In addition, if the aspect ratio of the plate in Example 2 were changed from 17 x 21 in. to 18 x 20 in., the required plate thickness using the working stress bearing pressures is 1 in. rather than 1.23 in. as shown in the example. This would tend to indicate that the 4-in. differential of *B* and *L* is too generous, and may lead to oversized plates. In fact, the optimum difference between *B* and *L* may be expressed as the formula:

$$(L - B) = 0.95d - 0.8b$$

See Table 3 for (*L - B*) tabulated for a range of column sizes.

Table 3. Optimum Plate Parameters



| <i>b</i> | <i>d</i> | Diff. = (<i>L - B</i>) | <i>Kl</i> = (<i>E - C</i>) |
|----------|----------|-----------------------------|---------------------------------|
| 8.00 | 8.00 | 1.200 | 0.600 |
| 10.00 | 10.00 | 1.500 | 0.750 |
| 10.00 | 12.00 | 3.400 | 0.700 |
| 12.00 | 12.00 | 1.800 | 0.900 |
| 10.00 | 14.00 | 5.300 | 0.650 |
| 12.00 | 14.00 | 3.700 | 0.850 |
| 14.00 | 14.00 | 2.100 | 1.050 |
| 15.50 | 14.75 | 1.613 | 1.181 |
| 16.00 | 16.00 | 2.400 | 1.200 |
| 16.50 | 18.50 | 4.375 | 1.187 |
| 16.75 | 19.00 | 4.650 | 1.200 |
| 18.00 | 22.00 | 6.500 | 1.250 |

For larger plates the difference in plate sizes is much more marked, i.e., with a W14X342 (50 ksi), a load of 2040 kips, concrete at $f'_c = 4000$, and base plate $F_y = 36,000$ psi, and with bearing on ½ area or less, the base plate size from nomograph is calculated to be 35 in. x 45⅝ in. x 39 in. Using the same data, the computer program (assuming 25 percent live load and 75 percent dead load) calculates a 23.4 in. x 3.11 in. x 27.1 in. plate at an ultimate bearing pressure of 4.76 kips/sq in. This represents a 68 percent savings in steel weight from the plate sized by the nomograph.

Obviously, engineers without access to computer programs can also use this ultimate strength design method to advantage, although they would, of necessity, have to go back to the old tried-and-true slide rule unless they can, as Mr. Sandhu did for the working stress design method, construct for themselves a nomograph or some other time saving aids.

Discussion by Paul Gordon

THE AUTHOR is to be commended for his desire to develop a time and labor saving design aid. However, in developing design aids, extreme caution must be taken not to encourage impropriety of engineering judgement.

To avert the misuse of the subject document and its contained alignment chart, the writer recommends that the chart not be used indiscriminately for determining column base plate thicknesses when the length and width of the proposed base plate are nearly equal to the depth and width, respectively, of the column section to be supported. When the projection of the base plate beyond the limits of the column flanges and web becomes negligible, the portion of the plate contained within the boundary of the column flanges and web becomes the portion of the plate that will determine the plate thickness. To determine the necessary thickness of a plate with negligible projection beyond the limits of the column section, the writer recommends analyzing the plate as one that is uniformly loaded and is "fixed" along the beam web, "simply supported" by the column flanges, and "free" at the edge between the column flanges and paralleling but remote from the web.

Obviously, if the method on pg. 3-95 of the AISC *Manual Of Steel Construction (7th Edition)* is to be used when the length and width of the column base plate are equal to the depth and width, respectively, of the column section, values of *m* and *n* will be equal to nearly zero and, consequently, base plate thicknesses approaching zero would be erroneously indicated.

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To avert this undesirable dangerous determination from being made, the writer suggests checking all base plate thicknesses, for plates having meager projection beyond the column section limits, using a method of analysis as suggested in the preceding.

A check of the author's Example 1 has been prepared by the writer. Following are the writer's findings:

1. The 14½-in. wide W14×87 will overhang the 14-in. wide base plate by ¼-in. on each side of the plate. The writer doubts the desirability of this condition being used to depict a typical condition. Generally it is best to have the column base plate larger in length and width than the depth and width of the concentrically supported column section.

2. The base plate thickness required to satisfy conditions of plate projections m and n beyond the column section are:

$$t_m = \sqrt{\frac{3F_p m^2}{F_b}} = \sqrt{\frac{3(0.95)(2.35)^2}{27}} = 0.76 \text{ in.}$$

$$t_n = \sqrt{\frac{3F_p n^2}{F_b}} = \sqrt{\frac{3(0.95)(1.35)^2}{27}} = 0.44 \text{ in.}$$

These thicknesses are less than the 1-in. thick plate recommended by the author.

3. Considering the base plate as having insufficient projection beyond the column limits to be governed by the procedure shown on pg. 3-95 of the AISC *Manual of Steel Construction (7th Edition)* and considering the base plate as a uniformly loaded plate with the two short edges "supported" by the column flanges, one long edge "fixed" at the column web and the other long edge free, the writer has computed that a plate thickness of about 1.82 in. would be required:

$$0.5B/0.95d = 0.53$$

Values of β :

| | | | | | |
|----------------|-----|---------------|---------------|---------------|-------|
| $0.5B/0.95d =$ | 0 | $\frac{1}{3}$ | $\frac{1}{2}$ | $\frac{2}{3}$ | 1.0 |
| $\beta =$ | 0.5 | 0.428 | 0.319 | 0.227 | 0.119 |

$$t_{p1} = \sqrt{\frac{6F_p(0.5B)^2(\beta)}{F_b}} = \sqrt{\frac{6(0.95)(49)(0.319)}{27}}$$

$$= 1.82 \text{ in.}$$

The basis for this solution can be found in "Theory of Plates and Shells" by S. Timoshenko & S. Woinowsky-Krieger, 2nd edition, 1959, pages 208 and 210.

Although not specifically recommended by the author, other conditions of minimal plate projection beyond the column section, as appearing in the author's alignment chart, would result in deficiently sized plate thicknesses.

Hopefully the writer's discussion will prompt further work by the author which will result in refinement of his design aid and possible extension of the present AISC recommended procedure to include column base plates having plan dimensions approximately equal to the section dimensions of the concentrically supported column.

Discussion by **BALBIR S. SANDHU**

THE AUTHOR wishes to express thanks to Messrs. Gerard Dixon, William H. Mooseker and Paul Gordon for their comments and constructive suggestions.

Mr. Gordon's comments in regard to engineering judgment in the development and use of design aids are highly appropriate. However, the method suggested by Mr. Gordon for designing the base plate thickness when the length and width of plate are nearly equal to the depth and width, respectively, of the column section would be applicable if the contact pressure under the bearing plate is truly uniform. Theoretically, the pressure will be uniform only if the base plates are infinitely rigid. In actual column bases, the base plates are flexible and bend, with the result that contact pressure is higher under the column web and flanges than under the rest of the bearing area. The plate bending problem is similar to the problem of beam on elastic foundation. The analysis can become very cumbersome if the column bases are to be designed using the rigorous analysis. The simplified method of the AISC Manual is expeditious and conservative. In cases when the plate dimensions are slightly larger than column dimensions, a minimum base plate thickness of ¾-in. or 1-in. may be used. The time consuming calculations required in rigorous analysis and the resulting minor savings in the weight of steel do not seem to justify such an analysis. The author agrees that the base plate width selected in Example 1 should have been 15 in. instead of 14 in.

The author acknowledges the constructive discussion by Messrs. Dixon and Mooseker on the steel column base plate design. Their computerized base plate design using the ultimate concrete bearing stress values of 1971 ACI Building Code is undoubtedly an economical design approach. The author has, however, some comments on the higher bearing stress values of 1971 ACI Code compared with 1963 Code. The conservative bearing stress values of 1963 ACI Code were applicable to transfer of stress by bearing at the base of reinforced concrete columns to concrete footings, as explained in Section 2306 of ACI 318-63. These conservative bearing stresses

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have been used in the AISC Manual for bearing of steel on concrete and form the basis of AISC method of column base plate design.

As mentioned earlier, the contact pressure between bearing area of steel plate and supporting concrete is not uniform, due to flexibility and bending of the steel plate. The actual pressure will be higher at the center and decreases towards the edges of base plate. The 1971 ACI Code liberalized the allowable bearing stress on the basis of tests by N. M. Hawkins published in a paper, "The Bearing Strength of Concrete Loaded Through Rigid Plates," Magazine of Concrete Research (London), V.20, No. 62, March, 1968, pp. 31-40. It is now a matter of engineering judgment whether the liberalized bearing stress values of 1971 ACI Code can be applicable to the design of base plates of steel columns. The steel base plates stressed to bending stress of 27.0 ksi behave as flexible plates and do not conform to the test conditions of rigid plates. The bearing of precast or cast-in-place reinforced concrete columns on concrete footings is the actual condition to which bearing stress values of 1971 ACI Code are applicable. For steel bearing plates, the bearing stresses smaller than those given in ACI 318-71 need to be used. For this purpose, reference should be made to published test results by N. M. Hawkins in his paper, "The Bearing Strength of Concrete Loaded Through Flexible Plates," Magazine of Concrete Research (London), V.20, No. 62, June 1968.

The assumption made in regard to live load being 25 percent of the total load in designing the base plates of Examples 1 and 2 by computer solution does not seem realistic. In industrial buildings, live load can be as high as three times the dead load. It would be more appropriate to use the unfactored column load and use allowable bearing stress value of alternate design method of ACI 318-71. The allowable bearing stress by alternate

design method is specified to be 35 percent of the ultimate bearing stress. Thus, allowable bearing stresses in the alternate design method are $0.21'f_c$ and $0.42'f_c$, for $A_2/A_1 = 1.0$ and $A_2/A_1 = 4.0$, respectively. These bearing stress values compare with allowable bearing stress of 1963 ACI Code. There seems to be some inconsistency in the bearing values of strength design method and alternate design method of ACI 318-71. The factor of safety in bearing provided by the alternate design method of 1971 ACI Code is much higher than that provided by the strength design method. In view of this, the author is of the opinion that concrete bearing stress values specified in the AISC Manual should be used in designing steel column bases, instead of the ultimate bearing stress values of ACI 318-71.

The author agrees with the suggestion that for optimum design the difference $(L - B)$ should be equal to $(0.95d - 0.8b)$. Since the alignment chart is made to determine plate thickness by aligning L and $0.95d$, the chart can still be used for values of width B other than those shown on the chart as long as the difference $(L - B)$ is not less than $(0.95d - 0.8b)$. The reason for using a 4-in. differential between L and B is that for most column sections the difference $(0.95d - 0.8b)$ is less than 4 in., except for some sections such as W14×61, W14×68, W14×605, W14×730, etc. For such sections, for which $(0.95d - 0.8b)$ is greater than 4 in., the equivalent value of $0.95d$ for alignment purpose is equal to $(0.8b + 4)$, and these columns are listed against this equivalent $0.95d$ rather than their true $0.95d$ value. In the construction of the alignment chart, an attempt has been made to simplify the base plate design as far as possible. However for more economy, the designer can choose an aspect ratio of L and B such that $(L - B) = (0.95d - 0.8b)$ for each column and determine the plate thickness by aligning L and $0.95d$.