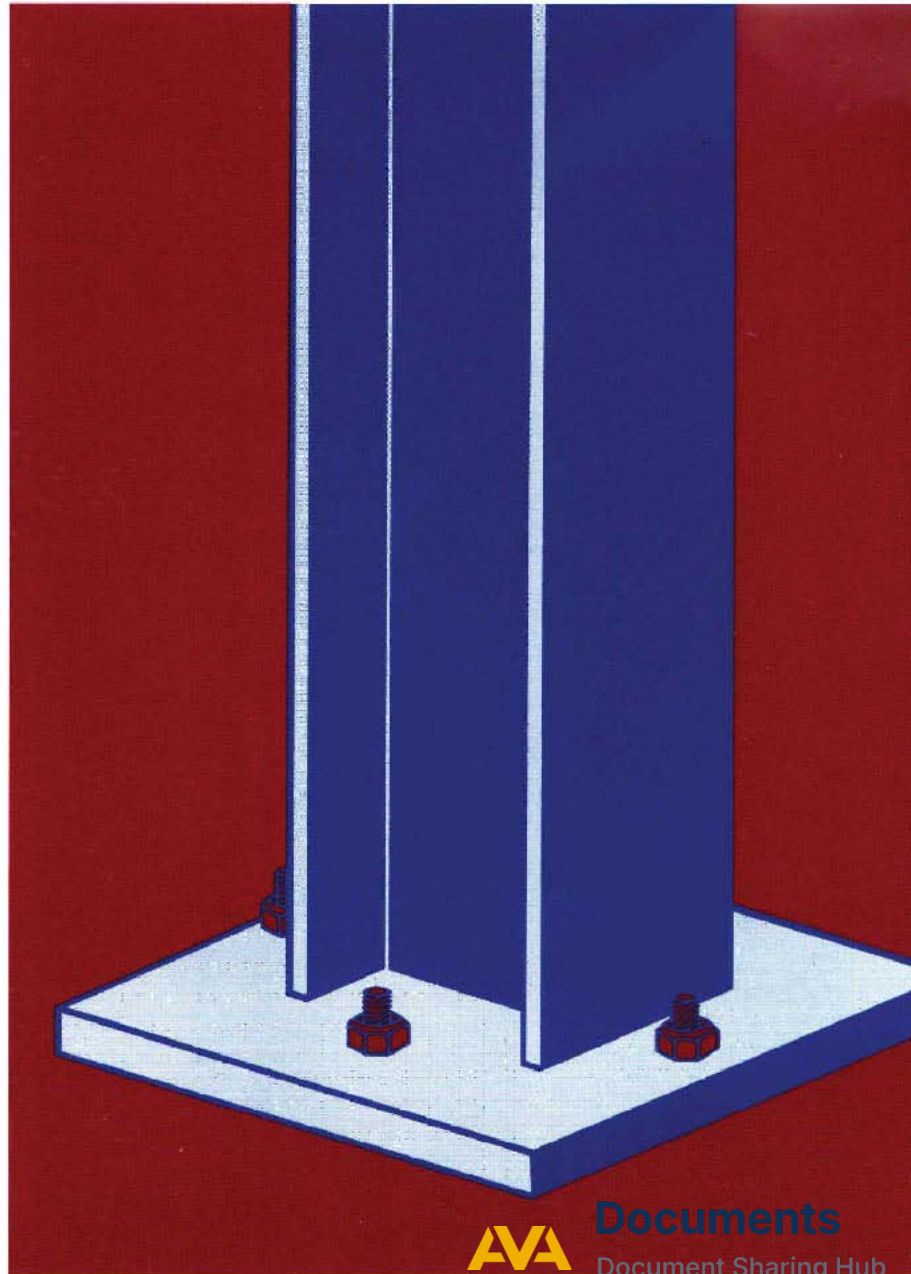




Steel Design Guide Series

Column Base Plates



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Column Base Plates

Design of Column Base Plates

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Some Practical Aspects of Column Base Selection

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By John T. DeWolf

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PREFACE

This booklet was prepared under the direction of the Committee on Research of the American Institute of Steel Construction, Inc. as part of a series of publications on special topics related to fabricated structural steel. Its purpose is to serve as a supplemental reference to the AISC Manual of Steel Construction to assist practicing engineers engaged in building design.

The design guidelines suggested by the author that are outside the scope of the AISC Specifications or Code do not represent an official position of the Institute and are not intended to exclude other design methods and procedures. It is recognized that the design of structures is within the scope of expertise of a competent licensed structural engineer, architect or other licensed professional for the application of principles to a particular structure.

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INTRODUCTION

This report contains a compilation of existing information on the design of base plates for steel columns. The material is taken from reports, papers, texts and design guides. The intent is to provide engineers with the research background and an understanding of the behavior of base plates and then to present information and guidelines for their design. The material is intended for the design of column base plates in building frames, though it can be used for related structures. Bearing plates for beams would be based on similar principles.

Three cases are covered, each involving different loads. These are shown in Fig. 1. The first is the axially loaded column, shown in Fig. 1 (a). The load is perpendicular to the plate and through the column centroid. It is used in frames in which the column bases are assumed pinned. A layer of grout is used for leveling of the plate and setting it at the specified elevation. Anchor bolts are also used to stabilize the column during erection, and the fixity which results is neglected in design. The column and base plate are normally centered on the concrete foundation. If the column load is relatively small, the required base plate size determined from the concrete bearing capacity only will be approximately equal to, or smaller, than the actual column size. These base plates are referred to as lightly loaded column base plates, and they require a modified design approach.

The second case, shown in Fig. 1 (b), includes both an axial load and a moment. This kind of connection would be used at the base of moment resistant frames where moment capacity is needed. It is also used where the load is applied eccentrically to the column and the resulting moment must be resisted by the base connection. If the moment is relatively small, the connection can be designed without the use of anchor bolts, other than those provided for stability during construction. The more common case involves the use of one or more bolts to resist the tension resultant from the moment.

The third case, shown in Fig. 1 (c), is a base plate with a horizontal, or shear load. This will occur in rigid frames. Often the shear component is small in relation to the friction developed. Shear is sometimes important when bracing is connected to the base of the column. The shear can be resisted through friction or the development of bearing in the horizontal direction.

Many variables influence the behavior and load resisting capacity of base plates. While some of these have been studied extensively, others have only received nominal study. The following material is based on the best available information, and some of it represents suggested guidelines based on the author's judgement. The design approaches given here are not intended as the only acceptable methods.

Provisions for the design of base plates have generally been developed in the Allowable Stress Design (ASD) format, as reflected in the AISC Manual of Steel Construction (AISC 1989a) and AISC Specification (AISC 1989). The AISC Load and Resistance Factor Design (LRFD) Manual (AISC 1986) and Specification (AISC 1986a) have translated these provisions into equivalent limit state design format which may be used as an alternative to ASD.

Since the provisions were initially developed in the ASD format, the discussions in the design chapters are based on this format, with appropriate references to LRFD design. The design procedures and examples which follow the discussions are given first in ASD format and then repeated in LRFD format.

The design methods chosen for this document are based on the listed references and the author's judgement but they are not the only approaches possible. Other rational design methods based on engineering judgement may also be adequate. See Appendix B for some practical aspects on column base selection.

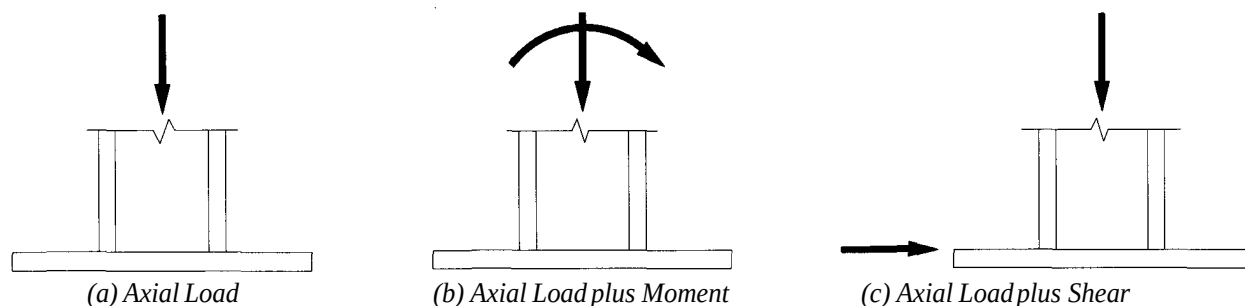


Fig. 1. Base Plate Design Cases

LITERATURE REVIEW - DESIGN PROVISIONS

The review of the research work is given in the Appendix. What follows is a review of applicable design provisions. This includes specification requirements, suggested approaches and design aids. The details are discussed more fully in the subsequent chapters.

Axially Loaded Base Plates

Axially loaded base plates, those with the load applied by a wide flange column to the center of the base plate, are designed according to the method in the ASD Manual of Steel Construction (AISC 1989a). This method is based on an allowable bearing stress defined in the ASD Specification (AISC 1989), which is a function of the concrete compressive strength and the ratio of the concrete to the plate areas. This allowable bearing stress has been increased from that in earlier Specifications to agree with the more liberalized value in the ACT Code (ACI 1983). This had been changed following the results of the studies by Hawkins (1967, 1967a, 1968, 1968a). The allowable bearing stress has been put in terms of load and resistance factor design (AISC 1986, ACI 1983a).

DeWolf (1978) and Narus (1976) have shown that the method in the Manual of Steel Construction is conservative. They have also noted that it does not consider the effects of reinforcement or the relative depth of the concrete foundation, nor does it allow for different plate thicknesses. Thus, plates designed under old specifications cannot be evaluated under the new one.

Design aids for the method in the Manual of Steel Construction have been developed by Blodgett (1966), Sandhu (1973), Dixon (1974), Stockwell (1975), Bird (1976, 1977) and Douty (1976). Good sources of detailing information are the Manual of Steel Construction, Detailing for Steel Construction (AISC 1983), Engineering for Steel Construction (AISC 1984) and Blodgett (1966).

Base plates with especially large loads require more than a simple plate. This may result in a double layer of plates, a grillage system, or the use of stiffeners to reduce the plate thickness. The design of these plates is covered by Blodgett (1966) and noted in Engineering for Steel Construction (AISC 1984).

Lightly Loaded Base Plates in which the plate size is approximately equal to the column size, were initially treated by Fling (1970) using an elastic plate bending approach and the assumption that the full plate is in contact with the concrete. The approach has been used

in the 8th Edition Manual of Steel Construction. This has been shown to be conservative. Stockwell (1975), with modifications by Murray (1983), developed a method which is based on the assumption that bearing occurs only under the column flanges and web. Murray also treats base plates subject to uplift. This approach has been adopted for the 1st Edition Load and Resistance Design Factor Manual (AISC 1986).

Base Plates with Moments

Base plates with both axial loads and moments are not covered in the AISC Specification or the Manual of Steel Construction. Engineers must refer to textbooks for design information, though not all texts cover this case. Two general approaches exist for design, one based on the elastic behavior and one based on the ultimate capacity. For each of these approaches, different assumptions are made.

The elastic approach is covered in the majority of texts which treat moments, including those of Ballio and Mazzolani (1983), Blodgett (1966), Gaylord and Gaylord (1972), McGuire (1968), and Salmon and Johnson (1980). Soifer (1966) has noted that the design can be based on that for reinforced concrete columns. He has stated that the anchor bolt force determination is the most important design element, and that the precise determination of the concrete bearing stress distribution is not essential. He based his discussion on the elastic approach. The approach based on the ultimate capacity, much like that used for the design of reinforced concrete columns today, is based on the study of Salmon, Schenker and Johnston (1957). The method is presented by Gaylord and Gaylord (1972) and McGuire (1968). Both used it to calculate the ultimate load for plates designed by the elastic approach.

DeWolf and Sarisley (1978, 1980) have compared both methods to test data. While they found that either normally provides an adequate factor of safety against collapse, the methods rely on the assumption of some of the variables. Consequently all of the test variables do not usually match with those used in design. They have made suggestions for alterations in the methods and have noted when they are not satisfactory. Thambiratnam and Paramasivam (1986) also conducted tests and compared the results with predictions from the elastic design method.

Maitra (1978, 1978a) has presented a graphical design aid for applying the elastic method.

Anchor Bolts for Tension

For all but the smallest moments, anchor bolts are needed. There are different ways of placing and anchoring these. Lee et. al. (1957) presents designs for placement following setting of the concrete. Others have treated anchorage for machines (Lee 1959, Engineering News Record 1960) and prestressing tendons (Schechter 1960). Hasselwander, Jirsa and Breen (1974) reviewed materials which are suitable for anchor bolts. Details and types of bolts are presented by Fisher (1981), Goldman (1983), Marsh and Burdette (1985, 1985a) as well as in AISC guides for engineering and detailing (AISC 1983, 1984).

The design of anchor bolts is not defined in present codes and specifications for steel construction and is thus left to the discretion of the engineer. Design information is available and has been based on work developed by the American Concrete Institute for nuclear structures (ACI 1978, 1983b). This has been used by Cannon, Godfrey and Moreadith (1981) to write a specification and commentary for anchors not used for nuclear structures. Fisher (1981), Klinger and Mendonca (1982), Shipp and Haninger (1983) and Marsh and Burdette (1985, 1985a) have used the ACI work as a basis for developing guidelines which can be used for the design of anchor bolts for base plates.

Marsh and Burdette also discuss the different types of drilled-in anchors, those that are placed following casting of the concrete foundation. These are not normally used for column base plates and are beyond the scope of this publication. Most of these are proprietary and would be designed according to the manufacturer's specification.

Shear Loads

The design for shear, i.e. loads applied horizontally, is not covered in the ASD Specification (AISC 1989) or in the ASD Manual (AISC 1989a).

Kharod (1980) presents a design based on the capacity of the bolts. It is applicable for smaller shear loads. He incorporates the interaction of shear and tension. Fisher (1981) gives details and general guidelines for using bolts and shear lugs, which he refers to as thrust bars. Cannon, Godfrey and Moreadith (1981) present a specification and commentary for the use of bolts to resist shear. Klinger, Mendonca and Malik (1982) give guidelines for placing reinforcing adjacent to the bolts when they are close to the edges.

Ballio and Mazzolani (1983) discuss the transfer of shear by friction, and the use of bolts and shear lugs. They include the combination of shear and tension. Goldman (1983) discusses the use of friction, bolts and shear lugs. He gives a design example for designing for shear and tension combined. Shipp and Haninger (1983) discuss the design of headed anchor bolts for tension and shear, and give a design example. Tronzo (1983-84) gives a design example using shear lugs to resist the full shear.

DESIGN OF AXIALLY LOADED BASE PLATES

Design Procedure

The method recommended for the design of axially loaded base plates, those assumed to be pinned at the base, is given in the AISC Manual of Steel Construction (AISC 1986, 1989a). The design case is shown in Fig. 2(a). It is assumed that the wide flange column is centered on the plate and that the plate is then centered on the concrete foundation. The AISC method is a two step approach. The required plate area is first determined, based on an assumed uniform allowable bearing stress defined in Section J9 in the AISC Specification (AISC 1989, 1986a). The allowable bearing stress F_p is a function of the concrete strength and the ratio of the concrete to plate areas, as follows:

$$F_p = 0.35 f'_c \sqrt{\frac{A_2}{A_1}} \leq 0.70 f'_c$$

where

f'_c = concrete compressive strength

A_1 = area of the base plate

A_2 = area of the supporting concrete foundation that is geometrically similar to the plate.

The increase in the allowable bearing stress when the concrete area is greater than the plate area accounts for the beneficial effects of confinement. The highest value then occurs when this ratio is equal to or greater than 4.0, and this results in the smallest plate. The full plate area is used to determine the plan dimensions. The loss of area due to anchor bolt holes, even though oversized, and due to holes used for the placement of grout is normally ignored.

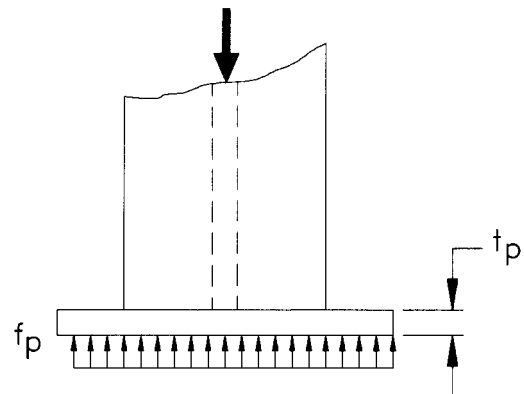
In LRFD format, the factored load on the column P_u should be governed by the following:

$$P_u = \phi_c P_p = 0.85 \phi_c f'_c A_1 \sqrt{\frac{A_2}{A_1}} \leq \phi_c 1.7 f'_c A_1$$

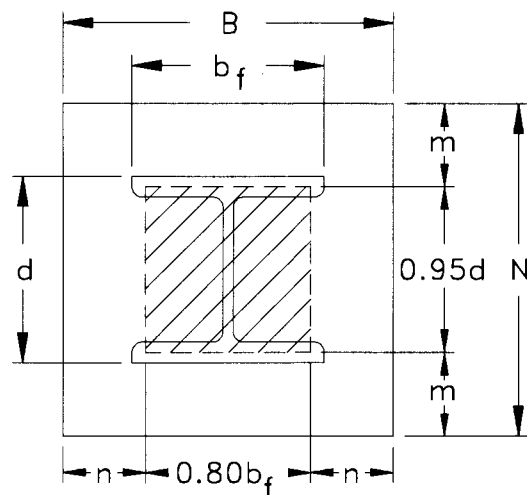
where

ϕ_c = resistance factor for bearing on concrete, equal to 0.60

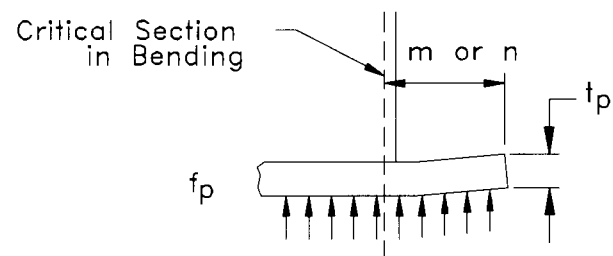
P_p = limit state capacity of the concrete in bearing.



(a) Assumed Bearing Stress



(b) Critical Sections



(c) Determination of Moment

Fig. 2. Design of Plate with Axial Load

The second step then is to determine the plate thickness. The allowable bearing stress has been based on the bearing stress used in the ACI Code (ACI 1983) which is in turn based on the work of Hawkins pertaining to rigid plates (1967, 1968). Thus the plate should be designed to behave like a rigid plate. The plate is assumed to bend about the critical sections as a cantilevered beam, loaded with the uniformly distributed bearing stress. The critical sections are near the edges of the column, shown in Fig. 2 (b), and the cantilever used in design is shown in Fig. 2 (c). The governing bending stress is computed from an elastic analysis based on the larger of m or n . The allowable plate bending stress F_b is equal to $0.75 F_y$ where F_y is the steel yield stress.

In LRFD format, the plastic moment is used for the plate capacity. It is equal to $Z F_y$, where Z is the plastic section modulus, equal to $t_p^2/4$ for a 1 in. wide strip of the plate. The resistance factor for bending ϕ_b is 0.90. The LRFD plastic moment strength is more generous than $0.75 F_y S$ for ASD, and thus LRFD will always result in thinner plates.

Design for Lightest Plate

The most economical plate occurs when m and n , shown in Fig. 2, are equal and the ratio of the concrete to plate area is equal to or greater than 4.0. The first occurs when the difference between B and N , shown in Fig. 2, is equal to the difference between $0.95d$ and $0.80 b_f$, where d is the depth and b_f is the flange width of the wide flange column. The following procedure gives the steps needed for obtaining the lightest plate:

ASD Procedure:

1. The allowable bearing stress F_p is:

$$F_p = 0.70 f'_c$$

2. The required plate area A_1 is:

$$A_1 = \frac{P}{F_p}$$

where P is the axial load.

3. The plate dimensions, B and N , should be determined so that m and n are approximately equal:

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

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

Then:

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

These values should be rounded up to the nearest half or whole inch.

4. Determine the actual bearing pressure:

$$f_p = \frac{P}{NB}$$

5. Determine m and n .

6. Determine the required plate thickness t_p , based on the larger value m and n :

$$t_p = (m \text{ or } n) \sqrt{\frac{f_p}{0.25 F_y}}$$

7. The pedestal dimensions are then determined. Since the procedure was based on the highest allowable bearing stress, the minimum concrete area should be:

$$A_2 = 4 N B$$

8. Check for plate bending in the portion between the column flanges, using the procedure for lightly loaded plates.

Example 1 (ASD Procedure): A W10 x 100 column, ($d = 11.10$ in., $b_f = 10.34$ in.) has a reaction of 500 kips. The smallest acceptable base plate is desired. $f'_c = 3$ ksi; $F_y = 36$ ksi.

1. The allowable bearing stress is:

$$F_p = 0.70 \times 3 = 2.1 \text{ ksi}$$

2. The required plate area is:

$$A_1 = \frac{500}{2.1} = 238.1 \text{ in.}^2$$

3. $\Delta = 0.5 [0.95 (11.1) - 0.8 (10.34)] = 1.13$ in.

Then N is approximately:

$$N = \sqrt{A_1} + 1.13 = 16.56 \text{ in.}$$

Use 17 in. Then B should be $\frac{238.1}{17}$ or 14 in.

4. The actual bearing stress is then:

$$f_p = \frac{500}{(17 \times 14)} = 2.1 \text{ ksi}$$

5. $m = \frac{[17 - (0.95 \times 11.1)]}{2} = 3.23$ in. 

$$n = \frac{[14 - (0.8 \times 10.34)]}{2} = 2.86 \text{ in.}$$

$$6. \quad t_p = 3.23 \sqrt{\frac{2.10}{(0.25 \times 36)}} = 1.56 \text{ in.}$$

Use 1½ in. thickness.

7. The pedestal area is then:

$$A_2 = 4 \times 17 \times 14 = 952 \text{ in.}^2$$

A 31-in. square pedestal is satisfactory.

8. The portion of the plate between the flanges should be checked, based on the procedure for lightly loaded base plates.

LRFD Procedure:

1. Determine the factored load P_u .
2. The required plate area A_1 is:

$$A_1 = \frac{P_u}{1.7 \phi_c f'_c}$$

where P_u is the factored load.

3. The plate dimensions, B and N , should be determined so that m and n are approximately equal.

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

where $\Delta = 0.50 (0.95d - 0.80 b_f)$

Then:

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

These values should be rounded up to the nearest half or whole inch.

4. Determine m and n .
5. Determine the required plate thickness t_p based on the larger value m and n :

$$t_p = (m \text{ or } n) \sqrt{\frac{2 P_u}{0.90 F_y B N}}$$

6. The pedestal dimensions are then determined. Since the procedure was based on the highest allowable bearing stress, the minimum concrete area should be:

$$A_2 = 4 N B$$

7. Check for plate bending in the portion between the column flanges, using the procedure for lightly loaded base plates.

Example 2 (LRFD Procedure): A W10 x 100 column ($d = 11.10$ in., $b_f = 10.34$ in.) is loaded with 180 kips dead load and 320 kips live load. The smallest acceptable base plate is desired. $f'_c = 3$ ksi; $F_y = 36$ ksi.

1. The factored load is:

$$P_u = 1.2(180) + 1.6(320) = 728 \text{ kips}$$

2. The required plate area is:

$$A_1 = \frac{728}{(1.7 \times 0.60 \times 3)} = 237.9 \text{ in.}^2$$

3. $\Delta = 0.5 [0.95 (11.1) - 0.8 (10.3)] = 1.15$ in.
Then N is approximately:

$$N = \sqrt{A_1} + 1.15 = 16.57 \text{ in.}$$

Use 17 in. then B should be $\frac{237.9}{17}$ or 14 in.

$$4. \quad m = \frac{[17 - (0.95 \times 11.1)]}{2} = 3.23 \text{ in.}$$

$$n = \frac{[14 - (0.80 \times 10.34)]}{2} = 2.86 \text{ in.}$$

$$5. \quad t_p = 3.23 \sqrt{\frac{2 \times 728}{(0.90 \times 36 \times 14 \times 17)}} = 1.40 \text{ in.}$$

Use 1½ in. thickness.

6. The pedestal area is then:

$$A_2 = 4 \times 17 \times 14 = 952 \text{ in.}^2$$

A 31 inch square pedestal is satisfactory.

7. The portion of the plate between the flanges should be checked, based on the procedure for lightly loaded base plates.

General Design Procedure

It is not always possible to have concrete pedestals equal to four times the plate area. If the ratio of the concrete to plate area is determined before designing the plate, the design would follow the previous example, with the appropriate change to the allowable bearing stress.

When the pedestal dimensions are known, it is not possible to calculate the allowable bearing stress directly. The following procedure, from the AISC Manuals should be used:

ASD Procedure:

1. The area of the plate should be equal to the larger of:

$$A_1 = \left(\frac{1}{A_2} \right) \left(\frac{P}{0.35 f'_c} \right)^2$$
$$A_1 = \frac{P}{0.70 f'_c}$$

(If the second equation governs, the concrete area A_2 is equal to or greater than four times the plate area A_1)

2. Same as 3 in previous ASD procedure.
3. Same as 4 previously.
4. Same as 5 previously.
5. Same as 6 previously.
6. Same as 8 previously.

Example 3 (ASD Procedure): Design a plate for a W10 x 100 column supporting a load of 525 kips, bearing on a 25 x 25 in. pedestal. $f'_c = 3$ ksi; $F_y = 36$ ksi.

1. $A_2 = 25 \times 25 = 625 \text{ in.}^2$

$$A_1 = \left(\frac{1}{625} \right) \times \left[\frac{525}{(0.35 \times 3)} \right]^2 = 400 \text{ in.}^2 \quad \leftarrow$$

$$A_1 = \frac{525}{(0.70 \times 3)} = 250 \text{ in.}^2$$

2. $\Delta = 1.13 \text{ in.}$, as determined in previous example. Then:

$$N = \sqrt{400} + 1.13 = 21.1 \text{ in.}$$

Use 21 in. Then $B = \frac{400}{21} = 19.1 \text{ in.}$ Use 19 in., which is close enough.

3. $f_p = \frac{525}{(21 \times 19)} = 1.32 \text{ ksi}$

4. $m = \frac{[21 - (0.95 \times 11.1)]}{2} = 5.23 \text{ in.}$

$$n = \frac{[19 - (0.80 \times 10.34)]}{2} = 5.36 \text{ in.} \quad \leftarrow$$

5. $t_p = 5.36 \sqrt{\frac{1.32}{(0.25 \times 36)}} = 2.05 \text{ in.}$

Use $2\frac{1}{8} \text{ in.}$

6. The portion of the plate between the flanges should be checked, based on the procedure for lightly loaded base plates.

LRFD Procedure:

1. Determine the factored load P_u .
2. The area of the plate should be equal to the larger of:

$$A_1 = \frac{1}{A_2} \left[\frac{P_u}{(0.60 \times 0.85 f'_c)} \right]^2$$

$$A_1 = \frac{P_u}{0.60 \times 1.7 f'_c}$$

(If the second equation governs, the concrete area A_2 is equal to or greater than 4 times the plate area A_1)

3. Same as previous LRFD procedure.
4. Same as 4 previously.
5. Same as 5 previously.
6. Same as 7 previously.

Example 4 (LRFD Procedure): Design a plate for a W10 x 100 column supporting a dead load of 188 kips and a live load of 338 kips, bearing on a 25 x 25 in. pedestal. $f'_c = 3$ ksi; $F_y = 36$ ksi.

1. $P_u = 1.2(188) + 1.6(338) = 766 \text{ kips}$

2. $A_2 = 25 \times 25 = 625 \text{ in.}^2$

$$A_1 = \frac{1}{625} \left[\frac{766}{(0.60 \times 0.85 \times 3)} \right]^2 = 401 \text{ in.}^2 \quad \leftarrow$$

$$A_1 = \frac{728}{(0.60 \times 1.7 \times 3)} = 238 \text{ in.}^2$$

3. $\Delta = 1.13 \text{ in.}$, as determined in previous example. Then:

$$N = \sqrt{401} + 1.13 = 21.2 \text{ in.}$$

Use 21 in. Then $B = \frac{401}{21} = 19.1 \text{ in.}$ Use 19 in., which is close enough.

4. $m = \frac{(21 - 0.95 \times 11.1)}{2} = 5.23 \text{ in.}$

$$n = \frac{[19 - (0.8 \times 10.34)]}{2} = 5.36 \text{ in.} \quad \leftarrow$$

5. $t_p = 5.36 \sqrt{\frac{(2 \times 766)}{(0.90 \times 36 \times 19 \times 21)}} = 1.85 \text{ in.}$

Use $1\frac{7}{8} \text{ in.}$

6. The portion of the plate between the flanges should be checked, based on the procedure for lightly loaded base plates.

Design Aid for Axially Loaded Base Plates

Stockwell (1975) prepared a useful allowable stress design aid for determining the values of N and B , the plate dimensions. A set of nomographs allows the engineer to rapidly determine plate sizes for different ratios of A_2/A_1 . This is illustrated in Fig. 3. The two quadrants in each chart have the bearing area A_1 as the common vertical axis. The horizontal axes are the concrete area A_2 and the base plate width B . The range of allowable bearing pressures is shown in the right quadrant. The engineer enters with the value of the load P , then follows horizontally to the zone showing the allowable bearing stresses. The engineer can then choose a value of the allowable stress along a circular segment shown by line 1-2. The two axes then give the areas for the plate and pedestal, A_1 and A_2 . If the area of the concrete is already known, the engineer can get the appropriate allowable stress and the required plate area A_1 from the intersection of the load line and the concrete area. The left quadrant is then used to determine the values of N and B . The curved line represents the values for a square plate. Figures 4 (a) through (f) give the design charts for f'_c equal to 3000 and 4000 psi.

$$A_1 = \frac{1}{A_2} \left[\frac{P}{0.35 f'_c} \right]^2$$

$$A_1 = \frac{1}{A_2} \left[\frac{P_u}{0.60 \times 0.85 f'_c} \right]^2 = \frac{1}{A_2} \left[\frac{P_u}{0.51 f'_c} \right]^2$$

$$= \frac{1}{A_2} \left[\frac{P_u / 1.46}{0.35 f'_c} \right]^2 = \frac{1}{A_2} \left[\frac{\bar{P}}{0.35 f'_c} \right]^2$$

$$\bar{P} = (P_u / 1.46),$$

$$\frac{DL + LL}{0.35} = \frac{1.2 DL + 1.6 LL}{0.60 \times 0.85}$$

$$\frac{DL + 1.8 DL}{0.35} = \frac{1.2 DL + 1.6 \times 1.8 DL}{0.51}$$

$$8DL = 8DL$$

For load ratios other than 1.8, the base plate areas determined by the two methods will differ (larger LRFD areas for greater ratios, smaller LRFD areas for lesser ratios).

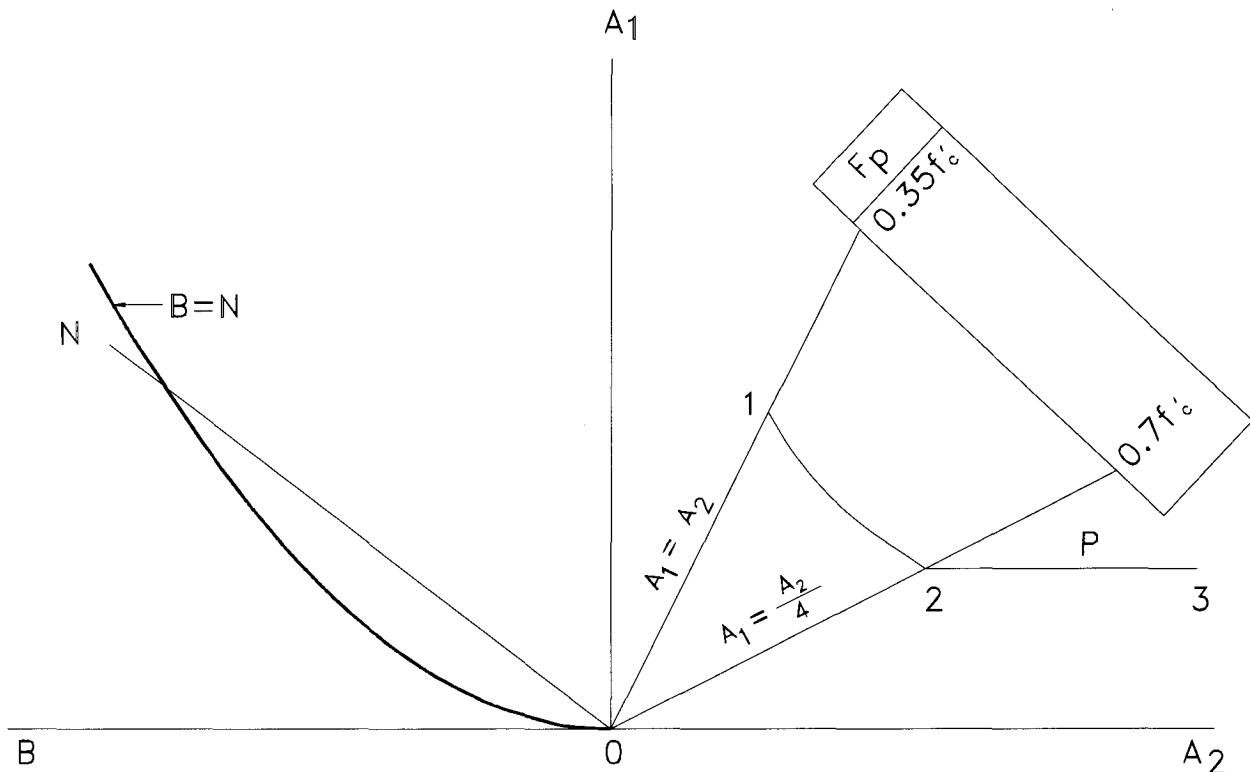


Fig. 3. Stockwell's Design Aid for Axially Loaded Plate.

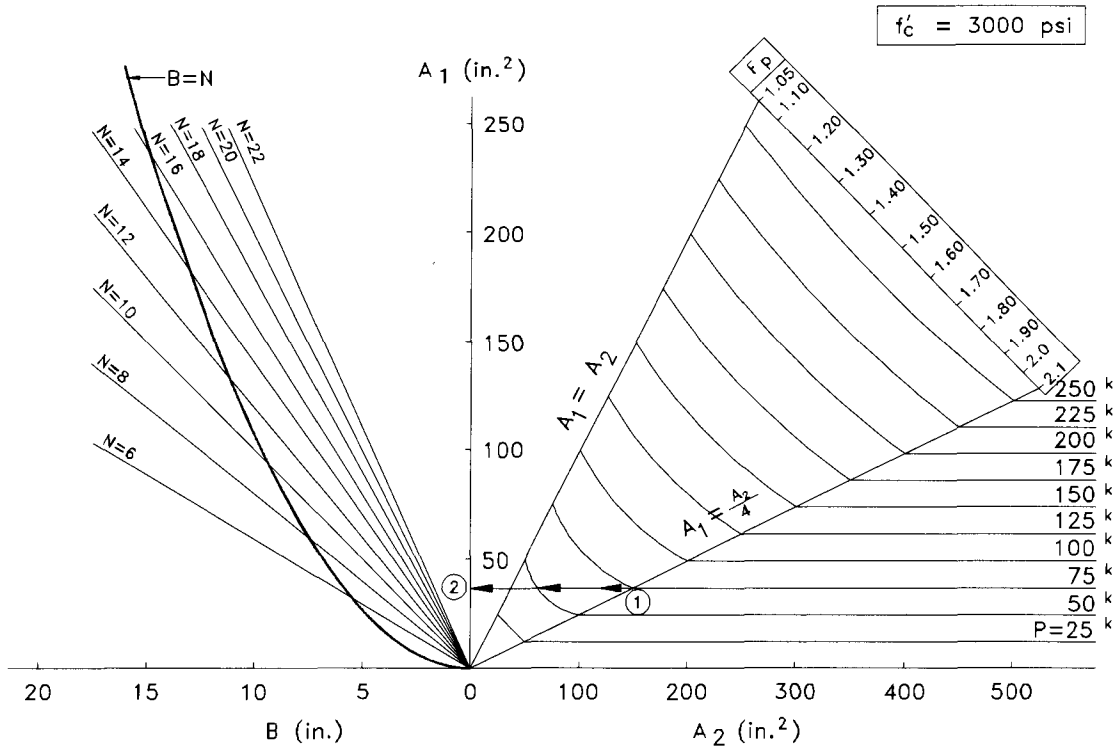


Fig. 4a. Design Aid for Axially Loaded Plates (Working Loads)

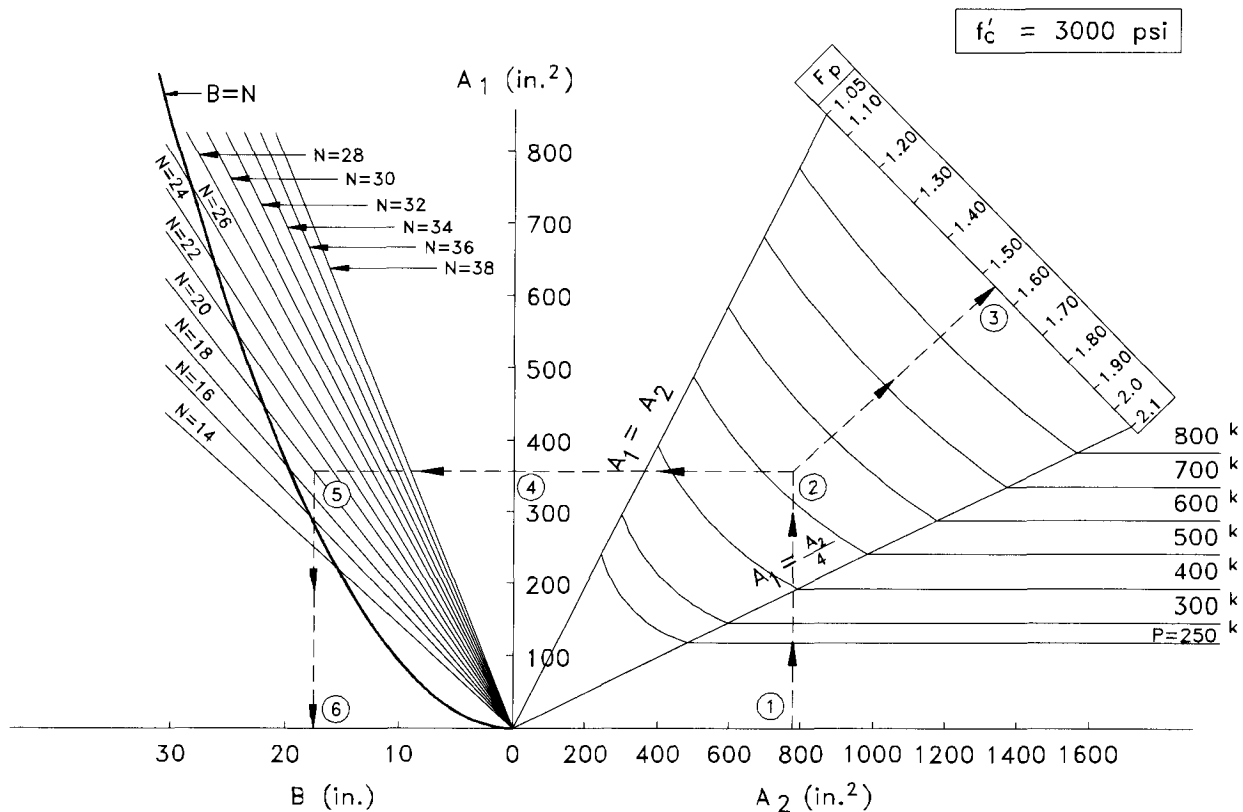


Fig. 4b. Design Aid for Axially Loaded Plates (Working Loads)

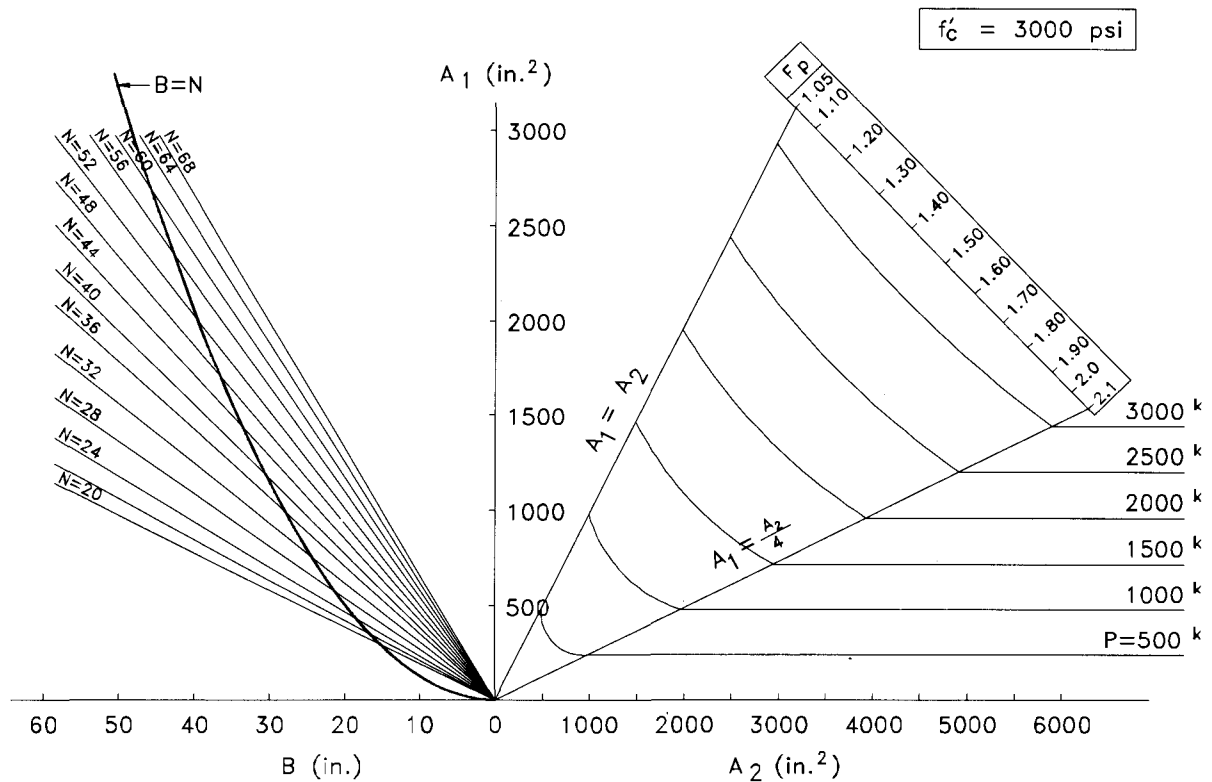


Fig.4c. Design Aid for Axially Loaded Plates (Working Loads)

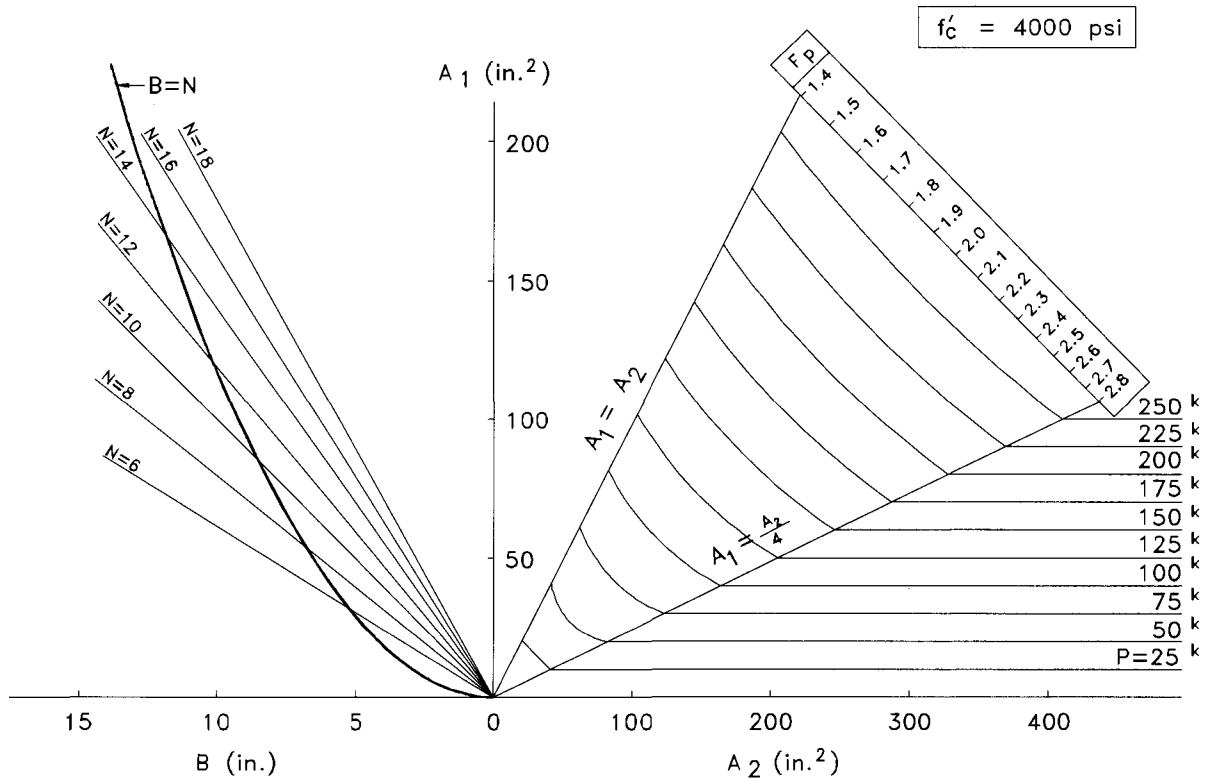
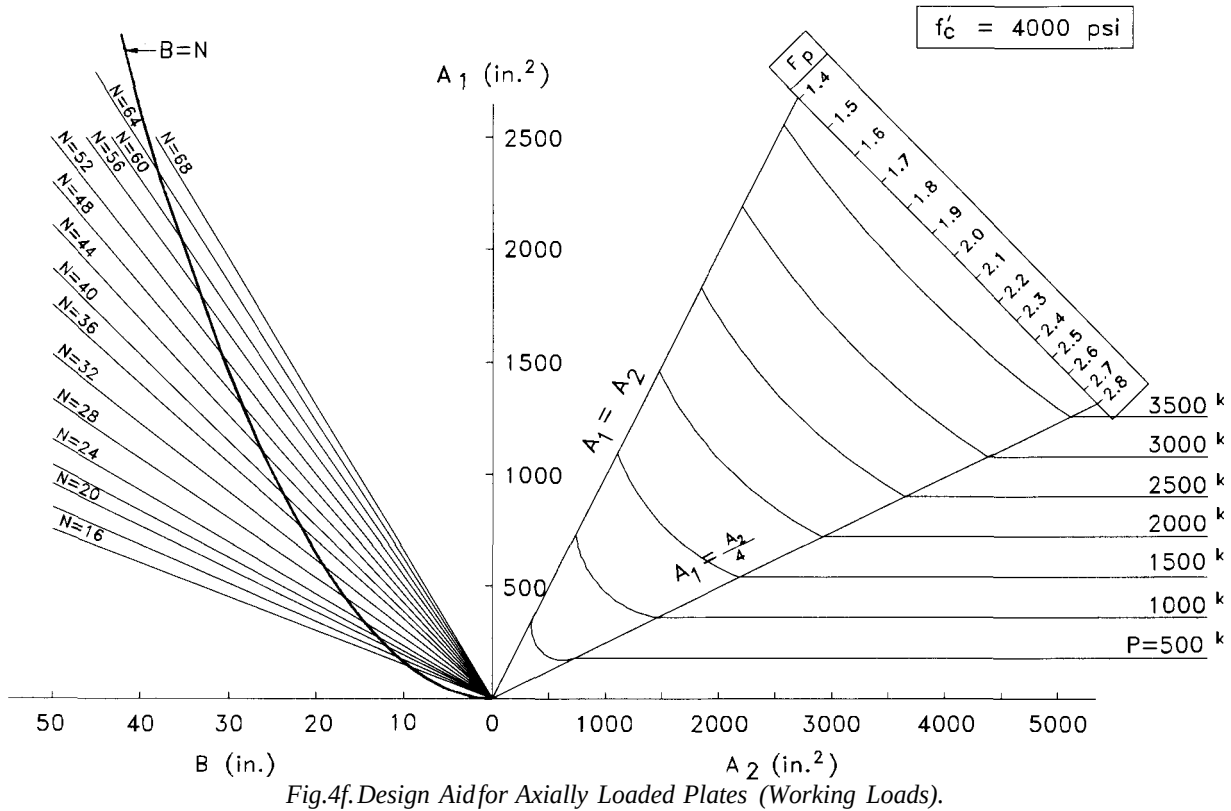
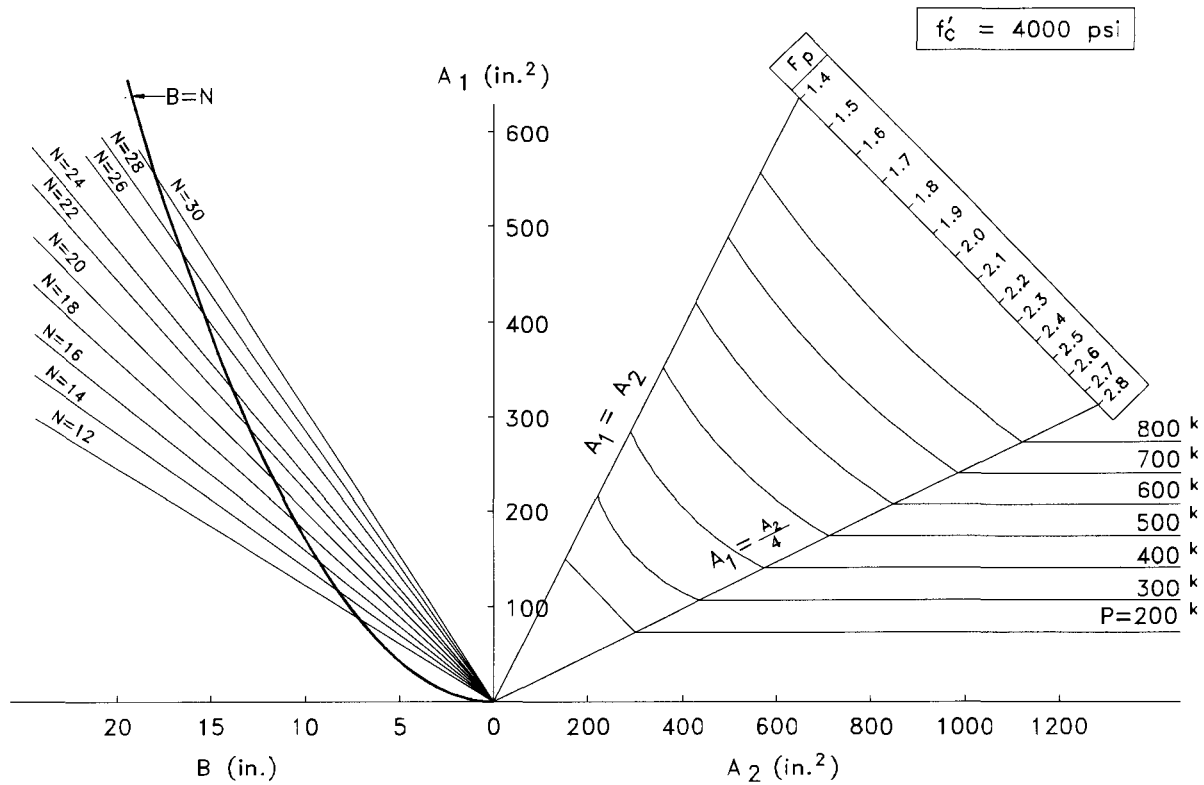


Fig.4d. Design Aid for Axially Loaded Plates (Working Loads)



The example, taken from Stockwell's paper, follows:

Example 5 (ASD Procedure): A base plate is to be selected for a W12 x 106 column supporting a load of 560 kips, bearing on a 28 x 28-in. pier. The concrete compressive strength f'_c is 3 ksi.

1. In Fig. 4(b), enter the first quadrant at $A_2 = 28 \times 28 = 784 \text{ in.}^2$
2. Proceed vertically to $P = 560$ kips.
3. Draw a line from the origin in the right quadrant through point 2 and find that the allowable bearing pressure is $F_p = 1.54$ ksi.
4. From point 2, proceed horizontally to $A_1 = 365$ in.
5. Continue horizontally to $N = 20$ in.
6. Proceed vertically to $B = 18.4$ in.
7. Use a 19 by 20 in. plate and determine the thickness as in the previous examples.

Example 6 (LRFD Procedure): A base plate is to be selected for a W12 x 106 column with a dead load of 200 kips and a live load of 360 kips. The pier is 28 in. square and f'_c is 3 ksi.

1. Determine the factored load:
 $P_u = 1.2(200) + 1.6(360) = 816$ kips
2. Determine $\bar{P}$ (equal to P_u divided by 1.46):
$$\bar{P} = \frac{816}{1.46} = 559 \text{ kips}$$
3. Follow steps 3 through 6 in the previous ASD Example 5.
4. Use P_u to compute the required plate thickness by the LRFD equation.

Base Plates Placed Eccentrically on the Concrete Foundations

When the plate is axially loaded, but placed eccentrically on the concrete foundation, Hawkins (1967,1968) found that the design could be conservatively based on using that portion of the concrete which is concentric around the plate. This is recommended for use here. The design approach already given can then be used, with the appropriate A_2 .

Determining the Design Load for Existing Base Plates

The method in the AISC Manual for designing base plates results in a unique plate thickness. It is not directly applicable for determining the allowable axial column load for an existing base plate that has been designed under different conditions. An example is a plate designed according to earlier AISC Specifications which specified lower allowable bearing stresses. It will have a greater area A_1 , with greater values of m and n . The resulting thickness, which was determined for the lower allowable bearing stress, will not allow evaluation of the plate with the new allowable bearing stresses. As an approximation, the following procedure can be used. It is based on assuming that only a portion of the plate is effective.

Example 7 (ASD Procedure): A plate has been designed for a W14 x 95 column ($d = 14.12$ in., $b_f = 14.545$ in.). $f'_c = 3$ ksi; $F_y = 36$ ksi. The plate was designed for a load of 480 kips using an older edition of the AISC Specification, with an allowable bearing stress

of $0.25 f'_c$. $\frac{A_2}{A_1}$ is equal to 1.0. The building is being remodeled, and it is desired to find out if an additional load of 70 kips can be applied without exceeding the allowable bearing stress in the present edition of the AISC Specification. The plate size is 25 x 1 5/8 in. x 2 ft 2 in.

The allowable plate bending stress is the same as used in the original design. It is thus not possible to use the new bearing stress based on the original values of A_1 and A_2 , without exceeding the allowable bending stress. Instead only a portion of the plate will be used. The two requirements are that the allowable bearing stress should not exceed $F_p = 0.35 f'_c \sqrt{\frac{A_2}{A_1}}$ and that the bending stress

F_b should not exceed $0.75 F_y$. The design aid prepared by Stockwell will be used.

1. For a load of 550 kips and $A_2 = 25 \times 26 = 650 \text{ in.}^2$, A_1 is found equal to approximately 425 in.^2 from Fig. 4(b).
2. $\Delta = 0.50 (0.95 \times 14.12 - 0.80 \times 14.545) = 0.89$ in.
 $N = \sqrt{425 + .89} = 20.6$ in. Use 22 in.
 $B = \frac{425}{22} = 19.3$ in. Use 20 in.
3. $f_p = \frac{550}{(22 \times 20)} = 1.25$ ksi.

$$4. \quad m = \frac{[22 - (0.95 \times 14.12)]}{2} = 4.29 \text{ in.}$$

$$n = \frac{[20 - (0.80 \times 14.545)]}{2} = 4.18 \text{ in.}$$

$$5. \quad t_p = 4.29 \sqrt{\frac{1.25}{(0.25 \times 36)}} = 1.60 \text{ in.}$$

This thickness is smaller than the actual value, so that it is possible to increase the allowable load to 550 kips from the original design value of 480 kips. A trial and error approach could be used to determine how much load could actually be added to the column without exceeding the new allowable bearing stress and the allowable bending stress.

Example 8 (LRFD Procedure): A plate has been designed with ASD provisions for a W 14 x 95 column ($d = 14.12 \text{ in.}$, $b_f = 14.545 \text{ in.}$, $f'_c = 3 \text{ ksi}$; $F_y = 36 \text{ ksi}$). The plate was designed for a dead load of 170 kips and a live load of 310 kips. An older edition of the AISC Specification was used with an allowable bearing stress of $0.25 f'_c \cdot \frac{A_2}{A_1}$ is equal to 1.0. It is desired to find out if an additional live load of 64 kips can be applied without exceeding the allowable bearing stress in the LRFD provisions. The plate size is 25 x 1 5/8 in. x 2 ft 2 in.

Only a portion of the plate will be assumed to be effective, as done with the ASD example. The two requirements are that the factored load on the column P_u should not exceed $0.85 \phi_c f'_c A_1 \sqrt{\frac{A_2}{A_1}}$ and that the required plate

effective thickness, equal to $(m \text{ or } n) \sqrt{\frac{2 P_u}{(0.90 F_y B N)}}$, should be equal to or smaller than the actual thickness.

1. Determine the factored load:

$$P_u = 1.2(170) + 1.6(310 + 64) = 802 \text{ kips}$$

2. Determine the equivalent ASD design load:

$$\bar{P} = \frac{802}{1.46} = 550 \text{ kips}$$

3. From Stockwell's design aid with a load of 550 kips and $A_2 = 650 \text{ in.}^2$, find $A_1 = 425 \text{ in.}^2$

4. Same as 2 in ASD sample.

5. Same as 4 in ASD example.

$$6. \quad t_p = 4.29 \sqrt{\frac{(2 \times 802)}{(0.90 \times 36 \times 20 \times 22)}} = 1.44 \text{ in.}$$

This is smaller than the actual thickness, and thus the additional live load can be added to the base plate.

Design of Lightly Loaded Base Plates

Lightly loaded base plates are those in which the plate size is equal to or slightly larger than the column dimensions. For these m and n are approximately zero, and the critical portion of the plate for bending is between the column flanges, adjacent to the web. As noted, the 8th Edition Manual of Steel Construction contains a procedure for this plate thickness determination. Recent work by Murray (1983) has been used for the new Load and Resistance Factor Design Manual (AISC 1986) and 9th Edition. It is based on the approach of Stockwell (1975) and is more realistic than the method in the 8th Edition Manual. The Murray/Stockwell method has been modified to allowable stress design format in the following procedure. The plate allowable bending stress partially reflects its compact bending capacity, $F_b = 0.75 F_y$.

Note: The following procedure includes both the check for the area between the column flanges and the general design procedure previously discussed. All plates can be fully designed with this procedure. If m or n is greater than either $b_f/2$ or $d/2$ (then c will not govern), the procedure for the area between the plates is unnecessary. Thus the earlier design procedures would then be sufficient.

An improved approach to the design of lightly loaded base plates is given in Appendix C. This new approach is included in the revised printing of the 9th Ed. Manual.

ASD Procedure:

1. The area of the plate A_1 should be equal to the larger of:

$$A_1 = \left(\frac{1}{A_2} \right) \left(\frac{P}{0.35 f'_c} \right)^2$$

$$A_1 = \frac{P}{0.70 f'_c}$$

$$A_1 = b_f d$$

2. The bearing area is based on the assumption that it is H-shaped and located just below the column elements. This is shown in Fig. 5. It is the larger of:

$$A_H = \frac{P}{0.35 f'_c \sqrt{\frac{A_2}{b_f d}}}$$

$$A_H = \frac{P}{0.70 f'_c}$$

3. The distance for the cantilevered section used to figure the bending stress is shown in Fig. 5 and can be calculated from:

$$2(d + b - 2c)c = \frac{P}{F_p} = A_H, \text{ therefore}$$