How to Design Column Base Plates

The function and purpose of column base plates are to provide a spread and distribution of column loads from the steel column to the weaker concrete footing. The base plate acts as an intermediate stress distributor in a similar way the concrete footing distributes load from the footing to the softer soils below. When the column load contains a moment, the base plate may require design to ensure uplift of the base plate does not occur which is achieved by designing anchor bolts to resist the tensile forces. Base plate design typically involves an iterative procedure to solve for unknowns which can be time consuming without a useful tool such as a formatted spreadsheet. A wide variety of base plate connection details are possible for the designer to employ, particularly when detailing a connection required to resist both axial load and moment. To provide focus within this report, a discussion of possibilities will be presented, however, the spreadsheet developed will focus on a single connection arrangement with a unidirectional load case. Base plates typically sit atop a concrete footing, although other possibilities such as masonry, timber, and stiff soil foundations may be possible. This report considers concrete foundations only. To accommodate alternate foundation types, the user can easily incorporate modification of the principals presented. Three categories of loading are possible on base plates which are conveniently separated for analysis and programming purposes. Each load scenario requires slightly different methods for calculating stresses within the steel and concrete and requires attention to specific design issues.

Load Scenario I:
This load scenario involves the application of direct axial load to the base plate with no corresponding moment in the column. As a result stress acting on the base plate is uniform over the surface and thus is the simplest case of the three to analyze.
Under this load scenario, we are primarily concerned with sizing the base plate to transfer a uniform load to the concrete that is low enough to prevent bearing failure of the concrete footing. Additionally, we require a design check on the stress within the base plate to ensure yielding of the base plate does not occur at the cantilever support of the base plate.

The stress acting on the concrete (p) is readily calculated by:

\[ p = \frac{C_f}{A_p} \]

where \( C_f \) = factored compression load

\[ A_p = BD \] = area of the base plate in plan

This stress is checked against the factored bearing resistance of the concrete \( (f_c) \) which is calculated from:

\[ f_c = 0.85\phi_c f'_c \]

Where \( \phi_c \) = resistance factor for concrete

\( f'_c \) = 28 day compressive strength of concrete

By equating these two expressions, the area of the base plate can be established from:

\[ A_b = \frac{C_f}{(0.85\phi_c f'_c)} \]

An approximation of the design stresses can be made to simplify the calculation of the base plate thickness by treating the concrete stress as uniform load acting over the cantilever portion of the base plate. The cantilever lengths \( n \) and \( m \) are assumed fixed at their origin and their lengths are defined as shown in the diagram below.
Considering a 1mm wide strip of plate cantilevered over a length of \( n \) or \( m \) we can show that the applied load \( (M_f) \) is expressed by:

\[
M_f = \frac{1}{2} p \ m^2 \quad \text{(or)} \quad \frac{1}{2} p \ n^2
\]

And the element resistance may be expressed as:

\[
Mr = \phi Z F_y
\]

By equating \( M_f = Mr \) we can solve for the plate thickness \( (t) \) shown as the maximum thickness of:

\[
t = \sqrt{\frac{2 \ p \ m^2}{\phi \ F_y}} \quad \text{or} \quad \sqrt{\frac{2 \ p \ n^2}{\phi \ F_y}}
\]

**Load Scenario II:**

Load scenario II is similar to load scenario I but is distinguished by having a moment in the column which produces a linearly varying load distribution over the surface of the contact area. It is limited to load distributions that remain in compression over the entire surface of the base plate. In other words, it is limited to relatively small moments that don’t cause uplift of the base plate from the concrete surface at any point along the base plate. With these definitions in place, we can design base plates falling into this category in the same manner as category I, with the exception that we need to determine the peak pressure and distribution of load.

Given a compression load \( C_f \) and moment \( M_f \) in the column, we can establish the maximum and minimum bearing pressures on the plate with the following formulae;

\[
p_{\text{max}} = \frac{C_f}{A_p} + \frac{M_f}{S}
\]

\[
p_{\text{min}} = \frac{C_f}{A_b} - \frac{M_f}{S}
\]

where \( S = \frac{1}{6} B \ D^2 \)
Once these pressures have been established, we can confirm that this is a Load Scenario II by ensuring $p_{\text{min}}>0$.

The plate plan dimensions can be determined by ensuring $p_{\text{max}}$ is less than the allowable bearing stress in the concrete.

$$p_{\text{max}} < 0.85 \phi_c f_c$$

The required plate thickness can be determined in a similar manner to Load Scenario I, with the exception of modifying the load as trapezoidal rather than uniform.

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**Load Scenario III:**

Load Scenario III is similar to Load Scenario II with the exception that the moment is large enough to cause tension or uplift on one side of the base plate. Anchor bolts are required to withstand these tensile loads and prevent uplift on the bearing plate. The analysis of this load condition is analogous to reinforced concrete design where the anchor bolts act as the tensile reinforcing and a compressive stress block of depth “a” forms a resisting moment couple with the tensile reinforcing.
The tensile capacity of the bolts (\(T_r\)) and the compressive resistance of the concrete (\(C_r\)), which form the resisting couple, can be expressed as:

\[
T_r = 0.75 \phi A_b F_u
\]

\[
C_r = 0.85 \phi_c f'_c a B
\]

Summing the forces in the vertical direction gives;

\[
C_f + T_r = C_r
\]

or,

\[
C_f + 0.75 \phi A_b F_u = 0.85 \phi_c f'_c a B
\]

Taking moments about the center line of the bolts gives;

\[
C_f (d' - 1/2 D) + M_f = C_r (d' - 1/2 a)
\]

or,

\[
C_f (d' - 1/2 D) + M_f = 0.85 \phi_c f'_c a B (d' - 1/2 a)
\]

The above set of equations represents 2 independent equations and 4 unknowns. A formatted spreadsheet can be used conveniently to solve the unknowns by first estimating \(d'\), \(B\), and \(D\) and then
solving for ‘a’ using the first equation and then substituting ‘a’ into the second equation and solving for D. The appropriate value of D can be solved by an iterative method.

**Connection Details and Design**

Several common base plate connection details exist and are largely dependent on the loading condition required on the base plate. Anchor bolts are typically provided regardless of loading condition, as erection loads require the use of nominal sized bolts. The connection detail of the base plate to the column can be, in its simplest form, a fillet weld connecting the two components. When larger moments are present, a combination of stiffening plates and welds can be used. The figures below demonstrate some typical connection details.

(A) Typical Details For Moments about Column Strong Axis

(B) Possible Detail for Moments about Column Weak Axis

Because of the large possibility of arrangements, this report will focus the discussion and spreadsheet calculations to a connection consisting of fillet welds connecting column to base plate and anchor bolts without stiffeners connecting base plate to concrete.