Discussion

The Effective Length of Unbraced Single Story Columns

Paper presented by CHRISTOPHER MARX
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Discussion by **Robert W. Green**

In examining Mr. Marx's contribution, some engineers are disturbed by the statement "The key word to keep in mind when using the alignment chart is *rigidly*. The expression *rigidly attached* in this case requires that the column base connection be designed for the full moment capacity of the column." These engineers have erected structures with column base connections that cannot develop the moment capacity of the columns. In the design process, moment requirements were either not apparent or of a lesser magnitude than the column moment capacity. Where no design moments are apparent, fabrication and erection tolerances introduce small moments but, as will be shown, these appear often to require no tensile bolts.

Mr. Marx is correct in stating that column connections must remain rigid in order to use the alignment chart. However, in the writer's opinion, the requirement that the base be rigidly connected should not be construed as requiring connection for the full moment capacity of the column section. The writer believes that "rigidly connected" should be interpreted as requiring adequate connection to prevent rotation between connected components under action of the forces imposed, with full recognition given to the flexibility of the members. In a great many cases, the line of action of the forces at the column base is within the kern, and no tensile bolts are required. For other cases, the eccentricity is small, the tendency to rotate is small, and therefore the positive restraint required to totally prevent rotation between components is small.

Unbraced columns that resist horizontal loading will have end moments, and the column base connection should be suitably designed. Unbraced columns with no design moments applied to the base will have small end moments introduced by fabrication and erection tolerances. Maximum out-of-plumb is $1/500$ and maximum sweep is $1/1000$. Assuming a point of inflection at mid-height of the column and combining these two tolerances, the maximum eccentricity of the point of inflection relative to the base connection is 0.002 times the column length. Axial load on the column will amplify this tolerance. Using these relationships, a vertical line through the point of inflection will remain within the kern of the base when

$$\Delta_{max} = \frac{0.85}{1 - \frac{f_a}{F_e'}}(0.002L) \leq \frac{b_f}{6} \text{ or } \frac{d}{6} \qquad (1)$$

depending on which axis is being examined, where b_f is the width of the column flange and d is the column depth. The factor 0.85 is the C_m used under AISC Specification Sect. 1.6. When Eq. (1) is satisfied, no tensile bolts are required for moment capacity up to column failure. In addition, the axial load multiplied by any reasonable coefficient of friction can provide horizontal shear capacity far in excess of shear load. The writer would nevertheless provide some minimum number of anchor bolts.

To reduce the amount of checking to be done with Eq. (1), a simple design rule can be developed as follows: For W, M, S, and HP shapes, b_f/r_y varies from 3.81 to 5.76 and d/r_x varies from 2.28 to 2.74. Choosing the most critical ratio as 2.28, it can be shown that, for A36 steel and L/r of less than 79, the line of force remains in the kern for unbraced columns with no design moments at the base.

For braced columns where an alignment chart is used to reduce the effective column length factor below 1, bracing stiffness will usually be some multiple of the column stiffness and will be added to the column stiffness. Amplification will then be small and an appropriate C_m factor of 0.4 will further reduce its effect. In the writer's opinion, amplification of the eccentricity by the axial load can be neglected. The maximum eccentricity introduced to the axial load can be approximated by the maximum out-of-plumbness for the full column length ($0.002L$). This yields the expression

$$\Delta_{max} = 0.002L \leq \frac{b_f}{6} \text{ or } \frac{d}{6} \qquad (2)$$

When Eq. (2) is satisfied, the line of force will remain within the kern, requiring no tensile anchor bolts. The writer would, nevertheless, provide a minimum number of anchor bolts. (Bracing that delivers the horizontal loads on the structure to the foundation must, of course, be developed.)

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When using alignment charts for braced or unbraced columns, the writer suggests the following design approach for the base connection. For columns using W, M, S, and HP shapes with no design moments at the base:

1. Some minimum connection should be provided for either of the following:
   a) All columns where $F_y = 36$ and $L/r < 79$
   b) All columns satisfying Eqs. (1) or (2)
2. For all other columns, the base need only be designed for the moment $P\Delta_{max}$, where P is the column design load.

For columns having design moments at the base, the connection should be proportioned for the design moments.