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DESIGNING BEAM COPES

BY BO DOWSWELL, PE, PHD

The latest edition of the AISC *Manual* includes updated design methods for beam copes.

THE DESIGN METHODS for single- and double-coped beams have been revised for the 15th Edition *Steel Construction Manual.*

Here, we'll discuss the new design provisions and provide some background information on the local strength of coped beams, as well as new design recommendations for axially loaded beams based on the latest research.

Beam to Beam

Let's start with beam-to-beam connections. In such connections, the top flange of the supported beam is usually coped to clear the supporting beam flange (see Figure 1). In some cases, the bottom flange must be coped to clear the supporting beam flange or to allow the beam to be dropped between two angles, as shown for the knife connection in Figure 2. For double-coped beams, where both the top and bottom flange are coped, a significant portion of the web is often removed. Figure 3 (opposite page) shows a skewed beam-to-beam connection with a long double cope at the supported beam.

For design purposes, the coped region can be modeled as a short beam with a length equal to the cope length. In addition to the constant shear force, *R*, the cope is subjected to a linearly-varying moment. The maximum moment is at the face of the cope, causing compressive flexural stresses at the reentrant corner, as shown in Figure 4. Due to the combined effect of the flexural and shear stresses, the cope

▲ Figure 1. Beam coped at the top flange.

▼ Figure 2. Beam coped at the bottom flange.

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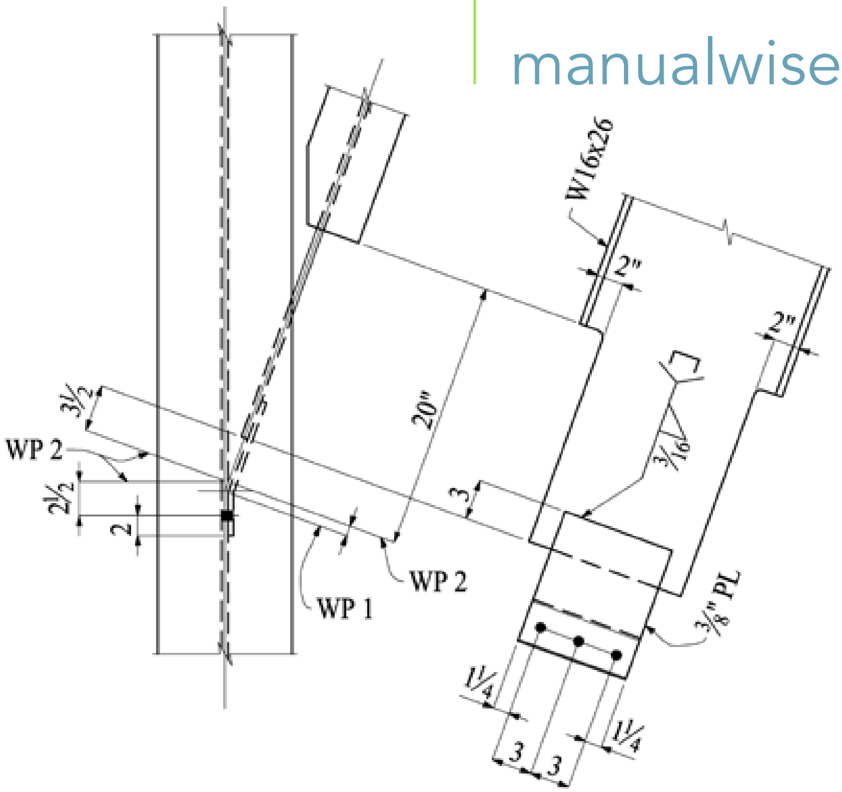


➤ Figure 3. Skewed beam-to-beam connection.

strength can be limited by either yielding or buckling.

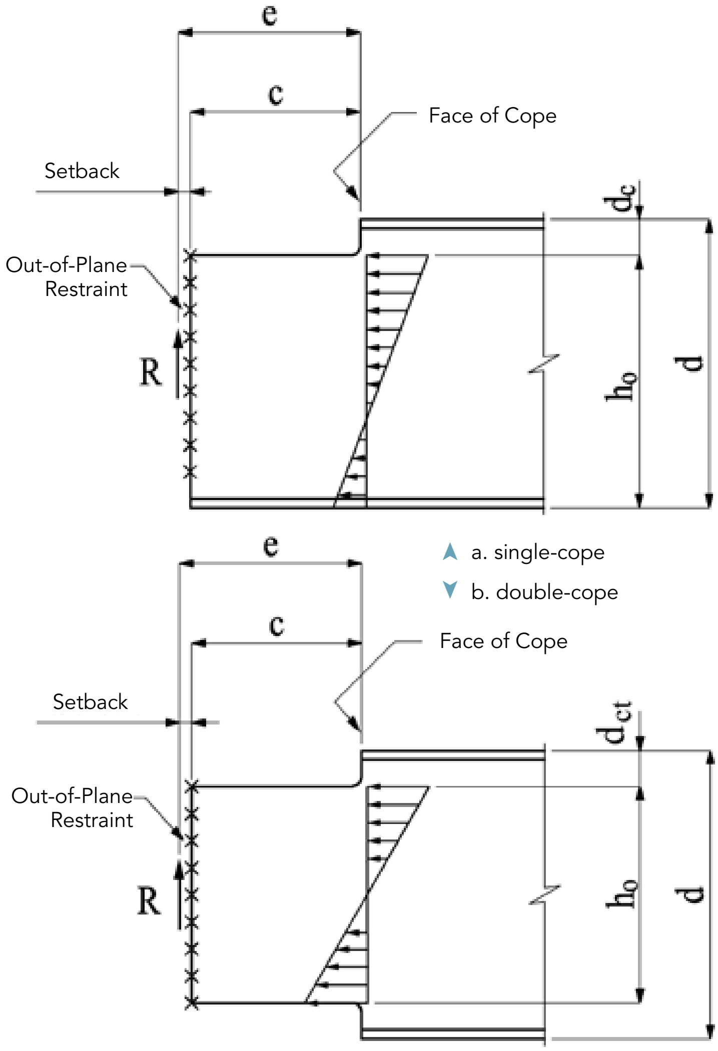
Design recommendations in previous editions of the AISC *Manual* imposed limits on the cope geometry and were based on an allowable stress philosophy, limiting the flexural strength to the first-yield moment. To eliminate the limits of applicability and provide equations that take advantage of any available post-yield strength, the design guidance in the 15th Edition *Manual* (**www.aisc.org/manual**) has been revised from these previous editions.

Single-Coped Beams

The web of a single-coped beam can buckle in a local mode, similar to the buckling of a tee stem in flexural compression. Therefore, the flexural strength equations in Part 9 of the *Manual* are similar to the three-part local buckling curves in Chapter F of the *Specification for Structural Steel Buildings* (ANSI/AISC 360, available at **www.aisc.org/specifications**). Figure 5 (page 18) shows the single-cope curve with the available experimental results. As with the *Specification*, the equations produce a linear transition between the plastic strength and the elastic buckling curve. The shear strength is calculated according to AISC *Specification* Section J4.2.

Flexural local buckling is likely to dominate the buckling mode for beams with long copes. Shear buckling, where the buckled shape is characterized by a single wave oriented at an angle of approximately 45° from vertical (Figure 6, page 18), occurs in beams with short cope lengths. Because most instabilities in single-coped beam webs are caused by a combination of shear buckling and flexural local buckling, the equations in *Manual* Part 9 use a buckling adjustment factor, *f*, to account for the effect of shear.

Combined block shear and cope buckling (block shear buckling) can occur at short copes with shallow end con-



▲ a. single-cope
▼ b. double-cope

➤ Figure 4. Design model.

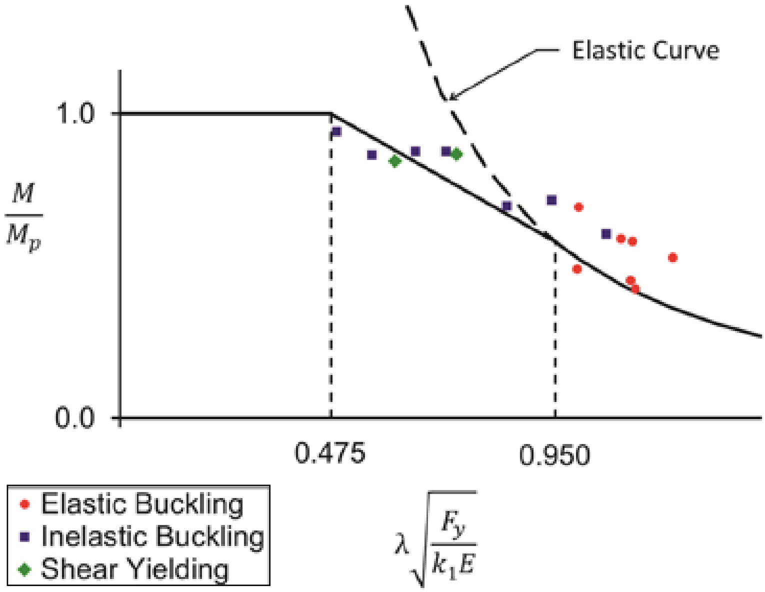


Figure 5. Buckling curve for single-coped beams.

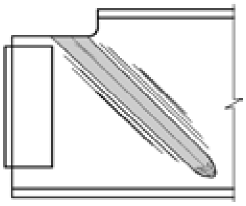


Figure 6. Shear buckling of a single-coped beam.

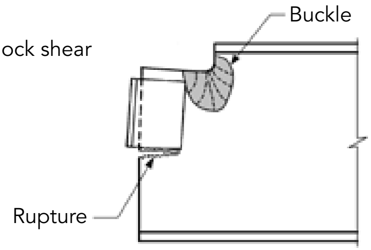


Figure 7. Block shear buckling.

nections, as shown in Figure 7. The failure is characterized by a combination of extensive yielding along the L-shape block shear failure pattern, with potential rupture at the tension plane, and localized buckling at the face of the cope. Based on the experimental results, it is believed that this failure mode can be eliminated by providing a minimum connection element depth of $h_0/2$, where h_0 is the depth of the coped section.

For further information on the background of the revised design guidelines for single-coped beams in the 15th Edition *Manual*, keep an eye out for the pending *Engineering Journal* article "Strength of Single-Coped Beams" (**www.aisc.org/ej**).

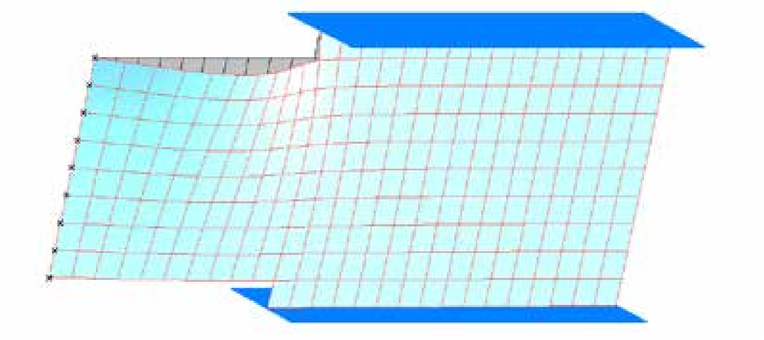
Double-Coped Beams

Figure 8 shows the buckled shape of a double-coped beam web, which is characterized by lateral translation and twisting. Because the behavior is similar to that of a rectangular beam, the design procedure was developed based on a lateral-torsional buckling model with an adjustment factor determined by curve fitting data from the finite element models. The flexural strength is determined in accordance with *Specification* Section F11, with C_b calculated using the equations in *Manual* Part 9. In most cases, the top and bottom cope lengths are equal and *Manual* Equation 9-15 is applicable.

An advantage of the new design procedures in the 15th Edition *Manual* is the ability to calculate the strength where different cope lengths are required at the top and bottom flanges (Figure 9). When the bottom cope is equal to or longer than the top cope length, the bottom cope size has a negligible effect on the cope strength and *Manual* Equation 9-15 is valid. When the top cope is longer than the bottom cope, C_b is calculated with *Manual* Equation 9-16.

In most cases, the shear strength of double-coped beams can be calculated according to the shear yielding limit state in *Specification* Section J4.2. However, the experimental results showed that beams with slender webs and short copes can fail by shear buckling, where the buckle extends into the beam web at an angle of approximately 45° from vertical, well

Figure 8. Buckled shape of a double-coped beam.



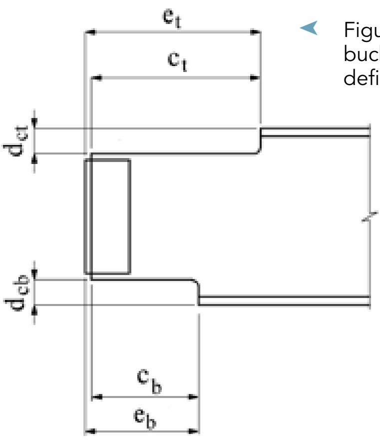


Figure 9. Shear buckling variable definitions.

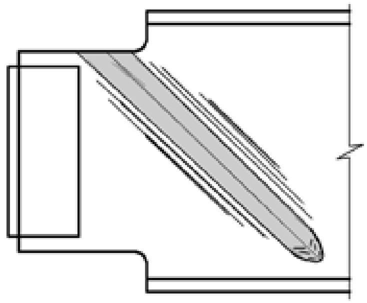
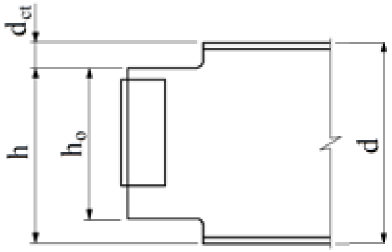


Figure 10. Shear buckling of a double-coped beam.

Figure 11. Shear buckling variable definitions.



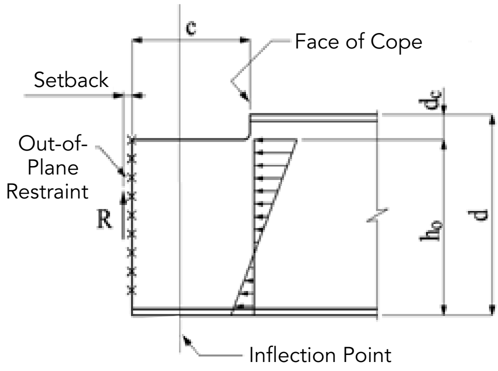
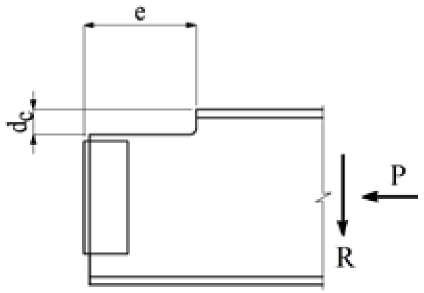


Figure 12. Inflection point location.

Figure 13. Axially loaded beam.



beyond the face of the cope (Figure 10). In this case, the shear strength can be calculated according to *Specification* Section G3, with $k_v = 3.2$, $\phi = 1.00$ and $A_w = h_o t_w$, where t_w is the web thickness. As shown in Figure 11, $h = d - d_{ct}$, where d is the beam depth and d_{ct} is the depth of the top cope.

For further information on the background of the revised design guidelines for single-coped beams in the 15th Edition *Manual*, see “Local Stability of Double-Coped Beams” in the First Quarter 2014 *Engineering Journal* (**www.aisc.org/ej**).

Inflection Point Location

For both single- and double-coped beams, the available flexural strength, M_c, must be equal to or greater than the required flexural strength, M_r. The required flexural strength is the maximum moment within the cope, $M_r = R_r e$, where R_r is the required beam end reaction. In Part 9 of the *Manual*, *e* is defined as the “distance from the face of the supporting member to the face of the cope, unless a lower value can be justified.” For idealized connections, *e* is the distance from the face of the supporting element to the face of the cope as shown in Figure 4. However, the rotational rigidity of real connections tends to move the inflection point toward the beam midspan as shown in Figure 12, reducing the moment at the face of the cope.

Due to difficulties in accurately predicting the inflection point location, standard design practice is to define *e* as shown in Figure 4, neglecting the influence of any connection rotational restraint. In some cases, it may seem appropriate to define *e* as the distance from the inflection point to the face of the cope. However, the design equations include the effects of shear stress and moment gradient over the cope length. Therefore, these effects must be considered before using the inflection point to define *e*.

Generally, the influence of the inflection point location increases as the cope slenderness decreases. For design purposes, it is recommended that *e* is defined as shown in Figure 4. The pending “Strength of Single-Coped Beams” article mentioned above will provide design recommendations for reducing *e* under some conditions for single-coped beams.

Axial Loads

As mention previously, copes subjected to shear are modeled as a short beam with a length equal to the cope length. This model is also applicable to copes subjected to axial loads (Figure 13). The axial tension strength of both single- and double-coped beams is calculated according to *Specification* Section J4.1. Similar to the flexural strength calculation, the axial compression strength is based on the expected buckling mode. Because flexural buckling is the controlling limit state for double-coped beams, *Specification* Section J4.4 is applicable.

For single-coped beams, web local buckling is the controlling limit state and the strength can be evaluated according to *Specification* Section E7. However, the cope length is usually less than the local buckling half-wavelength, causing some conservatism when applying the *Specification* equations to common cope geometries. A more accurate design method, based on a modified version of the *Specification* equations, will be discussed in the accompanying NASCC presentation.

The axial and flexural loads must be combined, and in some cases, an additional calculation combining the axial and shear loads may also be required. For both single- and double-coped beams, axial and flexural loads can be combined using linear interaction according to *Specification* Section H2. For coped beams subjected to axial tension, no axial-shear interaction is required. For single-coped beams subjected to axial compression, linear interaction of the axial and shear loads is required. For double-coped beams subjected to axial compression, linear interaction of the axial and shear loads is required only when $C_{v2} < 1.0$ (*Specification* Section G3).

Examples for axially loaded double-coped beams are featured in the Fourth Quarter 2016 *Engineering Journal* article “Stability of Rectangular Connection Elements” (**www.aisc.org/ej**). ■

This article is a preview of Session C4 “New Developments in Connection Design” at NASCC: The Steel Conference, taking place April 11-13 in Baltimore. Learn more about the conference at ***www.aisc.org/nascc****.*