All About Flexure

The 2005 AISC *Specification* combines flexural provisions for all shapes into one chapter.

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This is the third article in a series intended to give you a glimpse of the 2005 AISC *Specification for Structural Steel Buildings* (AISC 360-05) and the 13th edition of the *Manual of Steel Construction*. This is the first article to address any of the technical aspects of the *Specification*. It will discus the unification of ASD and LRFD provisions, provide an outline of the organization of Chapter F*: Design of Members for Flexure*, and look at what it takes to design a beam.

The *Specification* makes design according to ASD and LRFD available to all designers through a single standard. There is no preference for one approach over the other and the resulting designs are safe, practical, economical, and incorporate the latest understanding of the behavior of structural steel buildings.

To accomplish the unification of what many had believed to be two quite different design philosophies, the *Specification* links all strength provisions to the nominal strength of an element and then applies either a safety factor for ASD or a resistance factor for LRFD to determine the available strength. The result of this very simple concept is that there is a direct relationship between the safety factor and the resistance factor for every design consideration. (See box, below, right.)

For design to resist bending, Chapter F will appear to be much longer than the flexure chapters in any previous specification. That is because this specification incorporates all flexure provisions in this one chapter. That means that in addition to treating wide-flange beams, Chapter F also treats non-symmetric I-shapes, single angles, and HSS. And, unlike past specifications, there is no need to consult an appendix or a completely different specification for design of these members.

The chapter organizes its provisions so that the most often used come first. A recent informal poll of designers indicated that 90 – 95% of their beam designs were for compact wide-flange members. Thus, for this 95% of beam design, there will be no need to go further into Chapter F than Section F2: *Doubly-Symmetric Compact I-Shaped Members and Channels Bent About Their Major Axis*.

The most advantageous situation for a compact wide-flange bending member exists when there is sufficient lateral support so that the full strength of the cross-section may be used. For this situation, the strength of the member is controlled by yielding of the entire cross-section. The nominal bending strength is given as the plastic moment strength. Thus,

$$M_n = M_p = F_y Z_x$$

where Z_x is the Plastic Section Modulus (which can be found in the shape properties table of the *Manual*), F_y is the yield

Chapter F Reorganized

Chapter F applies to members subject to simple bending about one principal axis. For simple bending, the member is loaded in a plane parallel to a principal axis that passes through the shear center or is restrained against twisting at load points and supports. The chapter sections are as follows:

- **F1.** General Provisions
- **F2.** Doubly-Symmetric Compact I-Shaped Members and Channels Bent About their Major Axis
- **F3.** Doubly-Symmetric I-Shaped Members with Compact Webs and Noncompact or Slender Flanges Bent About their Major Axis
- **F4.** Other I-Shaped Members with Compact or Noncompact Webs Bent About their Major Axis
- **F5.** Doubly-Symmetric and Singly-Symmetric I-shaped Members with Slender Webs Bent About their Major Axis
- **F6.** I-Shaped Members and Channels Bent About their Minor Axis
- **F7.** Square and Rectangular HSS and Box-Shaped Members
- **F8.** Round HSS
- **F9.** Tees and Double Angles Loaded in the Plane of Symmetry
- **F10.** Single Angles
- **F11.** Rectangular Bars and Rounds
- **F12.** Unsymmetrical Shapes
- **F13.** Proportions of Beams and Girders

Different...But the Same!

Design in the 2005 *Specification* recognizes that the controlling modes of failure are the same for structures designed by ASD and LRFD. Thus, the same nominal strength forms the foundation of both. When considering available strength, the only difference between the two methods is the resistance factor in LRFD, ϕ, and the safety factor in ASD, Ω.

Historically, LRFD has been calibrated to ASD at a live load to dead load ratio of three. Thus, by equating the designs for the two methods at this ratio, the relationship between ϕ and Ω can be determined. Using the live load plus dead load combinations from the IBC or ASCE 7, and taking $L = 3D$, yields:

For LRFD:

$$\phi R_n = 1.2D + 1.6L = 1.2D + 1.6 \times 3D = 6D$$

$$R_n = \frac{6D}{\phi}$$

For ASD:

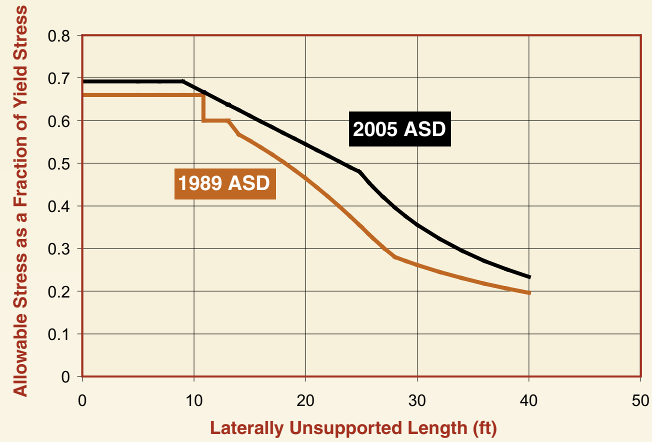
$$\frac{R_n}{\Omega} = D + L = D + 3D = 4D$$

$$R_n = \frac{4D}{\Omega}$$

Equating R_n from the LRFD and ASD formulations and solving for Ω yields:

$$\Omega = \frac{6D}{\phi} \times \frac{1}{4D} = \frac{1.5}{\phi}$$

This approach was used to obtain the majority of values of Ω throughout the *Specification*.



Comparison between the allowable stresses from the 1989 *ASD Specification* and the 2005 ASD provisions for a W36×182.

stress of the steel, and the resistance factor and safety factor are, respectively,

$$\phi_b = 0.90 \text{ (LRFD)} \qquad \Omega_b = 1.67 \text{ (ASD)}$$

Based on these provisions, for ASD the allowable moment is

$$M_a = 0.6F_yZ_x$$

and for LRFD, the design moment is

$$M_u = 0.9F_yZ_x$$

If the plastic section modulus is conservatively taken as 1.1 times the elastic section modulus, as it has been in all previous ASD specifications that recognized compact shapes, the allowable bending moment becomes $M_a = 0.66F_yS_x$. Thus, the 2005 ASD provisions are the same as the previous ASD provisions for the limit state of yielding. The new *Specification*, however, permits the designer to take advantage of the true ratio of plastic to elastic section modulus, which has a minimum value of 1.10 and a maximum value of 1.31. (See box, below.) Thus, the allowable bending stress for a specific W-shape could be as much as $0.79F_y$ and will not be less than $0.66F_y$. For LRFD, the 1999 and 2005 provisions for the limit state of yielding are identical.

Bending Stress Bonus

In order to make a simple comparison between the 2005 ASD provisions and the previous ASD provisions for bending of laterally braced compact shapes, the nominal moment strength is divided by the safety factor and multiplied by S_x/S_x. This results in

$$M_a = \frac{M_n}{\Omega_b} = \frac{F_y}{\Omega_b}\frac{Z_x}{S_x}S_x$$

Combining the terms that pre-multiply the section modulus and calling that the allowable stress yields

$$F_b = \frac{F_y}{\Omega_b}\frac{Z_x}{S_x} = 0.6F_y\left(\frac{Z_x}{S_x}\right)$$

A review of the wide flange shapes in the *Manual* indicates that the ratio of plastic section modulus to elastic section modulus ranges from a low of 1.1 to a high of 1.31. It is conservative to use the lowest value of 1.1.

When the unbraced length of the compression flange is a factor in beam design, the design process becomes a bit more complex, whether using ASD 1989 or LRFD 1999. Previous ASD design divided the unbraced length provisions into three distinct segments. One segment was for beams that were considered to have full lateral support, one for beams with an intermediate unbraced length, and the last region for beams with significant unbraced length. In the first two regions, the allowable stress was $0.66F_y$ and $0.6F_y$ respectively. In the third region, three equations were given and the largest allowable stress obtained through those three equations was selected.

The simplifications of the 2005 *Specification* mean that bending strength, considering unbraced length, never requires calculations from more than a single equation. For beams with an intermediate unbraced length, the strength is given by a linear equation that interpolates between two easily defined end points. For beams with a significant unbraced length, an elastic buckling equation is used.

A comparison between the allowable stresses from the 1989 *ASD Specification* and the 2005 ASD provisions for a W36×182 is shown in the figure. The nominal strength equations are recast into allowable stress equations by dividing by the safety factor, $\Omega_b = 1.67$ and the elastic section modulus, S_x. The comparison results in the five equations from the 1989 *ASD Specification* being replaced by three equations from the 2005 *Specification*. It can be seen in the figure that the allowable stresses in all cases for this beam are greater using the 2005 *Specification* than they would be using the 1989 *ASD Specification*. The 1999 and 2005 LRFD provisions are very close except that the actual equation for elastic buckling has been somewhat modified. ★

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