# Don't Stress Out

Allowable stress equations can be readily obtained in the 2005 specification with minor modifications to the strength equations.

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he 2005 AISC Specification for Structural Steel Buildings provides a basis for design according to the same provisions for both load and resistance factor design (LRFD) and allowable strength design (ASD). If LRFD load combinations are used, the required strength determined from them must be less than the design strength of the component being designed. If ASD load combinations are used, the required strength determined from them must be less than the allowable strength of the component being designed. These terms are defined as follows:

- → Required Strength. Forces, stresses, and deformations produced in a structural component, determined by structural analysis, for the LRFD or ASD load combinations.
- → **Design Strength.** The calculated strength of the component for LRFD design, equal to the resistance factor multiplied by the nominal strength,  $\phi R_n$ .
- → Allowable Strength. The calculated strength of the component for ASD design, equal to the nominal strength divided by the safety factor,  $R_n/\Omega$ .
- Allowable Stress. Allowable strength divided by the appropriate section property, such as section modulus or area.
- Design Stress. Design strength divided by the appropriate section property, such as section modulus or cross section area.
- $\Rightarrow \phi = resistance factor$
- $\rightarrow \Omega$  = safety factor

The term nominal strength represents the strength of a component without the resistance factor (LRFD) or safety factor (ASD) applied. Designers often think of the nominal strength of a component as the ultimate strength. This quantity is useful only in the subsequent determination of the design strength (for LRFD) or allowable strength (for ASD). The *Specification* gives the provisions for the determination of the nominal strength for each member type, connection, or other component for each applicable limit state. For each provision, the *Specification* also indicates the resistance factor,  $\phi$ , and the safety factor,  $\Omega$ , to be used.

The long-time user of allowable stress design will quickly realize that the *Specification* defines ASD as allowable strength design, not allowable stress design. However, with only minor modifications to the *Specification* strength equations, stress equations can be readily obtained. In fact, many of the *Specification* provisions include stress terms which are then multiplied by the appropriate section property to obtain nominal strengths. Thus, these stresses are easily identified.

An allowable stress design format for the 2005 AISC specification is available for designers who wish to use it. In some cases, approximations are used for simplicity. Only those sections that apply to W-shapes are presented because they are the most frequently used.

#### **Allowable Stresses**

When the Specification provides a critical stress value, as is the case for compression, the allowable stress is obtained by dividing the critical stress by the safety factor,  $\Omega$ , so that  $F_a = F_{cr}/\Omega$ . In cases where the nominal strength is provided in the Specification, the strength equation must be divided by the section property to obtain a nominal stress, and then the nominal stress is divided by the safety factor to obtain an allowable stress. The section properties used throughout the Specification are either area or section modulus (plastic or elastic). When area is being considered, it is a simple matter to determine stress. When plastic section modulus is needed, some additional choices must be considered.

## **Design of Members for Tension**

Two limit states should be checked in tension member design—yielding and rupture. The nominal strength for the limit state of yielding is given as  $P_n = F_y A_g$  and the safety factor is  $\Omega = 1.67$ . Thus, the allowable stress for yielding in the gross section is  $F_t = 0.6F_y$ .

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For the limit state of rupture,  $P_n = F_u A_e$ and the safety factor is  $\Omega = 2.00$ . Thus, the allowable stress for rupture in the effective net section is  $F_t = 0.5F_y$ .

It will be noted that these allowable stresses are the same as the allowable stresses contained in the 1989 AISC ASD specification.

### **Design of Members for Compression**

All of the buckling equations in Chapter E are presented in terms of critical stress,  $F_{cr}$ . The factor of safety for all compression members in Chapter E is  $\Omega$  = 1.67. Thus, to obtain allowable stresses,  $F_a = F_{cr}/1.67 = 0.6F_{cr}$ . Figure 1 shows the allowable stresses for compression as a function of slenderness ratio for ASTM A992 steel.

#### **Design of Members for Flexure**

Section F2 addresses doubly symmetric compact I-shaped members and channels bent about their major axes. Designers use this section most because it applies to W-shapes. The *Specification* user note in Section F2 points out that there are only seven rolled shapes that are not compact. If these sections are avoided by the designer, the provisions of Section F2 can be used without ever referring to the local buckling provisions in the *Specification*. To obtain allowable stresses, the provisions of Section F2 can be adjusted.

For the limit state of yielding of the cross section in bending about the strong axis, the *Specification* gives the nominal moment as  $M_n = M_p = F_y Z_x$  and the safety factor as  $\Omega = 1.67$ . The allowable stress





Slenderness Ratio, KL/r



can be determined by dividing the yield stress by the safety factor so that  $F_a = F_y/1.67 = 0.6F_y$ . It must be noted that this allowable stress is to be multiplied by the plastic section modulus,  $Z_x$ , not the elastic modulus,  $S_x$ . If the designer wishes to use the elastic section modulus, an additional correction must be made.

This modification requires that the nominal moment relation be multiplied by  $S_x/S_x$ , which yields

$$M_p = F_y Z_x \left(\frac{S_x}{S_x}\right) = F_y S_x \left(\frac{Z_x}{S_x}\right)$$

A review of all ASTM A6 W-shapes shows that the minimum value for the ratio of plastic to elastic section modulus is 1.1 and the maximum is 1.3. If the minimum value is selected, the allowable stress, which will be multiplied by the elastic section modulus, becomes

$$F_a = F_y \left(\frac{1.1}{1.67}\right) = 0.66 F_y$$

Figure 2 shows the allowable stress for the limit state of lateral torsional buckling of the compression flange of a W-shape beam bending about its strong axis. Note that for the linear variation of stress in the inelastic LTB region, the equation is that for straight-line interpolation from  $0.66F_y$  at  $L_p$  to  $0.42F_y$  at  $L_r$ . In the elastic buckling region, the allowable stress is  $0.6F_{cr}$ .

### **Design of Members for Shear**

The nominal shear strength for a Wshape meeting the web slenderness limits provided is given by  $V_n = 0.6F_yA_wC_v$ . For these members  $C_v = 1.0$  and the safety factor,  $\Omega = 1.50$ . By dividing  $V_n$  by  $A_w$  and substituting for  $C_v$ , the nominal shear stress is  $F_n = 0.6F_y$ . Dividing by  $\Omega$ , the allowable shear stress is then  $F_v = 0.4F_y$ . Users of ASD will note that this is the same allowable shear stress as found in the 1989 ASD specification.

## Design of Members for Combined Forces and Torsion

The interaction equations in the *Specification* are given in terms of strength but can be just as easily written in terms of stress since the section property will appear in both the numerator and the denominator. **★** 

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