Steel Beam Design

An Online Continuing Education Course for Engineers

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Steel Beam Design by
ASD / LRFD Steel Construction Manual
13th Edition

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Beams are flexural members that are subjected to shear and bending moments. The shear and moment vary with position along the beam. A beam's primary function is resisting bending moments. Beams usually have uniform loads, concentrated loads or both on them. We will be looking at W shaped members. *LRFD* stands for Load and Resistance Factor Design and was in three previous editions of the specifications. *ASD* stands for Allowable Strength Design which is similar to Allowable Stress Design that many engineers are familiar with.

Types of loads

D = dead load
D_i = weight of ice
E = earthquake load
F = load due to fluids with well-defined pressures and maximum heights
F_a = flood load
H = load due to lateral earth pressure, ground water pressure, or pressure of bulk materials
L = live load
L_r = roof live load
R = rain load
S = snow load
T = self-straining force
W = wind load

LRFD Load Combinations (ASCE 7-05)

1. $1.4(D + F)$
2. $1.2(D + F + T) + 1.6(L + H) + 0.5(L_r \text{ or } S \text{ or } R)$
3. $1.2D + 1.6(L_r \text{ or } S \text{ or } R) + (L \text{ or } 0.8W)$
4. $1.2D + 1.6W + L + 0.5(L_r \text{ or } S \text{ or } R)$
5. $1.2D + 1.0E + L + 0.2S$
6. $0.9D + 1.6W + 1.6H$
7. $0.9D + 1.0E + 1.6H$

ASD Load Combinations (ASCE 7-05)

1. $D + F$
2. $D + H + F + L + T$
3. $D + H + F + (L_r \text{ or } S \text{ or } R)$
4. $D + H + F + 0.75(L + T) + 0.75(L_r \text{ or } S \text{ or } R)$
5. $D + H + F + (W \text{ or } 0.7E)$
6. $D + H + F + 0.75(W \text{ or } 0.7E) + 0.75L + 0.75(L_r \text{ or } S \text{ or } R)$
7. $0.6D + W + H$
8. $0.6D + 0.7E + H$

We will analyze first and design later.

Let's say we have a 26 foot long beam that is simply supported at each end. It supports a live load equal to 0.60 k/ft and a dead load of 0.83 k/ft, including the weight of the beam.

LRFD

$$w_u = 1.2D + 1.6L = (1.2 \times 0.83k/ft) + (1.6 \times 0.60k/ft) = 1.96k/ft$$

$$V_u = \frac{w_u L}{2} = \frac{1.96k/ft \times 26\ ft}{2} = 25.43k$$

$$M_u = \frac{w_u L^2}{8} = \frac{1.96k/ft \times (26\ ft)^2}{8} = 165.3kip - ft$$

ASD

$$w_a = D + L = 0.83k/ft + 0.60k/ft = 1.43k/ft$$

$$V_a = \frac{w_a L}{2} = \frac{1.43k/ft \times 26\ ft}{2} = 18.59k$$

$$M_a = \frac{w_a L^2}{8} = \frac{1.43k/ft \times (26\ ft)^2}{8} = 120.8 kip-ft$$

Load and Resistance Factor Design (LRFD)

$$R_u \le \phi R_n$$

where

R_u = required strength (LRFD)
R_n = *nominal strength*, specified in Chapters B through K
ϕ = *resistance factor*, specified in Chapters B through K
ϕR_n = design strength

Also $M_u \le \phi M_n$ and $V_u \le \phi V_n$

Chapter F is *Design of Members for Flexure*

Allowable Strength Design (ASD)

$$R_a \le R_n / \Omega$$

where

R_a = required strength (ASD)
R_n = *nominal strength*, specified in Chapters B through K
Ω = safety factor, specified in Chapters B through K
R_n/Ω = allowable strength

Also $M_a \le \frac{M_n}{\Omega}$ and $V_a \le \frac{V_n}{\Omega}$

$\phi_b = 0.90$ (LRFD) $\Omega_b = 1.67$ (ASD)

Limit States

We will look at six limit states. The first five are strength limit states and the last is a serviceability limit state.

- **Yielding** has to do with the strength of the beam to resist bending moments without failure. Yielding depends on the loads, supports, span and the strength of the steel.
- **Lateral-Torsional Buckling** has to do with the twisting of the beam in a lateral direction. If the beam is adequately braced, it will not twist into failure.
- **Web Local Buckling** has to do with the strength of the web to resist failure. This means the width to thickness ratio must fall between certain limits so the web will not collapse or fail.
- **Flange Local Buckling** has to do with strength of the flange to resist failure. This means the width to thickness ratio must fall between certain limits so the flange will not collapse or fail.
- **Shear** has to do with shear failure of the beam. Chapter G covers *Design of Members for Shear*.
- **Deflection** is a serviceability limit state. This has to do with the beam deflecting too noticeable to people or so people feel uncomfortable.

The *nominal flexural strength*, M_n, shall be the lower value obtained according to the *limit states* of *yielding* (*plastic moment*) and *lateral-torsional buckling*.

Yielding

$$M_n = M_p = F_y Z_x \quad \text{(F2-1)}$$

where

F_y = *specified minimum yield stress* of the type of steel being used, ksi (MPa)
Z_x = plastic section modulus about the x-axis, in.^{3} (mm^3)

If the un-braced length, (L_b) <=L_p use equation F2-1.

Lateral-Torsional Buckling

When $L_p < L_b \leq L_r$

$$M_n = C_b \left[M_p - (M_p - 0.7 F_y S_x) \left(\frac{L_b - L_p}{L_r - L_p} \right) \right] \leq M_p \quad \text{(F2-2)}$$

C_b can be conservatively equal to 1.0
S_x comes from the shapes table
L_p and L_r can be found in Table 3-2 for W shapes in the AISC Manual or you can calculate them from the following equations.

$$L_p = 1.76 r_y \sqrt{\frac{E}{F_y}} \qquad \text{(F2-5)}$$

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