Today’s Focus on Steel Beams

- Overview of design tables
- Discussion of what is considered important in determining the capacity of the typical steel beam
- Use of design tables for member selection for adequately braced beams

Recall the shape factor

\[
\text{Shape Factor } sF = \frac{Z_x}{S_x}
\]

\[
Z_x = \frac{M_p}{F_y} = S_x \times sF
\]
Recall plastic behavior

\[ \sigma_p = \frac{M_p}{Z_p} = \frac{M_p}{Z_x} \]

where the "x" means for bending about the X-X axis as shown in the W tables.

A beam's view…

FIGURE 8.2
A plastic hinge.
With steel, we worry about proper lateral support

Limit State Discussion

- With steel beams we are concerned about a mode of failure called lateral-torsional buckling of the compression flange.
- What does this mean?
  - Usually the beam is loaded so that the top half is in compression.
  - The top part of the top half is the flange.
  - When the beam is loaded and not adequately supported out-of-plane, the flange can “twist” into a shape called lateral-torsional buckling.
Lateral-Torsional Buckling Diagram:
See movie on the course website

Yielding Behavior- Zone 1

The unbraced length \( L_b \) may not exceed the value \( L_p \) given by

\[
L_p = 1.76 r_y \sqrt{\frac{E}{F_{yf}}}
\]

\( r_y \) = radius of gyration

\( F_{yf} \) = specified minimum yield stress of flange, ksi

Yielding behavior: Full plastic moment, Zone 1.

The design flexural strength for plastic analysis is

\[
\phi_b M_n = \phi_b M_p
\]

where

\( \phi_b = 0.90 \)

\[
M_p = \frac{Z_x F_y}{12} \text{ [units of ft-kips]}
\]
In this class

• We will start with situations where we are given that the unbraced length is zero, that is, the compression flange is fully supported.
• We investigate these designs first.
• Then we look at the design tools available for finding moment capacities for other unbraced length conditions.

Example

• Select a beam section for the span and loading shown in the figure, assuming full lateral support is provided for the compression flange by the floor slab above (that is, $L_b=0$) and $F_y=50$ ksi. $w_D=1$ k/ft and $w_L=3$k/ft; the span length is 21 ft.
Solution

1. Find maximum moment induced by elastic analysis. 
Load factors for steel: 1.2*D; 1.6*L:

\[ w = 1.2w_0 + 1.6w_3 = 1.2(1.0k/ft) + 1.6(3.0k/ft) = 6k/ft \]

\[ wL = \left( \frac{6k}{ft} \right) \left( 21ft \right)^2 = 330.8ft-kips \]

2. Solve for plastic modulus, Z, required:

\[ Z_{x, \text{required}} \geq \frac{M_u}{0.9F_y} = \frac{12\text{ in/ft}(330.8\text{ ft-kips})}{0.9(50\text{ ksi})} = 88.2\text{ in}^3 \]

3. Select a trial member:
Go to the Load Factor Design Selection Table Z_x in the design tables [after the beam diagrams].
Go down column 6 "Z_x" until you find a value greater than or equal to 88.2 in^3:

\[ Z_x = 95.4 \text{ in}^3 \text{ for the "Shape" in column 7:} \]
\[ W21 \times 44 \]

4. Add effect of weight on the maximum moment:

\[ w = 1.2(1 + 0.044) + 1.6(3) = 6.05k/ft \]

\[ M_u = \frac{6.05(21)^2}{8} = 333.5\text{ ft-k} \]

5. Recheck section:

\[ Z_x \geq \frac{12\text{ in/ft}(333.5\text{ ft-k})}{0.9(50\text{ ksi})} = 88.9\text{ in}^3 \]

\[ \therefore \text{ use } W21 \times 44; F_y = 50\text{ ksi} \]
For more complex situations

- “Zone 2”
- Bending coefficients $C_b$ are used.
- Single or double curvature becomes important.
- $C_b$ is determined from the AISC LRFD equation in which $M_{\text{max}}$ is the largest moment in the unbraced segment of the beam, while $M_A, M_B$ and $M_C$ are the moments at the 1/4 point, 1/2 point and 3/4 point in the segment, respectively.

\[
C_b = \frac{12.5M_{\text{max}}}{2.5M_{\text{max}} + 3M_A + 4M_B + 3M_C} \quad \text{(LRFD Equation F1-3)}
\]
FIGURE 9.7

(a) Single curvature

(b) Double curvature

FIGURE 9.9

Sample $C_s$ values. (The X marks represent points of lateral bracing.)
$C_b = 1.67$ for this beam
$L_b = 17$ ft

In your handout for these cases...
Shear Design

- Shear affects the web and flanges differently.
- It is a more complex consideration than for other beam types.

[Diagrams of beam cross-sections showing:
(a) Local flange bending
(b) Local web yielding (sinks down and “pooches” out)
(c) Web crippling
(d) Sidesway web buckling]
References

• *AISC Manual for Structural Steel Design*.  
• McCormac and Nelson, *Structural Steel Design: LRFD*.  