Composite Sections and Steel Beam Design

- Steel Beam Selection - ASD
- Composite Sections
- Analysis Method
Steel W-sections for beams and columns

Standard section shapes:
W – wide flange
S – american standard beam
C – american standard channel
L – angle
WT or ST – structural T
Pipe
Structural Tubing

Source: University of Michigan, Department of Architecture
Steel W-sections for beams and columns

Columns:
Closer to square
Thicker web & flange

Beams:
Deeper sections
Flange thicker than web
Steel W-sections for beams and columns

Columns:
- Closer to square
- Thicker web & flange

Beams:
- Deeper sections
- Flange thicker than web

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Steel Beams by ASD

Yield Stress Values
- A36 Carbon Steel $ F_y = 36 \text{ ksi} $
- A992 High Strength $ F_y = 50 \text{ ksi} $

Allowable Flexure Stress
- $ F_b = 0.66 F_y $ $ = L_c $  
  - Compact Section
  - Braced against LTB $( l < L_c )$
- $ F_b = 0.60 F_y $ $ = L_u $  
  - Compact or Not
  - $ L_c < l < L_u $
- $ F_b < 0.60 F_y $  
  - Compact or Not
  - LTB failure mode $( l > L_u )$

Allowable Shear Stress
- $ F_v = 0.40 F_y $  
  - $ f_v = V / (t_w d) $
Section Modulus Table

- Calculate Required Moment
- Assume Allowable Stress
  - $F_b = 0.66F_y = 24$ ksi (A36)
  - $F_b = 0.60F_y = 21.6$ ksi (A36)
- Using the flexure equation,
  - set $fb = F_b$ and solve for $S$

$$f_b = \frac{Mc}{I} = \frac{M}{S} = F_b$$

$$S = \frac{M}{F_b}$$

- Choose a section based on $S$
  from the table (D-35 and D-36)
  - Bold faced sections are lighter
  - $F'\gamma$ is the stress up to which the section is compact ($\bullet \bullet$ is ok for all grades of $F_y$)

<table>
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<th>$S_x$ in. $^2$</th>
<th>Shape</th>
<th>$F'\gamma$ ksi</th>
<th>$S_x$ in. $^2$</th>
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*Source: Structural Principles, I. Engel 1984*
Example – Load Analysis of Steel Beam

1. Find the Section Modulus for the given section from the tables (D-35 and D-36).
2. Determine the maximum moment equation.

Given:
\[ f_b = 24 \, \text{ksi} \]
\[ W = 30 \times 116 \]

\[ \frac{W}{2}l = 64 \] in

For \( W = 30 \times 116 \), from table D-35 we get,

\[ S_x = 329 \, \text{in}^3 \]

For a simply supported, uniformly loaded beam,

\[ \text{Maximum Moment} \quad M = \frac{Wl}{8} \]

Source: University of Michigan, Department of Architecture
3. Using the flexure equation, \( fb = F_b \), solve for the moment, \( M \).

5. Using the maximum moment equation, solve for the distributed loading, \( w \).

\[
\frac{fb}{E} = \frac{M}{I} = \frac{M}{\frac{5a}{12}} = F_b
\]

\[
M = 5a \times F_b
\]

\[
M = 329 \text{ in}^3 \times 24 \text{ (k/lin)}
\]

\[
M = 7896 \text{ k-in} = \frac{7896}{12}
\]

\[
M = 658 \text{ k-in}
\]

\[
M = \frac{Wl^2}{8}
\]

\[
W = \frac{M \times 8}{l}
\]

\[
W = 658 \text{ k-in} \times 8
\]

\[
W = 8225 \text{ k}
\]

\[
w = 1.28 \text{ KLF}
\]

Source: University of Michigan, Department of Architecture
1. Use the maximum moment equation, and solve for the moment, $M$.

2. Use the flexure equation to solve for $S_x$.

\[ M = \frac{Wl^2}{8} \]

\[ M = \frac{(1.25 \text{ kip} \cdot \text{ft})(32 \text{ ft})^2}{8} \]

\[ M = 160 \text{ kip} \cdot \text{ft} \]

\[ \frac{f_b}{f_y} = \frac{M}{S} \]

\[ S = \frac{M}{f_b} = \frac{160 \text{ kip} \cdot \text{ft}}{30 \text{ ksi}} \]

\[ S = 64 \text{ in}^3 \]
Design of Steel Beam

Example

3. Choose a section based on $S_x$ from the table (D35 and D36).

4. Most economical section is: W16 x 40
   $S_x = 64.7 \text{ in}^3$

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Sections shown in **bold face** are "Weight Economy Sections."

**Theoretical maximum yield stress exceeds 60 ksi.

Source: I. Engel, Structural Principles, 1984
Design of Steel Beam

Example

5. Add member self load to M and recheck Fb (we skip this step here)

7. Check shear stress:

Allowable Stress

\[ F_v = 0.40 \times (50 \text{ ksi}) \]

\[ F_v = 20 \text{ ksi} \]

Actual Stress

\[ V = \frac{wL}{2} = \frac{1.25 \text{k} \times 32'}{2} \]

\[ V = 20 \text{k} \]

\[ f_v = \frac{V}{t_w d} \]

\[ f_v = \frac{20}{0.305 \times 16.01} = 4.09 \text{ ksi} \]

\[ 4.09 < 20 \text{ OK} \]
Design of Steel Beam

Example

6. Check Deflections
   calculate actual deflection
   compare to code limits
   if the actual deflection exceeds the code limit
   a stiffer section is needed

\[ \Delta e = \frac{5wL^4}{384EI} \]
\[ = \frac{5(1.25 \text{kips})(32')^4(1728)}{384(29000 \text{kips})(518 \text{in}^3)} \]
\[ = 1.96'' \]

\[ \frac{L}{240} = \frac{32'(12)}{240} = 1.6'' \]

\[ \frac{L}{120} = \frac{32'(12)}{120} = 3.2'' \]

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<td>Greenhouses</td>
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<td>L/120</td>
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Source: Standard Building Code, 1991
Composite Design

Steel W section with concrete slab “attached” by shear studs.

The slab acts as a wider and thicker compression flange.
Effective Flange Width

**Slab on both sides:**
(Least of the three)
- Total width: \( \frac{1}{4} \) of the beam span
- Overhang: \( 8 \times \) slab thickness
- Overhang: \( \frac{1}{2} \) the clear distance to next beam (i.e. the web on center spacing)

**Slab on one side:**
(Least of the three)
- Total width: \( \frac{1}{12} \) of the beam span
- Overhang: \( 6 \times \) slab thickness
- Overhang: \( \frac{1}{2} \) the clear distance to next beam

Source: University of Michigan, Department of Architecture
Analysis Procedure

1. Define effective flange width
2. Calculate \( n = \frac{E_c}{E_s} \)
3. Transform Concrete width = \( n b_c \)
4. Calculate Transformed \( I_{tr} \)
   \textit{do NOT include concrete in tension}

5. If load is known, calculate stress
   
   \[ f_{steel} = \frac{Mc}{I_{tr}} \]
   \[ f_{conc} = \frac{Mc \cdot n}{I_{tr}} \]

6. If finding maximum load use allowable stresses. The lesser \( M \) will determine which material controls the section.

   \[ M_s = \frac{F_{steel} I_{tr}}{c} \]
   \[ M_c = \frac{F_{conc} I_{tr}}{c \cdot n} \]
Given:
- \( DL_{slab} = 62.5 \text{ psf} \)
- \( DL_{beam} = 135 \text{ plf} \)
- \( n = 1/9 \)
- \( f_{\text{steel}} = 24 \text{ ksi} \) (\( F_y = 36 \) )
- \( f_{\text{conc}} = 1.35 \text{ ksi} \)

For this example the floor capacity is found for two different floor systems:

1. Find capacity of steel section independent from slab
2. Find capacity of steel and slab as a composite
Part 1 Non-composite Analysis

- Find section modulus, $S_x$ in chart.
- Assume an allowable stress, $F_b$.
- Determine the total moment capacity of the section, $M$.
- Subtract the DL moment to find the remaining LL moment.
- Calculate LL capacity in PSF.

Source: University of Michigan, Department of Architecture
Part 2 - Composite Analysis

1. Determine effective width of slab.
   (using 90”y92”)

2. Find \( n = Ec/Es \) \((1/9)\)

3. Draw transformed section
   (transform the concrete)

4. Calculate Transformed \( I_x \):

   - Locate neutral axis.

Source: University of Michigan, Department of Architecture
4. Calculate Transformed $I_x$:

Use parallel axis theorem.

$$I_a = I_g + A d^2$$
5. Calculate moment capacity for steel and concrete each assuming full allowable stress level.

\[
M_c = \frac{f_c \pi r^2}{c_0} \\
M_c = \frac{1.35 (17001)}{11.47 (1/9)} = \frac{18008.9}{11.47} = 1500.74 \text{k-in} \\
M_s = \frac{f_s I_{tr}}{c} \\
M_s = \frac{24 (17001)}{29.08} = \frac{14081.08}{29.08} = 483.45 \text{k-in} \\
\therefore f_c = \frac{M_c}{I_{tr}} = \frac{(14081.08)(11.47)(1/9)}{17001} \\
\therefore f_c = 1.052 \text{ksi} \\
\]

6. Choose the smaller moment. It will control capacity.
Composite Analysis cont.

7. Subtract the DL moment to find the remaining LL moment.

\[ M_{DL} = M_{T} - M_{DL} \]
\[ M_{LL} = 1169 \text{kip-ft} - 420 \text{kip-ft} = 749 \text{kip-ft} \]

8. Calculate the LL in PSF based on the \( M_{LL} \).

\[ \frac{w_u l^2}{8} = 748 \text{kip-ft} \]
\[ w_u = \frac{(8)(748)}{60^2} = 1.55 \text{kip/ft} \]
\[ P_{PSF} = \frac{1.55 \text{kip/ft} \times 13 \text{ft}}{13} = 1.57 \text{psf} \]

Source: University of Michigan, Department of Architecture