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ARCH 324 - Structures 2, Winter 2009

von Buelow, Peter

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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

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Columns:
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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
- \( F_b = 0.66 F_y \)  \( \bullet \) = \( L_c \)
  - 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
- \( F_v = 0.40 F_y \)
  - \( f_v = V/(t_w d) \)

Source: AISC, Manual of Steel Construction
Section Modulus Table

- Calculate Required Moment
- Assume Allowable Stress
  - \( F_b = 0.66F_y = 24 \text{ ksi (A36)} \)
  - \( F_b = 0.60F_y = 21.6 \text{ ksi (A36)} \)
- 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
  - \( F'\text{y} \) is the stress up to which the section is compact (\( \bullet\bullet \) is ok for all grades of \( F_y \))

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Source: Structural Principles, I. Engel 1984
1. Find the Section Modulus for the given section from the tables (D-35 and D-36).

2. Determine the maximum moment equation.

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**Find Load w in KLF**

\[ \text{GIVEN: } f_b = 24 \text{ ksi} \]
\[ W '30 \times 116' \]
\[ l = 64' \]

For 'W 30 x 116' from table D-35 we get, 
\[ S_x = 329 \text{ in}^3 \]

For a simply supported, uniformly loaded beam, 
\[ \text{maximum moment } M = \frac{wL}{8} \]
3. Using the flexure equation, \( fb = F_b \), solve for the moment, \( M \).

\[
\frac{fb}{M} = \frac{Mc}{E} = \frac{M}{Ea} = F_b
\]

\[
M = 5E x F_b
\]

\[
M = 329 \text{ (in})^3 \times 24 \text{ (k/ln^2)}
\]

\[
M = 7.896 \text{ k-in}^2 = \frac{7.896}{12} \text{ k-in}
\]

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

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

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

\[
W = \frac{658 \text{ k-in} \times 8}{64 \text{ ft}}
\]

\[
W = 8.225 \text{ k}
\]

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

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

4. Most economical section is: W16 x 40
$S_x = 64.7\text{ in}^3$
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
   \[ F_v = 0.40 \times F_y \]
   \[ F_v = 20 \text{ ksi} \]

   Actual Stress
   \[ f_v = \frac{V}{t_w d} \]
   \[ f_v = \frac{20}{(0.305 \times 16.01)} = 4.09 \text{ ksi} \]

   \[ 4.09 < 20 \text{ \oka } \]
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

\[ \Delta e = \frac{5wL^4}{384EI} \]
\[ = \frac{5(1.25 \text{ ksi})(32')^4(1728)}{384 (29,000 \text{ ksi})(518 \text{ in}^4)} \]
\[ = 1.96'' \]

\[ \frac{L}{240} = \frac{32'(12)}{240} = 1.6'' \]
\[ \frac{L}{120} = \frac{32'(12)}{120} = 3.2'' \]

<table>
<thead>
<tr>
<th>Construction</th>
<th>LL</th>
<th>DL + LL</th>
</tr>
</thead>
<tbody>
<tr>
<td>Roof member</td>
<td></td>
<td></td>
</tr>
<tr>
<td>supporting plaster, or floor member</td>
<td>L/360</td>
<td>L/240</td>
</tr>
<tr>
<td>Roof members</td>
<td></td>
<td></td>
</tr>
<tr>
<td>supporting nonplastered ceilings</td>
<td>L/240</td>
<td></td>
</tr>
<tr>
<td>Roof members not supporting ceilings</td>
<td>L/180</td>
<td></td>
</tr>
<tr>
<td>Exterior and Interior walls and</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Partitions</td>
<td></td>
<td></td>
</tr>
<tr>
<td>with brittle finishes</td>
<td>L/240</td>
<td></td>
</tr>
<tr>
<td>Exterior and Interior walls and</td>
<td></td>
<td></td>
</tr>
<tr>
<td>partitions with flexible finishes</td>
<td>L/120</td>
<td></td>
</tr>
<tr>
<td>Farm Buildings</td>
<td></td>
<td>L/180</td>
</tr>
<tr>
<td>Greenhouses</td>
<td></td>
<td>L/120</td>
</tr>
</tbody>
</table>

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: ¼ of the beam span
- Overhang: 8 x slab thickness
- Overhang: ½ the clear distance to next beam (i.e. the web on center spacing)

**Slab on one side:**
(Least of the three)
- Total width: 1/12 of the beam span
- Overhang: 6 x slab thickness
- Overhang: ½ the clear distance to next beam
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
   \[ f_{\text{steel}} = \frac{Mc}{I_{tr}} \]
   \[ f_{\text{conc}} = \frac{Mc \cdot n}{I_{tr}} \]
6. If finding maximum load use allowable stresses. The lesser \( M \) will determine which material controls the section.
   \[ M_s = \frac{F_{\text{steel}} I_{tr}}{c} \]
   \[ M_c = \frac{F_{\text{conc}} I_{tr}}{c \cdot n} \]
Non-composite vs. Composite Sections

Given:
- $DL_{slab} = 62.5 \text{ psf}$
- $DL_{beam} = 135 \text{ plf}$
- $n = 1/9$
- $f_{steel} = 24 \text{ ksi} \ (F_y = 36)$
- $f_{concrete} = 1.35 \text{ ksi}$

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.

\[
\begin{align*}
S_x &= 489 \text{in}^3 \\
F_b &= 24 \text{ksi} \ (0.66 \text{Fy}) \\
M &= F_b S = 24 \text{ksi} \times 489 \text{in}^3 = 10336 \text{ k
in} \\
M &= 878 \text{ k\in} \\
M_{ll} &= M_{all} + M_{dl} \\
M_{all} &= \frac{wl^2}{8} = \frac{0.9475 \ (60^2)}{8} = 436.4 \text{ k\in} \\
M_{dl} &= M_{all} - M_{ll} = 878 - 436.4 = 451.6 \text{ k\in} \\
\frac{wul^2}{8} &= 451.6 \text{ k\in} \\
wu &= \frac{(8 \times 451.6)}{60^2} = 1003 \text{ psf} \\
\text{PSF} &= \frac{1003 \text{ psf}}{13} = 77.2 \text{ psf} 
\end{align*}
\]

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

1. Determine effective width of slab. (using 90” y 92”)

2. Find \( n = E_c / E_s \) \((1/9)\)

3. Draw transformed section (transform the concrete)

4. Calculate Transformed \( I_x \):
   - Locate neutral axis.
4. Calculate Transformed $I_x$:
   Use parallel axis theorem.

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

\[ M_c = \frac{f_c I_c}{c} \]
\[ M_c = \frac{135 (17001)}{11.47 (1/4)} = 18008.9 \text{ ksi} = 15007.4 \text{ kip-ft} \]

\[ M_s = \frac{f_s I_s}{c} \]
\[ M_s = \frac{24 (17001)}{29.08} = 11461.88 \text{ kips} = 1169.26 \text{ kip-ft} \]

\[ \frac{M_c}{M_s} = \frac{18008.9}{11461.88} = 1.57 \text{ ksi controls} \]

\[ f_s = 24 \text{ ksi} \]
\[ f_c = \frac{M_0 (1 + \eta)}{I_c (1/4)} \]
\[ f_c = \frac{(11461.88) (11.47)(1/4)}{17001} \]
\[ f_c = 1.052 \text{ ksi} \]

6. Choose the smaller moment. It will control capacity.

Source: University of Michigan, Department of Architecture
7. Subtract the DL moment to find the remaining LL moment.

$$M_{DL} = M_T - M_{DL}$$

$$M_{DL} = 1169 k\cdot ft - 476 k\cdot ft = 743 k\cdot ft$$

Source: University of Michigan, Department of Architecture

8. Calculate the LL in PSF based on the $M_{LL}$.

$$\frac{w_u l^2}{8} = 743 k\cdot ft$$

$$w_u = \frac{(8)(743)}{60^2} = 1.550 k\cdot lb$$

$$PSSF_u = \frac{1.550 \text{ k}\cdot \text{lb}}{13} = 120 \text{ k}\cdot \text{lb}$$

Source: University of Michigan, Department of Architecture