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ARCH 324 - Structures 2, Winter 2009

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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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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
• \( F_b = 0.66 \ F_y \)
  - Compact Section
  \( = L_c \)
  - Braced against LTB \( l < L_c \)
• \( F_b = 0.60 \ F_y \)
  - Compact or Not
  \( = L_u \)
  - \( L_c < l < L_u \)
• \( F_b < 0.60 \ F_y \)
  - 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 \( f_b = F_b \) 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
  - \( F'y \) is the stress up to which the section is compact (\( \cdot \cdot \) is ok for all grades of \( F_y \))
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.

---

Find Load $w$ in KLF

**GIVEN:**
- $f_b = 24$ ksi
- $W = 30 \times 116$
- $l = 64$ ft

**FOR $W = 30 \times 116$ from table D-35 we get,**

$$S_x = 329 \text{ in}^3$$

**For a simply supported, uniformly loaded beam,**

$$M_{\text{max}} = \frac{Wl}{8}$$

---

Source: University of Michigan, Department of Architecture
Example – Load Analysis cont.

W30x116

3. Using the flexure equation, \( fb = F_b \), solve for the moment, \( M \).

\[
\frac{F_b}{5} = \frac{M}{6a} = F_b
\]

\[
M = 5a \times F_b
\]

\[
M = 329 \text{ in}^3 \times 24 \left( \frac{K}{\text{in}} \right) = 7896 \text{ in}^2 \left( \frac{K}{\text{in}} \right)
\]

\[
M = \frac{7896}{12} = 658 \frac{K}{\text{in}}
\]

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

\[
M = \frac{Wl}{8} \quad W = \frac{Mx8}{l}
\]

\[
W = \frac{658 \frac{K}{\text{in}} \times 8}{64} = 8.225 \frac{K}{\text{in}}
\]

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

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

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

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

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

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

\[
S = \frac{M}{f_b} = \frac{160 \text{ kip-ft}}{30 \text{ ksf}}
\]

\[
S = 64 \text{ in}^3
\]

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

Source: University of Michigan, Department of Architecture
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 $S_x = 64.7 \text{ in}^3$
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
   $f_v = \frac{V}{t_w d}$
   $f_v = \frac{20}{(0.305 \times 16.01)} = 4.09 \text{ ksi}$

$f_v \leq F_v$

$4.09 < 20 \checkmark$
6. Check Deflections
   calculate actual deflection
   compare to code limits
   if the actual deflection exceeds the code limit
   a stiffer section is needed

\[ \Delta_d = \frac{5wL^4}{384EI} \]

\[ = \frac{5(1.25 \times 10^5)(32')^4(1728)}{384 (29000 \times 10^6)(518 \times 10^6)} \]

\[ = 1.96'' \]

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

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

### Construction Table

<table>
<thead>
<tr>
<th>Construction</th>
<th>LL</th>
<th>DL + LL</th>
</tr>
</thead>
<tbody>
<tr>
<td>Roof member 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 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 \( I_{tr} \)
   *do NOT include concrete in tension*
5. If load is known, calculate stress
   
   or
6. If finding maximum load use allowable stresses. The lesser \( M \) will determine which material controls the section.

\[
f_{steel} = \frac{M_c}{I_{tr}}
\]

\[
f_{conc} = \frac{M_c \cdot n}{I_{tr}}
\]

\[
M_s = \frac{F_{steel} I_{tr}}{c}
\]

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

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

Source: University of Michigan, Department of Architecture
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.

\[
\begin{align*}
S_x &= 439 \text{in}^3 \\
F_b &= 24 \text{ksi (0.66 kN)} \\
M &= F_S = 24 \text{ksi} \times 439 \text{in}^3 = 10536 \text{ k-in} \\
M &= 878 \text{ k-in} \\
M_{T} &= M_{DA} + M_{u} \\
M_{DA} &= \frac{wL^2}{8} = \frac{0.9475 \times (60^2)}{8} = 426.4 \text{ k-in} \\
M_{u} &= M_{T} - M_{DA} = 878 - 426.4 = 451.6 \text{ k-in} \\
\frac{w_{u}L^2}{8} &= 451.6 \text{ k-in} \\
w_{u} &= \frac{(8 \times 451.6)}{60^2} = 1.008 \text{ k} \\
P_{SF_u} &= \frac{1003 \text{ psf}}{13} = 77.2 \text{ psf}
\end{align*}
\]

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

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

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

3. Draw transformed section
   (transform the concrete)

4. Calculate Transformed \( I_x \):
   - Locate neutral axis.
Composite Analysis  cont.

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.

\[
M_c = \frac{f_c A_c}{c_0}\\
M_c = \frac{1.35 (17001)}{11.47 (1/9)} = 1808.9 \text{ k}-\text{ft} = 1500.7 \text{ k}-\text{in}
\]

\[
M_b = \frac{f_b A_b}{c}\\
M_b = \frac{24 (17001)}{29.08} = 1169.2 \text{ k}-\text{ft} = 1169.2 \text{ k}-\text{in}
\]

\[
\therefore f_c = 24 \text{ ksi}
\]

\[
\therefore f_b = \frac{M_c}{A_b} = \frac{(1808.9)(1/9)}{17001}\\
\therefore f_c = 1.052 \text{ ksi}
\]

6. Choose the smaller moment. It will control capacity.
7. Subtract the DL moment to find the remaining LL moment.

\[ M_{DL} = M_t - M_{DL} \]
\[ M_{LL} = 1169 \text{ k}^3 - 4260 \text{ k}^3 = 743 \text{ k}^3 \]

Source: University of Michigan, Department of Architecture

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

\[ \frac{w_u l^2}{8} = 743 \text{ k}^3 \]
\[ w_u = \frac{(8)(743)}{60^2} = 1650 \text{ k}^3 \]
\[ PSF_u = \frac{1650 \text{ psi}}{18} = 91 \text{ psi} \]

Source: University of Michigan, Department of Architecture