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 W-sections for beams and columns

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Closer to square
Thicker web & flange

Beams:
Deeper sections
Flange thicker than web
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
- \( F_b = 0.60 \ F_y \) \( = L_u \)
  - Compact or Not
  - \( L_c < I < L_u \)
- \( F_b < 0.60 \ F_y \)
  - Compact or Not
  - LTB failure mode \( I > L_u \)

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 (\( * * \) is ok for all grades of \( F_y \))

---

### Section Modulus Table

<table>
<thead>
<tr>
<th>Section</th>
<th>( F_y ) ksi</th>
<th>( S_{xx} ) in.(^2)</th>
<th>Section</th>
<th>( F_y ) ksi</th>
<th>( S_{xx} ) in.(^2)</th>
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<td>19.1</td>
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</table>

**Theoretical maximum yield stress exceeds 60 ksi.**

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.

**Example – Load Analysis of Steel Beam**

Given: \( f_b = 24 \text{ ksi} \)

\( W' = 30 \times 116 \)

\( l = 64' \)

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

\[ S_w = 329 \text{ in}^3 \]

For a simply supported, uniformly loaded beam,

Maximum moment \( M = \frac{Wl}{8} \)

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

W30x116

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

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

\[
\begin{align*}
fb &= \frac{M_c}{I} = \frac{M}{S_a} = F_b \\
M &= S_a \times F_b \\
M &= 329 \text{ in}^3 \times 24 \left( \frac{k}{\text{in}^2} \right) \\
M &= 7896 \frac{k}{\text{in}} = \frac{7896}{12} \\
M &= 658 \frac{k}{\text{in}} \\
M &= \frac{W_2}{8} \quad W = \frac{M \times 8}{L} \\
W &= 658 \frac{k}{\text{in}} \times 8 \\
W &= 8225 \frac{k}{\text{in}} \\
w &= 1.28 \text{ KLF}
\end{align*}
\]

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 $S_x$.

Given: $f_b = 30$ kips

Maximum moment $M = \frac{Wl^2}{8}$

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

$M = 160$ kips-ft

$\frac{f_b}{f_c} = \frac{M}{S}$

$S = \frac{M}{f_b} = \frac{160 \text{ kips-ft} \times 12 \text{ in}}{30 \text{ kips}}$

$S = 64 \text{ in}^3$
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
   \( f_v = \frac{V}{t_w d} \)
   
   \( f_v \leq F_v \)
   \( V = \frac{wL}{2} = \frac{1.25 \text{ klf} \times (32')}{2} \)
   \( V = 20 \text{ k} \)
   
   \( f_v = \frac{V}{t_w d} \)
   \( f_v = \frac{20}{(0.305 \times 16.01)} = 4.09 \text{ ksi} \)
   \( 4.09 < 20 \text{ } \checkmark \text{ OK} \)
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

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

Source: Standard Building Code, 1991

### Construction

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<tr>
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<th>LL</th>
<th>DL + LL</th>
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<td>L/240</td>
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<tr>
<td>supporting plaster, or</td>
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<tr>
<td>floor member</td>
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<td>ceilings</td>
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<td>with flexible finishes</td>
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<td>L/180</td>
</tr>
<tr>
<td>Greenhouses</td>
<td></td>
<td>L/120</td>
</tr>
</tbody>
</table>
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 x 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 x slab thickness
- Overhang: \( \frac{1}{2} \) 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 \( I_{tr} \)
   
   \( \text{do NOT include concrete in tension} \)

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.

\[
\begin{align*}
  f_{steel} &= \frac{M_c}{I_{tr}} \\
  f_{conc} &= \frac{M_c \cdot n}{I_{tr}} \\
  M_s &= \frac{F_{steel} I_{tr}}{c} \\
  M_c &= \frac{F_{conc} I_{tr}}{c \cdot n}
\end{align*}
\]
Non-composite vs. Composite Sections

Given:

- $DL_{slab} = 62.5$ psf
- $DL_{beam} = 135$ plf
- $n = 1/9$
- $f_{steel} = 24$ ksi (Fy = 36)
- $f_{conc} = 1.35$ 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.

\[
\text{CAPACITY of W 36 x 135} \\
S_x = 439 \text{in}^3 \\
F_b = 24 \text{ ksi} \ (0.66 \text{ kN}) \\
M = F_b S = 24 \text{ ksi} \times 439 \text{ in}^3 = 10536 \text{ k-in} \\
M = 878 \text{ k-in} \\
M_T = M_{ax} + M_{ax} \\
M_{ax} = \frac{wL^2}{8} = \frac{0.9475 \times (60^2)}{8} = 426.4 \text{ k-in} \\
M_{ax} = M_T - M_{ax} = 878 - 426.4 = 451.6 \text{ k-in} \\
\frac{wL^2}{8} = 451.6 \text{ k-in} \\
w = \frac{(8)(451.6)}{60^2} = 1003 \text{ kF} \\
\text{PSF} = \frac{1003 \text{ psf}}{13'} = 77.2 \text{ psf}
\]

Source: University of Michigan, Department of Architecture
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.

Source: University of Michigan, Department of Architecture
4. Calculate Transformed $I_x$:
Use parallel axis theorem.

$I_a = I_g + A d^2$

\[
\begin{array}{c|c|c}
I_{PR} & I_g & A d^2 \\
\hline
10 & \frac{bd^3}{12} = \frac{10(5)^3}{12} = 104.17\text{in}^4 & 50(11.47\text{in})^2 \cdot 4023\text{in}^4 \\
I & 7800 & 39.7(11.3)^4 = 5073.78\text{in}^4 \\
\hline
\end{array}
\]

\[I_a = I_g + A d^2\]

\[I_a = 104.17 + 4023 = 4127.17\text{in}^4\]

\[I = 7800 + 5073.78 = 12873.78\text{in}^4\]

\[I_{PR} = 17000.99\text{in}^4\]
5. Calculate moment capacity for steel and concrete each assuming full allowable stress level.

\[ M_c = \frac{f_c I_c r}{c} \]

\[ M_c = \frac{1.35 (17001)}{11.47 (1/4)} = 1808.9 \text{ k-ft} = 1502.74 \text{ k-in} \]

\[ M_b = \frac{f_b I_b r}{c} \]

\[ M_b = \frac{24 (17001)}{29.08} = 14031.08 \text{ k-ft} = 1169.26 \text{ k-in} \]

\[ f_b = 24 \text{ ksi} \]

\[ f_c = \frac{M_c (1147) (1/9)}{I_c r} = \frac{14031.08 (1147) (1/9)}{17001} \]

\[ f_c = 1.052 \text{ ksi} \]

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

Source: University of Michigan, Department of Architecture
Composite Analysis cont.

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

\[
M_{ul} = M_{t} - M_{DL}
\]
\[
M_{ul} = 1169 k\cdot ft - 430 k\cdot ft = 739 k\cdot ft
\]

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

\[
\frac{w_u l^2}{8} = 743 k\cdot ft
\]
\[
w_u = \frac{(8)(743)}{60^2} = 1.550 kbf
\]
\[
PSF_w = \frac{1650 lbf}{13'} = 127 lbf
\]