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
Steel W-sections for beams and columns

Columns:
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
• \( F_b = 0.66 F_y \)  \( \Rightarrow L_c \)
  – Compact Section
  – Braced against LTB \( |L_c| < L_c \)
• \( F_b = 0.60 F_y \)  \( \Rightarrow L_u \)
  – Compact or Not
  – \( L_c < |L| < L_u \)
• \( F_b < 0.60 F_y \)  \( \Rightarrow \) 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
  - $F_b = 0.66F_y = 24$ ksi (A36)
  - $F_b = 0.60F_y = 21.6$ ksi (A36)

- Using the flexure equation,
  - set $f_b = F_b$ and solve for $S$

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

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

- 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 (•• is ok for all grades of $F_y$)

---

### Section Modulus Table

Sections shown in **bold face** are “Weight Economy Sections.”

<table>
<thead>
<tr>
<th>$S_x$ in.$^2$</th>
<th>Shape</th>
<th>$F'\gamma$ ksi</th>
<th>$S_x$ in.$^2$</th>
<th>Shape</th>
<th>$F'\gamma$ ksi</th>
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</table>

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

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: $f_b = 24$ ksi

$W' = 30 \times 116$

For $W' = 30 \times 116$ from table D-35 we get,

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

For a simply supported, uniformly loaded beam,

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

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, \( w \).

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

\[ M = 5a \times F_b \]

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

\[ M = 7,896 \text{ k-in} \]

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

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

\[ W = \frac{658 \text{ k-in} \times 8}{641} \]

\[ W = 8.25 \text{ k} \]

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

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 $S_x$.

\[
\begin{align*}
\text{GIVEN:} & \quad f_b = 30 \text{ kpsi} \\
& \quad w = 1.25 \text{ kips/ft} \\
& \quad l = 32 \text{ ft}
\end{align*}
\]

\[
\text{MAXIMUM MOMENT} \quad M = \frac{wl^2}{8}
\]

\[
M = \frac{160 \text{ kips}}{8} = 20 \text{ kips}
\]

\[
\begin{align*}
& \quad f_b = \frac{M}{I} = \frac{M}{S} \\
\therefore \quad S &= \frac{M}{f_b} = \frac{160 \text{ kips} \times 12 \text{ in}}{30 \text{ kpsi}} \\
\therefore \quad S &= 64 \text{ in}^3
\end{align*}
\]

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

$S_x = 64.7 \text{ in}^3$

---

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

<table>
<thead>
<tr>
<th>$S_x$</th>
<th>Shape</th>
<th>$F_y'$</th>
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</tbody>
</table>

Source: I. Engel, Structural Principles, 1984
5. Add member self load to $M$ and recheck $F_b$ (we skip this step here)

7. Check shear stress:

Allowable Stress
$F_v = 0.40 \times F_y$

Actual Stress
$\frac{V}{(t_wd)}$

$f_v \leq F_v$

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

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

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

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

\[
f_v = \frac{V}{(t_wd)}
\]

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

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

\[ \Delta_e = \frac{5 \cdot w \cdot L^4}{384 \cdot EI} \]

\[ \Delta_e = \frac{5 \cdot (1.25 \text{ kips}) \cdot (32\text{'s})^4}{384 \cdot (29000 \text{ kips})(578 \text{ in}^3)} \]

\[ \Delta_e = 1.96'' \]

\[ \frac{L}{240} = \frac{32\text{'s}(12)}{240} = 1.4'' \]

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

**Construction**

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<thead>
<tr>
<th></th>
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<tr>
<td>or floor member</td>
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<td>L/240</td>
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<tr>
<td>Roof members</td>
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<td>L/180</td>
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<td>with brittle finishes</td>
<td>L/240</td>
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<td>Exterior and Interior walls and partitions with flexible finishes</td>
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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
Analysis Procedure

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

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

or

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

   $$ M_s = \frac{F_{steel} \cdot I_{tr}}{c} $$
   $$ M_c = \frac{F_{conc} \cdot I_{tr}}{c \cdot n} $$
Non-composite vs. Composite Sections

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

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.

\[
\begin{align*}
S_x &= 439 \text{ in}^3 \\
F_b &= 24 \text{ ksi } (0.66 \text{ Fu}) \\
M &= F_b S = 24 \text{ ksi } \times 439 \text{ in}^3 = 10536 \text{ k``} \\
M &= 878 \text{ k``} \\
M_t &= M_\alpha + M_L \\
M_\alpha &= \frac{wL^2}{8} = \frac{0.9475 \cdot (60^\circ)}{8} = 426.4 \text{ k``} \\
M_L &= M_t - M_\alpha = 878 - 426.4 = 451.6 \text{ k``} \\
\frac{w practice L^2}{8} &= 451.6 \text{ k``} \\
w_{psf} &= \frac{(8 \text{ in} \times 451.6 \text{ k``})}{60^2} = 1.008 \text{ k``} \\
p_{psf} &= \frac{1003 \text{ psf}}{131} = 77.2 \text{ psf}
\end{align*}
\]
Part 2 - Composite Analysis

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

2. Find $n=E_c/E_s$ (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.

$$I_a = I_g + A d^2$$

Source: University of Michigan, Department of Architecture
5. Calculate moment capacity for steel and concrete each assuming full allowable stress level.

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

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

\[ M_{DL} = M_T - M_{DL} \]
\[ M_{DL} = 1169 \text{ ft-k} - 420 \text{ ft-k} = 749 \text{ ft-k} \]

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

\[ w_k l^2 = 748 \text{ k-ft} \]
\[ w_k = \frac{(8)(748)}{60^2} = 1.50 \text{ k-ft} \]
\[ PSF_{K} = \frac{1650 \text{ psf}}{13} = 127 \text{ psf} \]