Design for Strength +...

- strength design
  - forces & material
- serviceability
  - limit deflection and cracking
  - control noise & vibration
  - no excessive settlement of foundations
  - durability
  - appearance
  - component damage
  - ponding

Beam Deformations

- curvature relates to
  - bending moment
  - modulus of elasticity
  - moment of inertia

\[ \frac{1}{R} = \frac{M}{EI} \]

\[ \text{curvature} = \frac{M(x)}{EI} \]

\[ \theta = \text{slope} = \int \frac{M(x)}{EI} \, dx \]

\[ \Delta = \text{deflection} = \int \int \frac{M(x)}{EI} \, dx \]
Boundary Conditions

- at pins, rollers, fixed supports: \( y = 0 \)
- at fixed supports: \( \theta = 0 \)
- at inflection points from symmetry: \( \theta = 0 \)
- \( y_{\text{max}} \) at \( \frac{dy}{dx} = 0 \)

Superpositioning

- if \( w \) can be superpositioned
  - \( \theta \) & \( y \) can
  - elastic range only!

Deflection Limits

- based on service condition, severity

<table>
<thead>
<tr>
<th>Use</th>
<th>LL only</th>
<th>DL+LL</th>
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</thead>
<tbody>
<tr>
<td>Roof beams:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Industrial</td>
<td>L/180</td>
<td>L/120</td>
</tr>
<tr>
<td>Commercial</td>
<td></td>
<td></td>
</tr>
<tr>
<td>plaster ceiling</td>
<td>L/240</td>
<td>L/160</td>
</tr>
<tr>
<td>no plaster</td>
<td>L/360</td>
<td>L/240</td>
</tr>
<tr>
<td>Floor beams:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ordinary Usage</td>
<td>L/360</td>
<td>L/240</td>
</tr>
<tr>
<td>Roof or floor (damageable elements)</td>
<td>L/480</td>
<td></td>
</tr>
</tbody>
</table>

Lateral Buckling

- lateral buckling caused by compressive forces at top coupled with insufficient rigidity
- can occur at low stress levels
- stiffen, brace or bigger \( I_y \)
**Local Buckling**

- steel I beams
- flange
  - buckle in direction of smaller radius of gyration
- web
  - force
  - “crippling”

**Shear in Web**

- panels in plate girders or webs with large shear
- buckling in compression direction
- add stiffeners

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**Local Buckling**

- flange
- web

**Shear in Web**

- plate girders and stiffeners
**Beam Design**

1. Know $F_{ull}$ for the material or $F_U$ for LRFD

2. Draw $V$ & $M$, finding $M_{\text{max}}$

3. Calculate $S_{req'd}$ \( (f_b \leq F_b) \)

4. Determine section size \( S = \frac{bh^2}{6} \)

**Beam Design**

4*. Include self weight for $M_{\text{max}}$
   - and repeat 3 & 4 if necessary

5. Consider lateral stability

   Unbraced roof trusses were blown down in 1999 at this project in Moscow, Idaho.
   Photo: Ken Carper

**Beam Design**

6. Evaluate shear stresses - horizontal \( (f_v \leq F_v) \)
   - $W$ and rectangles \( f_{v-\text{max}} = \frac{3V}{2A} \approx \frac{V}{A_{\text{web}}} \)
   - thin walled sections \( f_{v-\text{max}} = \frac{VQ}{Ib} \)

**Beam Design**

7. Provide adequate bearing area at supports \( f_p = \frac{P}{A} \leq F_p \)
Beam Design
8. Evaluate torsion
\[ (f_v \leq F_v) \]
- circular cross section
\[ f_v = \frac{T\rho}{J} \]
- rectangular
\[ f_v = \frac{T}{c_1 ab^2} \]

9. Evaluate deflections
\[ y_{\text{max}}(x) = \Delta_{\text{actual}} \leq \Delta_{\text{allowable}} \]

Beam Design
9. – how to read charts