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>
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<td></td>
</tr>
<tr>
<td>Ordinary Usage</td>
<td>L/360</td>
<td>L/240</td>
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<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
Beam Design

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

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

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

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

Beam Design

6. Evaluate shear stresses - horizontal

   ($f_v \leq F_v$)

   - $W$ and rectangles $f_{v_{max}} = \frac{3V}{2A} \approx \frac{V}{A_{web}}$

   - thin walled sections $f_{v_{max}} = \frac{VQ}{Ib}$

Beam Design

7. Provide adequate bearing area at supports $f_p = \frac{P}{A} \leq F_p$
8. Evaluate torsion

\[ f_v \leq F_v \]

- circular cross section
  \[ f_v = \frac{T\rho}{J} \]
- rectangular
  \[ f_v = \frac{T}{c_1ab^2} \]

9. Evaluate deflections

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

9. – how to read charts

1. SIMPLE BEAM—UNIFORMLY DISTRIBUTED LOAD

\[ \text{Total Equiv. Uniform Load} = \frac{w}{2} \]
\[ R = V = \frac{w}{2} \]
\[ V_x = w \left( \frac{1}{2} - x \right) \]
\[ M_{\text{max}} \text{ (at center)} = \frac{wx}{2} \]
\[ M_x = \frac{wx^2}{2} 
\[ \Delta_{\text{max}} \text{ (at center)} = \frac{5wx^4}{384EI} \]
\[ \Delta_x = \frac{wx^2(3 - 2x^2 + x^4)}{24EI} \]