Wood Beam Design

- **National Design Specification**
  - National Forest Products Association
  - ASD & LRFD
  - adjustment factors \( \times \) tabulated stress = allowable stress
  - adjustment factors terms, \( C \) with subscript
  - i.e., bending:

\[
f_b \leq F'_b = F_b \times (\text{product of adjustment factors})
\]

Timber

- lightweight: strength ~ like steel
  - strengths vary
    - by wood type
    - by direction
    - by “flaws”
  - size varies by tree growth
  - renewable resource
  - manufactured wood
    - assembles pieces
    - adhesives

Wood Properties

- cell structure and density

Wood Properties

- cell structure and density


hardwood

softwood
Wood Properties

- moisture
  - exchanges with air easily
  - excessive drying causes warping and shrinkage
  - strength varies some
- temperature
  - steam
  - volatile products
  - combustion

Wood Properties

- load duration
  - short duration
    - higher loads
  - normal duration
    - > 10 years
- creep
  - additional deformation with no additional load

Structural Lumber

- dimension – 2 x’s (nominal)
- beams, posts, timber, planks
- grading
  - select structural
  - no. 1, 2, & 3
- tabular values
  by species
- glu-lam
- plywood

Adjustment Factors

- terms
  - \( C_D = \) load duration factor
  - \( C_M = \) wet service factor
    - 1.0 dry \( \leq \) 16% MC
  - \( C_F = \) size factor
    - visually graded sawn lumber and round timber > 12” depth
    \[
    C_F = \left( \frac{12}{d} \right)^{0.6} \leq 1.0
    \]

Table 5.2 (pg 177)
Adjustment Factors

- **terms**
  - $C_{fu} = \text{flat use factor}$
    - not decking
  - $C_i = \text{incising factor}$
    - increase depth for pressure treatment
  - $C_t = \text{temperature factor}$
    - lose strength at high temperatures

Adjustment Factors

- **terms**
  - $C_r = \text{repetitive member factor}$
  - $C_H = \text{shear stress factor}$
    - splitting
  - $C_v = \text{volume factor}$
    - same as $C_F$ for glue laminated timber
  - $C_L = \text{beam stability factor}$
    - beams without full lateral support
  - $C_C = \text{curvature factor for laminated arches}$

Allowable Stresses

- **design values**
  - $F_b$: bending stress
  - $F_t$: tensile stress
  - $F_v$: horizontal shear stress
  - $F_{c,\perp}$: compression stress (perpendicular to grain)
  - $F_c$: compression stress (parallel to grain)
  - $E$: modulus of elasticity
  - $F_p$: bearing stress (parallel to grain)

Load Combinations

- **design loads, take the bigger of**
  - $(\text{dead loads})/0.9$
  - $(\text{dead loads} + \text{any possible combination of live loads})/C_D$
- **deflection limits**
  - no load factors
  - for stiffer members:
    - $\Delta_T \text{ max from } LL + 0.5(DL)$
Beam Design Criteria

- **strength design**
  - bending stresses predominate
  - shear stresses occur
- **serviceability**
  - limit deflection and cracking
  - control noise & vibration
  - no excessive settlement of foundations
  - durability
  - appearance
  - component damage
  - ponding

---

Deflection Limits

- based on service condition, severity

<table>
<thead>
<tr>
<th>Use</th>
<th>LL only</th>
<th>DL+LL</th>
</tr>
</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/180</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 $I_y$

---

Beam Design Criteria

- **superpositioning**
  - use of beam charts
  - elastic range only!
  - “add” moment diagrams
  - “add” deflection CURVES (not maximums)
Design Procedure

1. Know $F_{all}$ 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

4*. Include self weight for $M_{max}$

– 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

$$f_{v\text{-max}} = \frac{3V}{2A} \approx \frac{V}{A_{\text{web}}}$$

- general

$$f_{v\text{-max}} = \frac{VQ}{I_b}$$

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
  \[ f_v = \frac{T}{c_1 ab^2} \]

<table>
<thead>
<tr>
<th>n/b</th>
<th>c1</th>
<th>c2</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.0</td>
<td>0.208</td>
<td>0.1006</td>
</tr>
<tr>
<td>1.2</td>
<td>0.219</td>
<td>0.1061</td>
</tr>
<tr>
<td>1.5</td>
<td>0.251</td>
<td>0.1058</td>
</tr>
<tr>
<td>2.0</td>
<td>0.246</td>
<td>0.229</td>
</tr>
<tr>
<td>2.5</td>
<td>0.258</td>
<td>0.249</td>
</tr>
<tr>
<td>3.0</td>
<td>0.267</td>
<td>0.263</td>
</tr>
<tr>
<td>4.0</td>
<td>0.282</td>
<td>0.281</td>
</tr>
<tr>
<td>5.0</td>
<td>0.291</td>
<td>0.291</td>
</tr>
<tr>
<td>10.0</td>
<td>0.312</td>
<td>0.312</td>
</tr>
<tr>
<td>oo</td>
<td>0.333</td>
<td>0.333</td>
</tr>
</tbody>
</table>

9. Evaluate deflections

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

Joists & Rafters

- allowable load tables
- allowable length tables for common live & dead loads
- lateral bracing needed
- common spacings

Engineered Wood

- plywood
  - veneers at different orientations
  - glued together
  - split resistant
  - higher and uniform strength
  - limited shrinkage and swelling
  - used for sheathing, decking, shear walls, diaphragms
Engineered Wood

• glued-laminated timber
  – glulam
  – short pieces glued together
  – straight or curved
  – grain direction parallel
  – higher strength
  – more expensive than sawn timber
  – large members (up to 100 feet!)
  – flexible forms

Engineered Wood

• I sections
  – beams
• other products
  – pressed veneer strip panels (Parallam)
• wood fibers
  – Hardieboard: cement & wood

Timber Elements

• stressed-skin elements
  – modular built-up “plates”
  – typically used for floors or roofs

Timber Elements

• built-up box sections
  – built-up beams
  – usually site-fabricated
  – bigger spans
Timber Elements

- trusses
  - long spans
  - versatile
  - common in roofs

Timber Elements

- folded plates and arch panels
  - usually of plywood

Timber Elements

- arches and lamellas
  - arches commonly laminated timber
  - long spans
  - usually only for roofs

Approximate Depths

![Diagram of approximate depths for timber systems](image-url)