wood construction: materials & beams
Wood Beam Design

• National Design Specification
  – National Forest Products Association
  – ASD & LRFD (combined in 2005)
  – adjustment factors x 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

http://www.swst.org/teach/set2/struct1.html
Wood Properties

• moisture
  – exchanges with air easily
  – excessive drying causes warping and shrinkage
  – strength varies some

• temperature
  – steam
  – volatile products
  – combustion

http://www.swst.org/teach/set2/struct1.html
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**
  - $C_D = \text{load duration factor}$
  - $C_M = \text{wet service factor}$
    - $1.0 \text{ dry } \leq 16\% \text{ MC}$
  - $C_F = \text{size factor}$
    - visually graded sawn lumber and round timber $> 12''$ depth

\[
C_F = \left( \frac{12}{d} \right)^{\frac{1}{9}} \leq 1.0
\]

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:
    • $\Delta_T \text{ max from } \text{LL} + 0.5(\text{DL})$
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
Beam Design Criteria

- superpositioning
  - use of beam charts
  - elastic range only!
  - “add” moment diagrams
  - “add” deflection CURVES (not maximums)
## Deflection Limits

- based on service condition, severity

<table>
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<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/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>
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<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 $I_y$
Design Procedure

1. Know $F_{\text{all}}$ 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
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**
  \[
  f_{v-\text{max}} = \frac{VQ}{Ib}
  \]
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 3.1. Coefficients for Rectangular Bars in Torsion**

<table>
<thead>
<tr>
<th>a/b</th>
<th>c_1</th>
<th>c_2</th>
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<tr>
<td>1.0</td>
<td>0.208</td>
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<td>1.2</td>
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<td>1.5</td>
<td>0.231</td>
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<td>2.0</td>
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<td>10.0</td>
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</tr>
<tr>
<td>∞</td>
<td>0.333</td>
<td>0.333</td>
</tr>
</tbody>
</table>
Beam Design

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
LRFD

- factored loads & reduced nominal capacity

\[ M_u = \gamma_D M_D + \gamma_L M_L \leq \phi_b M_n \]

\( \phi \) - Resistance factor

\( \gamma \) - Load factor for (D)ead & (L)ive load

- nominal adjusted – no \( C_D \)

\[ M_n = F_{bn} \times S \]

\[ F'_{bn} = F_{bn} (\phi_b \lambda)(\text{product of adjustment factors}) \]

\[ F_{bn} = F_b \times K_F \ (\text{conversion factor}) \]
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 showing approximate depths for various structural elements such as planking, joists, stressed-skin panels, laminated beams, box beams, trussed rafters, open-web joists, flat trusses, shaped trusses, plywood folded plates, and laminated arches. The diagram also includes a key for understanding the minimum, possible span range, and maximum span.](image-url)