wood construction: materials & beams
Wood Beam Design

- **National Design Specification**
  - National Forest Products Association
  - ASD & LRFD (combined in 2005)
  - 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*

[Image: Comparison of softwood and hardwood textures.]

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**
  - $C_D$ = 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

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

Table 10.3 (pg 376)
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**
  – (dead loads)/0.9
  – (dead loads + 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
Beam Design Criteria

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

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

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

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

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

\[
\Delta = \text{deflection} = \int \int \frac{M(x)}{EI} \, dx
\]
## 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><strong>Roof beams:</strong></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><strong>Floor beams:</strong></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 $I_y$
### Timber Beam Bracing

#### Table 9.3 Lateral bracing requirements for timber beams.

<table>
<thead>
<tr>
<th>Beam Depth/Width Ratio</th>
<th>Type of Lateral Bracing Required</th>
<th>Example</th>
</tr>
</thead>
<tbody>
<tr>
<td>2 to 1</td>
<td>None</td>
<td></td>
</tr>
<tr>
<td>3 to 1</td>
<td>The ends of the beam should be held in position</td>
<td><img src="image" alt="End blocking" /></td>
</tr>
<tr>
<td>5 to 1</td>
<td>Hold the compression edge in line (continuously)</td>
<td><img src="image" alt="Sheathing or decking" /></td>
</tr>
<tr>
<td>6 to 1</td>
<td>Diagonal bracing should be used</td>
<td><img src="image" alt="Nailing" /></td>
</tr>
<tr>
<td>7 to 1</td>
<td>Both edges of the beam should be held in line</td>
<td><img src="image" alt="Nailed sheathing/decking, top and bottom" /></td>
</tr>
</tbody>
</table>
Design Procedure

1. Know $F_{all}$ for the material or $F_{U}$ for LRFD

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

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

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

- \((f_v \leq F_v)\)

- rectangles and W’s

\[
f_{v_{-\text{max}}} = \frac{3V}{2A} \approx \frac{V}{A_{\text{web}}}
\]

- general

\[
f_{v_{-\text{max}}} = \frac{VQ}{Ib}
\]
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
  \[ f_v = \frac{T}{c_1 ab^2} \]

<table>
<thead>
<tr>
<th>a/b</th>
<th>c_1</th>
<th>c_2</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.0</td>
<td>0.208</td>
<td>0.1406</td>
</tr>
<tr>
<td>1.2</td>
<td>0.219</td>
<td>0.1661</td>
</tr>
<tr>
<td>1.5</td>
<td>0.231</td>
<td>0.1958</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>( \infty )</td>
<td>0.333</td>
<td>0.333</td>
</tr>
</tbody>
</table>
Beam Design

9. Evaluate deflections

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

- across beams or joists
- floors: 16 in. span common
  - ¾ in. tongue-in-groove plywood
  - 5/8 in. particle board over ½ in. plywood
  - hardwood surfacing
- roofs: 24 in. span common
  - ½ in. plywood
Joists & Rafters

- allowable load tables \((w)\)
- 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)
  - laminated veneer lumber (LVL)

- **wood fibers**
  - Hardieboard: cement & wood
Timber Elements

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

*Figure 1. Typical Two-Sided Stressed-Skin Panel*
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

![Approximate Depths Diagram](image)

FIGURE 15-3  Approximate span ranges for timber systems.