wood construction: materials & beams
Wood Beam Design

- National Design Specification
  - National Forest Products Association
  - ASD & LRFD (combined 2005)
  - adjustment factors x tabulated stress = allowable stress
  - adjustment factors terms, C with subscript
  - i.e, bending:

\[ f_b \leq F'_b = F_b \times \left( \text{product of adjustment factors} \right) \]
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
  - \( C_D \) = load duration factor
  - \( C_M \) = wet service factor
    - 1.0 dry \( \leq \) 19% MC sawn
    - 1.0 dry \( \leq \) 16% MC glu-lam
  - \( C_F \) = size factor
    - visually graded sawn lumber and round timber
      - depth > 12”

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

Fig. 9.23 (pg 477)
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**
  
  – $C_r =$ repetitive member factor
  
  – $C_H =$ shear stress factor
    
    • splitting
  
  – $C_V =$ volume factor
    
    • same as $C_F$ for glue laminated timber
  
  – $C_L =$ beam stability factor
    
    • beams without full lateral support
  
  – $C_C =$ 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)

1. SIMPLE BEAM—UNIFORMLY DISTRIBUTED LOAD

\[
R = \frac{wl}{2} \\
V_x = w\left(\frac{l}{2} - x\right) \\
M_{\text{max. (at center)}} = \frac{wx^2}{8} \\
M_x = \frac{wx}{2} (l - x) \\
\Delta_{\text{max. (at center)}} = \frac{5wx^4}{384EI} \\
\Delta_x = \frac{wx}{24EI} (l^3 - 2lx^2 + x^3)
\]
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>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 $I_y$
### Timber Beam Bracing

<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="Nailing" /></td>
</tr>
<tr>
<td>6 to 1</td>
<td>Diagonal bracing should be used</td>
<td><img src="image" alt="Nailed sheathing/decking" /></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 $S_{\text{req'd}}$ \( \left( f_b \leq F_b \right) \)

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

- \((f_v \leq F_v)\)

- 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 3.1: Coefficients for Rectangular Bars in Torsion

<table>
<thead>
<tr>
<th>a/b</th>
<th>c₁</th>
<th>c₂</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>∞</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

![Image of floor joists and rafters with bridging and finish flooring]

**Table 5.5 Allowable Spans in Feet and Inches for Floor Joists**

<table>
<thead>
<tr>
<th>Joist Size (in)</th>
<th>Spacing (ft)</th>
<th>1.3</th>
<th>1.4</th>
<th>1.5</th>
</tr>
</thead>
<tbody>
<tr>
<td>2 × 6</td>
<td>12.0</td>
<td>10-0</td>
<td>10-3</td>
<td>10-6</td>
</tr>
<tr>
<td></td>
<td>16.0</td>
<td>9-1</td>
<td>9-4</td>
<td>9-6</td>
</tr>
<tr>
<td></td>
<td>19.2</td>
<td>8-7</td>
<td>8-9</td>
<td>9-0</td>
</tr>
<tr>
<td></td>
<td>24.0</td>
<td>7-11</td>
<td>8-2</td>
<td>8-4</td>
</tr>
<tr>
<td>2 × 8</td>
<td>12.0</td>
<td>13-2</td>
<td>13-6</td>
<td>13-10</td>
</tr>
<tr>
<td></td>
<td>16.0</td>
<td>12-0</td>
<td>12-3</td>
<td>12-7</td>
</tr>
<tr>
<td></td>
<td>19.2</td>
<td>11-3</td>
<td>11-7</td>
<td>11-10</td>
</tr>
<tr>
<td></td>
<td>24.0</td>
<td>10-6</td>
<td>10-9</td>
<td>11-0</td>
</tr>
<tr>
<td>2 × 10</td>
<td>12.0</td>
<td>16-10</td>
<td>17-3</td>
<td>17-8</td>
</tr>
<tr>
<td></td>
<td>16.0</td>
<td>15-3</td>
<td>15-8</td>
<td>16-0</td>
</tr>
<tr>
<td></td>
<td>19.2</td>
<td>14-5</td>
<td>14-9</td>
<td>15-1</td>
</tr>
<tr>
<td></td>
<td>24.0</td>
<td>13-4</td>
<td>13-8</td>
<td>14-0</td>
</tr>
<tr>
<td>2 × 12</td>
<td>12.0</td>
<td>20-6</td>
<td>21-0</td>
<td>21-6</td>
</tr>
<tr>
<td></td>
<td>16.0</td>
<td>18-7</td>
<td>19-1</td>
<td>19-6</td>
</tr>
<tr>
<td></td>
<td>19.2</td>
<td>17-6</td>
<td>17-11</td>
<td>18-4</td>
</tr>
<tr>
<td></td>
<td>24.0</td>
<td>16-3</td>
<td>16-8</td>
<td>17-0</td>
</tr>
</tbody>
</table>

**Definitions**
- **Deflection:** For 40 psf (1.92 kN/m²) live load, limited to span in inches (mm) divided by 360.
- **Strength:** Live load of 40 psf (1.92 kN/m²) plus dead load of 10 psf (0.48 kN/m²) determined the Modulus of Elasticity, E, in 1,000,000 psi (0.008 ksi) for N/mm².
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
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

**FIGURE 15-3** Approximate span ranges for timber systems.

<table>
<thead>
<tr>
<th>Structural Type</th>
<th>Approximate Depths</th>
</tr>
</thead>
<tbody>
<tr>
<td>Planking</td>
<td>L/25–L/35</td>
</tr>
<tr>
<td>Joists</td>
<td>L/18–L/20</td>
</tr>
<tr>
<td>Stressed-skin panels</td>
<td>L/24–L/30</td>
</tr>
<tr>
<td>Laminated beams</td>
<td>L/18–L/20</td>
</tr>
<tr>
<td>Box beams</td>
<td>L/18–L/20</td>
</tr>
<tr>
<td>Trussed rafters</td>
<td>L/5–L/7</td>
</tr>
<tr>
<td>Open-web joists</td>
<td>L/18–L/20</td>
</tr>
<tr>
<td>Flat trusses</td>
<td>L/10–L/15</td>
</tr>
<tr>
<td>Shaped trusses</td>
<td>L/7–L/10</td>
</tr>
<tr>
<td>Plywood folded plates</td>
<td>L/7–L/12</td>
</tr>
<tr>
<td>Laminated arches</td>
<td>L/4–L/6</td>
</tr>
</tbody>
</table>

**Span Feet**

0 10 20 30 40 50 60 70 80 90 100 110 120 130 140 150 160 170 180

- **Minimum span**
- **Possible span range**
- **Maximum span**

- **Typical span for member**
- **Typical member length**