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:

$$f_b \leq F'_b = F_b \times \left( \text{product of adjustment factors} \right)$$
**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

softwood

hardwood
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**
  - $C_D = \text{load duration factor}$
  - $C_M = \text{wet service factor}$
  - $C_F = \text{size factor}$
  - 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**
  - $C_r$ = 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)
### 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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<tr>
<td><strong>Roof beams:</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Industrial</strong></td>
<td>L/180</td>
<td>L/120</td>
</tr>
<tr>
<td><strong>Commercial</strong></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><strong>Ordinary Usage</strong></td>
<td>L/360</td>
<td>L/240</td>
</tr>
<tr>
<td><strong>Roof or floor (damageable elements)</strong></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 $F_{all}$ 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 $M_{\text{max}}$
   - 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

- \((f_v \leq F_v)\)

- W and rectangles

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

- 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>( \frac{a}{b} )</th>
<th>( c_1 )</th>
<th>( c_2 )</th>
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<tr>
<td>( \infty )</td>
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</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

![Joist and Rafter Diagram]

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

<table>
<thead>
<tr>
<th>Joint Size (in.)</th>
<th>Spacing (in.)</th>
<th>1.3</th>
<th>1.4</th>
<th>1.5</th>
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<td></td>
<td>16.0</td>
<td>9-1</td>
<td>9-4</td>
<td>9-6</td>
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<td></td>
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<td>8-9</td>
<td>9-0</td>
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<tr>
<td></td>
<td>24.0</td>
<td>7-11</td>
<td>8-2</td>
<td>8-4</td>
</tr>
<tr>
<td>2 x 8</td>
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<td>13-6</td>
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<td>12-0</td>
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<td>11-7</td>
<td>11-10</td>
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<tr>
<td></td>
<td>24.0</td>
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<td>10-9</td>
<td>11-0</td>
</tr>
<tr>
<td>2 x 10</td>
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<td>24.0</td>
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<td>F_b</td>
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<td>1,251</td>
<td>1,314</td>
<td>1,376</td>
</tr>
</tbody>
</table>
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

FIGURE 15-3 Approximate span ranges for timber systems.