wood construction: materials & beams
Wood Beam Design

- **National Design Specification**
  - National Forest Products Association
  - ASD & LRFD (combined 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
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
    - $1.0 \text{ dry} \leq 16\% \text{ MC}$
  - $C_F =$ size factor
    - visually graded sawn lumber and round timber > 12” depth

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

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:
    • Δ_T 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

\[
\begin{align*}
\text{Total Equiv. Uniform Load} & = w \ell \\
R & = V = \frac{w \ell}{2} \\
V_x & = w \left( \frac{\ell}{2} - x \right) \\
M_{\text{max. (at center)}} & = \frac{wx^2}{8} \\
M_x & = \frac{wx}{2} (\ell - x) \\
\Delta_{\text{max. (at center)}} & = \frac{5wx^4}{384EI} \\
\Delta_x & = \frac{wx}{24EI} (\ell^3 - 2x^2 + x^3)
\end{align*}
\]
**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>
<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></td>
</tr>
<tr>
<td>5 to 1</td>
<td>Hold the compression edge in line (continuously)</td>
<td></td>
</tr>
<tr>
<td>6 to 1</td>
<td>Diagonal bracing should be used</td>
<td></td>
</tr>
<tr>
<td>7 to 1</td>
<td>Both edges of the beam should be held in line</td>
<td></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 $M_{\text{max}}$
   – 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**
  \[ f_v = \frac{T}{c_1ab^2} \]

**TABLE 3.1. Coefficients for Rectangular Bars in Torsion**

<table>
<thead>
<tr>
<th>a/b</th>
<th>c_1</th>
<th>c_2</th>
</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>0.1988</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

![Diagram of a typical two-sided stressed-skin panel with labels for plywood splice plate, vent holes, lumber header, scarf joint, lumber stringers, blanket insulation, ventilation openings, and lumber blocking.]
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.