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**

## Table: Design Values in Pounds per Square Inch

<table>
<thead>
<tr>
<th>Species and commercial grade</th>
<th>Size classification</th>
<th>Extreme fiber in bending (F_u)</th>
<th>Tension parallel to grain (F_t)</th>
<th>Horizontal shear (F_v)</th>
<th>Compression perpendicular to grain (F_{cl})</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Single-member uses</td>
<td>Repetitive-member uses</td>
<td></td>
<td></td>
</tr>
<tr>
<td>SOUTHERN PINE (Surfaced dry, Used at 19% max. m.c.)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Select Structural</td>
<td></td>
<td>2000</td>
<td>2300</td>
<td>1150</td>
<td>100</td>
</tr>
<tr>
<td>No. 1</td>
<td></td>
<td>1700</td>
<td>1950</td>
<td>1000</td>
<td>100</td>
</tr>
<tr>
<td>No. 1 Dense</td>
<td>2” to 4” thick</td>
<td>2000</td>
<td>2300</td>
<td>1150</td>
<td>100</td>
</tr>
<tr>
<td>No. 2</td>
<td>2” to 4” wide</td>
<td>1400</td>
<td>1650</td>
<td>825</td>
<td>90</td>
</tr>
<tr>
<td>No. 2 Dense</td>
<td></td>
<td>1650</td>
<td>1900</td>
<td>975</td>
<td>90</td>
</tr>
<tr>
<td>No. 3</td>
<td></td>
<td>775</td>
<td>900</td>
<td>450</td>
<td>90</td>
</tr>
<tr>
<td>No. 3 Dense</td>
<td>2” to 4” thick</td>
<td>925</td>
<td>1050</td>
<td>525</td>
<td>90</td>
</tr>
<tr>
<td>No. 3 Dense</td>
<td>2” to 4” wide</td>
<td>775</td>
<td>900</td>
<td>450</td>
<td>90</td>
</tr>
<tr>
<td>Stud</td>
<td></td>
<td>775</td>
<td>900</td>
<td>450</td>
<td>90</td>
</tr>
<tr>
<td>Construction</td>
<td>2” to 4” thick</td>
<td>1000</td>
<td>1150</td>
<td>600</td>
<td>100</td>
</tr>
<tr>
<td>Standard</td>
<td>2” to 4” thick</td>
<td>575</td>
<td>675</td>
<td>350</td>
<td>90</td>
</tr>
<tr>
<td>Utility</td>
<td>4” wide</td>
<td>275</td>
<td>300</td>
<td>180</td>
<td>90</td>
</tr>
<tr>
<td>Select Structural</td>
<td></td>
<td>1750</td>
<td>2000</td>
<td>1150</td>
<td>100</td>
</tr>
<tr>
<td></td>
<td></td>
<td>1750</td>
<td>2000</td>
<td>1150</td>
<td>100</td>
</tr>
</tbody>
</table>

Wood Beams 7
Lecture 12

Architectural Structures
ARCH 331

Su2014abn
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
  – $C_r$ = 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**

   - **Total Equiv. Uniform Load** = \( w l \)
   - **R = V** = \( \frac{w l}{2} \)
   - **\( V_x \)** = \( w \left( \frac{l}{2} - x \right) \)
   - **\( M_{\text{max. (at center)}} \)** = \( \frac{w l^2}{8} \)
   - **\( M_x \)** = \( \frac{w x}{2} \left(l - x\right) \)
   - **\( \Delta_{\text{max. (at center)}} \)** = \( \frac{5 w l^4}{384 E I} \)
   - **\( \Delta_x \)** = \( \frac{w x}{24 E I} \left( l^3 - 2l x^2 + x^3 \right) \)
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="Nailing and sheathing" /></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 $M_{max}$

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

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

- \( \left( f_v \leq F_v \right) \)

- 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

![Image of Hardwood finish flooring and Plywood subfloor](image)

**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>Modulus of Elasticity, (E), in 1,000,000 psi</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1.3</td>
<td>1.4</td>
</tr>
<tr>
<td>2 x 6</td>
<td>12.0</td>
<td>10-0</td>
</tr>
<tr>
<td></td>
<td>16.0</td>
<td>9-1</td>
</tr>
<tr>
<td></td>
<td>19.2</td>
<td>8-7</td>
</tr>
<tr>
<td>2 x 8</td>
<td>12.0</td>
<td>13-2</td>
</tr>
<tr>
<td></td>
<td>16.0</td>
<td>12-0</td>
</tr>
<tr>
<td></td>
<td>19.2</td>
<td>11-3</td>
</tr>
<tr>
<td>2 x 10</td>
<td>12.0</td>
<td>16-10</td>
</tr>
<tr>
<td></td>
<td>16.0</td>
<td>15-3</td>
</tr>
<tr>
<td></td>
<td>19.2</td>
<td>14-5</td>
</tr>
<tr>
<td></td>
<td>24.0</td>
<td>13-4</td>
</tr>
<tr>
<td>2 x 12</td>
<td>12.0</td>
<td>20-6</td>
</tr>
<tr>
<td></td>
<td>16.0</td>
<td>18-7</td>
</tr>
<tr>
<td></td>
<td>19.2</td>
<td>17-6</td>
</tr>
<tr>
<td>24.0</td>
<td>16-3</td>
<td>16-8</td>
</tr>
<tr>
<td>2 x 14</td>
<td>12.0</td>
<td>993</td>
</tr>
<tr>
<td></td>
<td>16.0</td>
<td>1,093</td>
</tr>
<tr>
<td></td>
<td>19.2</td>
<td>1,161</td>
</tr>
<tr>
<td>24.0</td>
<td>1,251</td>
<td>1,314</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)
  – 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](image)

- Plywood splice plate
- Vent holes
- Lumber header may be continuous or as shown on opposite end
- Scart joint in lower skin is preferred method (alternate: spliced butt joint)
- Lumber stringers
- Lumber blocking (not required if pre-spliced skins are used)
- Blanket insulation as required
- Ventilation openings
- Plywood lower skin
- Lumber headers
- Butt joint between plywood panels
- Glue joint
- Plywood top skin
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

Key:
- Minimum span
- Possible span range
- Maximum span
- Typical span for member
- Typical member length