Elements of Architectural Structures: Form, Behavior, and Design
ARCH 614
Dr. Anne Nichols
Spring 2014

Lecture Thirteen

Wood Construction: Materials & Beams
Wood Beam Design

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

[Images showing softwood and hardwood]

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>
<thead>
<tr>
<th>Species and commercial grade</th>
<th>Size classification</th>
<th>Single-member uses</th>
<th>Repetitive-member uses</th>
<th>Design values in pounds per square inch</th>
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<tr>
<td></td>
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<td>Extreme fiber in bending “F_b”</td>
<td>Tension parallel to grain “F_t”</td>
<td>Horizontal shear “F_V”</td>
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<td>SOUTHERN PINE (Surfaced dry, Used at 19% max. m.c.)</td>
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<td>Select Structural</td>
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<td>1000</td>
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<td>1150</td>
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<td>825</td>
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<td>1900</td>
<td>975</td>
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<td>775</td>
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<tr>
<td>Stud</td>
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<td>775</td>
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<td>450</td>
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<tr>
<td></td>
<td></td>
<td>1750</td>
<td>2000</td>
<td>1150</td>
</tr>
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</table>
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 5.2 (pg 177)
Adjustment Factors

- **terms**
  - $C_{fu}$ = flat use factor
    - not decking
  - $C_{i}$ = incising factor
    - increase depth for pressure treatment
  - $C_{t}$ = 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
  – \( \text{(dead loads)}/0.9 \)
  – \( \text{(dead loads + any possible combination of live loads)}/C_D \)

• 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 \( = \frac{wL}{2} \)
- \( R = V \) \( = \frac{wL}{2} \)
- \( V_x = w \left( \frac{L}{2} - x \right) \)
- \( M_{\text{max.}} \) (at center) \( = \frac{wL^2}{8} \)
- \( M_x = \frac{wL}{2} (L - x) \)
- \( \Delta_{\text{max.}} \) (at center) \( = \frac{wL^4}{384EI} \)
- \( \Delta_x = \frac{wL}{24EI} (L^2 - 2x^2 + x^3) \)
### Deflection Limits

- **based on service condition, severity**

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<tr>
<th>Use</th>
<th>LL only</th>
<th>DL+LL</th>
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<tr>
<td><strong>Roof beams:</strong></td>
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<td></td>
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<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>
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<td></td>
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<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>
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</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 $M_{\text{max}}$

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 $M_{max}$
   - 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

\[f_v = \frac{T}{c_1ab^2}\]

<table>
<thead>
<tr>
<th>(a/b)</th>
<th>(c_1)</th>
<th>(c_2)</th>
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<td>1.0</td>
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<td>0.1406</td>
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<td>1.2</td>
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<tr>
<td>(\infty)</td>
<td>0.333</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

![Diagram of Joists & Rafters]

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

<table>
<thead>
<tr>
<th>Joint Size</th>
<th>Spacing (in)</th>
<th>Spacing (mm)</th>
<th>Modulus of Elasticity, E, in 1,000,000 psi</th>
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<td>10-0</td>
<td>13-6</td>
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<td>16.0</td>
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<td>15-4</td>
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<td>19.2</td>
<td>13-6</td>
<td>16-8</td>
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<td></td>
<td>24.0</td>
<td>14-10</td>
<td>17-12</td>
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<tr>
<td>2 x 8</td>
<td>12.0</td>
<td>13-2</td>
<td>14-6</td>
</tr>
<tr>
<td></td>
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<td>16.0</td>
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<td>Fb</td>
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<td>24.0</td>
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DESIGN CRITERIA:
Deflection — For 40 psf (192 kN/m²) live load, limited to span in inches (mm) divided by 360.
Strength — Live load of 40 psf (192 kN/m²) plus dead load of 10 psf (48 kN/m²) determines the

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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

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

![Diagram of approximate depths for timber systems]

**Approximate depths**

- **Planking:** $L/25-L/35$
- **Joists:** $L/18-L/20$
- **Stressed-skin panels:** $L/24-L/30$
- **Laminated beams:** $L/18-L/20$
- **Box beams:** $L/18-L/20$
- **Trussed rafters:** $L/5-L/7$
- **Open-web joists:** $L/18-L/20$
- **Flat trusses:** $L/10-L/15$
- **Shaped trusses:** $L/7-L/10$
- **Plywood folded plates:** $L/7-L/12$
- **Laminated arches:** $L/4-L/6$

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

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