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:
    \[
    f_b \leq F'_b = F_b \times \text{(product of adjustment factors)}
    \]

Wood Properties

- cell structure and density

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

Timber properties include:
- cell structure and density
- specific gravity
- hardness

Wood properties vary by:
- Wood type
- Moisture content
- Direction of analysis

Wood construction:
materials & beams

- lightweight: strength ~ like steel
- strengths vary
  - by wood type
  - by direction
  - by “flaws”
- size varies by tree growth
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- manufactured wood
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Wood Properties

- cell structure and density

http://www.swst.org/teach/set2/struct1.html

hardwood

softwood
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

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
    • > 12” depth
    $C_F = (12 / d)^{1/6} \leq 1.0$

Fig. 9.23 (pg 477)
**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

**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:
    - $\Delta_T$ max from $LL + 0.5(DL)$

- $C_r$ = repetitive member factor
- $C_H$ = shear stress factor
- $C_V$ = volume factor
- $C_L$ = beam stability factor
- $C_c$ = curvature factor for laminated arches
**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 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>
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<tbody>
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<td>Roof beams:</td>
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<td>L/120</td>
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<td>Commercial</td>
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<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>
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<tr>
<td>Floor beams:</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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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 $S_{req'}$ ($f_b \leq F_b$)

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
   \( f_v \leq F_v \)
   \[
   f_{v,\text{max}} = \frac{3V}{2A} \approx \frac{V}{A_{\text{web}}}
   \]
   - rectangles and W's
   - general
   \[
   f_{v,\text{max}} = \frac{VQ}{I_b}
   \]

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
     \[
     f_v = \frac{T}{c_1 ab^2}
     \]

Beam Design

9. Evaluate deflections
   \[
   \Delta_{\text{max}}(x) = \Delta_{\text{actual}} \leq \Delta_{\text{allowable}}
   \]

<table>
<thead>
<tr>
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<tr>
<td>\infty</td>
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**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)
  - (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

**Approximate Depths**

![Approximate Depths Graph]

**Timber Elements**

- arches and lamellas
  - arches commonly laminated timber
  - long spans
  - usually only for roofs