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:

$$f_b \leq F_b' = F_b \times (\text{product of adjustment factors})$$

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/sw2/struct1.html

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Wood Properties

• moisture
  – exchanges with air easily
  – excessive drying causes warping and shrinkage
  – strength varies some

• temperature
  – steam
  – volatile products
  – combustion

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
  – $C_D = \text{load duration factor}$
  – $C_M = \text{wet service factor}$
    • 1.0 dry $\leq$ 16% MC
  – $C_F = \text{size factor}$
    • visually graded sawn lumber and round timber $> 12''$ depth

\[ C_F = \left( \frac{12}{d} \right)^{0.6} \leq 1.0 \]

Table 10.3 (pg 376)
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
  – $C_r$ = 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:
    • $\Delta_T$ 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 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>
<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>

- **Beam Design Criteria**

- **superpositioning**
  - use of beam charts
  - elastic range only!
  - “add” moment diagrams
  - “add” deflection CURVES (not maximums)

[Diagram of superpositioning]
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 $S_{req'd} \left( f_b \leq F_b \right)$

4. Determine section size $S = \frac{bh^2}{6}$

Timber Beam Bracing

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
   - \( f_v \leq F_v \)
   - 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
     \[
     f_v = \frac{T}{c_1 ab^2}
     \]

Beam Design

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

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

Timber Elements

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