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:

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

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

[Diagram of wood structure and density]

[Images of hardwood and softwood]

http://www.swst.org/teach/swst2/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/wood/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
  - $C_D = \text{load duration factor}$
  - $C_M = \text{wet service factor}$
    - 1.0 dry $\leq$ 16% MC
  - $C_F = \text{size factor}$
    - visually graded sawn lumber and round timber > 12” depth

$$C_F = \left( \frac{12}{d} \right)^{0.9} \leq 1.0$$

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
    • strong
  – $F_v$: horizontal shear stress
  – $F_{c,\perp}$: compression stress
    (perpendicular to grain)
  – $F_c$: compression stress
    (parallel to grain)
    • strong
  – $E$: 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

\[ \frac{1}{R} = \frac{M}{EI} \]

\[ \text{curvature} = \frac{M(x)}{EI} \]

\[ \theta = \text{slope} = \int \frac{M(x)}{EI} \, dx \]

\[ \Delta = \text{deflection} = \int \int \frac{M(x)}{EI} \, dx \]

Beam Design Criteria

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

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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<tr>
<td>Roof beams:</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>
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<tr>
<td>Floor beams:</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>
<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 $I_y$

Design Procedure

1. Know $F_{all}$ for the material or $F_{U}$ for LRFD

2. Draw $V$ & $M$, finding $M_{max}$

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

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
   \[ y_{\text{max}}(x) = \Delta_{\text{actual}} \leq \Delta_{\text{allowable}} \]
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)
  - (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

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**Approximate Depths**

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**Timber Elements**

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