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

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

[Diagram: wood properties]

[Hardwood and softwood images]
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
  – $C_D$ = 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
    \[
    C_F = \left( \frac{12}{d} \right)^{1/6} \leq 1.0
    \]

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
  – $F_c$: compression stress (perpendicular to grain)
  – $F_{c,\parallel}$: 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 Design Criteria

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

### 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>Roof beams:</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>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 $S = \frac{bh^2}{6}$

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
   \( f_v \leq F_v \)
   - \( f_v \) for 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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**Timber Elements**

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

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**Approximate Depths**

![Approximate Depths Diagram](image-url)