Wood Beam Design

- **National Design Specification**
  - National Forest Products Association
  - ASD & LRFD

  - 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
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/sed/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
    
    $C_F = \left( \frac{12}{d} \right)^{\frac{1}{3}} \leq 1.0$

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**
  - $C_r$ = 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
  - $F_{c\bot}$: 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**
  - $(\text{dead loads})/0.9$
  - $(\text{dead loads} + \text{any possible combination of live loads})/C_D$

- **deflection limits**
  - no load factors
  - for stiffer members:
    - $\Delta_T \text{ max from } \text{LL} + 0.5(\text{DL})$
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)

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>Roof beams:</td>
<td></td>
<td></td>
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<tr>
<td>Industrial</td>
<td>L/180</td>
<td>L/120</td>
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<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>
<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>

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

\( (f_v \leq F_v) \)

- $W$ and rectangles \[
f_{v-max} = \frac{3V}{2A} \approx \frac{V}{A_{web}}
\]

- general \[
f_{v-max} = \frac{VQ}{lb}
\]

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

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

Joists & Rafters

- allowable load tables
- allowable length tables for common live & dead loads
- lateral bracing needed
- common spacings

LRFD

- factored loads & reduced nominal capacity

\[ M_u = \gamma_D M_D + \gamma_L M_L \leq \phi_b M_n \]

- \( \phi_b \) - Resistance factor
- \( \gamma \) - Load factor for (D)ead & (L)ive load
- nominal adjusted – no \( C_D \)

\[ M_n = F_{bn} \times S \]

\[ F_{bn} = F_{bn} (\phi_b) (\lambda) (\text{product of adjustment factors}) \]

\[ F_{bn} = F_b \times K_F \text{ (conversion factor)} \]
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
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

<table>
<thead>
<tr>
<th>Approximate Depths</th>
<th>Feet</th>
<th>Meters</th>
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<tbody>
<tr>
<td>Purlins</td>
<td>4/16</td>
<td>0.31</td>
</tr>
<tr>
<td>Joists</td>
<td>1/8-1/2</td>
<td>0.13-0.16</td>
</tr>
<tr>
<td>Structural-wood</td>
<td>1/8-1/2</td>
<td>0.13-0.16</td>
</tr>
<tr>
<td>Box beams</td>
<td>1/8-1/2</td>
<td>0.13-0.16</td>
</tr>
<tr>
<td>Trussed rafters</td>
<td>1/8-1/2</td>
<td>0.13-0.16</td>
</tr>
<tr>
<td>Open-web plates</td>
<td>1/8-1/2</td>
<td>0.13-0.16</td>
</tr>
<tr>
<td>Flat trusses</td>
<td>1/8-1/2</td>
<td>0.13-0.16</td>
</tr>
<tr>
<td>Shoped trusses</td>
<td>1/8-1/2</td>
<td>0.13-0.16</td>
</tr>
<tr>
<td>Plywood</td>
<td>1/8-1/2</td>
<td>0.13-0.16</td>
</tr>
<tr>
<td>Laminated arches</td>
<td>1/8-1/2</td>
<td>0.13-0.16</td>
</tr>
</tbody>
</table>

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