Wood Beam Analysis and Design

- ASD approach
- NDS criteria
- Wood Beam Analysis
- Wood Beam Design

Allowable Stresses

From the NDS Supplement

<table>
<thead>
<tr>
<th>USE WITH TABLE 4A ADJUSTMENT FACTORS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Species and commercial grade</td>
</tr>
<tr>
<td>-------------------------------</td>
</tr>
<tr>
<td>機關 or species</td>
</tr>
<tr>
<td>Heartwood or Sesh</td>
</tr>
<tr>
<td>Heartwood or Sesh</td>
</tr>
<tr>
<td>Heartwood or Sesh</td>
</tr>
<tr>
<td>Heartwood or Sesh</td>
</tr>
<tr>
<td>Heartwood or Sesh</td>
</tr>
</tbody>
</table>
Allowable Stress Design by NDS

**Flexure**

\[ f_b' \geq f_b \]

**Allowable Flexure Stress** \( f_b' \)

- \( f_b' \) from NDS Supplement tables determined by species and grade
- \( f_b' = f_b \) (usage factors)
- Usage factors for flexure:
  - \( C_0 \): Load Duration Factor
  - \( C_M \): Moisture Factor
  - \( C_t \): Temperature Factor
  - \( C_b \): Beam Stability Factor
  - \( C_s \): Size Factor
  - \( C_F \): Flat Use Factor
  - \( C_i \): Incising Factor
  - \( C_r \): Repetitive Member Factor

**Actual Flexure Stress** \( f_b \)

\[ f_b = \frac{M_c}{I} = \frac{M}{S} \]

\[ S = \frac{I}{c} = \frac{bd^2}{6} \]

---

**Shear**

\[ F_v' \geq f_v \]

**Allowable Shear Stress** \( F_v' \)

- \( F_v' \) from tables determined by species and grade
- \( F_v' = F_v \) (usage factors)
- Usage factors for shear:
  - \( C_0 \): Load Duration Factor
  - \( C_M \): Moisture Factor
  - \( C_t \): Temperature Factor
  - \( C_i \): Incising Factor

**Actual Shear Stress** \( f_v \)

\[ f_v = \frac{VQ}{I} / l b = 1.5 \frac{V}{A} \]

Can use \( V \) at \( d \) from support as maximum

---

*Shear at Supports*
Allowable Stress Design by NDS Compression

Allowable Compression Stress $F'_c$

$F'_c$ from NDS Supplement tables determined by species and grade

$F'_c = F_c$ (usage factors)

usage factors for flexure:
- $C_D$ Load Duration Factor
- $C_M$ Moisture Factor
- $C_T$ Temperature Factor
- $C_f$ Size Factor
- $C_i$ Incising Factor
- $C_p$ Column Stability Factor

Actual Compression Stress $f_c$

$f_c = P/A$

Adjustment Factors

Table 4.3.1 Applicability of Adjustment Factors for Sawn Lumber

<table>
<thead>
<tr>
<th></th>
<th>ASD only</th>
<th>ASD and LRFD</th>
<th>LRFD only</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Load Duration Factor</td>
<td>Wet Service Factor</td>
<td>Temperature Factor</td>
</tr>
<tr>
<td>$F_b' = F_b$</td>
<td>$x$</td>
<td>$C_D$</td>
<td>$C_M$</td>
</tr>
<tr>
<td>$F_t' = F_t$</td>
<td>$x$</td>
<td>$C_D$</td>
<td>$C_M$</td>
</tr>
<tr>
<td>$F_s' = F_s$</td>
<td>$x$</td>
<td>$C_D$</td>
<td>$C_M$</td>
</tr>
<tr>
<td>$F_{cl}' = F_{cl}$</td>
<td>$x$</td>
<td>$- - - -$</td>
<td>$C_b$</td>
</tr>
<tr>
<td>$F_p' = F_p$</td>
<td>$x$</td>
<td>$C_D$</td>
<td>$C_M$</td>
</tr>
<tr>
<td>$E' = E$</td>
<td>$x$</td>
<td>$- - - -$</td>
<td>$C_i$</td>
</tr>
<tr>
<td>$E_{min}' = E_{min}$</td>
<td>$x$</td>
<td>$- - - -$</td>
<td>$C_i$</td>
</tr>
</tbody>
</table>
Adjustment Factors

Allowable Flexure Stress $F_b'$

$F_b'$ from tables determined by species and grade

$F_b' = F_b (C_D C_M C_f C_l C_f C_r) \quad (1)$

Usage factors for flexure:

- $C_D$ Load Duration Factor
- $C_M$ Load Modification Factor
- $C_l$ Live Load Duration Factor
- $C_f$ Frequency Factor
- $C_r$ Reduction Factor

### Table 2.3.2 Frequently Used Load Duration Factors, $C_D$

<table>
<thead>
<tr>
<th>Load Duration</th>
<th>$C_D$</th>
<th>Typical Design Loads</th>
</tr>
</thead>
<tbody>
<tr>
<td>Permanent</td>
<td>0.9</td>
<td>Dead Load</td>
</tr>
<tr>
<td>Ten years</td>
<td>1.0</td>
<td>Occupancy Live Load</td>
</tr>
<tr>
<td>Two months</td>
<td>1.15</td>
<td>Snow Load</td>
</tr>
<tr>
<td>Seven days</td>
<td>1.25</td>
<td>Construction Load</td>
</tr>
<tr>
<td>Ten minutes</td>
<td>1.6</td>
<td>Wind/Earthquake Load</td>
</tr>
<tr>
<td>Impact$^2$</td>
<td>2.0</td>
<td>Impact Load</td>
</tr>
</tbody>
</table>

1. Actual stress due to (DL) $\leq (0.9) \text{ (Design value)}$
2. Actual stress due to (DL+LL) $\leq (1.0) \text{ (Design value)}$
3. Actual stress due to (DL+WL) $\leq (1.6) \text{ (Design value)}$
4. Actual stress due to (DL+LL+SL) $\leq (1.15) \text{ (Design value)}$
5. Actual stress due to (DL+LL+WL) $\leq (1.6) \text{ (Design value)}$
6. Actual stress due to (DL+LL+SL+WL) $\leq (1.6) \text{ (Design value)}$

### Table 2.3.3 Temperature Factor, $C_t$

<table>
<thead>
<tr>
<th>Reference Design Values</th>
<th>In-Service Moisture Conditions$^1$</th>
<th>$C_t$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$F_r$, $E_r$, $E_{min}$</td>
<td>Wet or Dry</td>
<td>1.0</td>
</tr>
<tr>
<td>$F_r$, $F_r$, $F_f$, and $F_{LL}$</td>
<td>Dry</td>
<td>1.0</td>
</tr>
<tr>
<td></td>
<td>Wet</td>
<td>1.0</td>
</tr>
</tbody>
</table>

1. Wet and dry service conditions for sawn lumber, structural glued laminated timber, prefabricated wood I-joists, structural composite lumber, wood structural panels and cross-laminated timber are specified in 4.1.4, 5.1.4, 7.1.4, 8.1.4, 9.3.3, and 10.1.5 respectively.
**Adjustment Factors**

**Allowable Flexure Stress $F_b'$**

$F_b'$ from NDS tables

$$F_b' = F_b \left( C_D \ C_M \ C_t \ C_L \ C_F \ C_{fu} \ C_i \ C_r \right)$$

Usage factors for flexure:
- $C_M$ Moisture Factor
- $C_F$ Size Factor

---

**Wet Service Factor, $C_m$**

When dimension lumber is used where moisture content will exceed 19% for an extended time period, design values shall be multiplied by the appropriate wet service factors from the following table:

<table>
<thead>
<tr>
<th>Wet Service Factors, $C_m$</th>
<th>$F_b$</th>
<th>$F_i$</th>
<th>$F_s$</th>
<th>$F_{li}$</th>
<th>$F_u$</th>
<th>$E$ and $E_{min}$</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0.85*</td>
<td>1.0</td>
<td>0.97</td>
<td>0.67</td>
<td>0.8**</td>
<td>0.9</td>
</tr>
</tbody>
</table>

* when $(F_b/C_i) \leq 1.150$ psi, $C_m = 1.0$

**Usage Factors for Flexure:entiful**

- $C_{fu}$ Flat Use
- $C_r$ Repetitive Member Factor

---

**Flat Use Factor, $C_{fu}$**

Bending design values adjusted by size factors are based on edgewise use (load applied to narrow face). When dimension lumber is used flatwise (load applied to wide face), the bending design value, $F_{fu}$, shall also be permitted to be multiplied by the following flat use factors:

<table>
<thead>
<tr>
<th>Flat Use Factors, $C_{fu}$</th>
<th>Width (depth)</th>
<th>Thickness (breadth)</th>
<th>2&quot; &amp; 3&quot;</th>
<th>4&quot;</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>2&quot; &amp; 3&quot;, 4&quot;</td>
<td></td>
<td>1.0</td>
<td>1.0</td>
</tr>
<tr>
<td></td>
<td>4&quot;, 5&quot;, 6&quot;</td>
<td></td>
<td>1.1</td>
<td>1.1</td>
</tr>
<tr>
<td></td>
<td>8&quot; &amp; wider</td>
<td>Use No. 3 grade tabulated design values and size factors</td>
<td>1.0</td>
<td>1.0</td>
</tr>
</tbody>
</table>

---

**Ripetitive Member Factor, $C_r$**

Bending design values, $F_r$, for dimension lumber 2" to 4" thick shall be multiplied by the repetitive member factor, $C_r = 1.15$; when such members are used as joists, truss chords, rafters, studs, planks, decking, or similar members which are in contact or spaced not more than 24" on center, are not less than 3 in number and are joined by floor, roof, or other load distributing elements adequate to support the design load.
Adjustment Factors

Allowable Flexure Stress $F'_{b}$

$F'_{b} = F_{b} \left( C_{D} C_{M} C_{I} C_{L} C_{F} C_{fu} C_{i} C_{r} \right)$

Usage factors for flexure:

- $C_{i}$ Incising Factor

### Table 4.3.8 Incising Factors, $C_{i}$

<table>
<thead>
<tr>
<th>Design Value</th>
<th>$C_{i}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$E$, $E_{min}$</td>
<td>0.95</td>
</tr>
<tr>
<td>$F_{b}$, $F_{v}$, $F_{v}$, $F_{v}$</td>
<td>0.80</td>
</tr>
<tr>
<td>$F_{uv}$</td>
<td>1.00</td>
</tr>
</tbody>
</table>

### 4.4.1 Stability of Bending Members

- **2x4**  
  (a) $d/b \leq 2$; no lateral support shall be required.
- **2x8-8**  
  (b) $2 < d/b \leq 4$; the ends shall be held in position; as by full depth solid blocking, bridging, hangers, nailing, or bolting to other framing members, or other acceptable means.
- **2x10**  
  (c) $4 < d/b \leq 5$; the compression edge of the member shall be held in line for its entire length to prevent lateral displacement, as by adequate sheathing or subflooring, and ends at point of bearing shall be held in position to prevent rotation and/or lateral displacement.
- **2x12**  
  (d) $5 < d/b \leq 6$; bridging, full depth solid blocking or diagonal cross bracing shall be installed at intervals not exceeding 8 feet, the compression edge of the member shall be held in line as by adequate sheathing or subflooring, and the ends at points of bearing shall be held in position to prevent rotation and/or lateral displacement.
- **2x14**  
  (e) $6 < d/b \leq 7$; both edges of the member shall be held in line for their entire length and ends at points of bearing shall be held in position to prevent rotation and/or lateral displacement.

3.3.3 Beam Stability Factor, $C_{L}$

3.3.3.1 When the depth of a bending member does not exceed its breadth, $d \leq b$, no lateral support is required and $C_{L} = 1.0$.

3.3.3.2 When rectangular sawn lumber bending members are laterally supported in accordance with 4.4.1, $C_{L} = 1.0$.

3.3.3.3 When the compression edge of a bending member is supported throughout its length to prevent lateral displacement, and the ends at points of bearing have lateral support to prevent rotation, $C_{L} = 1.0$.

2012 NDS
**$C_L$ Beam Stability Factor**

In the case bracing provisions of 4.4.1 cannot be met, $C_L$ is calculated using equation 3.3.6

**The maximum allowable slenderness, $R_b$ is 50**

### Table 3.3.3 Effective Length, $l_{eq}$ for Bending Members

<table>
<thead>
<tr>
<th>Case</th>
<th>$l_{eq}$ when $l_{cr}d &lt; 7$</th>
<th>$l_{eq}$ when $l_{cr}d &gt; 7$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cantilever(^1)</td>
<td>$\ell' = 1.33 \ell_d$</td>
<td>$\ell' = 0.9 \ell_d + 3d$</td>
</tr>
<tr>
<td>Uniformly distributed load</td>
<td>$\ell' = 1.87 \ell_d$</td>
<td>$\ell' = 1.44 \ell_d + 3d$</td>
</tr>
<tr>
<td>Concentrated load at unsupported end</td>
<td>$\ell' = 1.2 \ell_d$</td>
<td>$\ell' = 0.85 \ell_d + 3d$</td>
</tr>
<tr>
<td>Single Span Beam(^2)</td>
<td>$\ell' = 2.06 \ell_d$</td>
<td>$\ell' = 1.63 \ell_d + 3d$</td>
</tr>
<tr>
<td>Uniformly distributed load</td>
<td>$\ell' = 1.1 \ell_d$</td>
<td>$\ell' = 0.7 \ell_d + 3d$</td>
</tr>
<tr>
<td>Concentrated load at center with lateral support</td>
<td>$\ell' = 1.3 \ell_d$</td>
<td>$\ell' = 0.9 \ell_d + 3d$</td>
</tr>
<tr>
<td>Concentrated load at center with lateral support at center</td>
<td>$\ell' = 1.11 \ell_d$</td>
<td>$\ell' = 0.78 \ell_d + 3d$</td>
</tr>
<tr>
<td>Two equal concentrated loads at 1/3 points with lateral support at 1/3 points</td>
<td>$\ell' = 1.54 \ell_d$</td>
<td>$\ell' = 1.16 \ell_d + 3d$</td>
</tr>
<tr>
<td>Three equal concentrated loads at 1/4 points with lateral support at 1/4 points</td>
<td>$\ell' = 1.66 \ell_d$</td>
<td>$\ell' = 1.28 \ell_d + 3d$</td>
</tr>
<tr>
<td>Four equal concentrated loads at 1/5 points with lateral support at 1/5 points</td>
<td>$\ell' = 1.68 \ell_d$</td>
<td>$\ell' = 1.33 \ell_d + 3d$</td>
</tr>
<tr>
<td>Five equal concentrated loads at 1/6 points with lateral support at 1/6 points</td>
<td>$\ell' = 1.75 \ell_d$</td>
<td>$\ell' = 1.38 \ell_d + 3d$</td>
</tr>
<tr>
<td>Six equal concentrated loads at 1/7 points with lateral support at 1/7 points</td>
<td>$\ell' = 1.86 \ell_d$</td>
<td>$\ell' = 1.43 \ell_d + 3d$</td>
</tr>
<tr>
<td>Seven or more equal concentrated loads, evenly spaced, with lateral support at points of load application</td>
<td>$\ell' = 2.07 \ell_d$</td>
<td>$\ell' = 1.5 \ell_d + 3d$</td>
</tr>
<tr>
<td>Equal end moments</td>
<td>$\ell' = 1.34 \ell_d$</td>
<td>$\ell' = 0.9 \ell_d + 3d$</td>
</tr>
</tbody>
</table>

1. For simple-span or continuous members with loading conditions not specified in Table 3.3.3:
   \[ \ell' = 1.67 \ell_d \quad \text{when} \quad \ell < 1.2 \ell_d \]
   \[ \ell' = 1.2 \ell_d \quad \text{when} \quad \ell > 1.2 \ell_d \]

2. Multiple span applications shall be based on tabular values or engineering analysis.

### 3.3.3.6 The slenderness ratio, $R_b$, for bending members shall be calculated as follows:

\[
R_b = \sqrt{\frac{l_{cr}d}{D^2}}
\]  \hspace{1cm} (3.3-5)

### 3.3.3.7 The slenderness ratio for bending members, $R_b$, shall not exceed 50.

### 3.3.3.8 The beam stability factor shall be calculated as follows:

\[
C_L = \frac{1 + (F_{rb}/F_0)}{1.9} - \left[ \frac{1 + (F_{rb}/F_0)}{1.9} \right]^2 \left( \frac{F_{rb}/F_0}{0.95} \right)
\]  \hspace{1cm} (3.3-6)

where:

- $F_{rb} = \text{reference bending design value multiplied by all applicable adjustment factors except } C_L, C_v$ (when $C_v \leq 1.0$), and $G_i$ (see 2.3), psi
- $F_{rb} = \frac{1.20 F_{ego}}{R_b^2}$
- $C_v = \text{structural stability factor}$
Adjustment Factors for Shear

Allowable Flexure Stress $F_v'$

$F_v$ from tables determined by species and grade

$F_v' = F_v \text{ (usage factors)}$

Usage factors for shear:

- $C_D$: Load Duration Factor
- $C_M$: Moisture Factor
- $C_t$: Temperature Factor
- $C_i$: Incising Factor

Analysis Procedure

Given: loading, member size, material and span.

Req'd: Safe or Unsafe (Pass/Fail)

1. Find Max Shear & Moment
   - Simple case – equations
   - Complex case - diagrams

2. Determine actual stresses
   - $f_b = M/S$
   - $f_v = 1.5 \cdot V/A$

3. Determine allowable stresses
   - $F_b$, and $F_v$ (from NDS)
   - $F_b' = F_b \text{ (usage factors)}$
   - $F_v' = F_v \text{ (usage factors)}$

4. Check that actual $\leq$ allowable
   - $f_b \leq F_b'$
   - $f_v \leq F_v'$

5. Check deflection

6. Check bearing ($F_{cl} \geq \frac{\text{Reaction}}{A_{bearing}}$) from NDS 2012
Analysis Example

Example – Pass / Fail

**Given:** loading, member size, material and span.

**Req’d:** Safe or Unsafe?

### Analysis Example

1. **Find Max Shear & Moment**
   - Simple cases – equations
   - Complex cases - diagrams

By equations:

\[
V = \frac{P}{2} = \frac{145}{2} = 72.5\text{ kips}
\]

\[
M_{\text{c}} = \frac{PL}{4} = \frac{145(6)}{4} = 217.5\text{ kip-ft}
\]

By Diagrams:
Analysis Example

2. Determine actual stresses
   - $f_b = \frac{M}{S}$
   - $f_v = 1.5 \frac{V}{A}$

$$f_b = \frac{M}{S_x} = \frac{b d^2}{6} \frac{1.5 (3.5)^2}{3} = 3.063 \text{ psi}$$

$$f_v = \frac{3}{2} \frac{V}{A} = 1.5 \left( \frac{72.5}{5.25} \right) = 20.71 \text{ psi}$$

Species and Grade

S-P-F No.2

$F_b = 875 \text{ psi}$

$F_v = 135 \text{ psi}$

Table 4A Reference Design Values for Visually Graded Dimension Lumber (2" - 4" thick)¹,²,³

(All species except Southern Pine—see Table 4B) (Tabulated design values are for normal load duration and dry service conditions. See NDS 4.3 for a comprehensive description of design value adjustment factors.)
Analysis Example

3. Determine allowable stresses
   - $F_b = 875$ psi
   - $F_v = 135$ psi

Determine factors:

<table>
<thead>
<tr>
<th>CD</th>
<th>CM</th>
<th>Ct</th>
<th>CL</th>
<th>CF</th>
<th>Cfu</th>
<th>Ci</th>
<th>Cr</th>
</tr>
</thead>
<tbody>
<tr>
<td>?</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>?</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
</tbody>
</table>

Adjustment Factors

<table>
<thead>
<tr>
<th>Allowable Flexure Stress $F_b'$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$F_b$ from tables determined by species and grade</td>
</tr>
<tr>
<td>$F_b' = F_b (C_D C_M C_I C_L C_F C_{fu} C_i C_r)$</td>
</tr>
</tbody>
</table>

Usage factors for flexure:

- $C_L$ Beam Stability Factor

3.3.3 Beam Stability Factor, $C_L$

3.3.3.1 When the depth of a bending member does not exceed its breadth, $d \leq b$, no lateral support is required and $C_L = 1.0$.

3.3.3.2 When rectangular sawn lumber bending members are laterally supported in accordance with 4.4.1, $C_L = 1.0$.

3.3.3.3 When the compression edge of a bending member is supported throughout its length to prevent lateral displacement, and the ends at points of bearing have lateral support to prevent rotation, $C_L = 1.0$.

Table 4.3.1 Applicability of Adjustment Factors for Sawn Lumber

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<th>LRFD only</th>
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<tbody>
<tr>
<td>Load Duration Factor</td>
<td>Wet Service Factor</td>
<td>Temperature Factor</td>
</tr>
<tr>
<td>$F_b' = F_b$</td>
<td>$x$</td>
<td>$C_D$</td>
</tr>
<tr>
<td>$F_v' = F_v$</td>
<td>$x$</td>
<td>$C_D$</td>
</tr>
</tbody>
</table>

4.4.1 Stability of Bending Members

2x4 (a) $d/b \leq 2$; no lateral support shall be required.
2x8-8 (b) $2 < d/b \leq 4$; the ends shall be held in position; as by full depth solid blocking, bridging, nailing, or bolting to other framing members, or other acceptable means.
2x10 (c) $4 < d/b \leq 5$; the compression edge of the member shall be held in line for its entire length to prevent lateral displacement, as by adequate sheathing or subflooring, and the ends at point of bearing shall be held in position to prevent rotation and/or lateral displacement.
2x12 (d) $5 < d/b \leq 6$; bridging, full depth solid blocking or diagonal cross bracing shall be installed at intervals not exceeding 8 feet. the compression edge of the member shall be held in line as by adequate sheathing or subflooring, and the ends at points of bearing shall be held in position to prevent rotation and/or lateral displacement.
2x14 (e) $6 < d/b \leq 7$; both edges of the member shall be held in line for their entire length and ends at points of bearing shall be held in position to prevent rotation and/or lateral displacement.
Analysis Example

C_D Load duration factor
Use 1.6 (10 minutes)

C_F Size factor
2 x 4
use 1.5

3. Determine allowable stresses
   \[ F_{b}' = F_b \cdot (C_D)(C_F) \]
   \[ F_{b}' = 875 \times 1.6 \times 1.5 = 2100 \text{ psi} \]

   \[ F_{v}' = F_v \cdot (C_D) \]
   \[ F_{v}' = 135 \times 1.6 = 216 \text{ psi} \]

4. Check that actual ≤ allowable
   \[ f_b < F_{b}' \]
   \[ f_v < F_{v}' \]

5. Check deflection

6. Check bearing (\( F_{c,\bot} \geq R/A_b \))
Analysis Procedure

Given: member size, material and span.
Req’d: Max. Safe Load (capacity)

1. Assume $f = F'$
   - Maximum actual = allowable stress

2. Solve stress equations for force
   - $M = F_b S$
   - $V = 0.66 F_v A$

3. Use maximum moment to find loads
   - Back calculate a load from moment
   - Assumes moment controls

4. Check Shear
   - Use load found in step 3 to check shear stress.
   - If it fails ($fv > F'v$), then find load based on shear.

5. Check deflection
6. Check bearing

Analysis Example

Given: member size, material and span.
Req’d: Max. Safe Load (capacity)

1. Assume $f = F'$
   - Maximum actual = allowable stress

2. Solve stress equation for moment
   - $M = F_b S$ (i.e. moment capacity)
Analysis Example (cont.)

3. **Use maximum forces to find loads**
   - Back calculate a maximum load from moment capacity

\[
M_d = \frac{PL}{4} \\
P = \frac{M_d A}{L} \\
P = \frac{536 (4)}{10} \\
P = 357 \text{ kN}
\]

4. **Check shear**
   - Check shear for load capacity from step 3.
   - Use \( P \) from moment to find \( V_{\text{max}} \)
   - Check that \( f_v < F_v' \)

\[
V_{\text{max}} = \frac{P}{2} = \frac{357}{2} = 178.5 \text{ kN} \\
f_v = \frac{3V_{\text{max}}}{2A} = \frac{3 \times 178.5}{2 \times 50} = 51 \text{ psi} \\
51 \text{ psi} < 180 \text{ psi} \quad \text{OK}
\]

4. **Check deflection** (serviceability)
5. **Check bearing** (serviceability)

---

### Analysis Example

**Given:** loading, member size, material and span.

**Req'd:** Safe or Unsafe

3. **Wood Beam Analysis**

   Analyze the given 4x dimensioned lumber beam to determine if it passes or fails the NDS code criteria. The beam carries both dead and live floor load plus its own self weight. Assume normal temperature, and no incising (\( C_l = C_i = 1.0 \)). Find the beam self-weight including the given moisture content. The beam is braced at the ends and the C.L. (meets criteria in 4.4.1) so \( C_l = 1.0 \).

<table>
<thead>
<tr>
<th>DATASET: 1</th>
<th>2</th>
<th>3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wood Species</td>
<td>HEM-FIR</td>
<td>Select Structural</td>
</tr>
<tr>
<td>Wood Grade</td>
<td>16 FT</td>
<td>12 FT</td>
</tr>
<tr>
<td>Span A</td>
<td>16 FT</td>
<td>12 IN</td>
</tr>
<tr>
<td>Span B</td>
<td>15 %</td>
<td>7 PSF</td>
</tr>
<tr>
<td>Nominal Depth of Beam, d</td>
<td>35 PSF</td>
<td></td>
</tr>
</tbody>
</table>
Analysis Example

Find Specific Gravity for Hem-Fir

- (from NDS)

### Analysis Example

#### Section Properties:

**4 x 12 (3.5" x 11.25")**

- Area = 39.38 in²

- Sx = 73.83 in³
Analysis Example

Determine Loading

- Floor loading (D+L)
  - Find Tributary area, \( A_T \)
    \[ 6' \times 8' = 48 \text{ SF} \]

\[
\begin{align*}
D_L &= 7 \text{ psf} \\
L_L &= 35 \text{ psf} \\
\text{TOTAL} &= 41.2 \text{ psf}
\end{align*}
\]

\[
P = A_T \times \text{psf} = 48 \times 4.2 = 201.6^* 
\]

- Determine member selfweight (w)

Selfweight of member:

Density at 0 m.c. = 62.4 x G (dry)
62.4 x 0.43 = 26.8 PCF

m.c. = 15% (given)

To include m.c. use NDS formula.

\[
D = 62.4 \left[ \frac{0.43}{1 + 0.43(0.009)(15)} \right] \left[ 1 + \frac{15}{100} \right] 
\]

\[
25.35 \times 1.15 = 29.16 \text{ PCF}
\]

\[
w = \text{PLF} = \frac{D \times \text{AREA}}{144} = 29.16 \times \frac{39.38}{144} \\
w = 7.975 \text{ plf}
\]

The following formula shall be used to determine the density in lbs/ft³ of wood:

\[
density = 62.4 \left[ \frac{G}{1 + G(0.009)(\text{m.c.})} \right] \left[ 1 + \frac{\text{m.c.}}{100} \right]
\]

where:

- G = specific gravity of wood
- m.c. = moisture content of wood, %
Analysis Example

Determine Beam Forces

by superposition equations or by diagrams

\[ R = \frac{w_1}{2} + \frac{P}{2} \]
\[ \frac{7.951(12)^2}{2} + \frac{2016}{2} \]
\[ V_{max} = R \]
\[ M_d = \frac{w_1(12)}{8} + \frac{PL}{4} \]
\[ \frac{7.975(12)^2}{8} + \frac{2016(12)}{4} \]
\[ 141.5 + 6048 = 6191.5 \]

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Analysis Example

Determine actual stresses

- \[ f_b = \frac{M}{S} \]
- \[ f_v = \frac{1.5 V}{A} \]

<table>
<thead>
<tr>
<th>Nominal Size</th>
<th>Standard Gross Size (S4S)</th>
<th>Area of Section A</th>
<th>Moment of Inertia Ix</th>
<th>Moment of Inertia Iy</th>
</tr>
</thead>
<tbody>
<tr>
<td>x x</td>
<td>in²</td>
<td>in²</td>
<td>in*</td>
<td>in*</td>
</tr>
<tr>
<td>1 x 2</td>
<td>2 x 2/16</td>
<td>3.750</td>
<td>1.56</td>
<td>1.93</td>
</tr>
<tr>
<td>2 x 4</td>
<td>4 x 2/16</td>
<td>5.250</td>
<td>5.06</td>
<td>11.39</td>
</tr>
<tr>
<td>2 x 6</td>
<td>6 x 2/16</td>
<td>6.250</td>
<td>7.56</td>
<td>20.90</td>
</tr>
<tr>
<td>2 x 8</td>
<td>8 x 2/16</td>
<td>7.250</td>
<td>10.06</td>
<td>41.53</td>
</tr>
<tr>
<td>2 x 10</td>
<td>10 x 2/16</td>
<td>8.250</td>
<td>13.56</td>
<td>88.93</td>
</tr>
<tr>
<td>2 x 12</td>
<td>12 x 2/16</td>
<td>9.250</td>
<td>16.88</td>
<td>150.94</td>
</tr>
<tr>
<td>2 x 14</td>
<td>14 x 2/16</td>
<td>10.250</td>
<td>19.88</td>
<td>290.80</td>
</tr>
<tr>
<td>2 1/2 x 3</td>
<td>3 1/2 x 2</td>
<td>5.750</td>
<td>5.13</td>
<td>5.932</td>
</tr>
<tr>
<td>2 1/2 x 4</td>
<td>4 1/2 x 2</td>
<td>7.750</td>
<td>6.44</td>
<td>18.96</td>
</tr>
<tr>
<td>2 1/2 x 5</td>
<td>5 1/2 x 2</td>
<td>9.750</td>
<td>8.44</td>
<td>34.96</td>
</tr>
<tr>
<td>2 1/2 x 6</td>
<td>6 1/2 x 2</td>
<td>11.750</td>
<td>10.44</td>
<td>61.96</td>
</tr>
<tr>
<td>2 1/2 x 7</td>
<td>7 1/2 x 2</td>
<td>13.750</td>
<td>12.44</td>
<td>92.96</td>
</tr>
<tr>
<td>2 1/2 x 8</td>
<td>8 1/2 x 2</td>
<td>15.750</td>
<td>14.44</td>
<td>124.96</td>
</tr>
<tr>
<td>2 1/2 x 9</td>
<td>9 1/2 x 2</td>
<td>17.750</td>
<td>16.44</td>
<td>157.96</td>
</tr>
<tr>
<td>2 1/2 x 10</td>
<td>10 1/2 x 2</td>
<td>19.750</td>
<td>18.44</td>
<td>190.96</td>
</tr>
<tr>
<td>3 x 2</td>
<td>2 x 2 1/2</td>
<td>6.750</td>
<td>7.53</td>
<td>10.32</td>
</tr>
<tr>
<td>3 x 4</td>
<td>4 x 2 1/2</td>
<td>8.750</td>
<td>8.64</td>
<td>18.96</td>
</tr>
<tr>
<td>3 x 6</td>
<td>6 x 2 1/2</td>
<td>10.750</td>
<td>9.64</td>
<td>34.96</td>
</tr>
<tr>
<td>3 x 8</td>
<td>8 x 2 1/2</td>
<td>12.750</td>
<td>10.64</td>
<td>61.96</td>
</tr>
<tr>
<td>3 x 10</td>
<td>10 x 2 1/2</td>
<td>14.750</td>
<td>11.64</td>
<td>92.96</td>
</tr>
<tr>
<td>3 x 12</td>
<td>12 x 2 1/2</td>
<td>16.750</td>
<td>12.64</td>
<td>124.96</td>
</tr>
<tr>
<td>3 x 14</td>
<td>14 x 2 1/2</td>
<td>18.750</td>
<td>13.64</td>
<td>157.96</td>
</tr>
<tr>
<td>3 x 16</td>
<td>16 x 2 1/2</td>
<td>20.750</td>
<td>14.64</td>
<td>190.96</td>
</tr>
<tr>
<td>4 x 2</td>
<td>2 x 2 1/4</td>
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<td>5.06</td>
<td>11.39</td>
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<td>4 x 2 1/4</td>
<td>7.250</td>
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<td>8.44</td>
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<td>8 x 2 1/4</td>
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<tr>
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<td>10 x 2 1/4</td>
<td>11.750</td>
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<td>61.96</td>
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<tr>
<td>4 x 12</td>
<td>12 x 2 1/4</td>
<td>13.750</td>
<td>14.44</td>
<td>92.96</td>
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<tr>
<td>4 x 14</td>
<td>14 x 2 1/4</td>
<td>15.750</td>
<td>16.44</td>
<td>124.96</td>
</tr>
<tr>
<td>4 x 16</td>
<td>16 x 2 1/4</td>
<td>18.750</td>
<td>18.44</td>
<td>157.96</td>
</tr>
</tbody>
</table>

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Analysis Example

3. Determine allowable stresses
   - \( F_b = 1400 \) psi
   - \( F_v = 150 \) psi

Determine factors:

\[
\begin{align*}
CD &= \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \ quad \ drunken
Analysis Example

Determine allowable stresses
M.C. = 15%    size: 4x12

<table>
<thead>
<tr>
<th>Nominal Size x d</th>
<th>Standard Dressed Size (S5S)</th>
<th>Area of Section A</th>
<th>X-X AXIS</th>
<th>Y-Y AXIS</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>b x d</td>
<td>in.²</td>
<td>in.³</td>
<td>b x d</td>
</tr>
<tr>
<td>Boards</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1 x 3</td>
<td>3/4 x 2-1/2</td>
<td>1.875</td>
<td>0.741</td>
<td>0.977</td>
</tr>
<tr>
<td>1 x 4</td>
<td>3/4 x 3-1/2</td>
<td>2.625</td>
<td>1.531</td>
<td>2.080</td>
</tr>
<tr>
<td>1 x 6</td>
<td>3/4 x 4-1/2</td>
<td>4.125</td>
<td>3.781</td>
<td>10.40</td>
</tr>
<tr>
<td>1 x 8</td>
<td>3/4 x 5-1/4</td>
<td>5.438</td>
<td>5.870</td>
<td>23.82</td>
</tr>
<tr>
<td>1 x 10</td>
<td>3/4 x 6-3/4</td>
<td>6.938</td>
<td>10.70</td>
<td>49.47</td>
</tr>
<tr>
<td>1 x 12</td>
<td>3/4 x 8-1-1/4</td>
<td>8.438</td>
<td>15.62</td>
<td>89.90</td>
</tr>
</tbody>
</table>

Adjustment Factors

Allowable Flexure Stress $F_b' = F_b \left( D_D D_M D_C D_L D_F D_W D_I \right)$

$F_b' = 3.5$ / 11.25 = 3.11 (case b)

Assuming ends are braced, $C_L = 1.0$

4.4.1 Stability of Bending Members

2x4 (a) $d/b \leq 2$; no lateral support shall be required.

2x4-8 (b) $d < b \leq 4$; the ends shall be held in position, as by full depth solid blocking, bridging, hangers, nailing, or bolting to other framing members, or other acceptable means.

2x10 (c) $4 < d/b \leq 5$; the compression edge of the member shall be held in line for its entire length to prevent lateral displacement, as by adequate sheathing or subflooring, and ends at points of bearing shall be held in position to prevent rotation and/or lateral displacement.

2x12 (d) $5 < d/b \leq 6$; bracing, full depth solid blocking or diagonal cross bracing shall be installed at intervals not exceeding 8 feet. The compression edge of the member shall be held in line as by adequate sheathing or subflooring, and the ends at points of bearing shall be held in position to prevent rotation and/or lateral displacement.

2x14 (e) $6 < d/b \leq 7$; both edges of the member shall be held in line for their entire length and ends at points of bearing shall be held in position to prevent rotation and/or lateral displacement.
Analysis Example

3. Determine allowable stresses
   • \( F'_{b} = F_{b} \) (usage factors)

\[
\begin{align*}
F'_{b} &= 1400 (1.1) = 1540 \text{ psi} \\
\text{Actual Stress:} \\
\sigma &= \frac{M_{x}}{I_{x}} = \frac{6191.5(12)}{73.83} = 1004.3 \text{ psi}
\end{align*}
\]

Analysis Example

3. Determine allowable stresses
   • \( F'_{v} = F_{v} \) (usage factors)

\[
\begin{align*}
F'_{v} &= 150 (1.10) = 165 \text{ psi} \\
\sigma &= \frac{3V}{2A} = 1.5 \frac{1055.8}{39.88} = 40.22 \text{ psi}
\end{align*}
\]
Analysis Example

Check that actual $\leq$ allowable

- $f_b \leq F_b'$
- $f_v \leq F_v'$

Check deflection
Check bearing ($F_{cl}$ ≥ Reaction/$A_{bearing}$)

Design Procedure

Given: load, wood, span  
Req'd: member size

1. Find Max Shear & Moment  
   - Simple case – equations
   - Complex case - diagrams

2. Determine allowable stresses

3. Solve $S=M/Fb'$

4. Choose a section from Table 1B  
   - Revise DL and $F_b'$

5. Check shear stress  
   - First for $V_{max}$ (easier)  
   - If that fails try $V$ at $d$ distance from support.
   - If the section still fails, choose a new section with $A=1.5V/F_v'$

6. Check deflection

7. Check bearing
Design Example

Given: load, wood, span
Req'd: member size

1. Find Max Shear & Moment
   • Simple case – equations
   • Complex case - diagrams

2. Determine allowable stresses
   (given in this example)
   \[ F'_b = 1000 \text{ psi} \]
   \[ F'_v = 100 \text{ psi} \]

3. Solve \( S = \frac{M}{F'_b} \)

4. Choose a section from \( S \) table
   • Revise DL and \( F'_b \)

5. Check shear stress
   • First for \( V_{\text{max}} \) (easier)
   • If that fails try \( V \) at \( d \) distance
     (remove load \( d \) from support)
   • If the section still fails, choose a
     new section with \( A = 1.5V/F'_v \)

6. Check deflection
7. Check bearing
Design Example

**Given:** load, wood, span

**Req’d:** member size

### 4. Wood Beam Design

Design a 2x dimensioned lumber floor joist to carry the given dead + live floor load. Assume the floor meets conditions of 4.4.1 & CL=1.0. Also C1, C2U, and CL = 1.0. Find the short term deflection of your chosen beam under live load only (100% LL is sustained). Compare your LL deflection with the code limit of L/360.

<table>
<thead>
<tr>
<th>DATASET: 1 2 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wood Species</td>
</tr>
<tr>
<td>Wood Grade No.</td>
</tr>
<tr>
<td>Span</td>
</tr>
<tr>
<td>Joist Spacing, o.c.</td>
</tr>
<tr>
<td>Moisture Content, m.c.</td>
</tr>
<tr>
<td>Floor DL</td>
</tr>
<tr>
<td>Floor LL</td>
</tr>
</tbody>
</table>

---

Design Example

Determine allowable stresses

- \( F_b \) and \( F_v \) (from NDS)

### Table 4A (Cont.)

**Reference Design Values for Visually Graded Dimension Lumber (2” - 4” thick)\(^1,2,3\)**

(All species except Southern Pine — see Table 4B) (Tabulated design values are for normal load duration and dry service conditions. See NDS 4.3 for a comprehensive description of design value adjustment factors.)

**USE WITH TABLE 4A ADJUSTMENT FACTORS**

<table>
<thead>
<tr>
<th>Species and commercial grade</th>
<th>Size classification</th>
<th>Design values in pounds per square inch (psi)</th>
<th>Modulus of Elasticity</th>
<th>Specific Gravity</th>
<th>Grading Styles Agency</th>
</tr>
</thead>
<tbody>
<tr>
<td>Select Structural</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>WCLIB WWPA</td>
</tr>
<tr>
<td>No. 1 &amp; Btr</td>
<td>7/8” &amp; wider</td>
<td>1,400 925 150      405 1,500 1,000,000 580,000</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>No. 2</td>
<td>7/8” &amp; wider</td>
<td>900 725 150        405 1,350 1,500,000 550,000</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>No. 3</td>
<td>7/8” &amp; wider</td>
<td>850 725            150        405 1,300 1,300,000 470,000</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Std</td>
<td>7/8” &amp; wider</td>
<td>875 600            150        405 800 1,200,000 440,000</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Construction</td>
<td></td>
<td>975 600            150        405 1,550 1,300,000 470,000</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Standard</td>
<td>2” - 4” wide</td>
<td>550 325            150        405 1,300 1,200,000 440,000</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Utility</td>
<td>2” - 4” wide</td>
<td>250 150            150        405 600 1,100,000 400,000</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Design Example

Determine allowable stresses.

Since the size is not known you have to skip $C_F$ (or make a guess).

$$F_b = F_o \left( \frac{V}{V_o} \right)$$

$$= 975 \left( \frac{1.0 \times 1.15 \times 1.0 \times C_F^2}{C_o \times C_r \times C_M} \right) \approx 121 \text{ psi}$$

$$F_V = F_o \left( C_D, C_M, C_k, C_I \right)$$

$$= 150 \left( 1.0 \times 1.0 \times 1.0 \times 1.0 \right) = 150 \text{ psi}$$
Design Example

Determine Moment from Loading

First find the uniform beam load, w, from the floor loading.

\[ w = (\text{psf}) \frac{0.0 \times 1}{12} = \frac{FLF}{12} \]

\[ (7+35) \frac{12}{12} = 42 \text{ psf} \]

With the beam loading, calculate the maximum moment.

\[ M = \frac{wL^2}{8} = \frac{42(20)^2}{8} = 2100 \text{ in}^3 \]

Design Example

Estimate the Required Section Modulus.

\[ S_x = \frac{M}{F_b} = \frac{2100(12)}{1121} = 22.47 \text{ in}^3 \]

Compare this required Sx to the actual Sx of available sections in NDS Table 1B. Remember CF will be multiplied which may make some pass which at first fail.

From Table 1B (NDS)

<table>
<thead>
<tr>
<th>Sx</th>
<th>2 x 10</th>
<th>21.39 (CF = 1.0) MIGHT WORK</th>
</tr>
</thead>
<tbody>
<tr>
<td>2 x 12</td>
<td>31.64 (CF = 1.0)</td>
<td></td>
</tr>
</tbody>
</table>
Design Example

Choose a section and test it (by analysis with all factors including $C_F$)

\[
\text{TRY } 2 \times 10 \quad C_F = 1.1
\]

\[
F_b = 975(1.15, 1.1) = 1233.3 \text{ psi}
\]

\[
f_b = \frac{M}{Sx} = \frac{2100 (12)}{2.139} = 1178 \text{ psi} < 1233 \text{ psi} \quad \checkmark
\]

\[
f_u = \frac{3V}{2A} = \frac{1.57 (420)}{13.8} = 45.39 \text{ psi} < 160 \text{ psi} \quad \checkmark
\]

\[
\therefore \text{ USE } 2 \times 10
\]

Design Example

Check Deflection

In this case LL only against code limit of $L/360$

<table>
<thead>
<tr>
<th>CONSTRUCTION</th>
<th>$L$ or $W^2h$</th>
<th>$L_D$</th>
<th>$L$ or $W^2h$</th>
<th>$L_D$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Roof members</td>
<td>$360$</td>
<td>$360$</td>
<td>$240$</td>
<td>$240$</td>
</tr>
<tr>
<td>Supporting plaster or stucco ceiling</td>
<td>$360$</td>
<td>$360$</td>
<td>$240$</td>
<td>$240$</td>
</tr>
<tr>
<td>Supporting nonplaster ceiling</td>
<td>$180$</td>
<td>$180$</td>
<td>$120$</td>
<td>$120$</td>
</tr>
<tr>
<td>Not supporting ceiling</td>
<td>$360$</td>
<td>$360$</td>
<td>$240$</td>
<td>$240$</td>
</tr>
<tr>
<td>Floor members</td>
<td>$360$</td>
<td>$360$</td>
<td>$240$</td>
<td>$240$</td>
</tr>
<tr>
<td>Exterior walls</td>
<td>$360$</td>
<td>$360$</td>
<td>$240$</td>
<td>$240$</td>
</tr>
<tr>
<td>With plaster or stucco finishes</td>
<td>$360$</td>
<td>$360$</td>
<td>$240$</td>
<td>$240$</td>
</tr>
<tr>
<td>With other brittle finishes</td>
<td>$360$</td>
<td>$360$</td>
<td>$240$</td>
<td>$240$</td>
</tr>
<tr>
<td>With flexible finishes</td>
<td>$360$</td>
<td>$360$</td>
<td>$240$</td>
<td>$240$</td>
</tr>
<tr>
<td>Interior partitions</td>
<td>$360$</td>
<td>$360$</td>
<td>$240$</td>
<td>$240$</td>
</tr>
<tr>
<td>With plaster or stucco finishes</td>
<td>$360$</td>
<td>$360$</td>
<td>$240$</td>
<td>$240$</td>
</tr>
<tr>
<td>With other brittle finishes</td>
<td>$360$</td>
<td>$360$</td>
<td>$240$</td>
<td>$240$</td>
</tr>
<tr>
<td>With flexible finishes</td>
<td>$360$</td>
<td>$360$</td>
<td>$240$</td>
<td>$240$</td>
</tr>
<tr>
<td>Farm buildings</td>
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<td>$240$</td>
<td>$240$</td>
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<tr>
<td>Greenhouses</td>
<td>$360$</td>
<td>$360$</td>
<td>$240$</td>
<td>$240$</td>
</tr>
</tbody>
</table>

\[
\Delta_L = \frac{5wL^4}{384EI} = \frac{5(35)(20)^4(1728)}{384(1500000)(98.93)} = 0.849''
\]

\[
\Delta_{\text{LIMIT}} = \frac{L}{360} = \frac{20'(12)}{360} = 0.667''
\]

\[
0.849 > 0.667 \therefore \text{FAILS}
\]