Glulam Curved Members

Glulam Design
• General Glulam Beams are Designed in the SAME Manner as Solid Sawn Beams
• There is an Additional Adjustment Factor, $C_v$, the Volume Factor
• $C_v$ and $C_L$ (Lateral Stability Factor) are NOT Considered Simultaneously

General Glulam Design
• $F_b' = F_b \cdot C_D \cdot C_M \cdot C_t \cdot C_r \cdot C_v \cdot C_{fu} \cdot C_r \cdot C_c \cdot C_t$
• $C_D$ = Load Duration Factor
• $C_M$ = Wet Service Factor (16% for Glulam)
• $C_t$ = Temperature Factor (125° & 150°)
General Glulam Design

• $C_L$ = Lateral Stability Factor (Compression Bracing)

• $C_F$ = Size Factor (Not Applicable)

• $C_V$ = Volume Factor (Details Later)

• $C_{fu}$ = Flat Use Factor (More Details Later)

General Glulam Design

• $C_r$ = Repetitive Member Factor

• $C_c$ = Curvature Factor (Details Later)

• $C_f$ = Form Factor (round or diagonal loading)

• All other design considerations are the same (i.e., shear, compression, etc.)

General Glulam Design

• $C_V$ = Volume Factor is used because of the size effects in timber.

• Weibull Statistics predict that the larger the volume the greater the chance for there to be a critical flaw to cause weakness

• Lumber uses the size factor, $C_F$, because the grading rules compensate for the rest.
General GLulam Design

• For Glulam, the total volume affects the strength due to the layup of the laminations and the visual grading rules.

• $C_v$ is ONLY applicable to bending about the beam's strong axis

• This is considered as loaded perpendicular to the wide face of the laminations.

General Glulam Design

• $C_{fu}$, the flat us factor if used when the beam bending is about the weak axis because the standard beam depth for design is 12 inches for all beams.

• This is considered as loaded parallel to the wide face of the laminations.

General Glulam Design

<table>
<thead>
<tr>
<th>Table 4.4 Flat Use Factor*, $C_{fu}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Member Dimensions Parallel to Wide Faces of Laminations</td>
</tr>
<tr>
<td>10-3/4 or 10-1/2</td>
</tr>
<tr>
<td>8-3/4 or 8-1/2</td>
</tr>
<tr>
<td>6-3/4</td>
</tr>
<tr>
<td>5-1/8 or 5</td>
</tr>
<tr>
<td>3-1/8 or 3</td>
</tr>
<tr>
<td>2-1/2</td>
</tr>
</tbody>
</table>

* Values for $C_{fu}$ are obtained from the equation $(12/d)^{0.4}$, where $d$ is the dimension of the wide faces of the laminations.
General Glulam Design

\[ C_T = K_L \left( \frac{5.125}{b} \right)^{1/4} \left( \frac{d}{d'} \right)^{1/4} \left( \frac{21}{L} \right)^{1/4} \leq 1.0 \]

- \( b \) = width of the bending member or widest lamination of multiple piece widths (\( b \leq 10.75 \) inches)
- \( d \) = Depth of bending member (inches)
- \( L \) = Length of bending member (distance between inflection points) (feet)
- \( x \) = 20 for Southern Pine
- \( x \) = 10 for Western species
- \( K_L \) = Loading Condition Coefficient

\[ C_T = K_L \left( \frac{1291.5}{Volume} \right)^{1/4} \]

General Glulam Design

<table>
<thead>
<tr>
<th>TABLE 4.11</th>
<th>Temperature Factors, ( C_i )</th>
</tr>
</thead>
<tbody>
<tr>
<td>Design Values</td>
<td>In Service Maturity Conditions</td>
</tr>
<tr>
<td>( T_G \leq 100^\circ F )</td>
<td>( T_R \geq 100^\circ F, T_G \leq 125^\circ F )</td>
</tr>
<tr>
<td>( F ) or ( F' )</td>
<td>Wet or Dry</td>
</tr>
<tr>
<td>( F_{w} ) or ( F_{v} )</td>
<td>Dry</td>
</tr>
<tr>
<td>and ( F_{e} )</td>
<td>Wet</td>
</tr>
</tbody>
</table>

1. Wet and dry service conditions for sawn lumber and glued laminated timber are specified in 4.1.4 and 5.1.5.

General Glulam Design

- \( C_v \) and \( C_L \) are not cumulative because the volume factor is to account for the material failure on the tension side of the beam and the stability is to control the elastic lateral torsional buckling failure possibility.

- For variable depth members, \( d \) should be for the location of interest.
Curved Glulam Beams

• The curvature factor is used to adjust the bending strength for members bent into curves.

• It does not apply to beams that are cambered because the camber causes little effect due to the curve at the radii used for camber.

Curved Glulam Beams

• The curvature of the beam causes the extreme fibers to be stressed differently than a prismatic straight beam.

• Residual stresses are also present for curved beams.

• The effect of curvature is less than 1% for use of 1½ inch lamination and a 56 ft radius.

Curved GLulam Beams

• Stress induced when the laminations are bent and does not completely relax over time.

• The extreme outer fibers is greater for curved beams than straight beams subjected to the same moment.
Curved Glulam Beams

\[ C_c = 1 - 2000 \left( \frac{t}{R} \right)^2 \]

This is an empirical equation that is based on test results and analysis.

- \( t \) = the thickness of the laminations (in)
- \( R \) = the radius of curvature of the inside face of the curved beam (in)

\( t/R \leq 1/100 \) for hardwoods and southern pine and \( \leq 1/125 \) for other softwoods.

\( C_c \) is not applied to the straight portions of the beam.

Tapered Glulam Beams

- The interaction factor should be included in tapered beams to account for the possible compression/shear failure that can occur due to bending stresses at an angle to the grain and the end to the wood fibers.
- This factor is dependent on the tangent of the slope of the cut.
Tapered Glulam Beams

Curved Members (Arches)

• The minimum radius of curvature is dependent on the thickness of the lamination.

• For 3/4 inch thick laminations:
  – R ≥ 9 ft 4 in for Western species
  – R ≥ 7 ft 0 in for Southern Pine
Curved Members (Arches)

- For 1½ inch thick laminations:
  - $R \geq 27 \text{ ft 6 in}$ for all species

- $t/R$ ratio must govern in all cases
  - $t/R \leq 1/100$ for hardwoods and Southern Pine
  - $t/R \leq 1/125$ for other softwoods

Curved Members

- Finally, Radial Tension occurs in curved members as they are bent.

- As the curved member is straightened, radial tension occurs

- As the curved member is bent into a sharper curve, radial compression occurs

Radial Stress

$$f_r = \frac{3M}{2R_mbd}$$

- $M = \text{Bending Moment (in-lb)}$
- $b = \text{width of rectangular member (in)}$
- $d = \text{depth of rectangular member (in)}$
- $R_m = \text{Radius of curvature of the centerline of the member (in)}$
Radial Stress

Radial Stress

For Curved Beams of Variable Cross Section

\[ f_r = K_r C_r \frac{6M}{bd_c^2} = K_r C_r f_0 \]

- \( f_r \) = radial stress factor
- \( K_r \) = radial stress factor from Curve or Polynomial and tabulated coefficients
- \( C_r \) = reduction factor, function of shape obtained from figures
- \( M \) = moment (in-lb)
- \( b \) = Width (in)
- \( d_c \) = Depth of cross section at centerline (in)

Radial Stress

Radial Tension Design Values

<table>
<thead>
<tr>
<th>Species</th>
<th>Loading other than Wind or Earthquake</th>
<th>Wind or Earthquake Loading</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alaska Cedar</td>
<td>15</td>
<td>63</td>
</tr>
<tr>
<td>California Redwood</td>
<td>62</td>
<td>62</td>
</tr>
<tr>
<td>Canadian Spruce Pine</td>
<td>15</td>
<td>53</td>
</tr>
<tr>
<td>Douglas Fir-Larch</td>
<td>15</td>
<td>55</td>
</tr>
<tr>
<td>Douglas Fir-South</td>
<td>15</td>
<td>50</td>
</tr>
<tr>
<td>Eastern Species</td>
<td>15</td>
<td>48</td>
</tr>
<tr>
<td>Heartwood</td>
<td>15</td>
<td>52</td>
</tr>
<tr>
<td>Softwood Species</td>
<td>15</td>
<td>47</td>
</tr>
<tr>
<td>Southern Pine</td>
<td>67</td>
<td>67</td>
</tr>
</tbody>
</table>
Radial Stress

### TABLE 2.6
Polynomial Approximation to $K_r$

<table>
<thead>
<tr>
<th>Angles of Upper</th>
<th>Factors</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tapered Surface, $\phi_y$ (degrees)</td>
<td>$A$</td>
</tr>
<tr>
<td>2.5</td>
<td>0.0079</td>
</tr>
<tr>
<td>3.8</td>
<td>0.0174</td>
</tr>
<tr>
<td>7.5</td>
<td>0.0179</td>
</tr>
<tr>
<td>10.0</td>
<td>0.0201</td>
</tr>
<tr>
<td>13.0</td>
<td>0.0029</td>
</tr>
<tr>
<td>20.0</td>
<td>0.0089</td>
</tr>
<tr>
<td>25.0</td>
<td>0.1214</td>
</tr>
<tr>
<td>30.0</td>
<td>0.0400</td>
</tr>
</tbody>
</table>

1. For intermediate values of $\phi_y$, use simple interpolation between tabulated values of $K_r$, as illustrated for $K_r$ in the design example for Douglas Fir Larch beams.

Radial Stress

$$K_r = A + B \left( \frac{d_t}{R_m} \right) + C \left( \frac{d_t}{R_m} \right)^2$$

A, B, C are from Table
$d_t$ = Depth at centerline of member (in)
$R_m$ = Radius of curvature of centerline of member (in)

Radial Stress

- $K_r$ is dependent on the ratio of the slope of the top of the beam to the slope of the bottom of the beam
- Tabulated method uses a single value of the ratio and the other ratios are more conservative.
Radial Stress

![Diagram of Radial Stress](image)

**TABLE 5.9**
Adjustment Factor for Ratios of $\frac{E}{E}$

<table>
<thead>
<tr>
<th>$\frac{E}{E}$</th>
<th>C, Adjustment Factor</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.0</td>
<td>0.75</td>
</tr>
<tr>
<td>2.0</td>
<td>0.80</td>
</tr>
<tr>
<td>3.0</td>
<td>0.85</td>
</tr>
<tr>
<td>$\geq$ 4.0</td>
<td>0.90</td>
</tr>
</tbody>
</table>

Curved Beams

![Diagram of Curved Beams](image)