STRUCTURAL GLUED LAMINATED TIMBER

5

5.1 General

5.1.1 Scope

5.1.1.1 Chapter 5 applies to engineering design with structural glued laminated timber. Basic requirements are provided in this Specification; for additional detail, see Reference 52.

5.1.1.2 Design procedures, reference design values and other information provided herein apply only to structural glued laminated timber conforming to all pertinent provisions of the specifications referenced in the footnotes to Tables 5A, 5B, 5C, and 5D and produced in accordance with ANSI A190.1.

5.1.2 Definition

The term "structural glued laminated timber" refers to an engineered, stress rated product of a timber laminating plant, comprising assemblies of specially selected and prepared wood laminations bonded together with adhesives. The grain of all laminations is approximately parallel longitudinally. The separate laminations shall not exceed 2" in net thickness and are permitted to be comprised of:

- one piece
- pieces joined end-to-end to form any length
- pieces placed or glued edge-to-edge to make wider ones
- pieces bent to curved form during gluing.

5.1.3 Standard Sizes

5.1.3.1 Normal standard finished widths of structural glued laminated members shall be as shown in Table 5.1.3. This Specification is not intended to prohibit other finished widths where required to meet the size requirements of a design or to meet other special requirements.

5.1.3.2 The length and net dimensions of all members shall be specified. Additional dimensions necessary to define non-prismatic members shall be specified.

Table 5.1.3 Net Finished Widths of Structural Glued Laminated Timbers

Nominal Width of Laminations (in.)	3	4	6	8	10	12	14	16
	Western Species							
Net Finished Width (in.)	2-½	3-1/8	5-1/8	6-¾	8-¾	10-¾	12-¼	14-¼
	Southern Pine							
Net Finished Width (in.)	2-½	3	5	6-¾	8-½	10-½	12	14

5.1.4 Service Conditions

5.1.4.1 Reference design values for dry service conditions shall apply when the moisture content in service is less than 16%, as in most covered structures.

5.1.4.2 Reference design values for glued laminated timber shall be multiplied by the wet service factors, C_M, specified in Tables 5A, 5B, 5C, and 5D when the moisture content in service is 16% or greater, as may occur in exterior or submerged construction, or humid environments.

5.2 Reference Design Values

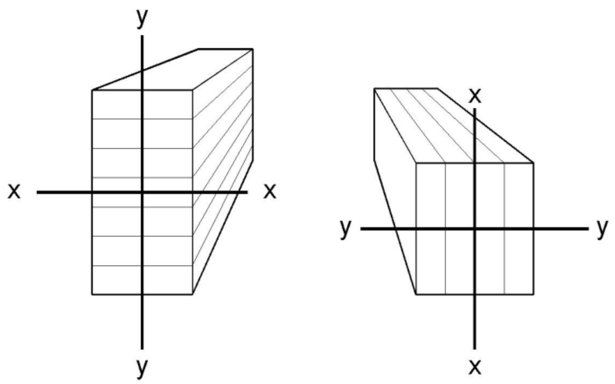
5.2.1 Reference Design Values

Reference design values for softwood and hardwood structural glued laminated timber are specified in Tables 5A, 5B, 5C, and 5D (published in a separate Supplement to this Specification). The reference design values in Tables 5A, 5B, 5C, and 5D are a compilation of the reference design values provided in the specifications referenced in the footnotes to the tables.

5.2.2 Orientation of Member

Reference design values for structural glued laminated timber are dependent on the orientation of the laminations relative to the applied loads. Subscripts are used to indicate design values corresponding to a given orientation. The orientations of the cross-sectional axes for structural glued laminated timber are shown in Figure 5A. The x-x axis runs parallel to the wide face of the laminations. The y-y axis runs perpendicular to the wide faces of the laminations.

Figure 5A Axis Orientations



5.2.3 Balanced and Unbalanced Layups

Structural glued laminated timbers are permitted to be assembled with laminations of the same lumber grades placed symmetrically or asymmetrically about the neutral axis of the member. Symmetrical layups are referred to as “balanced” and have the same design values for positive and negative bending. Asymmetrical layups are referred to as “unbalanced” and have lower design values for negative bending than for positive bending. The top side of unbalanced members is required to be marked “TOP” by the manufacturer.

5.2.4 Bending, F_{bx}^+, F_{bx}^-, F_{by}

The reference bending design values, $\mathbf{F_{bx}^+}$ and $\mathbf{F_{bx}}$, shall apply to members with loads causing bending about the x-x axis. The reference bending design value for positive bending, $\mathbf{F_{bx}^+}$, shall apply for bending stresses causing tension at the bottom of the beam. The reference bending design value for negative bending, $\mathbf{F_{bx}^-}$, shall apply for bending stresses causing tension at the top of the beam.

The reference bending design value, $\mathbf{F_{by}}$, shall apply to members with loads causing bending about the y-y axis.

5.2.5 Compression Perpendicular to Grain, $F_{c\perp x}$, $F_{c\perp y}$

The reference compression design value perpendicular to grain, $\mathbf{F_{c\perp x}}$, shall apply to members with bearing loads on the wide faces of the laminations.

The reference compression design value perpendicular to grain, $\mathbf{F_{c\perp y}}$, shall apply to members with bearing loads on the narrow edges of the laminations.

The reference compression design values perpendicular to grain are based on a deformation limit of 0.04" obtained from testing in accordance with ASTM D143. The compression perpendicular to grain stress associated with a 0.02" deformation limit shall be permitted to be calculated as 73% of the reference value (See also 4.2.6).

5.2.6 Shear Parallel to Grain, F_{vx}, F_{vy}

The reference shear design value parallel to grain, $\mathbf{F_{vx}}$ shall apply to members with shear loads causing bending about the x-x axis. The reference shear design value parallel to grain, $\mathbf{F_{vy}}$, shall apply to members with shear loads causing bending about the y-y axis.

The reference shear design values parallel to grain shall apply to prismatic members except those subject to impact or repetitive cyclic loads. For non-prismatic members and for all members subject to impact or repetitive cyclic loads, the reference shear design values parallel to grain shall be multiplied by the shear reduction factor specified in 5.3.10. This reduction shall also apply to the design of connections transferring loads through mechanical fasteners (see 3.4.3.3, 11.1.2 and 11.2.2).

Prismatic members shall be defined as straight or cambered members with constant cross-section. Non-prismatic members include, but are not limited to: arches, tapered beams, curved beams, and notched members.

The reference shear design value parallel to grain, $\mathbf{F_{vy}}$, is tabulated for members with four or more laminations. For members with two or three laminations, the reference design value shall be multiplied by 0.84 or 0.95, respectively.

5.2.7 Modulus of Elasticity, E_x, $E_{x\ min}$, E_y, $E_{y\ min}$

The reference modulus of elasticity, $\mathbf{E_x}$, shall be used for determination of deflections due to bending about the x-x axis.

The reference modulus of elasticity, $\mathbf{E_{x\ min}}$, shall be used for beam and column stability calculations for members buckling about the x-x axis.

The reference modulus of elasticity, $\mathbf{E_y}$, shall be used for determination of deflections due to bending about the y-y axis.

The reference modulus of elasticity, $\mathbf{E_{y\ min}}$, shall be used for beam and column stability calculations for members buckling about the y-y axis.

For the calculation of extensional deformations, the axial modulus of elasticity shall be permitted to be estimated as $\mathbf{E_{axial}} = 1.05\mathbf{E_y}$.

5.2.8 Radial Tension, F_{rt}

For curved bending members, the following reference radial tension design values perpendicular to grain, $\mathbf{F_{rt}}$, shall apply:

Table 5.2.8 Radial Tension Design Values, F_{rt}, for Curved Members

Southern Pine	all loading conditions	$F_{rt} = (1/3)F_{vx}C_{vr}$
Douglas Fir-Larch, Douglas Fir South, Hem-Fir, Western Woods, and Canadian softwood species	wind or earthquake loading	$F_{rt} = (1/3)F_{vx}C_{vr}$
	other types of loading	$F_{rt} = 15$ psi

5.2.9 Radial Compression, F_{rc}

For curved bending members, the reference radial compression design value, $\mathbf{F_{rc}}$, shall be taken as the reference compression perpendicular to grain design value on the side face, $\mathbf{F_{c\perp y}}$.

5.2.10 Other Species and Grades

Reference design values for species and grades of structural glued laminated timber not otherwise provided herein shall be established in accordance with Reference 22, or shall be based on other substantiated information from an approved source.

5.3 Adjustment of Reference Design Values

5.3.1 General

Reference design values (F_b, F_t, F_v, $F_{c\perp}$, F_c, F_{rt}, E, E_{min}) provided in 5.2 and Tables 5A, 5B, 5C, and 5D shall be multiplied by the adjustment factors specified in Table 5.3.1 to determine adjusted design values (F_b', F_t', F_v', $F_{c\perp}'$, F_c', F_{rt}', E', E_{min}').

5.3.2 Load Duration Factor, C_D (ASD only)

All reference design values except modulus of elasticity, E, modulus of elasticity for beam and column stability, E_{min}, and compression perpendicular to grain, $F_{c\perp}$, shall be multiplied by load duration factors, C_D, as specified in 2.3.2.

5.3.3 Wet Service Factor, C_M

Reference design values for structural glued laminated timber are based on the moisture service conditions specified in 5.1.4. When the moisture content of structural members in use differs from these moisture service conditions, reference design values shall be multiplied by the wet service factors, C_M, specified in Tables 5A, 5B, 5C, and 5D.

Table 5.3.1 Applicability of Adjustment Factors for Structural Glued Laminated Timber

	ASD only	ASD and LRFD										LRFD only		
	Load Duration Factor	Wet Service Factor	Temperature Factor	Beam Stability Factor [1]	Volume Factor [1]	Flat Use Factor	Curvature Factor	Stress Interaction Factor	Shear Reduction Factor	Column Stability Factor	Bearing Area Factor	Format Conversion Factor K_F	Resistance Factor ϕ	Time Effect Factor
$F_b' = F_b$ x	C_D	C_M	C_t	C_L	C_V	C_{fu}	C_c	C_I	-	-	-	2.54	0.85	λ
$F_t' = F_t$ x	C_D	C_M	C_t	-	-	-	-	-	-	-	-	2.70	0.80	λ
$F_v' = F_v$ x	C_D	C_M	C_t	-	-	-	-	-	C_{vr}	-	-	2.88	0.75	λ
$F_{rt}' = F_{rt}$ x	C_D	C_M[2]	C_t[2]	-	-	-	-	-	-	-	-	2.88	0.75	λ
$F_c' = F_c$ x	C_D	C_M	C_t	-	-	-	-	-	-	C_P	-	2.40	0.90	λ
$F_{c\perp}' = F_{c\perp}$ x	-	C_M	C_t	-	-	-	-	-	-	-	C_b	1.67	0.90	-
$E' = E$ x	-	C_M	C_t	-	-	-	-	-	-	-	-	-	-	-
$E_{min}' = E_{min}$ x	-	C_M	C_t	-	-	-	-	-	-	-	-	1.76	0.85	-

1. The beam stability factor, C_L, shall not apply simultaneously with the volume factor, C_V, for structural glued laminated timber bending members (see 5.3.6). Therefore, the lesser of these adjustment factors shall apply.
2. For radial tension, F_{rt}, the same adjustment factors (C_M and C_t) for shear parallel to grain, F_v, shall be used.

5.3.4 Temperature Factor, C_t

When structural members will experience sustained exposure to elevated temperatures up to 150°F (see Appendix C), reference design values shall be multiplied by the temperature factors, C_t, specified in 2.3.3.

5.3.5 Beam Stability Factor, C_L

Reference bending design values, F_b, shall be multiplied by the beam stability factor, C_L, specified in 3.3.3. The beam stability factor, C_L, shall not apply simultaneously with the volume factor, C_V, for structural glued laminated timber bending members (see 5.3.6). Therefore, the lesser of these adjustment factors shall apply.

5.3.6 Volume Factor, C_V

When structural glued laminated timber members are loaded in bending about the x-x axis, the reference bending design values, $\mathbf{F_{bx}}^+$, and $\mathbf{F_{bx}}^-$, shall be multiplied by the following volume factor:

$$C_V = \left(\frac{21}{L}\right)^{1/x}\left(\frac{12}{d}\right)^{1/x}\left(\frac{5.125}{b}\right)^{1/x} \leq 1.0 \qquad (5.3\text{-}1)$$

where:

L = length of bending member between points of zero moment, ft

d = depth of bending member, in.

b = width (breadth) of bending member. For multiple piece width layups, b = width of widest piece used in the layup. Thus, b ≤ 10.75".

x = 20 for Southern Pine

x = 10 for all other species

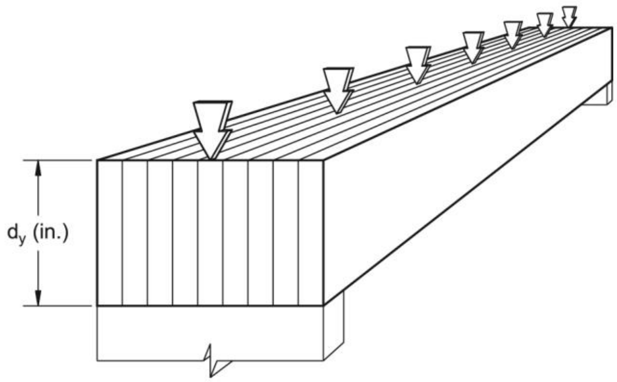
The volume factor, C_V, shall not apply simultaneously with the beam stability factor, C_L (see 3.3.3). Therefore, the lesser of these adjustment factors shall apply.

5.3.7 Flat Use Factor, C_{fu}

When structural glued laminated timber is loaded in bending about the y-y axis and the member dimension parallel to the wide face of the laminations, d_y (see Figure 5B), is less than 12", the reference bending design value, F_{by}, shall be permitted to be multiplied by the flat use factor, C_{fu}, specified in Tables 5A, 5B, 5C, and 5D, or as calculated by the following formula:

$$C_{fu} = \left(\frac{12}{d_y}\right)^{1/9} \qquad (5.3\text{-}2)$$

Figure 5B Depth, d_y, for Flat Use Factor



5.3.8 Curvature Factor, C_c

For curved portions of bending members, the reference bending design value shall be multiplied by the following curvature factor:

$$C_c = 1 - (2000)(t / R)^2 \qquad (5.3\text{-}3)$$

where:

t = thickness of laminations, in.

R = radius of curvature of inside face of member, in.

$t/R \leq 1/100$ for hardwoods and Southern Pine

$t/R \leq 1/125$ for other softwoods

The curvature factor shall not apply to reference design values in the straight portion of a member, regardless of curvature elsewhere.

5.3.9 Stress Interaction Factor, C_I

For the tapered portion of bending members tapered on the compression face, the reference bending design value, F_{bx}, shall be multiplied by the following stress interaction factor:

$$C_I = \frac{1}{\sqrt{1 + \left(F_b \tan\theta / F_v C_{vr}\right)^2 + \left(F_b \tan^2\theta / F_{c\perp}\right)^2}} \qquad (5.3\text{-}4)$$

where:

θ = angle of taper, degrees

For members tapered on the compression face, the stress interaction factor, C_I, shall not apply simultaneously with the volume factor, C_V, therefore, the lesser of these adjustment factors shall apply.

For the tapered portion of bending members tapered on the tension face, the reference bending design value, F_{bx}, shall be multiplied by the following stress interaction factor:

$$C_I = \frac{1}{\sqrt{1 + \left(F_b \tan\theta / F_v C_{vr}\right)^2 + \left(F_b \tan^2\theta / F_{rt}\right)^2}} \qquad (5.3\text{-}5)$$

where:

θ = angle of taper, degrees

For members tapered on the tension face, the stress interaction factor, C_I, shall not apply simultaneously with the beam stability factor, C_L, therefore, the lesser of these adjustment factors shall apply.

Taper cuts on the tension face of structural glued laminated timber beams are not recommended.

5.3.10 Shear Reduction Factor, C_{vr}

The reference shear design values, F_{vx} and F_{vy}, shall be multiplied by the shear reduction factor, C_{vr} = 0.72 where any of the following conditions apply:

1. Design of non-prismatic members.
2. Design of members subject to impact or repetitive cyclic loading.
3. Design of members at notches (3.4.3.2).
4. Design of members at connections (3.4.3.3, 11.1.2, 11.2.2).

5.3.11 Column Stability Factor, C_P

Reference compression design values parallel to grain, F_c, shall be multiplied by the column stability factor, C_P, specified in 3.7.

5.3.12 Bearing Area Factor, C_b

Reference compression design values perpendicular to grain, $F_{c\perp}$, shall be permitted to be multiplied by the bearing area factor, C_b, as specified in 3.10.4.

5.3.13 Pressure-Preservative Treatment

Reference design values apply to structural glued laminated timber treated by an approved process and preservative (see Reference 30). Load duration factors greater than 1.6 shall not apply to structural members pressure-treated with water-borne preservatives.

5.3.14 Format Conversion Factor, K_F (LRFD only)

For LRFD, reference design values shall be multiplied by the format conversion factor, K_F, specified in Table 5.3.1.

5.3.15 Resistance Factor, ϕ (LRFD only)

For LRFD, reference design values shall be multiplied by the resistance factor, ϕ, specified in Table 5.3.1.

5.3.16 Time Effect Factor, λ (LRFD only)

For LRFD, reference design values shall be multiplied by the time effect factor, λ, specified in Appendix N.3.3.

5.4 Special Design Considerations

5.4.1 Curved Bending Members with Constant Cross Section

5.4.1.1 Curved bending members with constant rectangular cross section shall be designed for flexural strength in accordance with 3.3.

5.4.1.2 Curved bending members with constant rectangular cross section shall be designed for shear strength in accordance with 3.4, except that the provisions of 3.4.3.1 shall not apply. The shear reduction factor from 5.3.10 shall apply.

5.4.1.3 The radial stress induced by a bending moment in a curved bending member of constant rectangular cross section is:

$$f_r = \frac{3M}{2Rbd} \tag{5.4-1}$$

where:

M = bending moment, in.-lbs

R = radius of curvature at center line of member, in.

Where the bending moment is in the direction tending to decrease curvature (increase the radius), the radial stress shall not exceed the adjusted radial tension design value perpendicular to grain, $f_r \le F_{rt}'$, unless mechanical reinforcing sufficient to resist all radial stresses is used (see Reference 52). In no case shall f_r exceed $(1/3)F_v'$.

Where the bending moment is in the direction tending to increase curvature (decrease the radius), the radial stress shall not exceed the adjusted radial compression design, $f_r \le F_{rc}'$.

5.4.1.4 The deflection of curved bending members with constant cross section shall be determined in accordance with 3.5. Horizontal displacements at the supports shall also be considered.

5.4.2 Double-Tapered Curved Bending Members

5.4.2.1 The bending stress induced by a bending moment, M, at the peaked section of a double-tapered curved bending member (see Figure 5C) shall be calculated as follows:

$$f_b = K_\phi \frac{6M}{bd_c^2} \tag{5.4-2}$$

where:

K_ϕ = empirical bending stress shape factor

= $1 + 2.7 \tan \phi_T$.

ϕ_T = angle of roof slope, degrees

M = bending moment, in.-lbs

d_c = depth at peaked section of member, in.

The stress interaction factor from 5.3.9 shall apply for flexural design in the straight-tapered segments of double-tapered curved bending members.

5.4.2.2 Double-tapered curved members shall be designed for shear strength in accordance with 3.4, except that the provisions of 3.4.3.1 shall not apply. The shear reduction factor from 5.3.10 shall apply.

5.4.2.3 The radial stress induced by bending moment in a double-tapered curved member shall be calculated as follows:

$$f_r = K_{rs} C_{rs} \frac{6M}{bd_c^2} \quad (5.4\text{-}3)$$

where:

K_{rs} = empirical radial stress factor

= $0.29(d_c/R_m) + 0.32 \tan^{1.2}\phi_T$

C_{rs} = empirical load-shape radial stress reduction factor

= $0.27 \ln(\tan \phi_T) + 0.28 \ln(\ell/\ell_c) - 0.8d_c/R_m + 1 \leq 1.0$ for uniformly loaded members where $d_c/R_m \leq 0.3$

= 1.0 for members subject to constant moment

ℓ = span length, in.

ℓ_c = length between tangent points, in.

M = bending moment, in.-lbs

d_c = depth at peaked section of member, in.

R_m = radius of curvature at center line of member, in.

= $R + d_c/2$

R = radius of curvature of inside face of member, in.

Where the bending moment is in the direction tending to decrease curvature (increase the radius), the radial stress shall not exceed the adjusted radial tension design value perpendicular to grain, $f_r \leq F_{rt}'$, unless mechanical reinforcing sufficient to resist all radial stresses is used (see Reference 52). In no case shall f_r exceed $(1/3)F_{vx}'$.

Where the bending moment is in the direction tending to increase curvature (decrease the radius), the radial stress shall not exceed the adjusted radial compression design value, $f_r \leq F_{rc}'$.

5.4.2.4 The deflection of double-tapered curved members shall be determined in accordance with 3.5, except that the mid-span deflection of a symmetrical double-tapered curved beam subject to uniform loads shall be permitted to be calculated by the following empirical formula:

$$\Delta_c = \frac{5\omega\ell^4}{32E_x' b\left(d_{equiv}\right)^3} \quad (5.4\text{-}4)$$

where:

Δ_c = vertical deflection at midspan, in.

ω = uniformly distributed load, lbs/in.

d_{equiv} = $(d_e + d_c)(0.5 + 0.735 \tan \phi_T) - 1.41d_c \tan \phi_B$

d_e = depth at the ends of the member, in.

d_c = depth at the peaked section of the member, in.

ϕ_T = angle of roof slope, degrees

ϕ_B = soffit slope at the ends of the member, degrees

The horizontal deflection at the supports of symmetrical double-tapered curved beams shall be permitted to be estimated as:

$$\Delta_H = \frac{2h\Delta_c}{\ell} \quad (5.4\text{-}5)$$

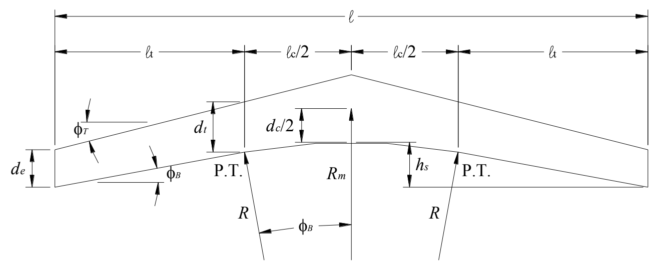
where:

Δ_H = horizontal deflection at either support, in.

h = $h_a - d_c/2 - d_e/2$

h_a = $\ell/2 \tan \phi_T + d_e$

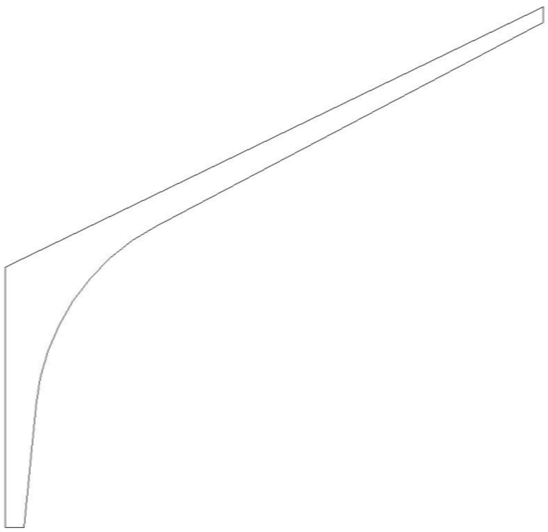
Figure 5C Double-Tapered Curved Bending Member



5.4.3 Lateral Stability for Tudor Arches

The ratio of tangent point depth to breadth (d/b) of tudor arches (see Figure 5D) shall not exceed 6, based on actual dimensions, when one edge of the arch is braced by decking fastened directly to the arch, or braced at frequent intervals as by girts or roof purlins. Where such lateral bracing is not present, d/b shall not exceed 5. Arches shall be designed for lateral stability in accordance with the provisions of 3.7 and 3.9.2.

Figure 5D Tudor Arch



5.4.4 Tapered Straight Bending Members

5.4.4.1 Tapered straight beams (see Figure 5E) shall be designed for flexural strength in accordance with 3.3. The stress interaction factor from 5.3.9 shall apply. For field-tapered members, the reference bending design value, F_{bx}, and the reference modulus of elasticity, E_x, shall be reduced according to the manufacturer's recommendations to account for the removal of high grade material near the surface of the member.

5.4.4.2 Tapered straight beams shall be designed for shear strength in accordance with 3.4, except that the provisions of 3.4.3.1 shall not apply. The shear reduction factor from 5.3.10 shall apply.

5.4.4.3 The deflection of tapered straight beams shall be determined in accordance with 3.5, except that the maximum deflection of a tapered straight beam subject to uniform loads shall be permitted to be calculated as equivalent to the depth, d_{equiv}, of an equivalent prismatic member of the same width where:

$$d_{equiv} = C_{dt} d_e \qquad (5.4\text{-}6)$$

where:

d_e = depth at the small end of the member, in.

C_{dt} = empirical constant derived from relationship of equations for deflection of tapered straight beams and prismatic beams.

For symmetrical double-tapered beams:

$C_{dt} = 1 + 0.66C_y$ when $0 < C_y \leq 1$

$C_{dt} = 1 + 0.62C_y$ when $0 < C_y \leq 3$

For single-tapered beams:

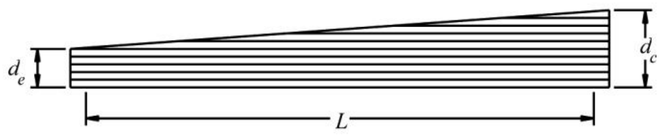
$C_{dt} = 1 + 0.46C_y$ when $0 < C_y \leq 1.1$

$C_{dt} = 1 + 0.43C_y$ when $1.1 < C_y \leq 2$

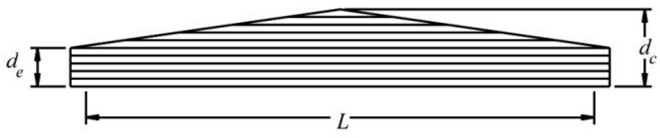
For both single- and double-tapered beams:

$$C_y = \frac{d_c - d_e}{d_e}$$

Figure 5E Tapered Straight Bending Members



(a)



(b)

5.4.5 Notches

5.4.5.1 The tension side of structural glued laminated timber bending members shall not be notched, except at ends of members for bearing over a support, and notch depth shall not exceed the lesser of 1/10 the depth of the member or 3".

5.4.5.2 The compression side of structural glued laminated timber bending members shall not be notched, except at ends of members, and the notch depth on the compression side shall not exceed 2/5 the depth of the member. Compression side end-notches shall not extend into the middle 1/3 of the span.

> **Exception:** A taper cut on the compression edge at the end of a structural glued laminated timber bending member shall not exceed 2/3 the depth of the member and the length shall not exceed three times the depth of the member, 3d. For tapered beams where the taper extends into the middle 1/3 of the span, design shall be in accordance with 5.4.4.

5.4.5.3 Notches shall not be permitted on both the tension and compression face at the same cross-section.

5.4.5.4 See 3.1.2 and 3.4.3 for the effect of notches on strength. The shear reduction factor from 5.3.10 shall apply for the evaluation of members at notches.