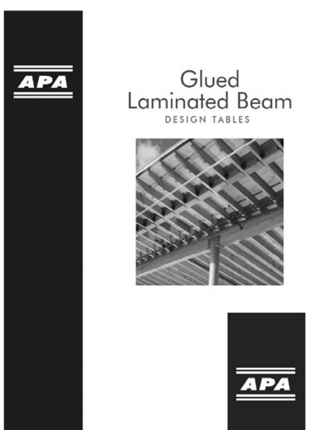
Architecture 544
Wood Structures

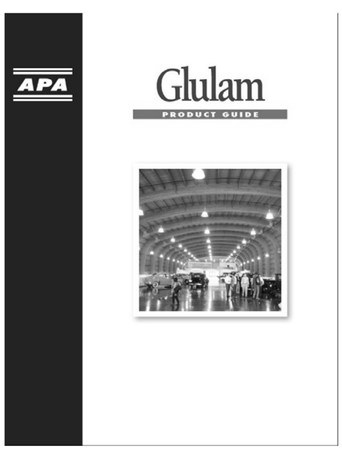
Glue Laminated Timbers
(Glulam)

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

APA Literature

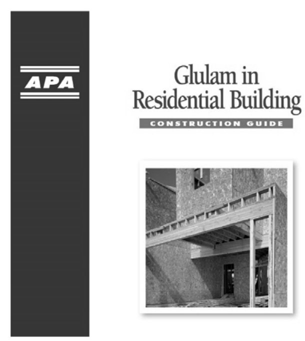
APA-S475

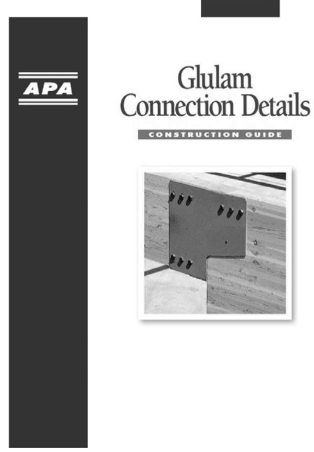




APA-X440

APA-X450



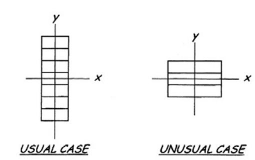


APA-T300

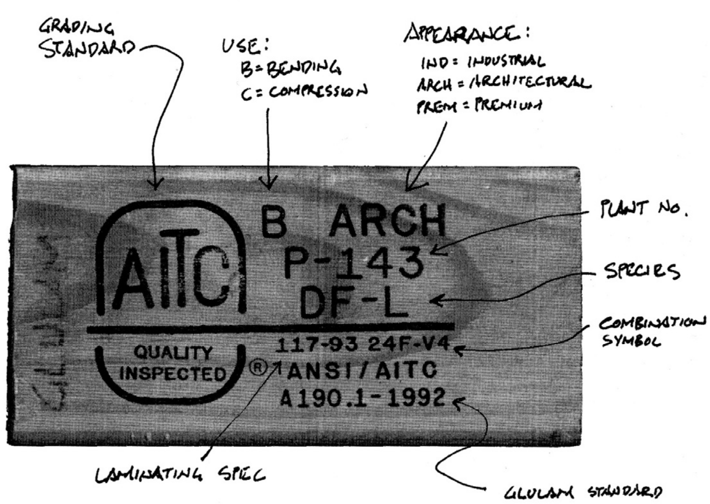
Glulam Production

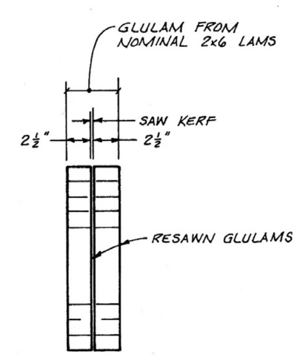
Glulam Properties

- Grading – AITC or APA-EWS
- Orientation – x and y axis
- Density values
- Resawn glulams for narrower sections



Type of glulam	Unit weight
Southern Pine	36 pcf
Western Species	
Douglas Fir-Larch	35 pcf
Alaska Cedar	35 pcf
Hem-Fir and California Redwood	27 pcf

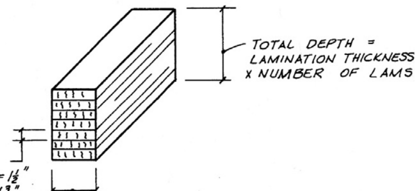


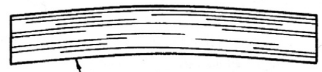


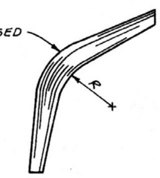
Glulam Properties

Dimensions

- Limited mostly by transport
- Standard dimension given in NDS Supplement
- Depth based on lam thickness and number
- Flatter members use 1 ½ ” or 1 3/8” lams
- Tightly curved members use thinner lams, ¾”



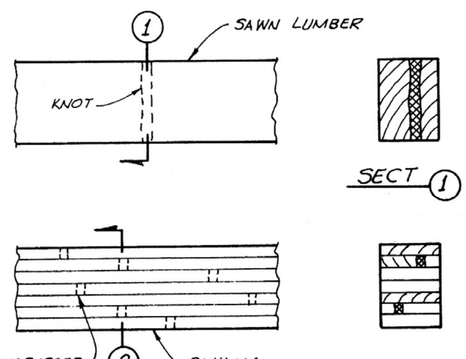


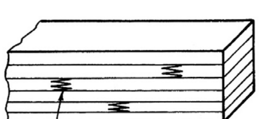


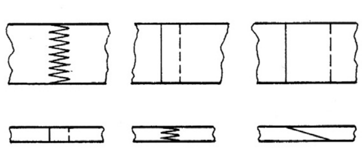
Glulam Properties

Effects of Defects

Joining methods



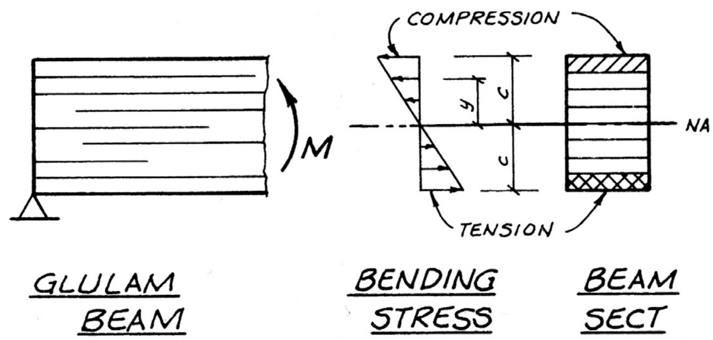


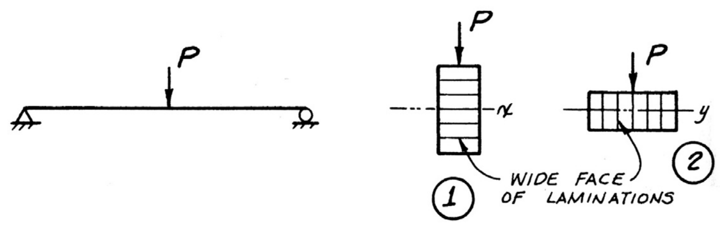


Glulam Properties

Layup Strategies

- outer vs core
- top vs bottom
- effects on stress
- effects of orientation





Allowable Stress Design by NDS – Ch. 5
Flexure

$F_b' \geq f_b$

Allowable Flexure Stress F_b'

F_b from tables determined by species and grade

F_b' = F_b (usage factors)

usage factors for flexure:
- C_D Load Duration Factor
- C_M Moisture Factor
- C_t Temperature Factor
- C_L Beam Stability Factor
- C_V Volume Factor
- C_{fu} Flat Use
- C_c Curvature Factor
- C_I Stress Interaction Factor

$\geq$

Actual Flexure Stress f_b

$f_b = Mc/I = M/S$

$S = I/c = bd^2/6$

Allowable Stress Design by NDS
Shear

$F_v' \geq f_v$

Allowable Shear Stress Fv'

F_v from tables determined by species and grade

F_v' = F_v (usage factors)

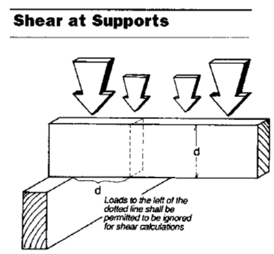
usage factors for shear:
- C_D Load Duration Factor
- C_M Moisture Factor
- C_t Temperature Factor
- C_{vr} Shear Reduction Factor

$\geq$

Actual Shear Stress fv

f_v = VQ / I b = 1.5 V/A

Can use V at d from support as maximum



Allowable Stress Design by NDS
Compression

$F_c' \geq f_c$

Allowable Compression Stress F_c'

F_c from 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_P Column Stability Factor

$\geq$

Actual Compression Stress f_b

f_c = P/A

Adjustment Factors

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.

Adjustment Factors

Allowable Flexure Stress F_b'

F_b from tables determined by species and grade

$F_b' = F_b\ (C_D\ C_M\ C_t\ C_L\ C_V\ C_{fu}\ C_c\ C_I)$

Usage factors for flexure:

- C_D Load Duration Factor
- C_t Temperature Factor

Table 2.3.2 Frequently Used Load Duration Factors, C_D[1]

Load Duration	C_D	Typical Design Loads
Permanent	0.9	Dead Load
Ten years	1.0	Occupancy Live Load
Two months	1.15	Snow Load
Seven days	1.25	Construction Load
Ten minutes	1.6	Wind/Earthquake Load
Impact[2]	2.0	Impact Load

(1) Actual stress due to (DL) ≤ (0.9) (Design value)
(2) Actual stress due to (DL+LL) ≤ (1.0) (Design value)
(3) Actual stress due to (DL+WL) ≤ (1.6) (Design value)
(4) Actual stress due to (DL+LL+SL) ≤ (1.15) (Design value)
(5) Actual stress due to (DL+LL+WL) ≤ (1.6) (Design value)
(6) Actual stress due to (DL+SL+WL) ≤ (1.6) (Design value)
(7) Actual stress due to (DL+LL+SL+WL) ≤ (1.6) (Design value)

Table 2.3.3 Temperature Factor, C_t

Reference Design Values	In-Service Moisture Conditions[1]	C_t $T \le 100°F$	$100°F < T \le 125°F$	$125°F < T \le 150°F$
F_t, E, E_{min}	Wet or Dry	1.0	0.9	0.9
F_b, F_v, F_c, and $F_{c\perp}$	Dry	1.0	0.8	0.7
	Wet	1.0	0.7	0.5

1. Wet and dry service conditions for sawn lumber, structural glued laminated timber, prefabricated wood I-joists, structural composite lumber, and wood structural panels are specified in 4.1.4, 5.1.5, 7.1.4, 8.1.4, and 9.3.3, respectively.

2012 NDS

Adjustment Factors

Allowable Flexure Stress F_b'

F_b from NDS tables

$F_b' = F_b\,(C_D\,C_M\,C_t\,C_L\,C_V\,C_{fu}\,C_c\,C_I)$

Usage factors for flexure:
- **C_M** Moisture Factor
- **C_{fu}** Flat Use

Wet Service Factor, C_M

When structural glued laminated timber is used where moisture content will be 16% or greater, design values shall be multiplied by the appropriate wet service factors from the following table:

Wet Service Factors, C_M

F_b	F_t	F_v	$F_{c\perp}$	F_c	E and E_{min}
0.8	0.8	0.875	0.53	0.73	0.833

Flat Use Factor, C_{fu}

Tabulated bending design values for loading parallel to wide faces of laminations, F_{by}, shall be multiplied by the following flat use factors when the member dimension parallel to wide faces of laminations is less than 12":

Flat Use Factors, C_{fu}

Member dimension parallel to wide faces of laminations	C_{fu}
10-3/4" or 10-1/2"	1.01
8-3/4" or 8-1/2"	1.04
6-3/4"	1.07
5-1/8" or 5"	1.10
3-1/8" or 3"	1.16
2-1/2"	1.19

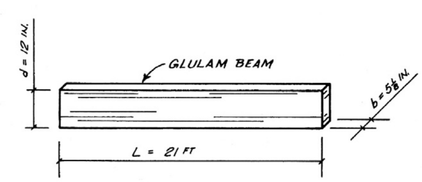
Adjustment Factors

Allowable Flexure Stress F_b'

F_b from NDS tables

$F_b' = F_b\,(C_D\,C_M\,C_t\,C_L\,C_V\,C_{fu}\,C_c\,C_I)$

Usage factors for flexure:
- **C_V** Volume Factor



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:

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

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

Adjustment Factors

Allowable Flexure Stress F_b'

F_b from NDS tables

$F_b' = F_b\ (C_D\ C_M\ C_t\ C_L\ C_V\ C_{fu}\ C_c\ C_I)$

Usage factors for flexure:

- C_c Curvature Factor
- C_I Stress Interaction 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.

Adjustment Factors - C_L

Allowable Flexure Stress F_b'

F_b from tables determined by species and grade

$F_b' = F_b\ (C_D\ C_M\ C_t\ C_L\ C_V\ C_{fu}\ C_c\ C_I)$

Table 3.3.3 Effective Length, ℓ_e, for Bending Members

Cantilever[1]	when $\ell_u/d < 7$		when $\ell_u/d \geq 7$
Uniformly distributed load	$\ell_e=1.33\ \ell_u$		$\ell_e=0.90\ \ell_u + 3d$
Concentrated load at unsupported end	$\ell_e=1.87\ \ell_u$		$\ell_e=1.44\ \ell_u + 3d$
Single Span Beam[1,2]	when $\ell_u/d < 7$		when $\ell_u/d \geq 7$
Uniformly distributed load	$\ell_e=2.06\ \ell_u$		$\ell_e=1.63\ \ell_u + 3d$
Concentrated load at center with no intermediate lateral support	$\ell_e=1.80\ \ell_u$		$\ell_e=1.37\ \ell_u + 3d$
Concentrated load at center with lateral support at center		$\ell_e=1.11\ \ell_u$	
Two equal concentrated loads at 1/3 points with lateral support at 1/3 points		$\ell_e=1.68\ \ell_u$	
Three equal concentrated loads at 1/4 points with lateral support at 1/4 points		$\ell_e=1.54\ \ell_u$	
Four equal concentrated loads at 1/5 points with lateral support at 1/5 points		$\ell_e=1.68\ \ell_u$	
Five equal concentrated loads at 1/6 points with lateral support at 1/6 points		$\ell_e=1.73\ \ell_u$	
Six equal concentrated loads at 1/7 points with lateral support at 1/7 points		$\ell_e=1.78\ \ell_u$	
Seven or more equal concentrated loads, evenly spaced, with lateral support at points of load application		$\ell_e=1.84\ \ell_u$	
Equal end moments		$\ell_e=1.84\ \ell_u$	

1. For single span or cantilever bending members with loading conditions not specified in Table 3.3.3:
   - $\ell_e = 2.06\ \ell_u$ when $\ell_u/d < 7$
   - $\ell_e = 1.63\ \ell_u + 3d$ when $7 \leq \ell_u/d \leq 14.3$
   - $\ell_e = 1.84\ \ell_u$ when $\ell_u/d > 14.3$
2. Multiple span applications shall be based on table values or engineering analysis.

C_L Beam Stability Factor

C_L is calculated using equation 3.3-6

The maximum allowable slenderness, R_B is 50

C_L is not used together with C_V. Use the lesser.
C_L is not used together with C_I. Use the lesser (see commentary).

3.3.3.6 The slenderness ratio, R_B, for bending members shall be calculated as follows:

$$R_B = \sqrt{\frac{\ell_e d}{b^2}} \qquad (3.3\text{-}5)$$

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:

$$C_L = \frac{1+(F_{bE}/F_b^*)}{1.9} - \sqrt{\left[\frac{1+(F_{bE}/F_b^*)}{1.9}\right]^2 - \frac{F_{bE}/F_b^*}{0.95}} \qquad (3.3\text{-}6)$$

where:

F_b^* = reference bending design value multiplied by all applicable adjustment factors except C_{fu}, C_V (when $C_V \leq 1.0$), and C_L (see 2.3), psi

$$F_{bE} = \frac{1.20\, E_{min}'}{R_B^2}$$

3.3.3.9 See Appendix D for background information concerning beam stability calculations and Appendix F for information concerning coefficient of variation in modulus of elasticity (COV_E).

3.3.3.10 Members subjected to flexure about both principal axes (biaxial bending) shall be designed in accordance with 3.9.2.

Adjustment Factors for Shear

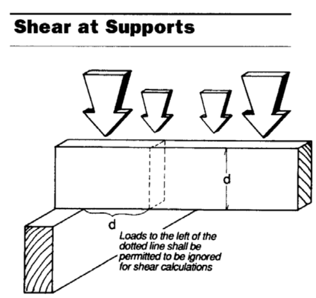
Allowable Flexure Stress F_v'

F_v from tables determined by species and grade

F_v' = F_v (usage factors)

Usage factors for flexure:

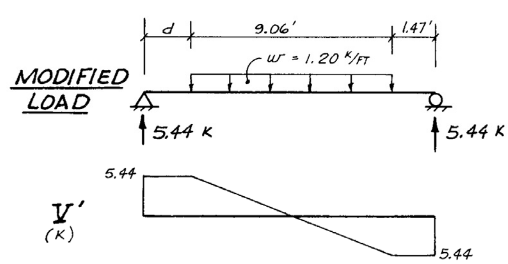
- C_D Load Duration Factor
- C_M Moisture Factor
- C_t Temperature Factor
- C_{vr} Shear Reduction Factor



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).



Modified shear V' used to compute reduced shear f_v'

Glulam - Analysis

Example Problem

7. Glulam - Beam

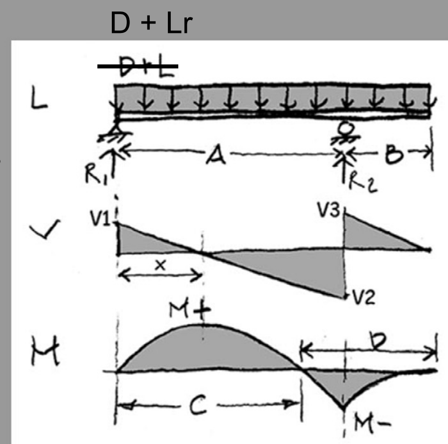
Analyze the cantilever Glulam beam for the given ~~floor~~ roof load (CD=~~1.0~~ 1.25). Determine the factored allowable stress and actual stress for the maximum positive and negative moments. Check shear stress using the maximum shear force. The beam is ~~continuously~~ braced by the ~~floor (CL=1.0)~~. The lengths C and D are used for L in calculating Cv for + and - moments respectively. Determine the required bearing length at the cantilever support.

CM = 1.0

braced at supports

DATASET: 2 -1-

Combination Symbol	20F-V2
Species (outer/core)	SP/SP
Section Size	3.5 x 13.75 IN
Tabulated Allowable x-x Bending Stress, Fbx+	2000 PSI
Tabulated Allowable x-x Bending Stress, Fbx-	1550 PSI
Tabulated Allowable x-x Comp.Perp. Stress, Fcpx (tension face)	740 PSI
Tabulated Allowable x-x Shear Stress, Fvx	300 PSI
Total load (D+L)	0.231231 KLF
Beam Span, A	25 FT
Cantilever Span, B	10 FT



Glulam - Analysis

Example Problem

1. calculate shear and moment.
2. determine point of contraflexure

$\Sigma M_{R_1} = 0 = 8.085(17.5) - R_2(25)$

$R_2 = 5.66^K \uparrow$

$\Sigma M_{R_2} = 0 = R_1(25) - 8.085(7.5)$

$R_1 = 2.43^K \uparrow$

DISTANCE TO V=0, M_{max}

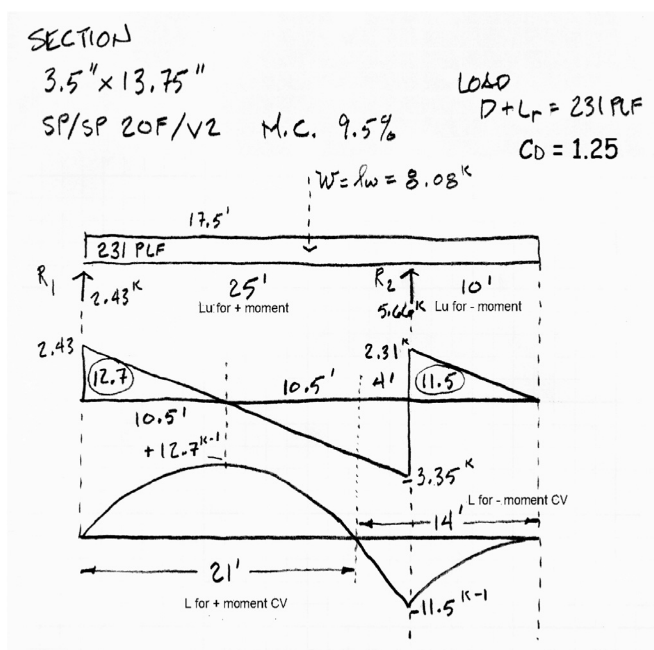
$x = 2.4255^K / 0.231 \text{ KLF} = 10.5'$

M_{max} POSITIVE $= 12.7^{K-'}$

M_{max} NEGATIVE $= 11.5^{K-'}$

$V_{max} = 3.35^K$

$R_{max} = 5.66^K$ (BEARING)



Glulam – Analysis - Example Problem 20F-V2 SP/SP

Table 5A Expanded - Reference Design Values for Structural Glued Laminated Softwood Timber Combinations[1]
(Members stressed primarily in bending) (Tabulated design values are for normal load duration and dry service conditions. See NDS 5.3 for a comprehensive description of design value adjustment factors.)

Use with Table 5A Adjustment Factors

Combination Symbol	Species Outer/ Core	Bending About X-X Axis (Loaded Perpendicular to Wide Faces of Laminations): Bending, Bottom of beam Stressed in tension (Positive Bending) F_{bx} (psi)	Bending, Top of Beam Stressed in Tension (Negative Bending) F_{bx} (psi)	Compression Perpendicular to Grain, Tension Face $F_{c\perp x}$ (psi)	Compression Perpendicular to Grain, Compression Face $F_{c\perp x}$ (psi)	Shear Parallel to Grain F_{vx} (2) (psi)	Modulus of Elasticity, For Deflection Calculations(8) $E_{x\,true}$ (10^6 psi)	$E_{x\,app}$ (10^6 psi)	For Stability Calculations $E_{x\,min}$ (10^6 psi)	Bending About Y-Y Axis (Loaded Parallel to Wide Faces of Laminations): Bending F_{by} (psi)	Compression Perpendicular to Grain $F_{c\perp y}$ (psi)	Shear Parallel to Grain F_{vy} (3) (psi)	Modulus of Elasticity, For Deflection Calculations(8) $E_{y\,true}$ (10^6 psi)	$E_{y\,app}$ (10^6 psi)	For Stability Calculations $E_{y\,min}$ (10^6 psi)	Axially Loaded: Tension Parallel to Grain F_t (psi)	Compression Parallel to Grain F_c (psi)	Fasteners: Specific Gravity for Fastener Design, Top or Bottom Face G	Side Face G
16F-1.3E		**1600**	**925**	**315**		**195**	**1.4**	**1.3**	**0.69**	**800**	**315**	**170**	**1.2**	**1.1**	**0.58**	**675**	**925**	**0.41**	
16F-V3	DF/DF	1600	1250	560	560	265	1.6	1.5	0.79	1450	560	230	1.6	1.5	0.79	975	1500	0.50	0.50
16F-V6	DF/DF	1600	1600	560	560	265	1.7	1.6	0.85	1450	560	230	1.6	1.5	0.79	1000	1600	0.50	0.50
16F-E2	HF/HF	1600	1050	375	375	215	1.5	1.4	0.74	1200	375	190	1.4	1.3	0.69	825	1150	0.43	0.43
16F-E3	DF/DF	1600	1200	560	560	265	1.7	1.6	0.85	1400	560	230	1.6	1.5	0.79	975	1600	0.50	0.50
16F-E6	DF/DF	1600	1600	560	560	265	1.7	1.6	0.85	1550	560	230	1.6	1.5	0.79	1000	1600	0.50	0.50
16F-E7	HF/HF	1600	1600	375	375	215	1.5	1.4	0.74	1350	375	190	1.4	1.3	0.74	875	1250	0.43	0.43
16F-V2	SP/SP	1600	1400	740	650	300	1.6	1.5	0.79	1450	650	260	1.5	1.4	0.74	1000	1300	0.55	0.55
16F-V3	SP/SP	1600	1450	740	740	300	1.5	1.4	0.74	1450	650	260	1.5	1.4	0.74	975	1400	0.55	0.55
16F-V5	SP/SP	1600	1600	650	650	300	1.7	1.6	0.85	1600	650	260	1.6	1.5	0.79	1000	1550	0.55	0.55
16F-E1	SP/SP	1600	1250	650	650	300	1.7	1.6	0.85	1400	650	260	1.7	1.6	0.85	1050	1550	0.55	0.55
16F-E3	SP/SP	1600	1600	650	650	300	1.8	1.7	0.90	1650	650	260	1.7	1.6	0.85	1100	1550	0.55	0.55
20F-1.5E		**2000**	**1100**	**425**		**195**	**1.6**	**1.5**	**0.79**	**800**	**315**	**170**	**1.3**	**1.2**	**0.63**	**725**	**925**	**0.41**	
20F-V3	DF/DF	2000	1450	650	560	265	1.7	1.6	0.85	1450	560	230	1.6	1.5	0.79	1000	1550	0.50	0.50
20F-V7	DF/DF	2000	2000	650	650	265	1.7	1.6	0.85	1450	560	230	1.7	1.6	0.85	1050	1600	0.50	0.50
20F-V12	AC/AC	2000	1400	560	560	265	1.6	1.5	0.79	1250	470	230	1.5	1.4	0.74	925	1500	0.46	0.46
20F-V13	AC/AC	2000	2000	560	560	265	1.6	1.5	0.79	1250	470	230	1.5	1.4	0.74	950	1550	0.46	0.46
20F-V14	POC/POC	2000	1450	560	560	265	1.6	1.5	0.79	1300	470	230	1.5	1.4	0.74	900	1600	0.46	0.46
20F-V15	POC/POC	2000	2000	560	560	265	1.6	1.5	0.79	1300	470	230	1.5	1.4	0.74	900	1600	0.46	0.46
20F-E2	HF/HF	2000	1400	500	500	215	1.7	1.6	0.85	1200	375	190	1.5	1.4	0.74	925	1350	0.43	0.43
20F-E3	DF/DF	2000	1200	560	560	265	1.8	1.7	0.90	1400	560	230	1.7	1.6	0.85	1050	1600	0.50	0.50
20F-E6	DF/DF	2000	2000	560	560	265	1.8	1.7	0.90	1550	560	230	1.7	1.6	0.85	1150	1650	0.50	0.50
20F-E7	HF/HF	2000	2000	500	500	215	1.8	1.6	0.85	1450	375	190	1.5	1.4	0.74	1050	1450	0.43	0.43
20F-E8	ES/ES	2000	1300	450	450	200	1.6	1.5	0.79	1000	315	175	1.5	1.4	0.74	825	1100	0.41	0.41
24F-E/SPF1	SPF/SPF	2400	2400	560	560	215	1.7	1.6	0.85	1150	470	190	1.7	1.6	0.85	1150	2000	0.42	0.42
24F-E/SPF3	SPF/SPF	2400	1550	560	650	215	1.7	1.6	0.85	1200	470	195	1.6	1.5	0.79	900	1750	0.42	0.42
→ 20F-V2	SP/SP	2000	1550	740	650	300	1.6	1.5	0.79	1450	650	260	1.5	1.4	0.74	1000	1400	0.55	0.55
20F-V3	SP/SP	2000	1450	650	650	300	1.6	1.5	0.79	1600	650	260	1.6	1.5	0.79	1000	1400	0.55	0.55
20F-V5	SP/SP	2000	2000	740	740	300	1.7	1.6	0.85	1450	650	260	1.5	1.4	0.74	1050	1500	0.55	0.55
20F-E1	SP/SP	2000	1300	650	650	300	1.8	1.7	0.90	1400	650	260	1.7	1.6	0.85	1050	1550	0.55	0.55
20F-E3	SP/SP	2000	2000	650	650	300	1.8	1.7	0.90	1700	650	260	1.7	1.6	0.85	1150	1600	0.55	0.55
24F-1.7E		**2400**	**1450**	**500**		**210**	**1.8**	**1.7**	**0.90**	**1050**	**315**	**185**	**1.4**	**1.3**	**0.69**	**775**	**1000**	**0.42**	
24F-V5	DF/HF	2400	1600	650	650	215	1.8	1.7	0.90	1350	375	200	1.6	1.5	0.79	1100	1450	0.50	0.43
24F-V10	DF/HF	2400	2400	650	650	215	1.9	1.8	0.95	1450	375	200	1.6	1.5	0.79	1150	1550	0.50	0.43
24F-E11	HF/HF	2400	2400	500	500	215	1.9	1.8	0.95	1550	375	190	1.6	1.5	0.79	1150	1550	0.43	0.43
24F-E15	HF/HF	2400	1600	500	500	215	1.9	1.8	0.95	1200	375	190	1.6	1.5	0.79	975	1500	0.43	0.43
24F-V1	SP/SP	2400	1750	740	650	300	1.8	1.7	0.90	1450	650	260	1.6	1.5	0.79	1100	1500	0.55	0.55
24F-V4 (4)	SP/SP	2400	1650	740	650	210	1.8	1.7	0.90	1350	470	230	1.6	1.5	0.79	975	1350	0.55	0.43
24F-V5	SP/SP	2400	2400	740	740	300	1.8	1.7	0.90	1700	650	260	1.7	1.6	0.85	1150	1600	0.55	0.55

Glulam - Analysis

Example Problem

3. determine factors

use lesser of CL or CV

SECTION
3.5" × 13.75"
SP/SP 20F/V2 M.C. 9.5%

LOAD
D + Lr = 231 PLF

FOR + MOMENT

$C_D = 1.25$

$C_V \quad \left(\frac{21}{21}\right)^{\frac{1}{20}} \times \left(\frac{12}{13.75}\right)^{\frac{1}{20}} \times \left(\frac{5.125}{3.5}\right)^{\frac{1}{20}}$

$1 \times .9932 \times 1.019 = 1.012 > 1.0$

∴ USE 1.0

Glulam - Analysis
Example Problem

3. Determine factors

use lesser of CL or CV

FOR + MOMENT

$F_b = 2000$ psi $E_{y\,MIN} = 740\,000$ psi (YES 'Y')

C_L

$l_u = 25' = 300"$ $l_u/d = 25(12)/13.75 = 21.82 > 14.3$

$l_e = 1.84\, l_u = 1.84\,(300") = 552"$ (see table footnote)

$$R_B = \sqrt{\frac{552\,(13.75)}{3.5^2}} = 24.89 < 50 \checkmark$$

$$F_{bE} = \frac{1.20\,(740\,000)}{24.4^2} = 1433.2 \text{ psi}$$

$F_b^* = 2000\,(1.25) = 2500$ psi

$C_L = 0.541$

$C_L < C_V$ ∴ USE C_L NOT C_V

Glulam - Analysis
Example Problem

4. Check stress

Table 1D Section Properties of *Southern Pine* Structural Glued Laminated Timber (Cont.)

Depth	Area	X-X Axis			Y-Y Axis	
d (in.)	A (in.^{2})	I_x (in.^{4})	S_x (in.^{3})	r_x (in.)	I_y (in.^{4})	S_y (in.^{3})
			3-1/2 in. Width		(r_y = 1.010 in.)	
5-1/2	19.25	48.53	17.65	1.588	19.65	11.23
6-7/8	24.06	94.78	27.57	1.985	24.56	14.04
8-1/4	28.88	163.8	39.70	2.382	29.48	16.84
9-1/4	32.38	230.8	49.91	2.670	33.05	18.89
9-1/2	33.25	250.1	52.65	2.742	33.94	19.40
9-5/8	33.69	260.1	54.04	2.778	34.39	19.65
11	38.50	388.2	70.58	3.175	39.30	22.46
11-1/4	39.38	415.3	73.83	3.248	40.20	22.97
11-7/8	41.56	488.4	82.26	3.428	42.43	24.24
12-3/8	43.31	552.7	89.33	3.572	44.21	25.27
13-3/4	48.13	758.2	110.3	3.969	49.13	28.07
14	49.00	800.3	114.3	4.041	50.02	28.58
15-1/8	52.94	1009	133.4	4.366	54.04	30.88
16	56.00	1195	149.3	4.619	57.17	32.67
16-1/2	57.75	1310	158.8	4.763	58.95	33.69
17-7/8	62.56	1666	186.4	5.160	63.87	36.49

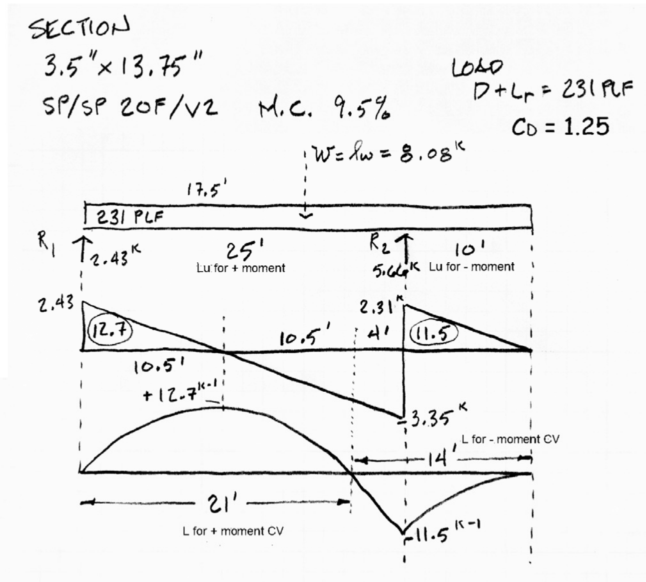
$F'_b = 2000\,(1.25\;\;0.541) = 1353$ psi

$$f_b = \frac{M}{S'_x} = \frac{12700\,(12)}{110.3} = 1385 \text{ psi} \leq 1353 \text{ psi} \quad \text{FAILS!}$$

Glulam - Analysis

Example Problem

Now check section with negative moment



FOR — MOMENT

$F_b = 1550$ psi $\quad E_{ymin} = 74000$ psi

$C_D = 1.25 \quad C_V = 1.03 \rightarrow$ USE 1.0
$L = 14' \quad x = 20$

C_L: $\ell_u = 10 \quad \ell_u/d = 8.73 \quad \ell_e = 149.25''$

$R_B = \sqrt{\dfrac{149\,(13.25)}{3.5}} = 12.94$

$F_{bE} = \dfrac{1.20\ 740000}{12.94^2} = 5301$ psi

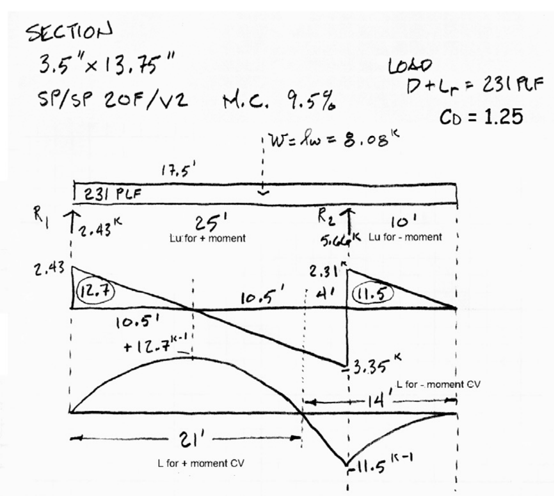
$F_b^* = 1550\,(1.25) = 1937$

$C_L = 0.973 < C_V \therefore$ USE C_L NOT C_V

Glulam - Analysis

Example Problem

Now check section with negative moment



$F_b' = 1550\,(1.25\ 0.973) = 1885$

$f_b = M/S_x = \dfrac{11.55\,(12)(1000)}{110.3} = 1257 < 1885$ ✓ OK

$F_V' = 300\,(1.25) = 375$ psi

$f_V = \dfrac{3}{2}\dfrac{V}{A} = \dfrac{1.5\,(3350)}{48.13} = 104 < 375$ ✓ OK

$F_{c\perp}' = 740\,(1.13) \quad$ SAY $3'' = \ell_b$ (CLOSE TO SQUARE DEPENDS ON BRACKET)
$= 836$ psi

$f_{c\perp} = \dfrac{P}{A} = \dfrac{5660^{\#}}{3 \times 3\frac{1}{2}} = 539$ psi < 836 ✓

Glulam - Design
Procedure

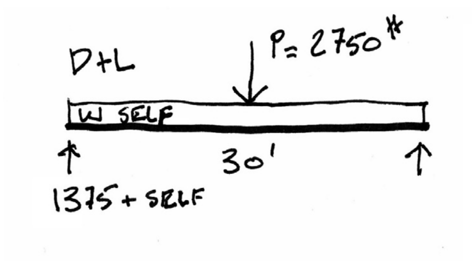
Given: Glulam grade, loading, bracing, conditions (moisture, temperature)

Find: section dimensions

1. Guess section: d in inches → 0.9 L in feet
   b/d → 1/3 to 1/5
2. Calculate C_V
3. Calculate C_L
4. Estimate DL
5. Calculate moment
6. Determine actual bending stress $f_b = M/Sx$
7. Determine F'_b
8. Check bending stress, revise if required
9. Check shear stress
10. Check bearing
11. Check deflection

Glulam - Design
Example Problem

GLULAM
DF/DF 20F-V3
F_{bx} = 2000 psi
F_{vx} = 265 psi
$E_{y\,min}$ = 790 000 psi
DENSITY 31.2 PCF
DRY



braced at supports and load point

1. Guess section: d" → 0.9 L'
   b/d → 1/3 to 1/5

GUESS SIZE:
$d'' \approx 0.9 L' = 0.9(30) = 27''$
$\frac{b}{d} \approx \frac{1}{3}$ TO $\frac{1}{5}$ TRY $5.125 \approx \frac{1}{5}$

TRY 5.125 x 27 $A = 138.4\,in^2$ $S_x = 622.7\,in^3$

Glulam – Analysis - Example Problem 20F-V2 SP/SP

Table 5A Expanded - Reference Design Values for Structural Glued Laminated Softwood Timber Combinations[1]
(Members stressed primarily in bending) (Tabulated design values are for normal load duration and dry service conditions. See NDS 5.3 for a comprehensive description of design value adjustment factors.)

Use with Table 5A Adjustment Factors

		Bending About X-X Axis (Loaded Perpendicular to Wide Faces of Laminations)								Bending About Y-Y Axis (Loaded Parallel to Wide Faces of Laminations)						Axially Loaded		Fasteners	
		Bending		Compression Perpendicular to Grain		Shear Parallel to Grain	Modulus of Elasticity			Bending	Compression Perpendicular to Grain	Shear Parallel to Grain	Modulus of Elasticity			Tension Parallel to Grain	Compression Parallel to Grain	Specific Gravity for Fastener Design	
		Bottom of beam Stressed in tension (Positive Bending)	Top of Beam Stressed in Tension (Negative Bending)	Tension Face	Compression Face		For Deflection Calculations[8]		For Stability Calculations				For Deflection Calculations[8]		For Stability Calculations			Top or Bottom Face	Side Face
Combination Symbol	Species Outer/ Core	F_{bx} (psi)	F_{bx} (psi)	$F_{c\perp x}$ (psi)		F_{vx} [2] (psi)	$E_{x\,true}$ (10^6 psi)	$E_{x\,app}$ (10^6 psi)	$E_{x\,min}$ (10^6 psi)	F_{by} (psi)	$F_{c\perp y}$ (psi)	F_{vy} [3] (psi)	$E_{y\,true}$ (10^6 psi)	$E_{y\,app}$ (10^6 psi)	$E_{y\,min}$ (10^6 psi)	F_t (psi)	F_c (psi)	G	
16F-1.3E		**1600**	**925**	**315**		**195**	**1.4**	**1.3**	**0.69**	**800**	**315**	**170**	**1.2**	**1.1**	**0.58**	**675**	**925**	**0.41**	
16F-V3	DF/DF	1600	1250	560	560	265	1.6	1.5	0.79	1450	560	230	1.6	1.5	0.79	975	1500	0.50	0.50
16F-V6	DF/DF	1600	1600	560	560	265	1.7	1.6	0.85	1450	560	230	1.6	1.5	0.79	1000	1600	0.50	0.50
16F-E2	HF/HF	1600	1050	375	375	215	1.5	1.4	0.74	1200	375	190	1.4	1.3	0.69	825	1150	0.43	0.43
16F-E3	DF/DF	1600	1200	560	560	265	1.7	1.6	0.85	1400	560	230	1.6	1.5	0.79	975	1600	0.50	0.50
16F-E6	DF/DF	1600	1600	560	560	265	1.7	1.6	0.85	1550	560	230	1.6	1.5	0.79	1000	1600	0.50	0.50
16F-E7	HF/HF	1600	1600	375	375	215	1.5	1.4	0.74	1350	375	190	1.4	1.3	0.74	875	1250	0.43	0.43
16F-V2	SP/SP	1600	1400	740	650	300	1.6	1.5	0.79	1450	650	260	1.5	1.4	0.74	1000	1300	0.55	0.55
16F-V3	SP/SP	1600	1450	740	740	300	1.5	1.4	0.74	1450	650	260	1.5	1.4	0.74	975	1400	0.55	0.55
16F-V5	SP/SP	1600	1600	650	650	300	1.7	1.6	0.85	1600	650	260	1.6	1.5	0.79	1000	1550	0.55	0.55
16F-E1	SP/SP	1600	1250	650	650	300	1.7	1.6	0.85	1400	650	260	1.7	1.6	0.85	1050	1550	0.55	0.55
16F-E3	SP/SP	1600	1600	650	650	300	1.8	1.7	0.90	1650	650	260	1.7	1.6	0.85	1100	1550	0.55	0.55
20F-1.5E		**2000**	**1100**	**425**		**195**	**1.6**	**1.5**	**0.79**	**800**	**315**	**170**	**1.3**	**1.2**	**0.63**	**725**	**925**	**0.41**	
→ 20F-V3	DF/DF	2000	1450	650	560	265	1.7	1.6	0.85	1450	560	230	1.6	1.5	0.79	1000	1550	0.50	0.50
20F-V7	DF/DF	2000	2000	650	650	265	1.7	1.6	0.85	1450	560	230	1.7	1.6	0.85	1050	1600	0.50	0.50
20F-V12	AC/AC	2000	1400	560	560	265	1.6	1.5	0.79	1250	470	230	1.5	1.4	0.74	925	1500	0.46	0.46
20F-V13	AC/AC	2000	2000	560	560	265	1.6	1.5	0.79	1250	470	230	1.5	1.4	0.74	950	1550	0.46	0.46
20F-V14	POC/POC	2000	1450	560	560	265	1.6	1.5	0.79	1300	470	230	1.5	1.4	0.74	900	1600	0.46	0.46
20F-V15	POC/POC	2000	2000	560	560	265	1.6	1.5	0.79	1300	470	230	1.5	1.4	0.74	900	1600	0.46	0.46
20F-E2	HF/HF	2000	1400	500	500	215	1.7	1.6	0.85	1200	375	190	1.5	1.4	0.74	925	1350	0.43	0.43
20F-E3	DF/DF	2000	1200	560	560	265	1.8	1.7	0.90	1400	560	230	1.7	1.6	0.85	1050	1600	0.50	0.50
20F-E6	DF/DF	2000	2000	560	560	265	1.8	1.7	0.90	1550	560	230	1.7	1.6	0.85	1150	1650	0.50	0.50
20F-E7	HF/HF	2000	2000	500	500	215	1.8	1.6	0.85	1450	375	190	1.5	1.4	0.74	1050	1450	0.43	0.43
20F-E8	ES/ES	2000	1300	450	450	200	1.6	1.5	0.79	1000	315	175	1.5	1.4	0.74	825	1100	0.41	0.41
24F-E/SPF1	SPF/SPF	2400	2400	560	560	215	1.7	1.6	0.85	1150	470	190	1.7	1.6	0.85	1150	2000	0.42	0.42
24F-E/SPF3	SPF/SPF	2400	1550	560	650	215	1.7	1.6	0.85	1200	470	195	1.6	1.5	0.79	900	1750	0.42	0.42
20F-V2	SP/SP	2000	1550	740	650	300	1.6	1.5	0.79	1450	650	260	1.5	1.4	0.74	1000	1400	0.55	0.55
20F-V3	SP/SP	2000	1450	650	650	300	1.6	1.5	0.79	1600	650	260	1.6	1.5	0.79	1000	1400	0.55	0.55
20F-V5	SP/SP	2000	2000	740	740	300	1.7	1.6	0.85	1450	650	260	1.5	1.4	0.74	1050	1500	0.55	0.55
20F-E1	SP/SP	2000	1300	650	650	300	1.8	1.7	0.90	1400	650	260	1.7	1.6	0.85	1050	1550	0.55	0.55
20F-E3	SP/SP	2000	2000	650	650	300	1.8	1.7	0.90	1700	650	260	1.7	1.6	0.85	1150	1600	0.55	0.55
24F-1.7E		**2400**	**1450**	**500**		**210**	**1.8**	**1.7**	**0.90**	**1050**	**315**	**185**	**1.4**	**1.3**	**0.69**	**775**	**1000**	**0.42**	
24F-V5	DF/HF	2400	1600	650	650	215	1.8	1.7	0.90	1350	375	200	1.6	1.5	0.79	1100	1450	0.50	0.43
24F-V10	DF/HF	2400	2400	650	650	215	1.9	1.8	0.95	1450	375	200	1.6	1.5	0.79	1150	1550	0.50	0.43
24F-E11	HF/HF	2400	2400	500	500	215	1.9	1.8	0.95	1550	375	190	1.6	1.5	0.79	1150	1550	0.43	0.43
24F-E15	HF/HF	2400	1600	500	500	215	1.9	1.8	0.95	1200	375	190	1.6	1.5	0.79	975	1500	0.43	0.43
24F-V1	SP/SP	2400	1750	740	650	300	1.8	1.7	0.90	1450	650	260	1.6	1.5	0.79	1100	1500	0.55	0.55
24F-V4 [4]	SP/SP	2400	1650	740	650	210	1.8	1.7	0.90	1350	470	230	1.6	1.5	0.79	975	1350	0.55	0.43
24F-V5	SP/SP	2400	2400	740	740	300	1.8	1.7	0.90	1700	650	260	1.7	1.6	0.85	1150	1600	0.55	0.55

Glulam - Design

Example Problem

2. Calculate C_V

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, F_{bx}^{+}, and F_{bx}^{-}, shall be multiplied by the following volume factor:

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

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

$$C_V = \left(\frac{21}{L}\right)^{1/x}\left(\frac{12}{d}\right)^{1/x}\left(\frac{5.125}{b}\right)^{1/x}$$

$x = 10$

$L = 30'$

$d = 27''$

$b = 5.125''$

$C_V = 0.89$

Glulam - Design
Example Problem

Table 3.3.3 Effective Length, ℓ_e, for Bending Members

Cantilever[1]	when $\ell_u/d < 7$	when $\ell_u/d \geq 7$
Uniformly distributed load	ℓ_e=1.33 ℓ_u	ℓ_e=0.90 ℓ_u + 3d
Concentrated load at unsupported end	ℓ_e=1.87 ℓ_u	ℓ_e=1.44 ℓ_u + 3d
Single Span Beam[1,2]	when $\ell_u/d < 7$	when $\ell_u/d \geq 7$
Uniformly distributed load	ℓ_e=2.06 ℓ_u	ℓ_e=1.63 ℓ_u + 3d
Concentrated load at center with no intermediate lateral support	ℓ_e=1.80 ℓ_u	ℓ_e=1.37 ℓ_u + 3d
Concentrated load at center with lateral support at center	ℓ_e=1.11 ℓ_u	

3. Calculate C_L

use lesser of C_V or C_L

C_L $\quad \ell_u = 15' \quad \ell_e = 1.11\,\ell_u = 199.8''$

$$R_B = \sqrt{\frac{\ell_e d}{b^2}} = \sqrt{\frac{199.8(27)}{5.125^2}} = 14.33$$

$$F_{bE} = \frac{1.2\,E_{y\,min}}{R_B^2} = \frac{1.2\,(790000)}{14.33^2} = 1688.6 \text{ psi}$$

$$F_b^* = 2000\,(C_b) = 2000$$

$$C_L = 0.739 < 0.889 = C_V \quad \therefore \text{ USE } C_L \text{ NOT } C_V$$

Glulam - Design
Example Problem

4. Estimate DL
5. Calculate moment
6. Determine actual bending stress
   fb = M/Sx
7. Determine F'b
8. Check bending stress, revise if required

$$w_{SELF} = D\,\frac{A}{144} = 31.2\,\frac{138.4}{144} = 30 \text{ PLF}$$

$$M = \frac{PL}{4} + \frac{w\ell^2}{8} = \frac{2750(30)}{4} + \frac{30(30)^2}{8}$$

$$M = 73125 + 3374 = 76499 \text{ '-\#}$$

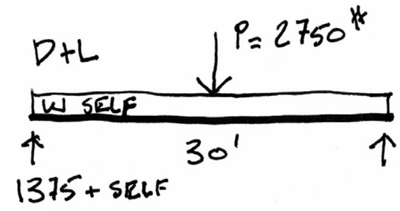
$$f_b = \frac{M}{S_x} = \frac{76499(12)}{622.7} = 1474 \text{ psi}$$

$$F'_b = F_b\,(C_L) = 2000\,(0.739) = 1478 \text{ psi}$$

$$F'_b = 1478 > 1474 = f_b \quad \therefore \text{ PASS}$$

Glulam - Design
Example Problem

9. Check shear stress
10. Check bearing
11. Check deflection



SHEAR

$$V_{max} = \frac{P}{2} + \frac{wl}{2} = \frac{2750}{2} + \frac{30(30)}{2} = 1375 + 450 = 1825^{\#}$$

$$f_v = \frac{3}{2}\frac{V}{A} = 1.5\,\frac{1825}{138.4} = 19.78 \text{ psi}$$

$$F'_v = 265 \text{ psi} > 19.78 = f_v \quad \therefore \text{ PASS}$$