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WOOD STRUCTURES

Commentary is opposite the text it annotates.

8.1—SCOPE

This Section specifies design requirements for structural components made of sawn lumber products, stressed wood, glued laminated timber, wood piles, and mechanical connections.

8.2—DEFINITIONS

Adjusted Design Value—Reference design value multiplied by applicable adjustment factors.

Beams and Stringers (B&S)—Beams and stringers are rectangular pieces that are 5.0 or more in. thick (nominal), with a depth more than 2.0 in. (nominal) greater than the thickness. B&S are graded primarily for use as beams, with loads applied to the narrow face.

Bent—Type of pier consisting of two or more columns or column-like components connected at their top ends by a cap, strut, or other component holding them in their correct positions.

Bonded Reinforcement—Reinforcing material that is continuously attached to a glulam beam through adhesive bonding.

Bumper Lamination—Sacrificial wood lamination continuously bonded to the outer face of reinforcement to protect the reinforcement from damage or fire, or for visual appearance. The bumper lam is an option, not a requirement.

Cap—Sawn lumber or glulam component placed horizontally on an abutment or pier to distribute the live load and dead load of the superstructure. Also, a metal, wood, or mastic cover to protect exposed wood end grain from wetting.

Combination Symbol—Product designation used by the structural glued laminated timber industry; see AITC 117.

Conventional Lamstock—Solid sawn wood laminations with a net thickness of 2.0 in. or less, graded either visually or through mechanical means, finger-jointed and face-bonded to form a glulam per ASTM D7199.

Crib—Structure consisting of a foundation grillage and a framework providing compartments that are filled with gravel, stones, or other material satisfactory for supporting the structure to be placed thereon.

Decking—Subcategory of dimension lumber, graded primarily for use with the wide face placed flatwise.

Delamination—Adhesive failure causing the separation of laminations.

Development Length—Length of the bond line along the axis of the beam required to develop the design tensile strength of the reinforcement.

Diaphragm—Blocking between two main longitudinal beams consisting of solid lumber, glued laminated timber, or steel cross bracing.

Dimension Lumber—Lumber with a nominal thickness of from 2.0 up to but not including 5.0 in. and having a nominal width of 2.0 in. or more.

Dowel—Relatively short length of round metal bar used to interconnect or attach two wood components in a manner to minimize movement and displacement.

Dressed Lumber—Lumber that has been surfaced by a planing machine on one or more sides or edges.

Dry—Condition of having a relatively low moisture content, i.e., not more than 19 percent for sawn lumber and 16 percent for glued laminated timber.

E-Glass—Low-alkali (borosilicate glass) electrical grade glass fiber commonly used by the composite industry for the manufacture of FRP composites.

Fiber-Reinforced Polymer (FRP)—Any material consisting of at least two distinct components: reinforcing fibers and a binder matrix (a polymer). The reinforcing fibers are permitted to be synthetic (e.g. glass), metallic, or natural (e.g. bamboo), and are permitted to be long and continuously-oriented or short and randomly oriented. The binder matrix is permitted to be either thermoplastic (e.g. polypropylene or nylon) or thermosetting (e.g. epoxy or vinyl-ester).

Frame Bent—Type of framed timber substructure.

Grade—Designation of the material quality of a manufactured piece of wood.

Grade Mark—Identification of lumber with symbols or lettering to certify its quality or grade.

Grain—Direction, size, arrangement, appearance, or quality of the fibers in wood or lumber.

Green Wood—Freshly sawn or undried wood. Wood that has become completely wet after immersion in water would not be considered green but may be said to be in the green condition.

Hardwood—Generally one of the botanical groups of trees that have broad leaves or the wood produced by such trees. The term does not refer to the actual hardness of the wood.

Horizontally Laminated Timber—Laminated wood in which the laminations are arranged with their wider dimension approximately perpendicular to the direction of applied transverse loads.

Laminate—Product made by bonding together two or more layers (laminations) of material or materials.

Laminated Wood—An assembly made by bonding layers of veneer or lumber with an adhesive, nails, or stressing to provide a structural continuum so that the grain of all laminations is essentially parallel.

Laminating—Process of bonding laminations together with adhesive, including the preparation of the laminations, preparation and spreading of adhesive, assembly of laminations in packages, application of pressure, and curing.

Lamination—Full-width and full-length layer contained in a component bonded together with adhesive. The layer itself may be composed of one or several wood pieces in width or length.

Machine Evaluated Lumber (MEL)—Mechanically graded lumber certified as meeting the criteria of a specific commercial grading system.

Machine Stress-Rated (MSR) Lumber—Mechanically graded lumber certified as meeting the criteria of a specific commercial grading system.

Mechanically Graded Lumber—Solid sawn lumber graded by mechanical evaluation in addition to visual examination.

Modulus of Rupture (MOR)—Maximum stress at the extreme fiber in bending, calculated from the maximum bending moment on the basis of an assumed stress distribution.

Moisture Content—Indication of the amount of water contained in the wood, usually expressed as a percentage of the weight of the oven-dry wood.

NDS®—*National Design Specification® for Wood Construction* by the American Forest and Paper Association.

NELMA—Grading rules by Northeastern Lumber Manufacturers Association.

NLGA—Grading rules by National Lumber Grades Authority.

Net Size—Size used in design to calculate the resistance of a component. Net size is close to the actual dry size.

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Nominal Size—As applied to timber or lumber, the size by which it is specified and sold; often differs from the actual size.

NSLB—Grading rules by Northern Softwood Lumber Bureau. Note: NSLB merged with NELMA.

Oil-Borne Preservative—Preservative that is introduced into wood in the form of an oil-based solution.

Plank—Broad board, usually more than 1.0 in. thick, laid with its wide dimension horizontal and used as a bearing surface or riding surface.

Posts and Timber (P&T)—Posts and timbers pieces with a square or nearly square cross section, 5.0 by 5.0 in. (nominal) and larger, with the width not more than 2.0 in. (nominal) greater than the thickness. Lumber in the P&T size classification is graded primarily for resisting axial loads.

Preservative—Any substance that is effective in preventing the development and action of wood-decaying fungi, borers of various kinds, and harmful insects.

Reinforcement (for Glulam)—Any material that is not a conventional lamstock lumber whose mean (ultimate) longitudinal unit strength exceeds 20 ksi for tension and compression, and whose mean tension and compression modulus of elasticity exceeds 3,000 ksi. Acceptable reinforcing materials include but are not restricted to fiber-reinforced polymer (FRP) plates and bars, and metallic plates and bars.

Reference Design Value—Allowable stress value or modulus of elasticity specified in the *NDS*®.

Rough Sawn Lumber—Lumber that has not been dressed but that has been sawn, edged, and trimmed.

Sawn Lumber—Product of a sawmill not further manufactured other than by sawing, resawing, passing lengthwise through a standard planing mill, drying, and cross-cutting to length.

Sawn Timbers—Lumber that is nominally 5.0 in. or more in least dimension.

Softwood—Generally, one of the conifers or the wood produced by such trees. The term does not refer to the actual hardness of the wood.

SPIB—Grading rules by Southern Pine Inspection Bureau.

Stress Grades—Lumber grades having assigned working stress and modulus of elasticity in accordance with accepted principles of resistance grading.

Structural Glued Laminated Timber (Glulam)—Engineered, stress-rated product of a timber laminating plant comprised of assemblies of specially selected and prepared wood laminations securely bonded together with adhesives. The grain of all laminations is approximately parallel longitudinally. Glued laminated timber is permitted to be comprised of pieces end-joined to form any length, of pieces placed or bonded edge-to-edge to make any width, or of pieces bent to curbed form during bonding.

Structural Lumber—Lumber that has been graded and assigned design values based on standardized procedures to ensure acceptable reliability.

Tension Reinforcement—Reinforcement placed on the tension side of a flexural member on the first glueline or on the face of the beam.

Vertically Laminated Timber—Laminated wood in which the laminations are arranged with their wider dimension approximately parallel to the direction of load.

Visually Graded Lumber—Structural lumber graded solely by visual examination.

Waterborne Preservative—Preservative that is introduced into wood in the form of a water-based solution.

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WCLIB—Grading rules by West Coast Lumber Inspection Bureau.

Wet-Use—Use conditions where the moisture content of the wood in service exceeds 16 percent for glulam and 19 percent for sawn lumber.

WWPA—Grading rules by Western Wood Products Association.

8.3—NOTATION

A	=	parameter for beam stability (8.6.2)
A_b	=	bearing area (in.^{2}) (8.8.3)
A_g	=	gross cross-sectional area of the component (in.^{2}) (8.8.2)
A_n	=	net cross-sectional area of the component (in.^{2}) (8.9)
a	=	coefficient (8.4.4.5)
B	=	parameter for compression (8.8.2)
b	=	width of the glued laminated timber component; thickness of lumber component (see Figure 8.3-1) (in.) (8.4.4.5)
C_b	=	bearing factor (8.8.3)
C_c	=	curvature factor (8.4.1.2)
C_d	=	deck factor (8.4.4.1) (8.4.4.8)
C_F	=	size factor (8.4.4.1) (8.4.4.4)
C_{fu}	=	flat use factor (8.4.4.1) (8.4.4.6)
C_i	=	incising factor (8.4.4.1) (8.4.4.7)
C_{KF}	=	format conversion factor (8.4.4.1) (8.4.4.2)
C_L	=	beam stability factor (8.6.2)
C_M	=	wet service factor (8.4.4.1) (8.4.4.3)
C_P	=	column stability factor (8.8.2)
C_V	=	volume factor (8.4.4.1) (8.4.4.5)
C_λ	=	time effect factor (8.4.4.1) (8.4.4.9)
c	=	coefficient (8.8.2)
d	=	depth of the beams or stringers or width of the dimension lumber component (8.4.4.4) or glulam depth (8.4.4.5) as shown in Figure 8.3-1 (in.) (8.4.1.1.1)
E	=	adjusted modulus of elasticity (ksi) (8.4.4.1)
E_o	=	reference modulus of elasticity (ksi) (8.4.1.1.4) (8.4.4.1)
$E_{o\ axial}$	=	modulus of elasticity, axially loaded (8.4.1.2.3)
E_{vo}	=	modulus of elasticity, y-y axis (8.4.1.2.3)
E_{xo}	=	modulus of elasticity, x-x axis (8.4.1.2.3) (8.4.1.3.4)
E_{yo}	=	modulus of elasticity, y-y axis (8.4.1.2.3)
F	=	adjusted design value (ksi) (8.4.4.1)
F_b	=	adjusted design value in flexure (ksi) (8.4.4.1)
F_{bo}	=	reference design value of wood in flexure (ksi) (8.4.1.1.4) (8.4.4.1)
$F_{by\text{-}y}$	=	bending about the y-y axis (C8.4.1.3.1)
F_{bvo}	=	extreme fiber in bending, y-y axis (8.4.1.2.3)
F_{bx}	=	tabulated design values for bending about the x-x axis (8.4.1.2.3)
F_{bxo}	=	extreme fiber in bending, x-x axis (8.4.1.2.3)
$F_{bxo}+$	=	extreme fiber in bending, tension zone stressed in tension (8.4.1.3.4)
$F_{bxo}-$	=	extreme fiber in bending, compression zone stressed in tension (8.4.1.3.4)
F_{byo}	=	extreme fiber in bending, y-y axis (8.4.1.2.3)
F_c	=	adjusted design value of wood in compression parallel to grain (ksi) (8.4.4.1) (C8.4.1.3.1)
$F_{c\perp}$	=	compression perpendicular to grain (C8.4.1.3.1)
F_{ce}	=	Euler buckling stress (8.8.2)
F_{co}	=	reference design value of wood in compression parallel to grain (ksi) (8.4.1.1.4) (8.4.4.1)
F_{cp}	=	adjusted design value of wood in compression perpendicular to grain (ksi) (8.4.4.1)
F_{cpo}	=	reference design value of wood in compression perpendicular to grain (ksi) (8.4.1.1.4) (Table 8.4.1.3.4-1) (8.4.4.1)
F_{epo}	=	compression perpendicular to grain, y-y axis (8.4.1.2.3)
F_o	=	reference design value (ksi) (8.4.4.1)
F_t	=	adjusted design value of wood in tension (ksi) (C8.4.1.3.1) (Table 8.4.1.3.4-1) (8.4.4.1)

F_{to} = reference design value of wood in tension (ksi) (8.4.1.1.4) (8.4.4.1)
F_v = adjusted design value of wood in shear (ksi) (8.4.1.1.4) (C8.4.1.3.1) (Table 8.4.1.3.4-1) (8.4.4.1)
F_{vo} = reference design value of wood in shear (ksi) (8.4.1.1.4) (8.4.4.1)
F_{vx} = design value for shear (8.4.1.2.3)
F_{vxo} = shear parallel to grain (Horizontal), x-x axis (8.4.1.2.3) (8.4.1.3.4)
F_{vy} = shear design value for transverse loads parallel to the wide faces of the laminations (8.4.1.2.3)
F_{vyo} = shear parallel to grain (Horizontal), y-y axis (8.4.1.2.3)
G = specific gravity (8.4.1.1.4)
G_o = specific gravity for fastener design (8.4.1.2.3)
K = effective buckling length factor (8.8.2)
K_{bE} = Euler buckling coefficient for beams (8.6.2)
K_{ce} = Euler buckling coefficient for columns (8.8.2)
L = length (ft) (8.4.4.5)
L_e = effective length (in.) (8.6.2)
L_u = laterally unsupported length of the component (in.) (8.6.2)
M_{DL} = moment due to dead load (8.4.4.2)
M_{LL} = moment due to live load (8.4.4.2)
M_n = nominal flexural resistance (kip-in.) (8.6)
M_r = factored flexural resistance, ϕM_n (kip-in.) (8.6)
M_u = factored moment (kip-in.) (8.10)
P_n = nominal compression or tension resistance (kips) (8.8.1) (8.8.2) (8.8.3) (8.9) (8.10.1) (8.10.2)
P_r = factored axial resistance (kips) (8.8.1) (8.9)
P_u = factored axial load (kips) (8.10)
S = section modulus (in.^{3}) (8.6.2)
V_n = nominal shear resistance (kips) (8.7)
V_r = factored shear resistance, ϕV_n (kips) (8.7)
ρ = referenced ratio (8.4.1.3.1)
ϕ = resistance factor (8.5.2.2)

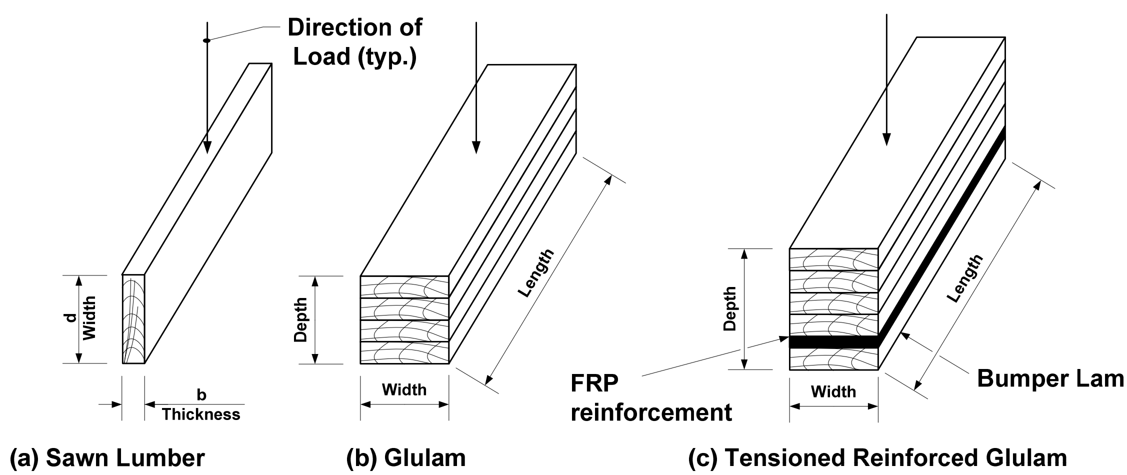

Figure 8.3-1—Dimensions as Defined for Various Types of Wood Products

8.4—MATERIALS

8.4.1—Wood Products

Nominal resistance for wood products shall be based on specified size and conditions of use with respect to moisture content and time effect. To obtain nominal resistance and stiffness values for design, the reference design values specified in Tables 8.4.1.1.4-1, 8.4.1.1.4-2 8.4.1.1.4-3, 8.4.1.2.3-1, 8.4.1.2.3-2, 8.4.1.3.4-1, and 8.4.1.4-1 shall be adjusted for actual conditions of use in accordance with Article 8.4.4.

C8.4.1

Reference design values are based on dry-use conditions, with the wood moisture content not exceeding 19 percent for sawn lumber and 16 percent for structural glued laminated timber. Reference design values are applied to material preservatively treated in accordance with AASHTO M 133.

Reference design values have been taken from the *National Design Specification® (NDS®) for Wood Construction*. The *NDS®* publishes reference values for allowable stress design (ASD) and provides format conversion factors for use of these values with the load and resistance factor design (LRFD) methodology. To facilitate the direct use of the values developed by the wood products industry and included in the *NDS®*, the same format has been adopted for AASHTO LRFD design.

Reference design values for tension-reinforced glulams have been developed following procedures in ASTM D7199 and AC 280 (ICC-ES).

8.4.1.1—Sawn Lumber

8.4.1.1.1—General

Sawn lumber shall comply with the requirements of AASHTO M 168.

When solid sawn beams and stringers are used as continuous or cantilevered beams, the grading provisions applicable to the middle third of the length shall be applied to at least the middle two thirds of the length of pieces to be used as two-span continuous beams and to the entire length of pieces to be used over three or more spans or as cantilevered beams.

8.4.1.1.2—Dimensions

Structural calculations shall be based on the actual net dimensions for the anticipated use conditions.

Dimensions stated for dressed lumber shall be the nominal dimensions. Net dimensions for dressed lumber shall be taken as 0.5 in. less than nominal, except that the net width of dimension lumber exceeding 6.0 in. shall be taken as 0.75 in. less than nominal.

For rough-sawn, full-sawn, or special sizes, the actual dimensions and moisture content used in design shall be indicated in the contract documents.

C8.4.1.1.2

These net dimensions depend on the type of surfacing, whether dressed, rough-sawn, or full-sawn.

The designer should specify surface requirements on the plans. Rough-sawn lumber is typically 0.125 in. larger than standard dry dressed sizes, associated with the F_{bo} value in Table 8.4.1.1.4-2 and full-sawn lumber, which is not widely used, is cut to the same dimensions as the nominal size. In both of the latter cases, thickness and width dimensions are variable, depending on the sawmill equipment. Therefore, it is impractical to use rough-sawn or full-sawn lumber in a structure that requires close dimensional tolerances.

For more accurate dimensions, surfacing can be specified on one side (S1S), two sides (S2S), one edge (S1E), two edges (S2E), combinations of sides and edges (e.g., S1S1E, S2S1E, S1S2E), or all sides (S4S).

8.4.1.1.3—Moisture Content

The moisture content of dimension lumber shall not be greater than 19 percent at the time of installation.

8.4.1.1.4—Reference Design Values

Reference design values for visually graded sawn lumber shall be as specified in Table 8.4.1.1.4-1.

Reference design values for mechanically graded dimension lumber shall be as specified in Table 8.4.1.1.4-2.

Unless otherwise indicated, reference design value in flexure for dimension lumber and posts and timbers shall apply to material where the load is applied to either the narrow or wide face. Reference design value in flexure for decking grades shall apply only with the load applied to the wide face.

Values for specific gravity, G, shear parallel to grain, F_v, and compression perpendicular to grain, F_{cpo}, for mechanically graded dimension lumber shall be taken as specified in Table 8.4.1.1.4-3. For species or species groups not given in Table 8.4.1.1.4-3, the G, F_{vo}, and F_{cpo} values for visually graded lumber may be used.

Reference design values for lumber grades not given in Table 8.4.1.1.4-1 and Table 8.4.1.1.4-2 shall be obtained from the *National Design Specification® (NDS®) for Wood Construction*.

Where the E_o or F_{to} values shown on a grade stamp differ from Table 8.4.1.1.4-2 values associated with the F_{bo} on the grade stamp, the values on the stamp shall be used in design, and the F_{co} value associated with the F_{bo} value in Table 8.4.1.1.4-2 shall be used.

For machine evaluated lumber (MEL) commercial grades M-17, M-20, and M-27, F_{co}, requires qualification and quality control shall be required.

Reference design values specified in Table 8.4.1.1.4-2 shall be taken as applicable to lumber that will be used under dry conditions. For 2.0-in. to 4.0-in. thick lumber, the dry dressed sizes shall be used regardless of the moisture content at the time of manufacture or use.

C8.4.1.1.4

In calculating design values in Table 8.4.1.1.4-2, the natural gain in strength and stiffness that occurs as lumber dries has been taken into consideration as well as the reduction in size that occurs when unseasoned lumber shrinks. The gain in load carrying capacity due to increased strength and stiffness resulting from drying more than offsets the design effect of size reductions due to shrinkage.

For any given bending design value, F_{bo}, the modulus of elasticity, E_o, and tension parallel to grain, F_{to}, design value may vary depending upon species, timber source, or other variables. The E_o and F_{to} values included in the F_{bo}-E_o grade designations in Table 8.4.1.1.4-2 are those usually associated with each F_{bo} level. Grade stamps may show higher or lower values if machine rating indicates the assignment is appropriate.

Higher G values may be claimed when (a) specifically assigned by the rules writing agency or (b) when qualified by test, quality controlled for G, and provided for on the grade stamp. When a different G value is provided on the grade stamp, higher F_{vo} and F_{cpo} design values may be calculated in accordance with the grading rule requirements.

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Table 8.4.1.1.4-1—Reference Design Values for Visually Graded Sawn Lumber

Species and Commercial Grade	Size Classification	Design Values (ksi) Bending F_{bo}	Tension Parallel to Grain F_{to}	Shear Parallel to Grain F_{vo}	Compression Perpendicular to Grain F_{cpo}	Compression Parallel to Grain F_{co}	Modulus of Elasticity E_o	Grading Rules Agency
Douglas Fir–Larch								
Select Structural	Dimension ≥2 in. Wide	1.500	1.000	0.180	0.625	1.700	1,900	WCLIB WWPA
No. 1 & Btr		1.200	0.800	0.180	0.625	1.550	1,800	
No. 1		1.000	0.675	0.180	0.625	1.500	1,700	
No. 2		0.900	0.575	0.180	0.625	1.350	1,600	
Dense Select Structural	Beams and Stringers	1.900	1.100	0.170	0.730	1.300	1,700	WCLIB
Select Structural		1.600	0.950	0.170	0.625	1.100	1,600	
Dense No. 1		1.550	0.775	0.170	0.730	1.100	1,700	
No. 1		1.350	0.675	0.170	0.625	0.925	1,600	
No. 2		0.875	0.425	0.170	0.625	0.600	1,300	
Dense Select Structural	Posts and Timbers	1.750	1.150	0.170	0.730	1.350	1,700	
Select Structural		1.500	1.000	0.170	0.625	1.150	1,600	
Dense No. 1		1.400	0.950	0.170	0.730	1.200	1,700	
No. 1		1.200	0.825	0.170	0.625	1.000	1,600	
No. 2		0.750	0.475	0.170	0.625	0.700	1,300	
Dense Select Structural	Beams and Stringers	1.900	1.100	0.170	0.730	1.300	1,700	WWPA
Select Structural		1.600	0.950	0.170	0.625	1.100	1,600	
Dense No. 1		1.550	0.775	0.170	0.730	1.100	1,700	
No. 1		1.350	0.675	0.170	0.625	0.925	1,600	
No. 2 Dense		1.000	0.500	0.170	0.730	0.700	1,400	
No. 2		0.875	0.425	0.170	0.625	0.600	1,300	
Dense Select Structural	Posts and Timbers	1.750	1.150	0.170	0.730	1.350	1,700	
Select Structural		1.500	1.000	0.170	0.625	1.150	1,600	
Dense No. 1		1.400	0.950	0.170	0.730	1.200	1,700	
No. 1		1.200	0.825	0.170	0.625	1.000	1,600	
No. 2 Dense		0.850	0.550	0.170	0.730	0.825	1,400	
No. 2		0.750	0.475	0.170	0.625	0.700	1,300	
Eastern Softwoods								
Select Structural	Dimension ≥2 in. Wide	1.250	0.575	0.140	0.335	1.200	1,200	NELMA
No. 1		0.775	0.350	0.140	0.335	1.000	1,100	
No. 2		0.575	0.275	0.140	0.335	0.825	1,100	
Hem–Fir								
Select Structural	Dimension ≥2 in. Wide	1.400	0.925	0.150	0.405	1.500	1,600	WCLIB WWPA
No. 1 & Btr		1.100	0.725	0.150	0.405	1.350	1,500	
No. 1		0.975	0.625	0.150	0.405	1.350	1,500	
No. 2		0.850	0.525	0.150	0.405	1.300	1,300	
Select Structural	Beams and Stringers	1.300	0.750	0.140	0.405	0.925	1,300	
No.1		1.050	0.525	0.140	0.405	0.750	1,300	
No.2		0.675	0.350	0.140	0.405	0.500	1,100	
Select Structural	Posts and Timbers	1.200	0.800	0.140	0.405	0.975	1,300	
No.1		0.975	0.650	0.140	0.405	0.850	1,300	
No.2		0.575	0.375	0.140	0.405	0.575	1,100	
Mixed Southern Pine								
Select Structural	Dimension 2 in.–4 in. Wide	2.050	1.200	0.175	0.565	1.800	1,600	SPIB
No.1		1.450	0.875	0.175	0.565	1.650	1,500	
No.2		1.100	0.675	0.175	0.565	1.450	1,400	
Select Structural	Dimension 5 in.–6 in. Wide	1.850	1.100	0.175	0.565	1.700	1,600	
No.1		1.300	0.750	0.175	0.565	1.550	1,500	
No.2		1.000	0.600	0.175	0.565	1.400	1,400	
Select Structural	Dimension 8 in. Wide	1.750	1.000	0.175	0.565	1.600	1,600	
No.1		1.200	0.700	0.175	0.565	1.450	1,500	
No.2		0.925	0.550	0.175	0.565	1.350	1,400	

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Table 8.4.1.1.4-1 (continued)—Reference Design Values for Visually Graded Sawn Lumber

Species and Commercial Grade	Size Classification	Design Values (ksi) Bending F_{bo}	Tension Parallel to Grain F_{to}	Shear Parallel to Grain F_{vo}	Compression Perpendicular to Grain F_{cpo}	Compression Parallel to Grain F_{co}	Modulus of Elasticity E_o	Grading Rules Agency
Mixed Southern Pine (continued)								
Select Structural	Dimension 10 in. Wide	1.500	0.875	0.175	0.565	1.600	1,600	SPIB
No.1		1.050	0.600	0.175	0.565	1.450	1,500	
No.2		0.800	0.475	0.175	0.565	1.300	1,400	
Select Structural	Dimension 12 in. Wide	1.400	0.825	0.175	0.565	1.550	1,600	
No.1		0.975	0.575	0.175	0.565	1.400	1,500	
No.2		0.750	0.450	0.175	0.565	1.250	1,400	
Select Structural	5 in. × 5 in. and Larger	1.500	1.000	0.165	0.375	0.900	1,300	
No.1		1.350	0.900	0.165	0.375	0.800	1,300	
No.2		0.850	0.550	0.165	0.375	0.525	1,000	
Northern Red Oak								
Select Structural	Dimension ≥2 in. Wide	1.400	0.800	0.220	0.885	1.150	1,400	NELMA
No. 1		1.000	0.575	0.220	0.885	0.925	1,400	
No. 2		0.975	0.575	0.220	0.885	0.725	1,300	
Select Structural	Beams and Stringers	1.600	0.950	0.205	0.885	0.950	1,300	
No.1		1.350	0.675	0.205	0.885	0.800	1,300	
No.2		0.875	0.425	0.205	0.885	0.500	1,000	
Select Structural	Posts and Timbers	1.500	1.000	0.205	0.885	1.000	1,300	
No.1		1.200	0.800	0.205	0.885	0.875	1,300	
No.2		0.700	0.475	0.205	0.885	0.400	1,000	
Red Maple								
Select Structural	Dimension ≥2 in. Wide	1.300	0.750	0.210	0.615	1.100	1,700	NELMA
No. 1		0.925	0.550	0.210	0.615	0.900	1,600	
No. 2		0.900	0.525	0.210	0.615	0.700	1,500	
Select Structural	Beams and Stringers	1.500	0.875	0.195	0.615	0.900	1,500	
No.1		1.250	0.625	0.195	0.615	0.750	1,500	
No.2		0.800	0.400	0.195	0.615	0.475	1,200	
Select Structural	Posts and Timbers	1.400	0.925	0.195	0.615	0.950	1,500	
No.1		1.150	0.750	0.195	0.615	0.825	1,500	
No.2		0.650	0.425	0.195	0.615	0.375	1,200	
Red Oak								
Select Structural	Dimension ≥2 in. Wide	1.150	0.675	0.170	0.820	1.000	1,400	NELMA
No. 1		0.825	0.500	0.170	0.820	0.825	1,300	
No. 2		0.800	0.475	0.170	0.820	0.625	1,200	
Select Structural	Beams and Stringers	1.350	0.800	0.155	0.820	0.825	1,200	
No.1		1.150	0.550	0.155	0.820	0.700	1,200	
No.2		0.725	0.375	0.155	0.820	0.450	1,000	
Select Structural	Posts and Timbers	1.250	0.850	0.155	0.820	0.875	1,200	
No.1		1.000	0.675	0.155	0.820	0.775	1,200	
No.2		0.575	0.400	0.155	0.820	0.350	1,000	

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Table 8.4.1.1.4-1 (continued)—Reference Design Values for Visually Graded Sawn Lumber

Species and Commercial Grade	Size Classification	Design Values (ksi) Bending F_{bo}	Tension Parallel to Grain F_{to}	Shear Parallel to Grain F_{vo}	Compression Perpendicular to Grain F_{cpo}	Compression Parallel to Grain F_{co}	Modulus of Elasticity E_o	Grading Rules Agency
Southern Pine								
Select Structural	Dimension 2 in.–4 in. Wide	2.350	1.650	0.175	0.565	1.900	1,800	SPIB
No.1		1.500	1.000	0.175	0.565	1.650	1,600	
No.2		1.100	0.675	0.175	0.565	1.450	1,400	
Select Structural	Dimension 5 in.–6 in. Wide	2.100	1.450	0.175	0.565	1.800	1,800	
No.1		1.350	0.875	0.175	0.565	1.550	1,600	
No.2		1.000	0.600	0.175	0.565	1.400	1,400	
Select Structural	Dimension 8 in. wide	1.950	1.350	0.175	0.565	1.700	1,800	
No.1		1.250	0.800	0.175	0.565	1.500	1,600	
No.2		0.925	0.550	0.175	0.565	1.350	1,400	
Select Structural	Dimension 10 in. Wide	1.700	1.150	0.175	0.565	1.650	1,800	
No.1		1.050	0.700	0.175	0.565	1.450	1,600	
No.2		0.800	0.475	0.175	0.565	1.300	1,400	
Select Structural	Dimension 12 in. Wide	1.600	1.100	0.175	0.565	1.650	1,800	
No.1		1.000	0.650	0.175	0.565	1.400	1,600	
No.2		0.750	0.450	0.175	0.565	1.250	1,400	
Select Structural	5 in. × 5 in. and Larger	1.500	1.000	0.165	0.375	0.950	1,500	
No. 1		1.350	0.900	0.165	0.375	0.825	1,500	
No. 2		0.850	0.550	0.165	0.375	0.525	1,200	
Spruce–Pine–Fir								
Select Structural	Dimension ≥2 in. Wide	1.250	0.700	0.135	0.425	1.400	1,500	NLGA
No. 1/ No. 2		0.875	0.450	0.135	0.425	1.150	1,400	
Select Structural	Beams and Stringers	1.100	0.650	0.125	0.425	0.775	1,300	
No.1		0.900	0.450	0.125	0.425	0.625	1,300	
No.2		0.600	0.300	0.125	0.425	0.425	1,000	
Select Structural	Posts and Timbers	1.050	0.700	0.125	0.425	0.800	1,300	
No.1		0.850	0.550	0.125	0.425	0.700	1,300	
No.2		0.500	0.325	0.125	0.425	0.500	1,000	
Spruce–Pine–Fir (South)								
Select Structural	Dimension ≥2 in. Wide	1.300	0.575	0.135	0.335	1.200	1,300	NELMA WCLIB WWPA
No. 1		0.875	0.400	0.135	0.335	1.050	1,200	
No. 2		0.775	0.350	0.135	0.335	1.000	1,100	
Select Structural	Beams and Stringers	1.050	0.625	0.125	0.335	0.675	1,200	
No.1		0.900	0.450	0.125	0.335	0.550	1,200	
No.2		0.575	0.300	0.125	0.335	0.375	1,000	
Select Structural	Posts and Timbers	1.000	0.675	0.125	0.335	0.700	1,200	
No.1		0.800	0.550	0.125	0.335	0.625	1,200	
No.2		0.475	0.325	0.125	0.335	0.425	1,000	
Yellow Poplar								
Select Structural	Dimension ≥2 in. Wide	1.000	0.575	0.145	0.420	0.900	1,500	NELMA
No. 1		0.725	0.425	0.145	0.420	0.725	1,400	
No. 2		0.700	0.400	0.145	0.420	0.575	1,300	

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Table 8.4.1.1.4-2—Reference Design Values for Mechanically Graded Dimension Lumber

Commercial Grade	Size Classification	Design Values (ksi) Bending F_{bo}	Tension Parallel to Grain F_{to}	Compression Parallel to Grain F_{co}	Modulus of Elasticity E_o	Grading Rules Agency
Machine Stress-Rated (MSR) Lumber						
900f-1.0E	≤2 in. Thick ≥2 in. Wide	0.900	0.350	1.050	1,000	WCLIB, WWPA, NELMA
1200f-1.2E		1.200	0.600	1.400	1,200	NLGA, WCLIB, WWPA, NELMA
1250f-1.4E		1.250	0.800	1.475	1,400	WCLIB
1350f-1.3E		1.350	0.750	1.600	1,300	NLGA, WCLIB, WWPA, NELMA
1400f-1.2E		1.400	0.800	1.600	1,200	NLGA
1450f-1.3E		1.450	0.800	1.625	1,300	NLGA, WCLIB, WWPA, NELMA
1450f-1.5E		1.450	0.875	1.625	1,500	WCLIB
1500f-1.4E		1.500	0.900	1.650	1,400	NLGA, WCLIB, WWPA, NELMA
1600f-1.4E		1.600	0.950	1.675	1,400	NLGA
1650f-1.3E		1.650	1.020	1.700	1,300	NLGA
1650f-1.5E		1.650	1.020	1.700	1,500	NLGA,SPIB,WCLIB,WWPA, NELMA
1650f-1.6E		1.650	1.175	1.700	1,600	WCLIB
1700f-1.6E		1.700	1.175	1.725	1,600	WCLIB
1800f-1.5E		1.800	1.300	1.750	1,500	NLGA
1800f-1.6E		1.800	1.175	1.750	1,600	NLGA,SPIB,WCLIB,WWPA, NELMA
1800f-1.8E		1.800	1.200	1.750	1,800	WCLIB
1950f-1.5E		1.950	1.375	1.800	1,500	SPIB
1950f-1.7E		1.950	1.375	1.800	1,700	NLGA,SPIB,WCLIB,WWPA, NELMA
2000f-1.6E		2.000	1.300	1.825	1,600	NLGA
2100f-1.8E		2.100	1.575	1.875	1,800	NLGA,SPIB,WCLIB,WWPA, NELMA
2250f-1.7E		2.250	1.750	1.925	1,700	NLGA
2250f-1.8E		2.250	1.750	1.925	1,800	NLGA, WCLIB
2250f-1.9E		2.250	1.750	1.925	1,900	NLGA,SPIB,WCLIB,WWPA, NELMA
2400f-1.8E		2.400	1.925	1.975	1,800	NLGA
2400f-2.0E		2.400	1.925	1.975	2,000	NLGA,SPIB,WCLIB,WWPA, NELMA
2500f-2.2E		2.500	1.750	2.000	2,200	WCLIB
2550f-2.1E		2.550	2.050	2.025	2,100	NLGA,SPIB,WCLIB,WWPA, NELMA
2700f-2.0E		2.700	1.800	2.100	2,000	WCLIB
2700f-2.2E		2.700	2.150	2.100	2,200	NLGA,SPIB,WCLIB,WWPA, NELMA
2850f-2.3E		2.850	2.300	2.150	2,300	NLGA,SPIB,WCLIB,WWPA, NELMA
3000f-2.4E		3.000	2.400	2.200	2,400	NLGA, SPIB
Machine Evaluated Lumber (MEL)						
M-5	≤2 in. Thick ≥2 in. Wide	0.900	0.500	1.050	1,100	SPIB
M-6		1.100	0.600	1.300	1,100	SPIB
M-7		1.200	0.650	1.400	1,100	SPIB

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Table 8.4.1.1.4-3—Reference Design Values of Specific Gravity, G, Shear, F_{vo}, and Compression Perpendicular to Grain, F_{cpo}, for Mechanically Graded Dimension Lumber

Species	Modulus of Elasticity E (ksi)	Design Values: Specific Gravity G	Design Values: Shear Parallel to Grain F_{vo} (ksi)	Design Values: Compression Perpendicular to Grain F_{cpo} (ksi)	Grading Rules Agency
Douglas Fir–Larch	≥1,000	0.500	0.180	0.625	WWPA
	2,000	0.510	0.180	0.670	WWPA
	2,100	0.520	0.180	0.690	
	2,200	0.530	0.180	0.715	
	2,300	0.540	0.185	0.735	
	2,400	0.550	0.185	0.760	
Hem–Fir	≥1,000	0.430	0.150	0.405	WCLIB, WWPA
	1,600	0.440	0.155	0.510	WCLIB, WWPA
	1,700	0.450	0.160	0.535	
	1,800	0.460	0.160	0.555	
	1,900	0.470	0.165	0.580	
	2,000	0.480	0.170	0.600	
	2,100	0.490	0.170	0.625	
	2,200	0.500	0.175	0.645	
	2,300	0.510	0.175	0.670	
	2,400	0.520	0.180	0.690	
Southern Pine	≥1,000	0.550	0.175	0.565	SPIB
	≥1,800	0.570	0.190	0.805	SPIB
	≥1,200	0.420	0.135	0.425	NLGA
Spruce–Pine–Fir	1,800–1,900	0.460	0.160	0.525	NLGA
	≥2,000	0.500	0.170	0.615	
	≥1,000	0.360	0.135	0.335	NELMA, WCLIB, WWPA
	1,200–1,900	0.420	0.150	0.465	NELMA
Spruce–Pine–Fir (South)	1,200–1,700	0.420	0.150	0.465	WWPA
	1,800–1,900	0.460	0.160	0.555	
	≥2,000	0.500	0.175	0.645	NELMA, WWPA

8.4.1.2—Structural Glued Laminated Timber (Glulam)

8.4.1.2.1—General

Structural glued laminated timber shall be manufactured using wet-use adhesives and shall comply with the requirements of ANSI A190.1. Glued laminated timber may be manufactured from any lumber species, provided that it meets the requirements of ANSI A190.1 and is treatable with wood preservatives in accordance with the requirements of Article 8.4.3.

The contract documents shall require that each piece of glued laminated timber be distinctively marked and provided with a Certificate of Conformance by an accredited inspection and testing agency, indicating that the requirements of ANSI A190.1 have been met and that straight or slightly cambered bending members have been stamped TOP on the top at both ends so that the natural camber, if any, shall be positioned opposite to the direction of applied loads.

C8.4.1.2.1

When wet-use adhesives are used, the bond between the laminations, which is stronger than the wood, will be maintained under all exposure conditions. Dry-use adhesives will deteriorate under wet conditions. For bridge applications, it is not possible to ensure that all areas of the components will remain dry. ANSI A190.1 requires the use of wet-use adhesives for the manufacture of structural glued laminated timber.

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Industrial appearance grade, as defined in AITC 110, *Standard Appearance Grades for Structural Glued Laminated Timber*, shall be used, unless otherwise specified.

Structural glued laminated timber is available in four standard appearance grades: framing, industrial, architectural, and premium. Architectural and premium grades are typically planed or sanded, and exposed irregularities are filled with a wood filler that may crack and dislodge under exterior exposure conditions. Framing grade is surfaced hit-or-miss to produce a timber with the same net width as standard lumber for concealed applications where matching the width of framing lumber is important. Framing grade is not typically used for bridge applications. In addition to the four standard appearance grades, certain manufacturers will use special surfacing techniques to achieve a desired look, such as a rough sawn look. Individual manufacturers should be contacted for details.

8.4.1.2.2—Dimensions

Dimensions stated for glued laminated timber shall be taken as the actual net dimensions.

In design, structural calculations shall be based on the actual net dimensions. Net width of structural glued laminated timber shall be as specified in Table 8.4.1.2.2-1 or other dimensions as agreed upon by buyer and seller.

C8.4.1.2.2

Structural glued laminated timber can be manufactured to virtually any shape or size. The most efficient and economical design generally results when standard sizes are used. Acceptable manufacturing tolerances are given in ANSI A190.1.

The use of standard sizes constitutes good practice and is recommended whenever possible. Nonstandard sizes should only be specified after consultation with the laminator.

Southern Pine timbers are typically manufactured from 1.375-in.-thick laminations, while timbers made from Western Species and Hardwoods are commonly manufactured from 1.5-in.-thick laminations. Curved members may be manufactured from thinner laminations depending on the radius of curvature. Radii of curvature of less than 27.0 ft, 6.0 in. normally require the use of thinner laminations.

Table 8.4.1.2.2-1—Net Dimensions of Glued Laminated Timber

Nominal Width of Laminations (in.)	Western Species Net Finished Dimension (in.)	Southern Pine Net Finished Dimension (in.)
3	$2\,^1/_8$ or $2\,^1/_2$	$2\,^1/_8$ or $2\,^1/_2$
4	$3\,^1/_8$	3.0 or $3\,^1/_8$
6	$5\,^1/_8$	5.0 or $5\,^1/_8$
8	$6\,^3/_4$	$6\,^3/_4$
10	$8\,^3/_4$	$8\,^1/_2$
12	$10\,^3/_4$	$10\,^1/_2$
14	$12\,^1/_4$	12.0
16	$14\,^1/_4$	14.0

The total glulam net depth shall be taken as the product of the thickness of the laminations and the number of laminations.

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8.4.1.2.3—Reference Design Values

Grade combinations for structural glued laminated timber shall be as provided in ANSI 117, *Standard Specifications for Structural Glued Laminated Timber of Softwood Species*, or AITC 119, *Standard Specifications for Structural Glued Laminated Timber of Hardwood Species*.

Reference Design Values for structural glued laminated timber shall be as specified in Tables 8.4.1.2.3-1 and 8.4.1.2.3-2:

- Table 8.4.1.2.3-1 contains design values for timbers with layups optimized to resist bending loads applied perpendicular to the wide face of the laminations (bending about the *x-x* axis). Design values are also included, however, for axial loads and bending loads applied parallel to the wide faces of the laminations. The design values in Table 8.4.1.2.3-1 are applicable to timbers with four or more laminations.
- Table 8.4.1.2.3-2 contains design values for timbers with uniform-grade layups. These layups are intended primarily for timbers loaded axially or in bending due to loads applied parallel to the wide faces of the laminations (bending about the *y-y* axis). Design values are also included, however, for bending due to loads applied perpendicular to the wide faces of the laminations. The design values in Table 8.4.1.2.3-2 are applicable to timbers with two or more laminations.

In Table 8.4.1.2.3-1, the tabulated design values for bending about the *x-x* axis, F_{bx}, require the use of special tension laminations. If these special tension laminations are omitted, values shall be multiplied by 0.75 for members greater than or equal to 15 in. in depth or by 0.85 for members less than 15 in. in depth.

In Table 8.4.1.2.3-1, the design value for shear, F_{vx}, shall be decreased by multiplying by a factor of 0.72 for nonprismatic members, notched members, and for all members subject to impact or cyclic loading. The reduced design value shall be used for design of members at connections that transfer shear by mechanical fasteners. The reduced design value shall also be used for determination of design values for radial tension and torsion. Design values, F_{vy}, shall be used for timbers with laminations made from a single piece of lumber across the width or multiple pieces that have been edge bonded. For timber manufactured from multiple-piece laminations (across width) that are not edge-bonded, in addition to other reduction, design value shall be multiplied by 0.4 for members with five, seven, or nine laminations or by 0.5 for all other members.

C8.4.1.2.3

The combinations in Table 8.4.1.2.3-1 are applicable to members consisting of four or more laminations and are intended primarily for members stressed in bending due to loads applied perpendicular to the wide faces of the laminations. However, design values are tabulated for loading both perpendicular and parallel to the wide faces of the laminations. The combinations and design values applicable to members loaded primarily axially or parallel to the wide faces of the laminations are specified in Table 8.4.1.2.3-2. Design values for members of two or three laminations are specified in Table 8.4.1.2.3-2.

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If combination 24F-V4 contains lumber with wane, then, in addition, the design value for shear parallel to grain, F_{vx}, shall be multiplied by 0.67 if wane is allowed on both sides. If wane is limited to one side, F_{vx} shall be multiplied by 0.83.

In Table 8.4.1.2.3-2, for members with two or three laminations, the shear design value for transverse loads parallel to the wide faces of the laminations, F_{vy}, shall be reduced by multiplying by a factor of 0.84 or 0.95, respectively. For members with five, seven, or nine laminations, in addition, F_{vy} shall be multiplied by 0.4 for members manufactured from multiple-piece laminations (across width) that are not edge bonded. The shear design value, F_{vy}, shall be multiplied by 0.5 for all other members manufactured from multiple-piece laminations with unbonded edge joints.

In Table 8.4.1.2.3-2, the design value for shear, F_{vx}, shall be decreased by multiplying by a factor of 0.72 for nonprismatic members, notched members, and for all members subject to impact or cyclic loading. The reduced design value shall be used for design of members at connections that transfer shear by mechanical fasteners. The reduced design value shall also be used for determination of design values for radial tension and torsion.

In Table 8.4.1.2.3-2, the tabulated design values shall apply to timbers without special tension laminations. If special tension laminations are used, for members up to 15 in. deep, the design value for bending, F_{bx}, may be increased by multiplying by 1.18. For members greater than 15 in. deep and without special tension laminations, the bending design value, F_{bx}, shall be reduced by multiplying by a factor of 0.88.

Reference design values for combinations not given in Table 8.4.1.2.3-1 or Table 8.4.1.2.3-2 shall be obtained from ANSI 117.

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Table 8.4.1.2.3-1—Reference Design Values, ksi, for Structural Glued Laminated Softwood Timber Combinations (members stressed primarily in bending)

Combination Symbol	Species Outer/Core	Bending about *X-X* Axis (Loaded Perpendicular to Wide Faces of Laminations): Extreme Fiber in Bending: Tension Zone Stressed in Tension F_{bxo}^{+}	Bending about *X-X* Axis: Extreme Fiber in Bending: Compression Zone Stressed in Tension F_{bxo}^{-}	Bending about *X-X* Axis: Compression Perpendicular to Grain: Tension Face F_{cpo}	Bending about *X-X* Axis: Compression Perpendicular to Grain: Compression Face F_{cpo}	Bending about *X-X* Axis: Shear Parallel to Grain (Horizontal) F_{vxo}	Bending about *X-X* Axis: Modulus of Elasticity E_{xo} (10^3)	Bending about *Y-Y* Axis (Loaded Parallel to Wide Faces of Laminations): Extreme Fiber in Bending F_{byo}	Bending about *Y-Y* Axis: Compression Perpendicular to Grain F_{cpo}	Bending about *Y-Y* Axis: Shear Parallel to Grain (Horizontal) F_{vyo}	Bending about *Y-Y* Axis: Modulus of Elasticity E_{yo} (10^3)	Axially Loaded: Tension Parallel to Grain F_{to}	Axially Loaded: Compression Parallel to Grain F_{co}	Axially Loaded: Modulus of Elasticity $E_{o\,axial}$ (10^3)	Fasteners: Specific Gravity for Fastener Design: Top or Bottom Face G_o	Fasteners: Specific Gravity for Fastener Design: Side Face G_o
20F-1.5E		2	1.1	0.425		0.195	1.5	0.8	0.315	0.170	1.2	0.725	0.925	1.3	0.41	
20F-V3	DF/DF	2.000	1.450	0.650	0.560	0.265	1.6	1.45	0.56	0.23	1.5	1.000	1.550	1.6	0.5	0.5
20F-V7	DF/DF	2.000	2.000	0.650	0.650	0.265	1.6	1.45	0.56	0.23	1.6	1.050	1.600	1.6	0.5	0.5
20F-V9	HF/HF	2.000	2.000	0.500	0.500	0.215	1.5	1.35	0.38	0.19	1.4	0.975	1.400	1.5	0.43	0.43
20F-V12	AC/AC	2.000	1.400	0.560	0.560	0.265	1.5	1.25	0.47	0.23	1.4	0.925	1.500	1.4	0.46	0.46
20F-V13	AC/AC	2.000	2.000	0.560	0.560	0.265	1.5	1.25	0.47	0.23	1.4	0.950	1.550	1.5	0.46	0.46
20F-V2	SP/SP	2.000	1.550	0.740	0.650	0.300	1.5	1.45	0.65	0.26	1.4	1.000	1.400	1.5	0.55	0.55
20F-V3	SP/SP	2.000	1.450	0.650	0.650	0.300	1.5	1.60	0.65	0.26	1.5	1.000	1.400	1.5	0.55	0.55
20F-V5	SP/SP	2.000	2.000	0.740	0.740	0.300	1.6	1.45	0.65	0.26	1.4	1.050	1.500	1.5	0.55	0.55
24F-1.7E		2.4	1.45	0.5		0.21	1.7	1.05	0.315	0.185	1.3	0.775	1	1.4	0.42	
24F-V5	DF/HF	2.400	1.600	0.650	0.650	0.215	1.7	1.35	0.375	0.20	1.5	1.100	1.450	1.6	0.5	0.43
24F-V10	DF/HF	2.400	2.400	0.650	0.650	0.215	1.8	1.45	0.375	0.20	1.5	1.150	1.550	1.6	0.5	0.43
24F-V1	SP/SP	2.400	1.750	0.740	0.650	0.300	1.7	1.45	0.65	0.26	1.5	1.100	1.500	1.6	0.55	0.55
24F-V4	SP/SP	2.400	1.650	0.740	0.650	0.210	1.7	1.35	0.47	0.23	1.5	0.975	1.350	1.5	0.55	0.43
24F-V5	SP/SP	2.400	2.400	0.740	0.740	0.300	1.7	1.70	0.65	0.26	1.6	1.150	1.600	1.6	0.55	0.55
24F-1.8E		2.4	1.45	0.65		0.265	1.8	1.45	0.56	0.23	1.6	1.1	1.6	1.7	0.5	
24F-V4	DF/DF	2.400	1.850	0.650	0.650	0.265	1.8	1.45	0.56	0.23	1.6	1.100	1.650	1.7	0.5	0.5
24F-V8	DF/DF	2.400	2.400	0.650	0.650	0.265	1.8	1.55	0.56	0.23	1.6	1.100	1.650	1.7	0.5	0.5
24F-V3	SP/SP	2.400	2.000	0.740	0.740	0.300	1.8	1.75	0.65	0.26	1.6	1.150	1.650	1.7	0.55	0.55
26F-1.9E		2.6	1.95	0.65		0.265	1.9	1.6	0.56	0.23	1.6	1.15	1.6	1.7	0.5	
26F-V1	DF/DF	2.600	1.950	0.650	0.650	0.265	2.0	1.850	0.560	0.230	1.8	1.350	1.850	1.9	0.5	0.5
26F-V2	DF/DF	2.600	2.600	0.650	0.650	0.265	2.0	1.850	0.560	0.230	1.8	1.350	1.850	1.9	0.5	0.5
26F-V2	SP/SP	2.600	2.100	0.740	0.740	0.300	1.9	1.95	0.740	0.260	1.8	1.300	1.850	1.9	0.55	0.55
26F-V4	SP/SP	2.600	2.600	0.740	0.740	0.300	1.9	1.70	0.650	0.260	1.8	1.200	1.600	1.9	0.55	0.55

Table 8.4.1.2.3-2—Reference Design Values, ksi, for Structural Glued Laminated Softwood Timber (members stressed primarily in axial tension and compression)

			All Loading		Axially Loaded			Bending about Y-Y Axis Loaded Parallel to Wide Faces of Laminations				Bending about X-X Axis Loaded Perpendicular to Wide Faces of Laminations	
					Tension Parallel to Grain	Compression Parallel to Grain		Bending			Shear Parallel to Grain	Bending	Shear Parallel to Grain
Identification Number	Species	Grade	Modulus of Elasticity E_o (10^3)	Compression Perpendicular to Grain F_{cpo}	2 or more Laminations F_{to}	4 or more Laminations F_{cpo}	2 or 3 Laminations F_{cpo}	4 or more Laminations F_{byo}	3 Laminations F_{byo}	2 Laminations F_{byo}	F_{vyo}	2 Laminations up to 15 in. Deep F_{bxo}	F_{vxo}
Visually Graded Western Species													
1	DF	L3	1.5	0.560	0.950	1.550	1.250	1.450	1.250	1.000	0.230	1.250	0.265
2	DF	L2	1.6	0.560	1.250	1.950	1.600	1.800	1.600	1.300	0.230	1.700	0.265
3	DF	L2D	1.9	0.650	1.450	2.300	1.900	2.100	1.850	1.550	0.230	2.000	0.265
5	DF	L1	2.0	0.650	1.650	2.400	2.100	2.400	2.100	1.800	0.230	2.200	0.265
14	HF	L3	1.3	0.375	0.800	1.100	1.050	1.200	1.050	0.850	0.190	1.100	0.215
15	HF	L2	1.4	0.375	1.050	1.350	1.350	1.500	1.350	1.100	0.190	1.450	0.215
16	HF	L1	1.6	0.375	1.200	1.500	1.500	1.750	1.550	1.300	0.190	1.600	0.215
17	HF	L1D	1.7	0.500	1.400	1.750	1.750	2.000	1.850	1.550	0.190	1.900	0.215
69	AC	L3	1.2	0.470	0.725	1.150	1.100	1.100	0.975	0.775	0.230	1.000	0.265
70	AC	L2	1.3	0.470	0.975	1.450	1.450	1.400	1.250	1.000	0.230	1.350	0.265
71	AC	L1D	1.6	0.560	1.250	1.900	1.900	1.850	1.650	1.400	0.230	1.750	0.265
Visually Graded Southern Pine													
47	SP	N2M14	1.4	0.650	1.200	1.900	1.150	1.750	1.550	1.300	0.260	1.400	0.300
48	SP	N2D14	1.7	0.740	1.400	2.200	1.350	2.000	1.800	1.500	0.260	1.600	0.300
49	SP	N1M16	1.7	0.650	1.350	2.100	1.450	1.950	1.750	1.500	0.260	1.800	0.300
50	SP	N1D14	1.9	0.740	1.550	2.300	1.700	2.300	2.100	1.750	0.260	2.100	0.300

8.4.1.3—Tension-Reinforced Glulams

8.4.1.3.1—General

Tension-reinforced glulams shall incorporate a continuous reinforcement material placed on the tension side of a flexural member to increase its flexural bending strength and stiffness. Reinforcement may be any material that is not a conventional lamstock whose mean longitudinal unit strength exceeds 20 ksi for tension and compression mean ultimate strength, and whose mean tension and compression modulus of elasticity exceeds 3,000 ksi, when placed into a glulam timber. Acceptable reinforcing materials include but are not restricted to: fiber-reinforced polymer (FRP) plates and bars using E-glass fibers (GFRP) or carbon fibers (CFRP), and metallic plates and bars.

The reinforced ratio, ρ, shall be determined as the cross-sectional area of tension reinforcement divided by cross-sectional area of beam above the center of gravity of tension reinforcement, expressed in percent. Typical reinforcement ratios and modulus of elasticity values for various types of reinforcement given in Table 8.4.1.3.1-1 shall apply.

Table 8.4.1.3.1-1—Typical Reinforcement Ratios

	Reinforcement Material			
	E-Glass FRP	Aramid FRP	Carbon FRP	Steel Plate
MOE (ksi)	6,000	10,000	20,000	30,000
Min. ρ%	1	0.6	0.3	0.2
Typical ρ %	2	1.2	0.6	0.4
Max. ρ %	3	1.8	0.9	0.6

Tension-reinforced glued laminated timber shall be manufactured using wet-use adhesives in accordance with applicable provisions of ANSI A190.1, and shall comply with the requirements listed in Article 8.4.1.2, except as described in detail in ASTM D7199. The additional requirements cited in ASTM D7199 to be investigated shall include bond strength and durability requirements for the tension reinforcement, preservative treatment, volume factor, and fatigue considerations.

8.4.1.3.2—Dimensions

Dimensions stated for tension-reinforced glued laminated timber shall be taken as the actual net dimensions.

In design, structural calculations shall be based on the actual net dimensions. Net width of tension-reinforced structural glued laminated timber shall be as specified in Table 8.4.1.2.2-1 or other dimensions as agreed upon by buyer and seller. The total reinforced glulam net depth shall be the

C8.4.1.3.1

The determination of reinforcement ratio, ρ, is analogous to that used for reinforced concrete.

The scope of ASTM D7199 pertains to the analysis of FRP-glulams in bending. The addition of FRP reinforcement in the tension region of the glulam does not require new test or analytical methods to determine the secondary design properties (shear, compression perpendicular to grain, tension parallel to grain, compression parallel to grain, etc.). These properties are determined for glulam layups following ASTM D3737.

Tension-reinforced glulam beams subject to axial compression loads are outside the scope of this specification. This specification does not cover unbonded reinforcement (i.e. material not continuously bonded to the beam), prestressed reinforcement (i.e. material pretensioned before being bonded or anchored to the beam), nor shear reinforcement (i.e. material intended to increase the shear strength of the beam).

ASTM D7199 also provides a mechanics-based approach for predicting the mechanical properties of tension-reinforced glulams, and may be used by engineers who have applications with unique reinforcement requirements. ASTM D7199 addresses methods to obtain bending properties parallel to grain about the *x-x* axis ($MOR_{5\%}$ and *MOE*) for horizontally-laminated reinforced glulam beams. Secondary properties such as bending about the *y-y* axis ($F_{by\text{-}y}$), shear parallel to grain (F_v), tension parallel to grain (F_t), compression parallel to grain (F_c), and compression perpendicular to grain ($F_{c\perp}$) are determined following methods described in ASTM D3737 or testing according to other applicable methods such as ASTM D198 or ASTM D143.

sum of the thicknesses of all laminations including the thickness of the tension reinforcement lamination(s). The gross section properties shall be calculated using the net depth and the net width.

8.4.1.3.3—Fatigue

Except as noted herein, tension reinforcement shall extend the full length of the beam or girder and be confined by the supports.

For E-glass FRP reinforcement produced using the pultrusion process, beams that satisfy the requirements for design for static loads specified herein may be considered to have adequate fatigue design capacity. For reinforcements other than pultruded E-glass reinforcements, coupon-level fatigue testing of the reinforcing material per ASTM D3479 or a similar procedure shall be required to develop the strength–load cycle relationship for the reinforcing material. A minimum of three representative FRP samples shall be tested to establish the strength–load cycle relationship. This strength–load cycle relationship shall be the basis for checking fatigue capacity of the FRP under specific end-use environment.

Full-scale fatigue testing shall be required where partial-length reinforcement is used to evaluate the effectiveness of reinforcement end-confinement detail. The reinforcement termination for partial-length FRP reinforcement shall be confined over the length at least equal to the width of the reinforcing material. Unconfined, partial-length reinforcement shall not be permitted in bridge applications where fatigue loading exists.

Full-scale fatigue testing shall be required on FRP-glulam beams where the allowable stress is more than 75 percent greater than conventional glulam (F_b > 4,000 psi).

Where fatigue is a design consideration, the reinforcement used shall not increase the $MOR_{5\%}$ of the beam by more than 75 percent relative to the strength of the unreinforced beam.

C8.4.1.3.3

The research that was performed utilized confinement achieved by end-bearing support. Confinement proposed by alternative methods may require full-scale testing.

Under the specified conditions, testing has shown that the fatigue resistance of tension-reinforced glulam beams is similar to that of conventional glulam beams. These tests have included both fatigue and hygrothermal cyclic tests (Davids et al., 2005 and 2008).

For pultruded E-glass FRP reinforcement, full-scale tension-reinforced glulam beam flexural fatigue tests, where the reinforcement extends the full length of the beam, have shown that the reinforced beams properly designed for static loads will have fatigue design capacity in excess of two million constant-amplitude sinusoidal cycles. Each of these cycles applied an extreme fiber stress range starting from the dead load bending stress to a bending stress equivalent to the full allowable design stress. Under these conditions, no degradation in bending strength or stiffness has been observed.

Full-scale fatigue testing has been performed on FRP-reinforced glulam beams, considering both full-length and partial-length reinforced glulams. These tests were conducted for tension-reinforced beams where the allowable design stresses were up to 75 percent greater than the conventional unreinforced glulam. This testing has shown that premature failure due to fatigue in FRP-glulams is not a concern if (1) the FRP reinforcement has been fatigue-tested at the coupon level and (2) the FRP tension reinforcement runs for the full length of the glulam over the supports. For partial-length reinforcement (where the FRP is terminated before the supports) and for FRP-glulams where the allowable stress is more than 75 percent greater than conventional glulam (F_b > 4,000 psi), full-scale fatigue testing is required. Guidance on performing such tests can be found in Davids et al. (2005 and 2008). In fatigue tests where $MOR_{5\%}$ has been increased by more than 75 percent, flexural compression and shear failures have been observed in addition to flexural tension failures.

FRP coupon fatigue design data should be available from reinforced beam manufacturers or FRP suppliers. The vast majority of applications will not require full-scale fatigue testing of beams.

8.4.1.3.4—Reference Design Values for Tension-Reinforced Glulams

Reference design values for tension-reinforced glulams shall be taken as specified in Table 8.4.1.3.4-1 for beams with no bumper-lams. For the beam lay-ups given in

C8.4.1.3.4

Axial compression is outside the scope of this specification. For tension-reinforced glulam subjected to axial compression, ASTM D3737 provides a method to

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Table 8.4.1.3.4-1, the volume factor shall be taken equal to 1. The values are for dry use, with adjustment factors given in Article 8.4.4.3, and shall be used in the same manner as conventional glulam design values except as specified in Article 8.4.1.3. These design values shall be used with the overall gross section properties of the beam, including the reinforcement.

account for the neutral axis (NA) change in unbalanced layups. FRP stiffness and shift in the neutral axis shall be accounted for when developing axial compression design values. Bending properties about the *y-y* axis may be conservatively taken as those of the wood portion of the beam, neglecting the reinforcement.

Analysis has shown that with the level of FRP extreme fiber tension reinforcement typically envisioned (up to 3 percent for GFRP or 1 percent for CFRP), the maximum shear stress at the reinforced beam neutral axis is very similar to that of an unreinforced rectangular section. In addition, under the same conditions, the shear stress at the FRP–wood interface is always significantly smaller than the shear stress at the reinforced beam neutral axis.

Table 8.4.1.3.4-1—Reference Design Values for Tension-Reinforced Structural Glued Laminated Douglas Fir Combinations (ksi)[1]

		Bending about *x-x* Axis					
		Extreme Fiber in Bending		Compression Perpendicular to Grain		Shear	
		Tension Zone Stressed in Tension	Compression Zone Stressed in Tension	Tension Face	Compression Face		Modulus of Elasticity
Combination Symbol	Species (Outer/Core)	F_{bxo+}	F_{bxo-}	F_{cpo}	F_{cpo}	F_{vxo}	$E_{xo} \times 10^3$
30F-1.9E							
30F-V1R	DF/DF	3.000	1.900	0.56	0.56	0.265	1.9
30F-2.0E							
30F-V4R	DF/DF	3.000	1.900	0.56	0.56	0.265	2.0
30F-2.1E							
30F-V7R	DF/DF	3.000	2.100	0.56	0.56	0.265	2.1
32F-2.1E							
32F-V1R	DF/DF	3.200	2.100	0.56	0.56	0.265	2.2
34F-2.2E							
34F-V1R	DF/DF	3.400	2.100	0.56	0.56	0.265	2.2

[1] Species other than Douglas Fir may be used if evaluated in accordance with ASTM D7199.

8.4.1.3.5—Volume Effect

Volume factors for the tension-reinforced glulams listed in Table 8.4.1.3.4-1 shall be taken equal to 1 except where the unreinforced compression zone is stressed in tension. In this latter case, the volume factor used in conventional glulams shall apply for the determination of this value.

C8.4.1.3.5

The addition of tension reinforcement diminishes the volume effect in glulams, and with enough reinforcement in tension, the volume effect disappears (Lindyberg, 2000). The tension reinforcement that is necessary to eliminate the volume effect varies with the wood species and grade, as well as the type of reinforcement used (e.g., E-glass, carbon, or Aramid FRP). For example, western species glulam reinforced with E-glass FRP in tension, approximately 1.5–3 percent FRP by volume will eliminate the volume effect (Lindyberg, 2000). For the particular glulams listed in Table 8.4.1.3.4-1, the E-glass tension reinforcement ratio is over 3 percent, and the corresponding volume factor is equal to 1. If

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the tension reinforcement ratio is reduced, the actual volume factor is a function of the reinforcement ratio and the reinforcement longitudinal stiffness. A numerical model that predicts the volume factor for reinforced glulams for any layup and type of reinforcement is available (Lindyberg, 2000).

8.4.1.3.6—Preservative Treatment

Designers shall specify that the effect of preservative treatment on the properties of the FRP reinforcement and on the strength and durability of the FRP–wood bond shall be evaluated as described in ASTM D7199. Preservative treatment shall be applied after bonding of the reinforcement. GFRP reinforced beams shall not be post-treated with CCA preservatives.

C8.4.1.3.6

CCA preservative has been shown to cause severe cracking in the E-glass reinforcement.

8.4.1.4—Piles

Wood piles shall comply with the requirements of AASHTO M 168.

Reference design values for round wood piles shall be as specified in Table 8.4.1.4-1.

C8.4.1.4

The reference design values for wood piles are based on wet-use conditions.

Table 8.4.1.4-1—Reference Design Values for Piles, ksi

Species	F_{co}	F_{bo}	F_{cpo}	F_{vo}	E_o
Pacific Coast Douglas Fir[1]	1.25	2.45	0.23	0.115	1500
Red Oak[2]	1.10	2.45	0.35	0.135	1250
Red Pine[3]	0.90	1.90	0.155	0.085	1280
Southern Pine[4]	1.20	2.40	0.25	0.11	1500

1 For connection design, use Douglas Fir–Larch reference design values.
2 Red Oak reference strengths apply to Northern and Southern Red Oak.
3 Red Pine reference strengths apply to Red Pine grown in the U.S. For connection design, use Northern Pine reference design values.
4 Southern Pine reference strengths apply to Loblolly, Longleaf, Shortleaf, and Slash Pine.

8.4.2—Metal Fasteners and Hardware

8.4.2.1—General

Structural metal, including shapes, plates, bars, and welded assemblies, shall comply with the applicable material requirements of Section 6.

8.4.2.2—Minimum Requirements

8.4.2.2.1—Fasteners

Bolts and lag screws shall comply with the dimensional and material quality requirements of ANSI/ASME B18.2.1, *Square and Hex Bolts and Screws—Inch Series*. Strengths for low-carbon steel bolts, Grade 1 through Grade 8, shall be as specified in Society of Automotive Engineers (SAE) specification SAE-429, *Mechanical and Material Requirements for Externally*

Threaded Fasteners. Bolt and lag screw grades not given in SAE-429 shall have a minimum tensile yield strength of 33.0 ksi.

8.4.2.2.2—Prestressing Bars

Prestressing bars shall comply with the requirements of AASHTO M 275M/M 275 (ASTM A722/A722M) and the applicable provisions of Section 5.

8.4.2.2.3—Split Ring Connectors

Split ring connectors shall be manufactured from hot-rolled carbon steel complying with the requirements of SAE-1010. Each circular ring shall be cut through in one place in its circumference to form a tongue and slot.

8.4.2.2.4—Shear Plate Connectors

Shear plate connectors shall be manufactured from pressed steel, light-gauge steel, or malleable iron. Pressed steel connectors shall be manufactured from hot-rolled carbon steel meeting SAE-1010. Malleable iron connectors shall be manufactured in accordance with ASTM A47, Grade 32510.

Each shear plate shall be a circle with a flange around the edge, extending at right angles to the plate face from one face only.

8.4.2.2.5—Nails and Spikes

Nails and spikes shall be manufactured from common steel wire or high-carbon steel wire that is heat treated and tempered. When used in withdrawal-type connections, the shank of the nail or spike shall be annularly or helically threaded.

8.4.2.2.6—Drift Pins and Bolts

Drift pins and drift bolts shall have a minimum flexural yield strength of 30.0 ksi.

8.4.2.2.7—Spike Grids

Spike grids shall conform to the requirements of ASTM A47, Grade 32510, for malleable iron casting.

8.4.2.2.8—Toothed Metal Plate Connectors

Metal plate connectors shall be manufactured from galvanized sheet steel that complies with the requirements of ASTM A653, Grade A, or better, with the following minimum mechanical properties:

Yield Point .... 33.0 ksi

Ultimate Strength ....45.0 ksi
Elongation in 2.0 in. ....20 percent

8.4.2.3—Corrosion Protection

8.4.2.3.1—Metallic Coating

Except as permitted by this section, all steel hardware for wood components shall be galvanized in accordance with AASHTO M 232M/M 232 (ASTM A153/A153M) or cadmium plated in accordance with ASTM B696.

Except as otherwise permitted, all steel components, timber connectors, and castings other than malleable iron shall be galvanized in accordance with AASHTO M 111M/M 111 (ASTM A123/A123M).

C8.4.2.3.1

Galvanized nuts should be retapped to allow for the increased diameter of the bolt due to galvanizing.

Protection for the high-strength bars used in stress-laminated decks should be clearly specified. Standard hot-dip galvanizing can adversely affect the properties of high-strength post-tensioning materials. A lower-temperature galvanizing is possible with some high-strength bars. The manufacturer of the bars should be consulted on this issue.

8.4.2.3.2—Alternative Coating

Alternative corrosion protection coatings may be used when the demonstrated performance of the coating is sufficient to provide adequate protection for the intended exposure condition during the design life of the bridge. When epoxy coatings are used, minimum coating requirements shall comply with ASTM A775/A775M.

Heat-treated alloy components and fastenings shall be protected by an approved alternative protective treatment that does not adversely affect the mechanical properties of the material.

8.4.3—Preservative Treatment

8.4.3.1—Requirement for Treatment

All wood used for permanent applications shall be pressure impregnated with wood preservative in accordance with the requirements of AASHTO M 133.

Insofar as is practicable, all wood components should be designed and detailed to be cut, drilled, and otherwise fabricated prior to pressure treatment with wood preservatives. When cutting, boring, or other fabrication is necessary after preservative treatment, exposed, untreated wood shall be specified to be treated in accordance with the requirements of AASHTO M 133.

8.4.3.2—Treatment Chemicals

Unless otherwise approved, all structural components that are not subject to direct pedestrian contact shall be treated with oil-borne preservatives. Pedestrian railings and nonstructural components that are subject to direct pedestrian contact shall be treated with water-borne preservatives or oil-borne preservatives in light petroleum solvent.

C8.4.3.2

The oil-borne preservative treatments have proven to provide adequate protection against wood-attacking organisms. In addition, the oil provides a water repellant coating that reduces surface effects caused by cyclic moisture conditions. Water-borne preservative treatments do not provide the water repellency of the oil-borne treatment, and components frequently split and check, leading to poor field performance and reduced service life.

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Direct pedestrian contact is considered to be contact that can be made while the pedestrian is situated anywhere in the access route provided for pedestrian traffic.

Treating of glued laminated timbers with water-borne preservatives after gluing is not recommended. Use of water-borne treatments for glued laminated timber after gluing may result in excessive warping, checking, or splitting of the components due to post-treatment redrying.

8.4.3.3—Inspection and Marking

Preservative treated wood shall be tested and inspected in accordance with the requirements of AASHTO M 133. Where size permits, each piece of treated wood that meets treatment requirements shall be legibly stamped, branded, or tagged to indicate the name of the treater and the specification symbol or specification requirements to which the treatment conforms.

When requested, a certification indicating test results and the identification of the inspection agency shall be provided.

8.4.3.4—Fire Retardant Treatment

Fire retardant treatments shall not be applied unless it is demonstrated that they are compatible with the preservative treatment used, and the usable resistance and stiffness are reduced as recommended by the product manufacturer and applicator.

C8.4.3.4

Use of fire retardant treatments is not recommended because the large sizes of timber components typically used in bridge construction have inherent fire resistance characteristics. The pressure impregnation of wood products with fire retardant chemicals is known to cause certain resistance and stiffness losses in the wood. Resistance and stiffness losses vary with specific resistance characteristic (e.g., bending resistance; tension parallel to grain resistance); treatment process; wood species and type of wood product (e.g., solid sawn, glued laminated, or other).

8.4.4—Adjustment Factors for Reference Design Values

8.4.4.1—General

Adjusted design values shall be obtained by adjusting reference design values by applicable adjustment factors in accordance with the following equations:

$$F_b = F_{bo}\, C_{KF}\, C_M\, (C_F \text{ or } C_v)\, C_{fu}\, C_i\, C_d\, C_\lambda \qquad (8.4.4.1\text{-}1)$$

$$F_v = F_{vo}\, C_{KF}\, C_M\, C_i\, C_\lambda \qquad (8.4.4.1\text{-}2)$$

$$F_t = F_{to}\, C_{KF}\, C_M\, C_F\, C_i\, C_\lambda \qquad (8.4.4.1\text{-}3)$$

$$F_c = F_{co}\, C_{KF}\, C_M\, C_F\, C_i\, C_\lambda \qquad (8.4.4.1\text{-}4)$$

$$F_{cp} = F_{cpo}\, C_{KF}\, C_M\, C_i\, C_\lambda \qquad (8.4.4.1\text{-}5)$$

$$E = E_o\, C_M\, C_i \qquad (8.4.4.1\text{-}6)$$

where:

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F = applicable adjusted design values F_b, F_v, F_t, F_c, or F_{cp} (ksi)
F_o = reference design values F_{bo}, F_{vo}, F_{to}, F_{co}, or F_{cpo} specified in Article 8.4 (ksi)
C_{KF} = format conversion factor specified in Article 8.4.4.2
C_M = wet service factor specified in Article 8.4.4.3
C_F = size factor for visually-graded dimension lumber and sawn timbers specified in Article 8.4.4.4
C_V = volume factor for structural glued laminated timber specified in Article 8.4.4.5
C_{fu} = flat-use factor specified in Article 8.4.4.6
C_i = incising factor specified in Article 8.4.4.7
C_d = deck factor specified in Article 8.4.4.8
C_λ = time effect factor specified in Article 8.4.4.9
E = adjusted modulus of elasticity (ksi)
E_o = reference modulus of elasticity specified in Article 8.4.1.1.4 (ksi)

8.4.4.2—Format Conversion Factor, C_{KF}

The reference design values in Tables 8.4.1.1.4-1, 8.4.1.1.4-2, 8.4.1.1.4-3, 8.4.1.2.3-1, 8.4.1.2.3-2, 8.4.1.3.4-1, and 8.4.1.4-1 and reference design values specified in the *NDS*® shall be multiplied by a format conversion factor, C_{KF}, for use with load and resistance factor design (LRFD). $C_{KF} = 2.5/\phi$, except for compression perpendicular to grain, which shall be obtained by multiplying the allowable stress by a format conversion factor of $C_{KF} = 2.1/\phi$.

C8.4.4.2

The conversion factors were derived so that LRFD design will result in same size member as the allowable stress design (ASD) specified in *NDS*®. For example, a rectangular component in flexure has to satisfy:

$$1.25\ M_{DL} + 1.75\ M_{LL} \leq \phi\ S\ F_{bo}\ C_{KF}\ C_M\ (C_F \text{ or } C_v)\ C_{fu}\ C_i\ C_d\ C_\lambda\ C_L \tag{C8.4.4.2-1}$$

or:

$$(1.25\ M_{DL} + 1.75\ M_{LL}) / (\phi C_{KF}\ C_\lambda) \leq S\ F_{bo}\ C_M\ (C_F \text{ or } C_v)\ C_{fu}\ C_i\ C_d\ C_L \tag{C8.4.4.2-2}$$

where:

M_{DL} = moment due to dead load
M_{LL} = moment due to live load

Alternatively, the allowable stress design (ASD) has to satisfy:

$$M_{DL} + M_{LL} \leq S\ F_{bo}\ C_M\ (C_F \text{ or } C_v)\ C_{fu}\ C_i\ C_d\ C_D\ C_L \text{ or}$$
$$(M_{DL} + M_{LL}) / (C_D) \leq S\ F_{bo}\ C_M\ (C_F \text{ or } C_v)\ C_{fu}\ C_i\ C_d\ C_L \tag{C8.4.4.2-3}$$

Therefore:

$$(1.25\ M_{DL} + 1.75\ M_{LL}) / (\phi C_{KF}\ C_\lambda) = (M_{DL} + M_{LL}) / (C_D) \tag{C8.4.4.2-4}$$

$$C_{KF} = [(1.25\ M_{DL} + 1.75\ M_{LL})(C_D)] / [(M_{DL} + M_{LL})(\phi\ C_\lambda)] \tag{C8.4.4.2-5}$$

The format conversion factor is calculated assuming the ratio of M_{DL} and M_{LL} is 1:10, $\phi = 0.85$, $C_\lambda = 0.8$, and $C_D = 1.15$.

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8.4.4.3—Wet Service Factor, C_M

The reference design values specified in Tables 8.4.1.1.4-1, 8.4.1.1.4-2, 8.4.1.1.4-3, 8.4.1.2.3-1, 8.4.1.2.3-2, 8.4.1.3.4-1, and 8.4.1.4-1 are for dry use conditions and shall be adjusted for moisture content using the wet service factor, C_M, specified below:

- For sawn lumber with an in-service moisture content of 19 percent or less, C_M shall be taken as 1.0.
- For glued laminated and tension-reinforced glued laminated (reinforced and unreinforced) timber with an in-service moisture content of 16 percent or less, C_M shall be taken as 1.0.
- Otherwise, C_M shall be taken as specified in Tables 8.4.4.3-1 for sawn lumber and Table 8.4.4.3-2 for reinforced and unreinforced glued laminated timber, respectively.

Reference design values for Southern Pine and Mixed Southern Pine sawn timbers 5 in. × 5 in. and larger shall be taken to apply to wet or dry use.

The wet service factors for reinforced and unreinforced glued laminated timber shall be the same.

C8.4.4.3

An analysis of in-service moisture content should be based on regional, geographic, and climatological conditions. In the absence of such analysis, wet-use conditions should be assumed.

Reduction for wet use is not required for Southern Pine and Mixed Southern Pine sawn timbers 5 in. × 5 in. and larger.

Table 8.4.4.3-1—Wet Service Factor for Sawn Lumber, C_M

Nominal Thickness	$F_{bo}C_F \leq 1.15$ ksi	$F_{bo}C_F > 1.15$ ksi	F_{to}	$F_{co}C_F \leq 0.75$ ksi	$F_{co}C_F > 0.75$ ksi	F_{vo}	F_{cpo}	E_o
≤4 in.	1.00	0.85	1.00	1.00	0.80	0.97	0.67	0.90
>4.0 in.	1.00	1.00	1.00	0.91	0.91	1.00	0.67	1.00

Table 8.4.4.3-2—Wet Service Factor for Glued Laminated Timber and Tension-Reinforced Glued Laminated Timber, C_M

F_{bo}	F_{vo}	F_{to}	F_{co}	F_{cpo}	E_o
0.80	0.875	0.80	0.73	0.53	0.833

8.4.4.4—Size Factor, C_F, for Sawn Lumber

The size factor, C_F, shall be 1.0 unless specified otherwise herein. For visually-graded dimension lumber of all species except Southern Pine and Mixed Southern Pine, C_F shall be as specified in Table 8.4.4.4-1.

Reference design values for Southern Pine and Mixed Southern Pine dimension lumber have been size-adjusted; no further adjustment for size shall be applied.

For Southern Pine and Mixed Southern Pine dimension lumber wider than 12.0 in., the tabulated bending, compression, and tension parallel to grain design values, for the 12.0 in. depth, shall be multiplied by the size factor, $C_F = 0.9$.

C8.4.4.4

C_F does not apply to mechanically-graded lumber (MSR, MEL) or to structural glued laminated timber.

Tabulated design values for visually-graded lumber of Southern Pine and Mixed Southern Pine species groups have already been adjusted for size. Further adjustment by the size factor is not permitted.

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Table 8.4.4.4-1—Size Effect Factor, C_F, for Sawn Dimension Lumber

Grade	Width (in.)	F_{bo}		F_{to}	F_{co}	All Other Properties
		Thickness				
		2.0 in. and 3.0 in.	4.0 in.	All	All	All
	Structural Light Framing: 2.0 in × 2.0 in. through 4.0 in. × 4.0 in. Structural Joists and Planks: 2.0 in × 5.0 in. through 4.0 in. × 16.0 in.					
	≤4	1.5	1.54	1.5	1.15	
Select Structural	5	1.4	1.4	1.4	1.1	
No. 1	6	1.3	1.3	1.3	1.1	
No. 2	8	1.2	1.3	1.2	1.05	1.00
	10	1.1	1.2	1.1	1.0	
	12	1.0	1.1	1.0	1.0	
	≥14	0.9	1.0	0.9	0.9	

For sawn beams and stringers with loads applied to the narrow face and posts and timbers with loads applied to either face, F_{bo} shall be adjusted by C_F determined as:

- If $d \leq 12.0$ in., then

$$C_F = 1.0 \tag{8.4.4.4-1}$$

- If $d > 12.0$ in., then

$$C_F = \left(\frac{12}{d}\right)^{\frac{1}{9}} \tag{8.4.4.4-2}$$

where:

d = net width as shown in Figure 8.3-1

For beams and stringers with loads applied to the wide face, F_{bo} shall be adjusted by C_F as specified in Table 8.4.4.4-2.

Table 8.4.4.4-2—Size Factor, C_F, for Beams and Stringers with Loads Applied to the Wide Face

Grade	F_{bo}	E_o	Other Properties
Select Structural	0.86	1.00	1.00
No. 1	0.74	0.90	1.00
No. 2	1.00	1.00	1.00

8.4.4.5—Volume Factor, C_V, (Glulam)

For horizontally-laminated glulam with loads applied perpendicular to the wide face of the laminations, F_{bo} shall be reduced by C_V, given below, when the depth, width, or length of a glued laminated timber exceeds 12.0 in., 5.125 in., or 21.0 ft, respectively:

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$$C_V = \left[\left(\frac{12.0}{d}\right)\left(\frac{5.125}{b}\right)\left(\frac{21}{L}\right)\right]^a \leq 1.0 \qquad (8.4.4.5\text{-}1)$$

where:

d = depth of the component (in.)
b = width of the component (in.) For layups with multiple piece laminations (across the width), b = width of widest piece. Therefore: $b \leq 10.75$ in.
L = length of the component measured between points of contraflexure (ft)
a = 0.05 for Southern Pine and 0.10 for all other species.

The volume factor, C_V, shall not be applied simultaneously with the beam stability factor, C_L; therefore, the lesser of these factors shall apply.

The conventional glulam volume factor shall not be applied to tension-reinforced glulams except when unreinforced compression zone is stressed in tension (see Article C8.4.1.3.5). For tension-reinforced glulam beams where unreinforced compression zone is stressed in tension the volume factor, C_v, the same as for conventional glulam, shall be used.

8.4.4.6—Flat-Use Factor, C_{fu}

When dimension lumber graded as Structural Light Framing or Structural Joists and Planks is used flatwise (load applied to the wide face), the bending reference design value shall be multiplied by the flat use factor specified in Table 8.4.4.6-1. The flat-use factor shall not apply to dimension lumber graded as Decking.

Table 8.4.4.6-1—Flat-Use Factor, C_{fu}, for Dimension Lumber

Width (in.)	Thickness (in.) 2 and 3	Thickness (in.) 4
2 and 3	1.00	—
4	1.10	1.00
5	1.10	1.05
6	1.15	1.05
8	1.15	1.05
≥10	1.20	1.10

Reference design values for flexure of vertically laminated glulam (loads applied parallel to wide faces of laminations) shall be multiplied by the flat use factors specified in Table 8.4.4.6-2 when the member dimension parallel to wide faces of laminations is less than 12.0 in.

C8.4.4.6

Design values for flexure of dimension lumber adjusted by the size factor, C_F, are based on edgewise use (load applied to the narrow face). When dimension lumber is used flatwise (load applied to the wide face), the bending reference design value should also be multiplied by the flat use factor specified in Table 8.4.4.6-1.

Design values for dimension lumber graded as Decking are based on flatwise use. Further adjustment by the flat-use factor is not permitted.

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Table 8.4.4.6-2—Flat-Use Factor, C_{fu}, for Glulam

Member Dimension Parallel to Wide Faces of Laminations (in.)	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 $^1/_2$ or 2 $^1/_8$	1.19

8.4.4.7—Incising Factor, C_i

Reference design values for dimension lumber shall be multiplied by the incising factor specified in Table 8.4.4.7-1 when members are incised parallel to grain a maximum depth of 0.4 in., a maximum length of $^3/_8$ in., and a density of incisions up to 1,100/ft^2. Incising factors shall be determined by test or by calculation using reduced section properties for incising patterns exceeding these limits.

Table 8.4.4.7-1—Incising Factor, C_i, for Dimension Lumber

Design Value	C_i
E_o	0.95
F_{bo}, F_{to}, F_{co}, F_{vo}	0.80
F_{cpo}	1.00

8.4.4.8—Deck Factor, C_d

Unless specified otherwise in this Article, the deck factor, C_d, shall be equal to 1.0.

For stressed wood, nail-laminated, and spike-laminated decks constructed of solid sawn lumber 2.0 in. to 4.0 in. thick, F_{bo} may be adjusted by C_d as specified in Table 8.4.4.8-1.

Table 8.4.4.8-1—Deck Factor, C_d, for Stressed Wood and Laminated Decks

Deck Type	Lumber Grade	C_d
Stressed Wood	Select Structural No. 1 or No. 2	1.30 1.50
Spike-Laminated or Nail-Laminated	All	1.15

C8.4.4.8

Mechanically laminated decks made of stressed wood, spike-laminated, or nail-laminated solid sawn lumber exhibit an increased resistance in bending. The resistance of mechanically laminated solid sawn lumber decks is calculated by multiplying F_{bo} in Table 8.4.1.1.4-1 by the deck factor.

Deck factor is used instead of the repetitive member factor that is used in *NDS*®.

For planks 4 × 6 in., 4 × 8 in., 4 × 10 in., and 4 × 12 in., used in plank decks with the load applied to the wide face of planks, F_{bo} may be adjusted by C_d as specified in Table 8.4.4.8-2.

Table 8.4.4.8-2—Deck Factor, C_d, for Plank Decks

Size (in.)	C_d
4 × 6	1.10
4 × 8	1.15
4 × 10	1.25
4 × 12	1.50

The deck factors for planks in plank decks shall not be applied cumulatively with the flat use factor, C_{fu}, specified in Article 8.4.4.6.

The specified deck factors for planks in plank decks are based test results comparing the modulus of rupture (MOR) for plank specimens with load applied in narrow face and wide face (*Stankiewicz and Nowak*, *1997*). These deck factors can be applied cumulatively with the size factor, C_F, specified in Article 8.4.4.4.

8.4.4.9—Time Effect Factor, C_λ

The time effect factor, C_λ shall be chosen to correspond to the appropriate strength limit state as specified in Table 8.4.4.9-1.

Table 8.4.4.9-1—Time Effect Factor, C_λ

Limit State	C_λ
Strength I	0.8
Strength II	1.0
Strength III	1.0
Strength IV	0.6
Extreme Event I	1.0

C8.4.4.9

NDS® and ANSI 117 reference design values (based on 10-year loading) multiplied by the format conversion factors specified in Article 8.4.4.2, transform allowable stress values to strength level stress values based on 10-min. loading. It is assumed that a cumulative duration of bridge live load is 2 months and the corresponding time effect factor for Strength I is 0.8. A cumulative duration of live load in Strength II is shorter and the corresponding time effect factor for Strength II is 1.0. Resistance of wood subjected to long-duration loads is reduced. Load combination IV consists of permanent loads, including dead load and earth pressure.

8.5—LIMIT STATES

8.5.1—Service Limit State

The provisions of Article 2.5.2.6.2 should be considered.

8.5.2—Strength Limit State

8.5.2.1—General

Factored resistance shall be the product of nominal resistance determined in accordance with Articles 8.6, 8.7, 8.8, and 8.9 and the resistance factor as specified in Article 8.5.2.2.

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8.5.2.2—Resistance Factors

Resistance factors, ϕ, shall be as given below:

Flexure	$\phi = 0.85$
Shear	$\phi = 0.75$
Compression Parallel to Grain	$\phi = 0.90$
Compression Perpendicular to Grain	$\phi = 0.90$
Tension Parallel to Grain	$\phi = 0.80$
Resistance During Pile Driving	$\phi = 1.15$
Connections	$\phi = 0.65$

C8.5.2.2

In the case of timber pile foundations, the resistance factor may be raised to 1.0 when, in the judgment of the Engineer, a sufficient number of piles is used in a foundation element to consider it to be highly redundant. This is indicated to be a judgment issue because there are no generally accepted quantitative guidelines at this writing.

For timber piles, the resistance factor to be applied when determining the maximum allowable driving resistance accounts for the short duration of the load induced by the pile driving hammer.

8.5.2.3—Stability

The structure as a whole or its components shall be proportioned to resist sliding, overturning, uplift, and buckling.

8.5.3—Extreme Event Limit State

For extreme event limit state, the resistance factor shall be taken as 1.0.

8.6—COMPONENTS IN FLEXURE

8.6.1—General

The factored resistance, M_r, shall be taken as:

$$M_r = \phi M_n \tag{8.6.1-1}$$

where:

M_n = nominal resistance specified herein (kip-in.)
ϕ = resistance factor specified in Article 8.5.2

8.6.2—Rectangular Section

The nominal resistance, M_n, of a rectangular component in flexure shall be determined from:

$$M_n = F_b S C_L \tag{8.6.2-1}$$

in which:

$$C_L = \frac{1 + A}{1.9} - \sqrt{\frac{(1 + A)^2}{3.61} - \frac{A}{0.95}} \tag{8.6.2-2}$$

$$A = \frac{F_{bE}}{F_b} \tag{8.6.2-3}$$

C8.6.2

If lateral support is provided to prevent rotation at the points of bearing, but no other lateral support is provided throughout the bending component length, the unsupported length, L_u, is the distance between such points of intermediate lateral support.

The volume factor for the tension-reinforced glulams listed in Table 8.4.1.3.4-1 is equal to 1; therefore, for these beams, C_L will always be less than or equal to C_V, and C_L will control the modification factor for the allowable bending strength, F_b.

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$$F_{bE} = \frac{K_{bE}E}{R_B^{\ 2}} \quad (8.6.2\text{-}4)$$

$$R_b = \sqrt{\frac{L_e d}{b^2}} \leq 50 \quad (8.6.2\text{-}5)$$

where:

C_L = beam stability factor for both conventional glulam and tension-reinforced glulam
A = parameter for beam stability (8.6.2)
F_b = adjusted design value in flexure specified in Article 8.4.4.1 (ksi)
K_{bE} = 0.76 for visually graded lumber
K_{bE} = 0.98 for MEL lumber
K_{bE} = 1.06 for MSR lumber
K_{bE} = 1.10 for glulam and tension-reinforced glulam
E = adjusted modulus of elasticity specified in Article 8.4.4.1 (ksi)
L_e = effective unbraced length (in.)
d = net depth specified in Article 8.4.1.1.1 (in.)
b = net width, as specified in Article 8.4.4.5 (in.)
S = section modulus (in.^{3})

Where the depth of a flexural component does not exceed its width, or where lateral movement of the compression zone is prevented by continuous support and where points of bearing have lateral support to prevent rotation, the stability factor, $C_L = 1.0$. For other conditions, the beam stability factor shall be determined in accordance with the provisions specified herein.

The beam stability factor shall not be applied simultaneous with the volume factor for structural glued laminated timber, therefore, the lesser of these factors shall apply.

The effective unbraced length, L_e, may be determined as:

- If $L_u/d < 7$, then $L_e = 2.06\ L_u$
- If $7 \leq L_u/d \leq 14.3$, then $L_e = 1.63\ L_u + 3d$
- If $L_u/d > 14.3$, then $L_e = 1.84\ L_u$

where:

L_u = distance between point of lateral and rotational support (in.)

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8.6.3—Circular Section

The nominal resistance, M_n, of a circular component in flexure shall be taken as:

$$M_n = F_b S \quad (8.6.3\text{-}1)$$

8.7—COMPONENTS UNDER SHEAR

Shear shall be investigated at a distance away from the face of support equal to the depth of the component. When calculating the maximum design shear, the live load shall be placed so as to produce the maximum shear at a distance from the support equal to the lesser of either three times the depth, *d,* of the component or one quarter of the span, *L*.

The factored shear resistance, V_r, of a component of rectangular cross section shall be calculated from:

$$V_r = \phi V_n \quad (8.7\text{-}1)$$

in which:

$$V_n = \frac{F_v bd}{1.5} \quad (8.7\text{-}2)$$

where:

ϕ = resistance factor specified in Article 8.5.2.2
F_v = adjusted design value of wood in shear, specified in Article 8.4.4.1 (ksi)

C8.7

The critical section is between one and three depths from the support.

The critical shear in flexural components is horizontal shear acting parallel to the grain of the component. The resistance of bending components in shear perpendicular to grain need not be investigated.

Note that Eq. 4.6.2.2.2a-1 requires a special distribution factor in the calculation of the live load force effect when investigating shear parallel to the grain.

8.8—COMPONENTS IN COMPRESSION

8.8.1—General

The factored resistance in compression, P_r, shall be taken as:

$$P_r = \phi P_n \quad (8.8.1\text{-}1)$$

where:

ϕ = resistance factor specified in Article 8.5.2.2
P_n = nominal resistance as specified in Articles 8.8.2 and 8.8.3 (kips)

8.8.2—Compression Parallel to Grain

Where components are not adequately braced, the nominal stress shall be modified by the column stability factor, C_p. If the component is adequately braced, C_p shall be taken as 1.0.

The nominal resistance, P_n, of a component in the compression parallel to grain shall be taken as:

C8.8.2

The coefficient of variation of the bending modulus of rupture (*MOR*) of tension-reinforced glulams has been shown through extensive testing to be less than or equal to that of conventional unreinforced glulams. Therefore, it is conservative to use K_{cE} = 0.76 for tension-reinforced glulams.

$$P_n = F_c A_g C_p \tag{8.8.2-1}$$

in which:

$$C_p = \frac{1+B}{2c} - \sqrt{\left(\frac{1+B}{2c}\right)^2 - \frac{B}{c}} \leq 1.0 \tag{8.8.2-2}$$

$$B = \frac{F_{cE}}{F_c} \leq 1.0 \tag{8.8.2-3}$$

$$F_{cE} = \frac{K_{cE} E d^2}{L_e^2} \tag{8.8.2-4}$$

where:

A_g = gross cross-sectional area of the component (in.^{2})
c = coefficient
= 0.8 for sawn lumber
= 0.85 for round timber piles
= 0.9 for glulam
F_c = adjusted design value in compression parallel to the grain specified in Article 8.4.4.1 (ksi)
F_{ce} = Euler buckling stress
K_{cE} = Euler buckling coefficient for columns
= 0.52 for visually graded lumber
= 0.67 for MEL lumber
= 0.73 for MSR lumber
= 0.76 for glulam, tension-reinforced glulam, and round piles
L_e = effective length taken as KL (in.)

8.8.3—Compression Perpendicular to Grain

The nominal resistance, P_n, of a component in compression perpendicular to the grain shall be taken as:

$$P_n = F_{cp} A_b C_b \tag{8.8.3-1}$$

where:

F_{cp} = adjusted design value in compression perpendicular to grain, as specified in Article 8.4.4.1 (ksi)
A_b = bearing area (in.^{2})
C_b = bearing adjustment factor specified in Table 8.8.3-1

When the bearing area is in a location of high flexural stress or is closer than 3.0 in. from the end of the component, C_b shall be taken as 1.0. In all other cases, C_b shall be as specified in Table 8.8.3-1.

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Table 8.8.3-1—Adjustment Factors for Bearing

	Length of Bearing Measured along the Grain, in.						
C_b	0.5	1.0	1.5	2.0	3.0	4.0	≥6.0
	1.75	1.38	1.25	1.19	1.13	1.10	1.00

8.9—COMPONENTS IN TENSION PARALLEL TO GRAIN

The factored resistance, P_r, of a component in tension shall be taken as:

$$P_r = \phi P_n \tag{8.9-1}$$

in which:

$$P_n = F_t A_n \tag{8.9-2}$$

where:

ϕ = resistance factor specified in Article 8.5.2.2
F_t = adjusted design value of wood in tension specified in Article 8.4.4.1 (ksi)
A_n = smallest net cross-sectional area of the component (in.^{2})

8.10—COMPONENTS IN COMBINED FLEXURE AND AXIAL LOADING

8.10.1—Components in Combined Flexure and Tension

Components subjected to flexure and tension shall satisfy:

$$\frac{P_u}{P_r} + \frac{M_u}{M_r^*} \leq 1.0 \tag{8.10.1-1}$$

and

$$\frac{M_u - \dfrac{d}{6} P_u}{M_r^{**}} \leq 1.0 \tag{8.10.1-2}$$

where:

P_u = factored tensile load (kips)
P_r = factored tensile resistance calculated as specified in Article 8.9 (kips)
M_u = factored flexural moment (kip-in.)
M_r* = $F_b S$
M_r** = factored flexural resistance adjusted by all applicable adjustment factors except C_V

C8.10.1

Satisfying Eq. 8.10.1-1 ensures that stress interaction on the tension face of the bending member does not cause beam rupture. M_r^* in this formula does not include modification by the beam stability factor, C_L.

Eq. 8.10.1-2 is applied to ensure that the bending/tension member does not fail due to lateral buckling of the compression face.

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8.10.2—Components in Combined Flexure and Compression Parallel to Grain

Components subjected to flexure and compression parallel to grain shall satisfy:

$$\left(\frac{P_u}{P_r}\right)^2 + \frac{M_u}{M_r\left(1-\dfrac{P_u}{F_{cE}A_g}\right)} \leq 1.0 \qquad (8.10.2\text{-}1)$$

where:

P_u = factored compression load (kips)
P_r = factored compressive resistance calculated as specified in Article 8.8 (kips)
M_u = factored flexural moment (kip-in.)
M_r = factored flexural resistance calculated as specified in Article 8.6 (kip-in.)
F_{cE} = Euler buckling stress as defined in Eq. 8.8.2-4
A_g = gross cross-sectional area (in.^{2})

8.11—BRACING REQUIREMENTS

8.11.1—General

Where bracing is required, it shall prevent both lateral and rotational deformation.

C8.11.1

In detailing of the diaphragms, the potential for shrinkage and expansion of the beam and the diaphragm should be considered. Rigidly connected steel angle framing may cause splitting of the beam and diaphragm as the wood attempts to swell and shrink under the effects of cyclic moisture.

8.11.2—Sawn Wood Beams

Beams shall be transversely braced to prevent lateral displacement and rotation of the beams and to transmit lateral forces to the bearings. Transverse bracing shall be provided at the supports for all span lengths and at intermediate locations for spans longer than 20.0 ft. The spacing of intermediate bracing shall be based on lateral stability and load transfer requirements but shall not exceed 25.0 ft. The depth of transverse bracing shall not be less than three fourths the depth of the stringers or girders.

Transverse bracing should consist of solid wood blocking or fabricated steel shapes. Wood blocking shall be bolted to stringers with steel angles or suspended in steel saddles that are nailed to the blocks and stringer sides. Blocking shall be positively connected to the beams.

Transverse bracing at supports may be placed within a distance from the center of bearing equal to the stringer or girder depth.

C8.11.2

The effectiveness of the transverse bracing directly affects the long-term durability of the system. The bracing facilitates erection, improves load distribution, and reduces relative movements of the stringers and girders, thereby reducing deck deformations. Excessive deformation can lead to mechanical deterioration of the system.

Bracing should be accurately framed to provide full bearing against stringer sides. Wood cross-frames or blocking that are toe-nailed to stringers have been found to be ineffective and should not be used.

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8.11.3—Glued Laminated Timber Girders

Transverse bracing should consist of fabricated steel shapes or solid wood diaphragms.

Girders shall be attached to supports with steel shoes or angles that are bolted through the girder and into or through the support.

C8.11.3

Bracing should be placed tight against the girders and perpendicular to the longitudinal girder axis.

8.11.4—Bracing of Trusses

Wood trusses shall be provided with a rigid system of lateral bracing in the plane of the loaded chord. Lateral bracing in the plane of the unloaded chord and rigid portal and sway bracing shall be provided in all trusses having sufficient headroom. Outrigger bracing connected to extensions of the floorbeams shall be used for bracing through-trusses having insufficient headroom for a top chord lateral bracing system.

C8.11.4

Bracing is used to provide resistance to lateral forces, to hold the trusses plumb and true, and to hold compression elements in line.

8.12—CAMBER REQUIREMENTS

8.12.1—Glued Laminated Timber Girders

Glued laminated timber girders shall be cambered a minimum of two times the dead load deflection at the service limit state.

C8.12.1

The initial camber offsets the effects of dead load deflection and long-term creep deflection.

8.12.2—Trusses

Trusses shall be cambered to sufficiently offset the deflection due to dead load, shrinkage, and creep.

C8.12.2

Camber should be determined by considering both elastic deformations due to applied loads and inelastic deformations such as those caused by joint slippage, creep of the timber components, or shrinkage due to moisture changes in the wood components.

8.12.3—Stress Laminated Timber Deck Bridge

Deck bridges shall be cambered for three times the dead load deflection at the service limit state.

8.13—CONNECTION DESIGN

The design of timber connections using mechanical fasteners including, wood screws, nails, bolts, lag screws, drift bolts, drift pins, shear plates, split rings, and timber rivets shall be in accordance with the 2018 *NDS*®.

8.14—REFERENCES

AITC. *Standard Specifications for Structural Glued Laminated Timber of Hardwood Species*. AITC 119. American Institute of Timber Construction, Centennial, CO, 1996.

AITC. *Standard Appearance Grades for Structural Glued Laminated Timber.* AITC 110. American Institute of Timber Construction, Centennial, CO, 2001.

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American Wood Council. *National Design Specification® (NDS®) for Wood Construction*. ANSI/AWC NDS, Leesburg, VA, 2018.

APA. *Standard Specifications for Structural Glued Laminated Timber of Softwood Species*. ANSI 117. APA – The Engineering Wood Association, Tacoma, WA, 2015.

APA. *Structural Glued Laminated Timber*. ANSI A190.1. APA – The Engineered Wood Association, Tacoma, WA, 2017.

Davids, W. G, E. Nagy, and M. Richie. Fatigue Behavior of Composite-Reinforced Glulam Bridge Girders. *Journal of Bridge Engineering*. American Society of Civil Engineers, Reston, VA, March/April 2008.

Davids, W. G., M. Richie, and C. Gamache. Fatigue of Glulam Beams with Fiber-Reinforced Polymer Tension Reinforcing. *Forest Products Journal*, Vol. 55, No. 1. Forest Products Society, Madison, WI, 2005.

ICC-ES. *Acceptance Criteria for Fiber-Reinforced-Polymer Glue-Laminated Timber Using Mechanics Based Models*. AC280. ICC Evaluation Service, Inc., Whittier, CA, 2005.

Lindyberg, R. L. ReLAM: A Nonlinear Probablistic Model for the Analysis of Reinforced Glulam Beams in Bending. Document ID CIE2000-001. University of Maine, Orono, ME, Ph.D Dissertation, 2000.

Nowak, A. S. *Load Distribution for Plank Decks*. UMCEE 97-11. Report submitted to U.S. Forest Service, U.S. Department of Agriculture, Washington, DC, April 1997.

Nowak, A. S. *National Cooperative Highway Research Report 368: Calibration of LRFD Bridge Design Code*. National Cooperative Highway Research Program, Transportation Research Board, Washington, DC, 1999.

Nowak, A. S., C. Eamon, M. A. Ritter, and J. Murphy. *LRFD Calibration for Wood Bridges*. UMCEE 01-01. Report submitted to U.S. Forest Service, U.S. Department of Agriculture, Washington, DC, April 2001.

Nowak, A. S., P. R. Stankiewicz, and M. A. Ritter. Bending Tests of Bridge Deck Planks. *Construction and Building Materials Journal*, Vol. 13, No. 4, 1999, pp. 221–228.

Ritter, M. A. *Timber Bridges, Design, Construction, Inspection, and Maintenance*. EM7700-B. U.S. Forest Service, U.S. Department of Agriculture, Washington, DC, 1990.

Stankiewicz, P. R., and A. S. Nowak. *Material Testing for Wood Plank Decks*. UMCEE 97-10. Report submitted to U.S. Forest Service, U.S. Department of Agriculture, Washington, DC, April 1997.

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