8.6.3.7—Shear Resistance

The shear resistance for tubular members under transverse loads or torsion may be calculated as follows:

$$F_{vr} = \phi_v \left[\frac{0.533F_{tu}\left(1+\mu_{12}\right)}{\mu}\right]\left[\frac{G}{F_{vr}}\right]\left[\frac{t}{R_1}\right] \leq \phi_v F_{vu} \tag{8.6.3.7-1}$$

where μ is determined according to Article 8.6.3.2.

C8.6.3.7

The shear resistance equation is provided for orthotropic materials, but may be used for planar isotropic materials by setting $E_1 = E_2$ in the equation for μ. To determine the computed shear stress, f_v, equations to compute maximum shear stresses due to transverse loads and torsion are provided in Appendix B.

8.6.4—Combined Stresses

Members subjected to combined bending, axial compression, or tension may be proportioned to meet the limitations of Article 8.6.4.1 or Article 8.6.4.2, as applicable.

8.6.4.1—Bending and Compression

Members subjected to bending and compression may satisfy the following equations:

$$\frac{f_a}{\phi_c F_{cr}} + \frac{B_2 f_b}{\phi_b F_{br}} \leq 1.0 \tag{8.6.4.1-1}$$

where:

$$B_2 = 1 - \frac{f_a}{F_e'} \tag{8.6.4.1-2}$$

$$F_e' = \phi_c \frac{\pi^2 E_c}{\left(\dfrac{k_b L}{r_b}\right)^2} \tag{8.6.4.1-3}$$

and:

$$\frac{f_a}{\phi_c F_{cr}} + \frac{f_b}{\phi_b F_{br}} \leq 1.0 \tag{8.6.4.1-4}$$

where F_{cr} in Eq. 8.6.4.1-2 is the compression resistance due to local buckling.

C8.6.4.1

For practical design, simplified combined resistance ratio equations similar to those used for metal structures have been adopted for FRP (ASCE 1985). Although composite materials do not fail according to maximum principal stress criterion, the simplified equations should give conservative approximations. Research is needed in this area to develop equations based on the failure criteria of FRP.

Two equations are presented to check combined bending and compression stresses. Eq. 8.6.4.1-1 includes the term:

$$B_2 = 1 - \frac{f_a}{F_e'} \tag{C8.6.4.1-1}$$

which accounts for the second-order moments that occur as a result of the P-Δ effect. The equation is intended for intermediate unbraced locations where the member is susceptible to lateral displacement. Eq. 8.6.4.1-4 is intended for locations at the end of the member where lateral displacement is restrained. The combined stresses at such locations may, in some cases, exceed those at the intermediate points. B_2 is 1.0 where the second-order moments are determined from analysis per Section 4.

For biaxial bending, except for round and polygonal tubular sections, the second term of Eq. 8.6.4.1-1 can be substituted by:

$$\frac{f_{bx}}{\phi_b F_{brx}\left(1-\dfrac{f_a}{F_{ex}'}\right)} + \frac{f_{by}}{\phi_b F_{bry}\left(1-\dfrac{f_a}{F_{ey}'}\right)} \leq 1.0 \tag{C8.6.4.1-2}$$

and the second term $f_b/\phi F_{br}$ of Eq. 8.6.4.1-2 can be substituted by $f_{bx}/\phi F_{brx} + f_{by}/\phi F_{bry}$.

8.6.4.2—Bending and Tension

Members subjected to bending and tension may satisfy the following equation:

$$\frac{f_t}{\phi_t F_{tr}} + \frac{f_b}{\phi_b F_{br}} \leq 1.0 \qquad (8.6.4.2\text{-}1)$$

C8.6.4.2

With the exception of round tubular sections and polygonal sections, the term $f_b/\phi F_{br}$ can be substituted by $f_{bx}/\phi F_{brx} + f_{by}/\phi F_{bry}$ in Eq. 8.6.4.2-1.

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SECTION 9: WOOD DESIGN

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SECTION 9:

WOOD DESIGN

9.1—SCOPE

This Section specifies design provisions for wood structural supports for highway signs, luminaires, and traffic signals. The provisions of this Section apply only to cantilevered wood posts and poles. The design provisions for wood posts and poles are generally based on the *National Design Specification for Wood Construction* (NDS, 2010), including the *Design Values for Wood Construction* (NDS Supplement, 2012), except as modified herein.

C9.1

The design provisions of this Section are applicable to common post and pole usages. Additional design provisions given in the NDS may be required for other member types or usages.

9.2—DEFINITIONS

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

Class—Group of poles that have approximately the same load-carrying capacity regardless of species.

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

Dry Condition—Condition of having relatively low moisture content, i.e., not more than 19 percent for sawn lumber.

Effective Modulus of Elasticity—Modulus of elasticity multiplied by applicable adjustment factors listed in Table 9.4.3.3-2.

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

Grade Mark—The 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 Condition—Condition of having relatively high moisture content, i.e., more than 19 percent for sawn lumber.

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

Moisture Content—An 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 Wood Council.

NELMA—Northeastern Lumber Manufacturers Association, a grading agency.

NLGA—Grading rules by National Lumber Grades Authority.

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

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

Normal Load Duration—Condition of fully stressing a member to its adjusted design stress by the application of the full design load for a cumulative period of approximately 10 years.

NSLB—Northern Softwood Lumber Bureau, a grading agency.

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

Pole—Solid wood member, round in cross-section, of any size or length, usually used with the larger end in the ground.

Post—Solid wood member with a square or nearly square cross-section, with the width not more than 2 in. greater than the thickness.

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

Size Adjustment Factors—Factors that adjust reference design values listed in Table 9.4.2.3-1 for effects of member size.

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

SPIB—Southern Pine Inspection Bureau, a grading agency.

Strain Pole—Poles that support span-wires for traffic signals

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

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

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

WCLIB—West Coast Lumber Inspection Bureau, a grading agency.

Wet-Use—Use conditions where the moisture content of the wood in service exceeds the dry condition.

WWPA—Western Wood Products Association, a grading agency.

9.3—NOTATION

a = support condition parameter (0.7 for cantilever members) (9.4.3.2) (C9.4.3.2)
b = width of rectangular bending member (in.) (C9.7)
C_M = wet service factor (9.4.3.2) (9.4.3.3) (9.4.4.2.1)
C_u = untreated factor for timber poles (9.4.2.3) (9.4.3.3) (9.4.4.4)
D = diameter of round section (in.) (9.4.3.2) (C9.7)
D_b = diameter at groundline section of the member (in.) (9.4.3.2) (C9.4.3.2)
D_t = diameter at top of the member (in.) (9.4.3.2)
d = depth of rectangular bending member (in.) (9.4.3.2) (C9.7) (9.9)
d_b = dimension of one side of the rectangular section at groundline section of the member (in.) (9.4.3.2) (C9.4.3.2)
d_t = dimension of one side of the rectangular section at top of the member (in.) (9.4.3.2)
E = reference modulus of elasticity (ksi) (9.4.2.3) (9.4.3.3) (9.4.4.2.1)
E' = adjusted modulus of elasticity (ksi) (9.4.2.3) (9.4.3.3) (9.9)
F_b = reference bending design value (ksi) (9.4.2.3) (9.4.3.3) (9.4.4.2.1) (9.6) (C9.6) (9.9)
F'_b = adjusted bending stress (ksi) (9.4.2.3) (9.4.3.3)
F'_{bx} = adjusted bending stress about x axis (strong axis) (ksi) (C9.9)
F'_{by} = adjusted bending stress about y axis (weak axis) (ksi) (C9.9)
F_c = reference compression design value parallel to grain (ksi) (9.4.2.3) (C9.4.2.3) (9.4.3.2) (9.4.3.3) (9.4.2.2.1)
F'_c = adjusted compression stress parallel to grain (ksi) (9.4.2.3) (9.8) (9.9)
F_{cE} = critical buckling stress for compression members (ksi) (9.9) (C9.9)
F_{cp} = reference compression design value perpendicular to grain (ksi) (9.4.2.3) (9.4.2.1) (9.4.3.3) (9.4.4.2.1)
F'_{cp} = adjusted compression stress perpendicular to grain (ksi) (9.4.2.3) (9.4.3.3)
F_t = reference tension design value parallel to grain (ksi) (9.4.2.3) (9.4.3.3) (9.4.4.2.1)
F'_t = adjusted tension stress parallel to grain (ksi) (9.4.2.3)
F_v = reference shear design value parallel to grain (horizontal shear) (ksi) (9.4.2.3) (9.4.3.3) (9.4.4.2.1)
F'_v = adjusted shear stress parallel to grain (horizontal shear) (ksi) (9.4.2.3) (9.4.3.3) (9.7)

f_b = computed bending stress (ksi) (9.6) (9.9)
f_{bx} = computed bending stress about x axis (strong axis) (ksi) (C9.9)
f_{by} = computed bending stress about y axis (weak axis) (ksi) (C9.9)
f_c = computed compression stress parallel to grain (ksi) (C9.4.2.3) (C9.7) (9.8) (9.9) (C9.9)
f_v = computed shear stress parallel to grain (ksi) (9.7)
I = moment of inertia of cross-section about centroidal axis (in.^{4}) (C9.6) (9.7)
K_{cE} = Euler buckling coefficient for columns (9.9)
K_F = LRFD conversion factor (9.4.2.3) (9.4.3.3) (9.5.2.3)
L_e = effective length of a bending or compression member (in.) (9.9)
L_u = unsupported length of bending member (in.) (9.9)
M = bending moment (kip-in.) (C9.6)
Q = static moment of area about the neutral axis (in.^{3}) (C9.7)
V = shear force (kips) (C9.7)
y = distance to the outer fiber (in.) (C9.6)
λ = time effect factor (9.4.2.3) (9.4.3.3) (9.4.4.3)
ϕ = resistance factor (9.4.2.3) (9.4.3.3)
ϕ_b = resistance factor for bending (9.5.2.2)
ϕ_c = resistance factor for compression (9.5.2.2)
ϕ_{cperp} = resistance factor for compression perpendicular (9.5.2.2)
ϕ_{Emin} = resistance factor for elastic modulus minimum (9.5.2.2)
ϕ_t = resistance factor for tension (9.5.2.2)
ϕ_v = resistance factor for shear (9.5.2.2)

9.4—MATERIAL

9.4.1—General

This Article addresses the following wood products for:

- Posts and
- Round poles.

C9.4.1

Posts and poles are the most commonly used wood products for structural supports for highway signs, luminaires, and traffic signals. This Article is limited to the coverage of wood posts from visually graded lumber and round timber poles.

Visually graded lumber is a type of structural lumber graded by visual examination based on certain rules established by the grading agency.

In general, posts are used to support small structures such as roadside signs. Round timber poles are used as vertical supports for street lighting or strain poles for temporary span-wire configurations.

Engineered wood products such as laminated veneer lumber may be used for structural supports such as posts. Design of these products, however, should be based on technical information provided by the manufacturer and approved by the Owner, because the reference design values could vary for products from different manufacturers.

Reference design values apply to normal load duration. Normal load duration is defined as the condition of fully stressing a member to its adjusted stress by the application of the full design load for a cumulative period of approximately 10 yr.

9.4.2—Posts

9.4.2.1—General

In calculating stresses for posts, the net section of the member shall be used. The net section shall be determined by deducting from the gross section the projected area of all material removed by boring, grooving, dapping, notching, or other means.

9.4.2.2—Dimensions

Stresses in posts shall be computed on the basis of the net dimension of the cross-section. For 4-in. (nominal) wide posts, the net dry dressed dimensions shall be used in stress checks regardless of the moisture content at the time of manufacture or use. For 5-in. (nominal) and wider posts, the net green dressed dimensions shall be used in stress checks regardless of the moisture content at the time of manufacture or use.

C9.4.2.2

For all standard dressed posts 4 in. (nominal) and wider, the dressed dimensions used in stress checks are equal to 0.5 in. less than the nominal dimensions.

9.4.2.3—Reference Design Values

Reference design values for posts are given in Tables 9.4.2.3-1 and 9.4.2.3-2.

Reference design values shall be multiplied by all applicable factors as shown in Table 9.4.2.3-3 to determine the adjusted stresses and the effective modulus of elasticity of wood members.

C9.4.2.3

Reference design values listed in Tables 9.4.2.3-1 and 9.4.2.3-2 are provided for some common species and grades of lumber for posts. For other species or grades not listed in these tables, the NDS values should be used.

Round or square cross-sections are not susceptible to lateral torsional buckling. However, lateral torsional buckling should be considered in the case of rectangular sections bent about their major axis. A beam stability factor is provided by the NDS to modify the adjusted stresses in cases of bending of rectangular members. The modification of the adjusted bending stress for rectangular sign posts may be neglected when the post depth does not exceed the post thickness by more than 2 in.

Cantilever members such as those covered by this Section (i.e., posts and poles) are usually subjected to small axial compressive loads. Therefore, a reduction in the compressive stress to account for the slenderness of the member is not considered herein. Slenderness should be considered for members subjected to appreciable axial compressive loads. As conservative criteria, slenderness effects should be considered when f_c/F_c is greater than 0.1. A column stability factor is provided by the NDS to modify the adjusted compressive stresses for the effects of member slenderness.

Table 9.4.2.3-1—Reference Design Values for Visually Graded Lumber Posts for 4 × 4 in. through 4 × 6 in. (See note d for adjustments of reference design values.)

Species and Commercial Grade	Bending F_b ksi	Tension Parallel to Grain, F_t ksi	Shear Parallel to Grain, F_v ksi	Compression Perpendicular to Grain, F_{cp} Ksi	Compression Parallel to Grain, F_c ksi	Modulus of Elasticity, E ksi $\times 10^3$	Grading Rules Agency
Douglas Fir-Larch							WCLIB WWPA
Select Structural	1.500	1.000	0.180	0.625	1.700	1.900	
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	
Hem Fir							WCLIB WWPA
Select Structural	1.400	0.925	0.150	0.405	1.500	1.600	
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	
Southern Pine 4 × 4 in.							SPIB
Select Structural	2.850	1.600	0.175	0.565	2.100	1.800	
No. 1	1.850	1.050	0.175	0.565	1.850	1.700	
No. 2	1.500	0.825	0.175	0.565	1.650	1.600	
Southern Pine 4 × 5 or 6 in.							SPIB
Select Structural	2.550	1.400	0.175	0.565	2.000	1.800	
No. 1	1.650	0.900	0.175	0.565	1.750	1.700	
No. 2	1.250	0.725	0.175	0.565	1.600	1.600	
Spruce-Pine-Fir (South)							NELMA NSLB WCLIB WWPA
Select Structural	1.300	0.575	0.135	0.335	1.200	1.300	
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	
Western Cedar							WCLIB WWPA
Select Structural	1.000	0.600	0.155	0.425	1.000	1.100	
No. 1	0.725	0.425	0.155	0.425	0.825	1.000	
No. 2	0.700	0.425	0.155	0.425	0.650	1.000	

Notes:

a. Reference design values for other grades or species of posts are given in the NDS.

b. Reference design values are based on dry service conditions (i.e., moisture content less than or equal to 19 percent). For wet service conditions (i.e., moisture content greater than 19 percent), provisions of Article 9.4.4.2.1 shall be considered.

c. Values for modulus of elasticity are average values that conform to ASTM D245 and ASTM D1990. Adjustments in modulus of elasticity have been taken to reflect appropriate increases for seasoning; increases for density where applicable; and, where required, reductions have been made to account for the effect of grade on stiffness.

d. For all species other than southern pine, the tabulated bending, tension, and compression parallel to grain reference design values shall be multiplied by the following size-adjustment factors to determine the actual reference design values (size adjustment factors have already been incorporated in the tabulated values for southern pine):

Size-Adjustment Factors

Post Size	F_b	F_t	F_c
4 × 4 in.	1.5	1.5	1.15
4 × 5 in.	1.4	1.4	1.1
4 × 6 in.	1.3	1.3	1.1

Table 9.4.2.3-2—Reference Design Values for Visually Graded Lumber Posts 5 × 5 in. and Larger

Species and Commercial Grade	Bending F_b ksi	Tension Parallel to Grain, F_t ksi	Shear Parallel to Grain, F_v ksi	Compression Perpendicular to Grain, F_{cp} ksi	Compression Parallel to Grain, F_c ksi	Modulus of Elasticity, E ksi × 10^3	Grading Rules Agency
Douglas Fir-Larch							WCLIB
Select Structural	1.500	1.000	0.170	0.625	1.150	1.600	
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	
Douglas Fir-Larch							WWPA
Select Structural	1.500	1.000	0.170	0.625	1.150	1.600	
No. 1	1.200	0.825	0.170	0.625	1.000	1.600	
No. 2	0.700	0.475	0.170	0.625	0.700	1.300	
Hem Fir							WCLIB
Select Structural	1.200	0.800	0.140	0.405	0.950	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	
Hem Fir							WWPA
Select Structural	1.200	0.800	0.140	0.405	0.950	1.300	
No. 1	0.950	0.650	0.140	0.405	0.800	1.300	
No. 2	0.525	0.350	0.140	0.405	0.575	1.100	
Southern Pine							SPIB
Select Structural	1.500	1.000	0.165	0.425	0.950	1.500	
No. 1	1.350	0.900	0.165	0.425	0.825	1.500	
No. 2	0.850	0.550	0.165	0.425	0.525	1.200	
Spruce-Pine-Fir (South)							NELMA
Select Structural	1.000	0.475	0.125	0.335	0.700	1.200	NSLB
No. 1	0.800	0.550	0.125	0.335	0.625	1.200	WWPA
No. 2	0.475	0.325	0.125	0.335	0.425	1.000	
Western Cedar							WCLIB
Select Structural	1.100	0.725	0.140	0.425	0.925	1.000	
No. 1	0.875	0.600	0.140	0.425	0.800	1.000	
No. 2	0.550	0.350	0.140	0.425	0.550	0.800	
Western Cedar							WWPA
Select Structural	1.100	0.725	0.140	0.425	0.925	1.000	
No. 1	0.875	0.600	0.140	0.425	0.800	1.000	
No. 2	0.500	0.350	0.140	0.425	0.550	0.800	

Notes:

a. Reference design values for other grades or species of posts are given in the NDS.

b. Reference design values are based on dry service conditions (i.e., moisture content less than or equal to 19 percent), except for Southern Pine. For wet service conditions (i.e., moisture content greater than 19 percent), provisions of Article 9.4.4.2.1 shall be considered. Reference design values for Southern Pine are based on wet service conditions, and they may be used for dry service conditions.

c. Values for modulus of elasticity are average values that conform to ASTM D245 and ASTM D1990. Adjustments in modulus of elasticity have been taken to reflect appropriate increases for seasoning; increases for density where applicable; and, where required, reductions have been made to account for the effect of grade on stiffness.

Table 9.4.2.3-3—Adjusted Stresses and Effective Modulus of Elasticity for Posts

Adjusted bending stress	$F'_b = \phi\,\lambda\,K_F\,C_M F_b$
Adjusted tension stress (parallel to grain)	$F'_t = \phi\,\lambda\,K_F\,C_M F_t$
Adjusted compression stress (perpendicular to grain)	$F'_{cp} = \phi\,\lambda\,K_F\,C_M F_{cp}$
Adjusted compression stress (parallel to grain)	$F'_c = \phi\,\lambda\,K_F\,C_M F_c$
Adjusted shear stress (parallel to grain)	$F'_v = \phi\,\lambda\,K_F\,C_M F_v$
Effective modulus of elasticity	$E' = C_M E$

Notes:

a. C_M is the wet service factor defined in Article 9.4.4.2.1 for posts.

c. The F_b, F_t, and F_c values for posts shall include applicable adjustments from the size-adjustment factors given in Table 9.4.2.3-1.

d. λ is the time effect factor.

e. ϕ is the resistance factor.

9.4.3—Poles

9.4.3.1—General

In calculating stresses for posts, the net section of the member shall be used. The net section shall be determined by deducting from the gross section the projected area of all material removed by boring, grooving, dapping, notching, or other means.

9.4.3.2—Dimensions

Design dimensions of poles shall conform to applicable provisions of ASTM D3200.

For the calculations of compression stresses and buckling loads of tapered compression members with rectangular cross-section, the representative dimension, d, for each face of the member shall be determined as:

$$d = d_t + (d_b - d_t)\left[a - 0.15\left(1 - \frac{d_t}{d_b}\right)\right] \qquad (9.4.3.2\text{-}1)$$

For the design of tapered members with round cross-section, the representative diameter, D, shall be derived using Eq. 9.4.3.2-1 by replacing d_b by D_b, and d_t by D_t.

Calculations of the computed compression stress parallel to grain, f_c, shall be based on the representative dimensions of d, for rectangular members, or the representative diameter, D, for round members.

C9.4.3.2

Poles are grouped by class according to their required minimum circumference at 6 ft. from the butt of the pole. Tables C9.4.3.2-1 and C9.4.3.2-2 provide typical dimensions for wood poles. For other species not presented in the tables, reference should be made to ASTM D3200.

Poles of a given class and length have approximately the same load-carrying capacity regardless of species. Therefore, poles can be specified by class number and length without reference to species.

Eq. 9.4.3.2-1 provides the cross-section dimensions of wood members at the critical section for compression. The support condition parameter a in Eq. 9.4.3.2-1 accounts for the particular support conditions at the ends of the tapered member. The value a = 0.70 is valid only for tapered cantilever posts and poles.

The values of d_b and D_b are at the groundline section of the member. The taper of a pole may be approximated from the tabulated values for minimum circumference at top of pole and at 6 ft from the butt.