PART XI: WOOD SCREWS

11.1-GENERAL

11.1.1-Quality of Wood Screws

In the 1986 and earlier editions, wood screws were not required to meet particular dimensional and thread type standards to qualify for the design values given in the Specification. The general performance requirement in these editions was that the wood screws be of sufficient strength to cause failure in the wood rather than the metal.

The 1991 edition requires wood screws to conform to the dimensional data of ANSI/ASME Standard B18.6.1-1981 in order to qualify for tabulated design values and related design provisions. Standard B18.6.1, which covers both cut and rolled thread screw types, does not specify minimum metal strength properties. However, bending yield strength of the screw is a required input to the lateral design value yield mode equations of 11.3.1. Additionally, the actual tensile stress in the screw at the root diameter is required to be checked when designing the connection for withdrawal loads (see 11.2.3 of the Specification).

Tabulated lateral design values for wood screws in Tables 11.3A and 11.3B apply to screws with specified strength properties. Irrespective of whether the lateral design values in these tables are used or lateral design values are developed directly from the yield mode equations of 11.3.1, it is the designer's responsibility to specify the metal strength properties of the wood screws that are to be employed for the job.

11.1.2-Fabrication and Assembly

11.1.2.1 Prior to the 1962 edition, lead hole requirements for wood screws were 90 percent of the screw root diameter for hardwoods and 70 percent of the root diameter for softwood species. These provisions were based on early research involving flat head wood screws up to 24 gage and 5 inches in length in seven species, including southern pine, cypress and oak (55). In the 1962 edition, the lead hole requirements were referenced to new fastener species groups established on the basis of specific gravity. The 90 percent of root diameter requirement was applied to Group I species, those with a specific gravity greater than 0.60; and the 70 percent of root diameter requirement was applied to species of lower specific gravity in Groups II, III and IV.

In the 1982 edition, the provision allowing the insertion of wood screws in Group III and IV species without a lead hole when the screw was subject to withdrawal loads only was introduced. The specific gravity of species in these groups was less than 0.51. This provision for use of screws without a lead hole paralleled that made for 3/8 inch and smaller diameter lag screws in the same edition and was supported by both research results and field experience (see Commentary for 9.1.2.2).

The lead hole provisions for screws in withdrawal in the 1991 edition continue the requirements of the 1982 and earlier editions except that the species group designations have been replaced by specific gravity ranges.

11.1.2.2 In the 1960 and earlier editions, wood screws resisting lateral loads were required to have shank and threaded portion lead holes in hardwoods equal to the shank and thread root diameters, respectively; and in softwood species equal to seven-eighths the shank and thread root diameters, respectively. These provisions were based on early lateral load tests of wood screws (57,62,98). The hardwoods and softwoods designations were replaced in the 1962 edition with species Group I and Groups II, III and IV, respectively, based on specific gravity. Species classified in Group I were those with specific gravities greater than 0.60 while those with lower specific gravities were classified in the higher numbered groups.

In the 1991 edition, lateral design values for wood screws are no longer tabulated in terms of species groups but are given for each individual species combination. Thus the lead hole requirements for screws resisting lateral loads that were given in previous editions are applied in terms of whether the specific gravity of the species is greater than 0.60 or equal to or less than 0.60. It is to be noted that lead holes are required for all wood screws subject to lateral loads regardless of wood specific gravity.

11.1.2.3 Insertion of wood screws by turning rather than driving has been a requirement since the 1944 edition. All tests on which wood screw provisions in the Specification are based involved joints made with this method of assembly (55,62,98).

11.1.2.4 Use of lubrication to facilitate screw insertion and avoid screw damage, a recommendation since the 1944 edition, has been made mandatory in the

1991 edition. Early tests show the lubricant has no significant effect on design values (55,57,98).

11.2-WITHDRAWAL DESIGN VALUES

11.2.1-Withdrawal from Side Grain

Background

Withdrawal design values for wood screws are based on the equation

$$W = K_W G^2 D \qquad \text{(C11.2-1)}$$

where:

W = nominal withdrawal design value per inch of screw length or per inch of penetration of the threaded portion, lbs

K_W = constant based on ultimate load tests and screw length basis

G = specific gravity, oven dry weight and volume

D = shank diameter of the screw, in.

This equation was based on early extensive testing with cut thread wood screws and seven wood species (55). In the 1960 and earlier editions, the equation was published in the Specification in lieu of tabulated withdrawal design values. In the 1944 edition, a value of 2040 was used for the constant K_W. This value gave a withdrawal design value per inch of total screw length assuming the depth of penetration into the piece receiving the point was at least two-thirds the length of the screw; and a withdrawal design value which was approximately one-fifth the ultimate load determined from screw withdrawal tests (55). The one-fifth factor represented an originally recommended one-sixth factor on ultimate load (57) increased by twenty percent as part of the World War II emergency adjustment in design values. Following the war, this 1.2 factor was codified as 10 percent for the change from permanent to normal loading and 10 percent for experience (see Commentary for 2.3.2).

In the 1950 edition, the basis for W was changed from design value per inch of total screw length to design value per inch of penetration of the threaded part of the screw. The value of the constant K_W was changed to adjust the equation for this new index point (57,62). The equation became

$$W = 2850\, G^2 D \qquad \text{(C11.2-2)}$$

where:

W = nominal withdrawal design value per inch of penetration of the threaded portion of the screw in the piece receiving the point, lbs

A table of allowable screw withdrawal design values based on Equation C11.2-2 also was introduced in the 1950 edition.

In the 1960 edition, the table of screw gages and lengths, which had been part of the Specification since the 1944 edition, was dropped. In the 1962 edition, Equation C11.2-2 also was dropped from the Specification in favor of the tabulated withdrawal design values alone.

1991 Edition

The wood screw withdrawal design values in Table 11.2A of the 1991 edition are based on Equation C11.2-2 and remain unchanged from those given in earlier editions. The specific application of the tabulated withdrawal design values to rolled thread wood screws as well as cut thread screws is a new provision. Previous editions did not specify thread type, although the early research on which wood screw withdrawal design values are based was conducted on cut thread screws.

The shank or body diameter of a cut thread screw is the same as the outside diameter of the thread. The shank or body diameter of the rolled thread screw is the same as the root diameter. For the same gage and nominal diameter of screw, both screw thread types have the same threads per inch, the same outside diameter of thread and the same thread depth. If the tensile strength of the screw is adequate and the lead hole provisions based on root diameter are employed, the withdrawal resistance of rolled thread screws is considered equivalent to that of cut thread screws. This is supported by comparative tests of one type of tapping screw and cut thread wood screws. Although, the thread depth of tapping and rolled thread screws are not the same, both types have outside thread diameters that are larger than their body diameters. The comparative tests showed that, for comparable diameters and penetrations of the threaded portion of the screws, the withdrawal design values of the tapping screw were slightly higher than those of the cut thread fastener (65,204).

Screw length as well as screw gage or nominal diameter must be specified. The ANSI/ASME B18.6.1 standard requires thread length to be equivalent to at least two-thirds of the nominal screw length. The screw diameters associated with the screw gages given in Table 11.2A are shown in Tables 11.3A and 11.3B.

Table 11.2A is entered with the specific gravity of the lumber species combination receiving the threaded portion of the screw. Specific gravity values are given for current commercial lumber species combinations in Table 11A. Species specific gravity values tabulated in the Specification have changed in various editions as a result of new property information, changes in the commercial importance of some species, and the introduction of new species groupings. Specific gravity values tabulated in the 1991 edition reflect a number of such changes from values given in previous editions.

11.2.2-Withdrawal from End Grain

Early tests of wood screws in withdrawal from end grain surfaces of oak, southern pine, maple and cypress gave somewhat erratic results relative to those for withdrawal from side grain (55). These irregular results were attributed to the tendency of the screw to split the wood in the end grain configuration. Average ratios of end grain withdrawal resistance to side grain withdrawal resistance ranged from 52 to 108 percent (55). Because of this variability, structural loading of wood screws in withdrawal from end grain has been prohibited since the 1944 edition. Where splitting is avoided, use of an end grain to side grain withdrawal design value ratio of 75 percent has been suggested (57,66).

11.2.3-Tensile Strength of Wood Screw

(See Commentary for 11.1.1)

11.3-LATERAL DESIGN VALUES

11.3.1-Wood-to-Wood Connections

Background

From the 1944 through the 1986 editions, lateral design values for wood screws loaded at any angle to grain were based on the equation

$$Z = K_L D^2 \qquad \text{(C11.3-1)}$$

where:

Z = nominal wood screw lateral design value, lbs
K_L = species group constant based on specific gravity (G) of wood members
= 4800 Group I G = 0.62 - 0.75
= 3960 Group II G = 0.51 - 0.55
= 3240 Group III G = 0.42 - 0.49
= 2520 Group IV G = 0.31 - 0.41
D = shank diameter, in.

The equation was based on early lateral load tests of wood screws in southern pine, cypress and oak in which the depth of penetration of the screw into the piece receiving the block was at least 7 times the shank diameter (57,98). The values shown for the constant K_L provided lateral design values which were about 75 percent of those associated with test proportional limit values. The K_L values included the originally recommended adjustment of 1.6 (57) increased 20 percent as part of the World War II emergency increase in wood design values. The latter adjustment was subsequently codified as a 10 percent adjustment for the change from permanent to normal loading and 10 percent for experience (see Commentary for 2.3.2). Lateral design values of 75 percent of proportional limit values are about one-fifth maximum test loads (57).

Beginning with the 1950 edition, tabulated wood screw lateral design values based on Equation C11.3-1 were included in the Specification. Presentation of the equations for each group was subsequently discontinued beginning with the 1962 edition. In the 1960 and earlier editions, a wood screw fastener group between Groups II and III was provided in the Specification. This group for intermediate density hardwood species also was dropped beginning with the 1962 edition.

Prior to 1971, grain type and other features than specific gravity were considered in classifying certain lower density softwood species into K_L factor groups. This was evidenced by some species having the same specific gravities as those in Group III being classified in Group IV (57,62). Beginning with the 1971 edition, specific gravity was used as the sole criterion for assignment of species for wood screw lateral design value constants. The specific gravity class limits for K_L values shown in the legend for Equation C11.3-1 were used to classify species from 1971 through the 1986 edition.

1991 Edition

Similar to the treatment of bolts and lag screws, lateral design values for wood screws in the 1991 edition are based on application of the yield limit model (see Commentary for 7.2.1 and 8.2.1). The same general equations used to describe different modes of yielding of lag screws are also used with wood screws (see Commentary for 9.3.1). Three modes of yielding are provided for: bearing in the side member or cleat (Mode I_s), development of a plastic hinge in the screw in the main member (Mode III_s), and development of plastic hinges in both main and side members (Mode IV).

The term K_D in the denominator of the yield mode equations of 11.3.1 relates yield mode equation design values based on a 5 percent diameter offset dowel bearing strength to the general level of proportional limit based lateral design values previously given in the Specification. For small diameter dowel type fasteners (wood screws and nails), this conversion factor was set at 2.2 when the fastener penetration in the member receiving the point is sufficient to develop the full lateral load capacity of the joint.

In the 1986 and earlier editions of the Specification, lateral design values for small diameter lag screws were lower than those for wood screws of comparable diameter. This difference was a result of the different methodologies used to establish lateral design values for the two fastener types, primarily the reduction factor applied to proportional limit test values. In the 1991 edition, this difference in lateral design values between small diameter lag screws loaded parallel to grain and wood screws of similar diameter has been minimized by using a conversion factor, K_D, of 3.0 for the largest diameter wood screws. This value relates to the 2.8, 4.0 and 3.0 conversion factors associated with the Mode I_s, III_s and IV yield mode equations, respectively, for lag screws loaded parallel to grain (see Commentary for 9.3.1 - Yield Mode Equations). To provide for a gradual transition of K_D values between small and large diameter wood screws, a variable value of K_D is used for intermediate diameter screws as shown below.

Unthreaded shank diameter, inches = D
Diameter coefficient for wood screws = K_D

$$D \le 0.17 \qquad K_D = 2.2$$
$$0.17 < D < 0.25 \qquad K_D = 10(D) + 0.5$$
$$D \ge 0.25 \qquad K_D = 3.0$$

No adjustment of wood screw yield mode equation design values are made for varying angles of load to grain. This is a continuation of procedures in previous editions of the Specification which assigned the same wood screw lateral design values to both parallel and perpendicular to grain loading conditions.

The lowest value of Z obtained from the three yield mode equations of 11.3.1 is selected as the nominal lateral design value for the connector. The equations are entered with unthreaded screw shank diameter, side member thickness and dowel bearing strengths, F_{es} and F_{em}, for the species of wood being used for the side or main member. Such dowel bearing strength values are given in Table 11A and are based on the equation

$$F_e = (16{,}600)\, G^{1.84} \qquad \text{(C11.3-2)}$$

where:

G = specific gravity based on oven dry weight and volume

The research on which Equation C11.3-2 is based involved nail bearing tests on five species (203). Tests of three nail diameters (0.148 - 0.225 in.) with one species showed diameter to have no significant effect on small-diameter dowel bearing strength (203).

The bending yield strength value, F_{yb}, for the wood screw being used also is an input to the yield mode equations. For screws having a diameter equal to or larger than 3/8 inch, F_{yb} may be taken as 45,000 psi (see Appendix I). Bending tests of nails of various diameters show bending yield strength tends to increase as diameter decreases (106). Wood screw bending yield strength values based on the relationships found in this nail research have been used to develop wood screw lateral design values tabulated in the Specification for screws less than 3/8 inch diameter (see Appendix I).

Tabulated Wood-to-Wood Lateral Design Values. Lateral design values given in Table 11.3A apply to single shear connections made only with cut thread wood screws having the unthreaded shank diameters tabulated. The table provides lateral design values for screw gages from 6 to 24 and for major individual species combinations. In earlier editions, lateral design values were tabulated in terms of four fastener groups based on specific gravity classes.

Tabulated lateral design values apply to connections made with side member and main member of the same species. Where different species are used, tabulated lateral design values for the species with the lowest specific gravity may be applied or lateral design values may be determined from the yield mode equation directly. For connections involving species not listed in the table, lateral design values given for a species of lower specific gravity may be used.

Lateral design values in Table 11.3A apply to screws having the bending yield strengths, F_{yb}, given in footnote 2 of the table. For screw gages 6 to 20, the strengths shown are based on Equation C12.3-2 (see Commentary for 12.3.1) developed from the tests of common nails. For screws, this equation is entered with the unthreaded shank diameter as D.

Comparison of 1991 and Earlier Edition Lateral Design Values. The lateral design values in the 1991 edition are based on side member thickness, screw shank diameter, dowel bearing strengths of the side and main members, and the bending yield strength of the wood screw. Lateral design values in earlier editions were based on screw shank diameter and fastener group or specific gravity class. Both the 1991 and earlier editions assume wood screw penetration into the main member of at least 7 times the shank diameter. The effect of these different bases and the conversion factors, K_D, used to relate yield mode lateral design values to the level of previous tabulated lateral design values are shown by the comparisons of 1991 and 1986 lateral design values in Table C11.3-1.

Table C11.3-1 - Comparison of 1991 and 1986 NDS Wood-to-Wood Wood Screw Lateral Design Values

Side Member Thickness, in.	Wood Screw Gage	Wood Screw Diameter, in.	Wood Screw Lateral Design Value, lbs 1991	1986	Ratio
Southern pine:					
1/2	8*g*	0.164	108	106	1.02
	12*g*	0.216	138	185	0.75
	18*g*	0.294	190	342	0.56
	24*g*	0.372	-	548	-
3/4	8*g*	0.164	132	106	1.25
	12*g*	0.216	159	185	0.86
	18*g*	0.294	210	342	0.61
	24*g*	0.372	283	548	0.52
1-1/2	8*g*	0.164	148	106	1.40
	12*g*	0.216	200	185	1.08
	18*g*	0.294	284	342	0.83
	24*g*	0.372	394	548	0.72
Spruce-Pine-Fir:					
1/2	8*g*	0.164	79	87	0.91
	12*g*	0.216	103	151	0.68
	18*g*	0.294	145	280	0.52
	24*g*	0.372	-	448	-
3/4	8*g*	0.164	90	87	1.03
	12*g*	0.216	112	151	0.74
	18*g*	0.294	152	280	0.54
	24*g*	0.372	207	448	0.46
1-1/2	8*g*	0.164	115	87	1.32
	12*g*	0.216	155	151	1.03
	18*g*	0.294	204	280	0.73
	24*g*	0.372	268	448	0.60

The lower 1991/1986 lateral design value ratios for the larger gage wood screws relative to the lateral design value ratios for the 8*g* screw reflect the use of larger K_D factors in the yield mode equations for the larger gages in order to bring wood screw lateral design values in line with lateral design values for lag screws of similar diameter. The differences between the 1991/1986 lateral design value ratio for the joint with 8*g* screw and 1/2 inch side members and that with 8*g* screw and 1-1/2 inch side members (1.02 vs. 1.40 and 0.91 vs. 1.32 for southern pine and spruce-pine-fir respectively) indicates the significant effect of side member thickness. The generally higher lateral design value ratios for southern pine compared to spruce-pine-fir is due to the fact southern pine was at the upper limit of its 1986 fastener group (specific gravity) class whereas spruce-pine-fir was near the lower limit of its class. In the 1991 edition, use of the specific gravity value for each species combination to establish dowel bearing strength values ties wood screw lateral design values for each combination more closely to its own properties.

11.3.2-Wood-to-Metal Connections

11.3.2.1 In the 1986 and earlier editions of the Specification, design values for wood screws in lateral resistance were increased 25 percent when metal side plates were used (57). This adjustment was similar to that used for bolted joints with metal side plates prior to 1982 (see Commentary for 8.2.2).

Under the provisions of the 1991 edition, wood screw lateral design values for joints made with metal side members are determined from the Mode III_s and Mode IV equations of 11.3.1. The Mode I_s equation is not used as bearing in the metal side members is considered separately in the design of metal parts (see 11.3.2.2). The yield mode equations are entered with the dowel bearing strength of the metal as F_{es} and the thickness of the metal as the side member thickness. Earlier editions did not account for the effect of the metal gage used.

Table 11.3B gives lateral design values for cut thread wood screw joints made with steel side members from 0.048 inches (18 gage) to 0.239 inches (3 gage) thick. A dowel bearing strength of 45,000 psi, applicable to ASTM A446 Grade A galvanized steel, was assumed for all thicknesses. The same wood screw bending yield strengths, F_{yb}, used to develop the wood-to-wood joint lateral design values in Table 11.3A were used to develop the Table 11.3B lateral design values.

Comparison of 1991 and Earlier Edition Lateral Design Values. Differences in 1991 and earlier edition wood screw lateral design values are illustrated in Table C11.3-2. Lateral design values shown for both editions are based on a penetration of the threaded portion of the screw in the main member of seven times the shank diameter. The 1986 lateral design values are applicable to any metal side plate thickness that permits this screw penetration requirement to be met.

Table C11.3-2 - Comparison of 1991 and 1986 NDS Wood-to-Metal Wood Screw Lateral Design Values

Steel Side Member Thickness, in.	Wood Screw Gage	Wood Screw Diameter, in.	Wood Screw Lateral Design Value, lbs		
			1991	1986	Ratio
Southern pine:					
0.075	8g	0.164	132	132	1.00
(14g)	12g	0.216	176	231	0.76
	18g	0.294	249	428	0.58
0.134	8g	0.164	147	132	1.11
(10g)	12g	0.216	188	231	0.81
	18g	0.294	260	428	0.61
	24g	0.372	356	685	0.52
0.075	8g	0.164	106	109	0.97
(14g)	12g	0.216	141	189	0.75
	18g	0.294	199	350	0.57
0.134	8g	0.164	119	109	1.09
(10g)	12g	0.216	152	189	0.80
	18g	0.294	209	350	0.60
	24g	0.372	286	560	0.51

The lower lateral design value ratios in Table C11.3-2 for the larger screw gages are a result of the procedures introduced in the 1991 edition to bring lateral design values for the larger wood screws into line with those for lag screws of comparable diameter (see Commentary for 11.3.1 - Comparison). The comparisons made show that, for equivalent screw sizes, an approximate 80 percent increase in steel side member thickness is associated with an increased lateral design value of 11 percent or less.

11.3.2.2 (See Commentary for 7.2.3)

11.3.3-Penetration Depth Factor, C_d

Use of reduced lateral design values for penetrations of the threaded portion of the screw in the main member of less than 7 times the shank diameter (D) has been a provision of the Specification since the 1944 edition. The minimum penetration requirement of $4D$ and the use of the ratio of actual penetration to that required for full lateral design value ($p/7D$) as the factor for adjusting lateral design values for penetration are based on early wood screw research (57,98).

11.3.4-End Grain Factor, C_{eg}

Use of two-thirds the lateral design value for wood screws inserted in side grain as the design value for wood screws inserted in the end grain of the main member has been a provision of the Specification since the 1944 edition. This is the same end grain factor as that used for lag screws.

11.3.5-Combined Lateral and Withdrawal Loads

Earlier editions of the Specification assumed the capacity of wood screws subject to withdrawal and lateral loads at the same time was the same as the capacity of the screw under each load acting separately. In the 1991 edition, the interaction equation introduced for combined withdrawal and lateral loading on lag screws (see Commentary for 9.3.5) has been applied to wood screws. Although available lag screw test data indicate withdrawal and lateral load components interact only at total load angles less than 45° and only with larger diameter screws (115), the lag screw interaction equation has been applied to wood screws for purposes of uniformity and conservatism. The equation, which is of similar form to the bearing angle to grain equation (see Appendix J), is

$$Z'_\alpha = \frac{Z'\,(W'\,p)}{Z'\,cos^2\alpha + (W'\,p)\,sin^2\alpha} \qquad \text{(C11.3-3)}$$

where:

Z'_α = allowable design value for wood screw loaded at angle to the surface of main member

Z' = lateral design value for wood screw joint

W' = withdrawal design value for wood screw joint per inch of thread penetration in main member

p = length of thread penetration of the wood screw in the main member

α = angle between wood surface and direction of applied load

Equation C11.3-3 can also be used to determine the allowable design value of wood screws embedded at an angle to grain in the wood member and loaded in a direction normal to the wood member. For this condition α would be defined as the angle between the wood surface and the lag screw as shown in Figure C11.3-1.

11.4-PLACEMENT OF WOOD SCREWS

11.4.1-Edge Distance, End Distance, Spacing

The absence of splitting has been used as a performance criterion to determine the adequacy of end and edge distances and spacing for wood screws since the 1944 edition.

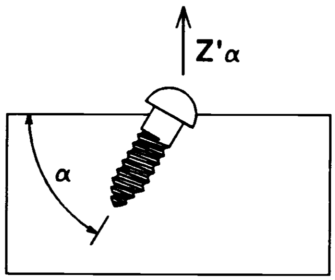

Figure C11.3-1 Combined Lateral and Withdrawal Load for Wood Screw Inserted at Angle to Wood Surface

In lieu of specific code requirements for end and edge distance for wood screws, Table C11.4-1 may be used to establish wood screw patterns. Designers should note that specie type, moisture content and grain orientation will affect spacing (pitch) between fasteners in a row.

11.4.2-Multiple Wood Screws

Lateral design values for wood screws are not subject to the group action factor, C_g, for fasteners aligned in the direction of load (see 7.3.6). The design value for a connection involving more than one wood screw is the sum of the design values for each individual wood screw when all wood screws in the connection are of the same type, diameter and length, join the same members and resist load in the same shear plane.

Table C11.4-1 Wood Screw Minimum Spacing Tables

	Wood Side Members	
	Not Prebored	Prebored
Edge distance	2.5*d*	2.5*d*
End distance		
- tension load parallel to grain	15*d*	10*d*
- compression load parallel to grain	10*d*	5*d*
Spacing (pitch) between fasteners in a row		
- parallel to grain	15*d*	10*d*
- perpendicular to grain	10*d*	5*d*
Spacing (gage) between rows of fasteners		
- in-line	5*d*	3*d*
- staggered	2.5*d*	2.5*d*

	Steel Side Members	
	Not Prebored	Prebored
Edge distance	2.5*d*	2.5*d*
End distance		
- tension load parallel to grain	10*d*	5*d*
- compression load parallel to grain	5*d*	3*d*
Spacing (pitch) between fasteners in a row		
- parallel to grain	10*d*	5*d*
- perpendicular to grain	5*d*	2.5*d*
Spacing (gage) between rows of fasteners		
- in line	3*d*	2.5*d*
- staggered	2.5*d*	2.5*d*