PART IX: LAG SCREWS

9.1-GENERAL

9.1.1-Quality of Lag Screws

Methodology given in the Specification for the establishment of design values for lag screws prior to the 1957 edition was referenced to lag screws having a yield strength of 45,000 psi and a tensile strength of 77,000 psi. Where lag screws having other strength properties were used, withdrawal design values and lateral design values were to be adjusted in proportion to the ratio of tensile strength and in proportion to the ratio of the square root of the yield strength, respectively. In the 1957 edition these adjustment provisions, based on early lag screw research (134), were continued but the reference to specific strength metals was replaced with reference to common lag screws.

A new provision was added in the 1977 edition indexing lag screw design provisions and design values to metal conforming to ASTM Standard A307 (see Commentary for 8.1.1). In addition, a requirement was added that the tensile strength of the lag screw at root section was not to be exceeded in withdrawal loads. Use of the ratio of the square roots of the yield strengths to adjust tabulated lateral design values for use of metal of other properties was continued. These 1977 provisions were continued through the 1986 edition.

The 1991 edition references ANSI/ASME Standard B18.2.1-1981 as the quality basis for lag screws in place of ASTM A307. The latter standard is applicable only to bolts and studs and now is specific to steel having a strength of 60,000 psi. Standard B18.2.1 provides standard lag screw dimensions (see Appendix L of the Specification) but does not specify metal of particular strength properties. In the 1991 edition, the designer is responsible for specifying the metal strength of the lag screws that are to be used. Bending yield strength of the lag screw is a required input variable to the lateral design value yield mode equations of 9.3.1. Additionally, the actual tensile stress in the lag screw at the root diameter must be checked when designing lag screw connections for withdrawal (see 9.2.3 of Specification).

9.1.2-Fabrication and Assembly

9.1.2.1 Provisions relating to the clearance hole of the shank and the lead hole size for the threaded portion of the lag screw have been part of the Specification since the 1944 edition. The lead hole requirements for the three specific gravity classes are based on early lag screw research involving tests of Douglas-fir, southern pine, white oak, redwood and northern white pine (134).

9.1.2.2 The provision for allowing 3/8 inch and smaller diameter lag screws loaded primarily in withdrawal to be inserted in wood of medium to low specific gravity was added to the Specification in the 1982 edition. Consideration of this limited exception to the lead hole requirement was initiated by field inquiries concerning the acceptability of using power driven tools to insert small lag screws to join members in factory built housing construction. On the basis of early lag screw research (134), available information on the withdrawal resistance of tapping screws inserted with different size lead holes (204), and field experience, use of small lag screws without lead holes was judged acceptable when the following conditions were met: the screws were being designed primarily for withdrawal loading, woods classified in fastener Groups III and IV for specific gravity (G) were the foundation members, and placement of screws was such that excessive splitting was avoided. The maximum specific gravity value for those species classified in fastener Groups III and IV in the 1982 and 1986 editions was 0.49.

The exception and related qualifying conditions to the lead hole requirement for 3/8 inch and smaller diameter lag screws introduced in 1982 have been continued in the 1991 edition except that the maximum specific gravity limitation is now expressed in terms of a specific gravity value (0.50) rather than in terms of eligible fastener species groups. The latter are no longer being used in the 1991 edition.

A lag screw subjected to both combined withdrawal and lateral loading may be considered loaded primarily in withdrawal when the axis of the screw is at angle of 75° or more to the grain of the wood member holding the threaded portion of the screw. The requirement that unusual splitting be avoided when lead holes are not used is to be considered a performance requirement that (i) is related to the ability of the screw to hold the cleat or side member to the main or foundation member, and (ii) is applicable to both members being joined.

9.1.2.3 The provision that lag screws be inserted by turning with a wrench and not by driving with a hammer has been a good practice requirement of the Specification since the 1944 edition.

9.1.2.4 Use of a lubricant to facilitate lag screw insertion also has been a good practice requirement since 1944. This requirement is not waived when small diameter screws are inserted without the use of lead holes.

9.2-WITHDRAWAL DESIGN VALUES

9.2.1-Withdrawal from Side Grain

The methodology used to establish the lag screw withdrawal design values given in Table 9.2A is the same as that incorporated in the 1944 edition of the Specification. Tabulated design values are computed from the following equation based on the results of early research (62,134):

$$W = K_W G^{3/2} D^{3/4} \quad \text{(C9.2-1)}$$

where:

W = withdrawal design value per inch of penetration into main member, lbs

K_W = 1800

G = specific gravity based on oven dry weight and volume

D = lag screw shank diameter, in.

The value of K_W represents one-fifth of the average constant at oven dry weight and volume obtained from ultimate load tests of joints made with five different species and seven sizes of lag screw (134), increased by 20 percent; or

$$K_W = (7500/5)1.2 = 1800 \quad \text{(C9.2-2)}$$

The twenty percent adjustment was introduced as part of the World War II emergency increase in wood design values, and then subsequently codified for lag screws as 10 percent for the change from permanent to normal loading and 10 percent for experience (see Commentary for 2.3.2).

The withdrawal design value equation above was included in the early editions of the Specification. Beginning with the 1960 edition, the equation was replaced by a table of lag screw withdrawal design values for the full range of species specific gravity values.

It is to be noted that when the total allowable withdrawal design value on a lag screw is determined by multiplying the tabulated design value by the length of penetration of the threaded portion into the side grain of the main member, the length of the tapered tip of the screw is not to be included. This tapered portion at the tip of the screw was not considered as part of the effective penetration depth in the original joint tests (134). In addition, the thickness of any washer used between the screw head and the cleat or side member should be taken into account when determining the length of penetration of the threaded portion in the main member. Standard lag screw dimensions, including thread length and length of tapered tip, are given in Appendix L of the Specification.

9.2.2-End Grain Factor, C_{eg}

Tabulated withdrawal design values for lag screws are reduced 25 percent when the screw is inserted in the end grain (radial-tangential plane) of the main member rather than the side grain (radial-longitudinal or tangential-longitudinal plane). This adjustment, based on lag screw joint tests (134), has been a provision of the Specification since the 1944 edition. Because of the greater possibility of splitting when subject to lateral load, it has long been recommended that insertion of lag screws in end grain surfaces be avoided (62,128).

9.2.3-Tensile Strength of Lag Screw

In the original lag screw joint tests (134), penetration of the threaded portion of the screw into the main member ranging from 7 diameters for the highest density wood and 11 diameters for the lowest density wood tested was found to develop lag screw strengths approximately equal to the tensile strength of the lag screw. However, because tabulated withdrawal design values represent only about 25 percent of average ultimate test loads, the allowable tensile strength of the screw associated with the root diameter will not generally limit the withdrawal design value. This will be the case even when tabulated design values are increased 1.6 for wind or earthquake load. (See also Commentary for 7.2.3 and 9.1.1.)

9.3-LATERAL DESIGN VALUES

9.3.1-Wood-to-Wood Connections

Background

Lag screws perform the same general function as bolts but do not require a nut on the joint face opposite the fastener head. The threaded portion of the screw replaces the nut in providing resistance to withdrawal. Lag screws typically range from 0.19 to 1-1/4 inch in diameter and lengths of less than 1 to more than 12 inches. The threaded portion of the screw is generally one-half the screw length plus 1/2 inch or 6 inches, whichever is shorter (see Appendix L).

Lag screw lateral design values provided in the 1986 and all earlier editions of the Specification were established using the same procedures. This methodology was developed from the results of early lag screw research (134) which showed that proportional limit design values in lag screw connections loaded parallel to grain were a function of the specific gravity of the members being joined, the shank diameter of the screw, the ratio of the cleat or side member thickness to the shank diameter, the location of the shank/thread boundary relative to the edge of the main or foundation member, and the depth of penetration of the screw in the main member. For perpendicular to grain loading, an additional adjustment was introduced for area of bearing as related to the diameter of the screw. This adjustment for grain direction was adapted from a similar relationship developed for bolted connections (62,117,183). The specific formulas used to establish lag screw values in previous editions are shown below:

Parallel to grain loading:

$$P_1 = K_L D^2 F_1 F_2 F_3 \qquad \text{(C9.3-1)}$$

where:

P_1 = design load, lbs

K_L = species constant based on specific gravity (G) of wood members

= 2640 Group I G 0.62 - 0.75

= 2280 Group II G 0.51 - 0.55

= 2040 Group III G 0.42 - 0.49

= 1800 Group IV G 0.31 - 0.41

D = shank diameter, in.

F_1 = adjustment for ratio of cleat thickness (t) to shank diameter (ranging from 0.62 at ratio of 2 to 1.00 at ratio of 3.5 to 1.22 at ratio of 6.5)

F_2 = adjustment for location of shank/thread boundary

$$SP = S - (t+w)$$

where:

S = length of shank

w = washer thickness

= 1/8 in. for $D \geq 1/2$ in.

= 0 in. for $D < 1/2$ in.

For $SP/D < 0$: $F_2 = 1.0 - 0.2(t+w-S)/t$

For $SP/D \geq 0$: F_2 function of SP/D (ranging from 1.08 for ratio of 1 to 1.17 for ratio of 2 to 1.26 for ratio of 3 to 1.39 for ratio of 7)

F_3 = adjustment for depth of penetration in main member

= $DP/RP \leq 1.0$

where:

DP = $T-E+SP$

T = length of thread

E = length of tapered tip

RP = $RSP\,F_1F_2$ when $F_1F_2 < 1.0$

= $RSP(F_1F_2)^{1/2}$ when $F_1F_2 \geq 1.0$

RSP = required standard penetration

= $7D$ for Group I

= $8D$ for Group II

= $10D$ for Group III

= $11D$ for Group IV

Perpendicular to grain load:

$$P_2 = P_1 F_4 \qquad \text{(C9.3-2)}$$

where:

P_2 = design load perpendicular to grain

P_1 = design load parallel to grain

F_4 = adjustment for shank diameter (ranging from 1.00 for 3/16 in. to 0.85 for 5/16 in. to 0.70 for 7/16 in. to 0.50 for 1 in.)

The complexity of the foregoing methodology reflects the number of variables that affect lag screw connection performance. The equations are based on parallel to grain tests of northern white pine, Douglas-fir, southern pine and white oak connections made with dry material (15 percent moisture content) and lag screws having an average tensile strength of 77,000 psi (134). The values of K_L in the equation for P_1 represent average proportional limit joint design values divided by 2.25 and then increased 20 percent for normal loading and experience (see Commentary for 9.2.1 related to the latter adjustment).

In the earlier editions, not all species were assigned to fastener groups based on their specific gravity alone. Some softwood species having the same specific gravities as species classified in Group III were classified in Group IV (62). These assignments paralleled early group assignments for wood screws and nails. Beginning with the 1971 edition, classification of species into fastener groups for the purpose of assignment of K_L factors was based solely on specific gravity. The specific gravity classes for K_L assignments shown in the legend of Equation C9.3-1 were used from the 1971 through the 1986 editions.

The foregoing procedures were included as part of the Specification until the 1960 edition when they were replaced with a table of design values for a range of lag screw sizes for each of the four lag screw groups. This change in presentation, which was made to facilitate design and use of lag screw connections, was continued through the 1986 edition. In accordance with recommendations based on the original research (134), tabulated design values in the 1960 through the 1986 editions were considered directly applicable to lag screws having a yield strength of 45,000 psi. For lag screws having other yield strengths, adjustment of tabulated values in proportion to the square root of the ratio of the yield strength of the metal to 45,000 was allowed.

1991 Edition. As with bolts and other dowel type fasteners, lateral design values for lag screw connections in the 1991 edition are based on application of the yield limit model (see Commentary for 7.2.1 and 8.2.1). In the case of lag screws, three general modes of yielding can occur: bearing in the side member or cleat (Mode I_s), development of a plastic hinge in the screw in the main member (Mode III) and development of plastic hinges in the screw in both main and side members (Mode IV). However, three possible conditions may exist within both Modes III and IV depending upon whether the maximum bending occurs in the shank or threaded portion of the screw or bending occurs at a location other than at the point of maximum moment (114,117).

Behavioral equations for each of the seven possible conditions were developed (114,117) and used to predict the joint design values of all configurations tested in the original research (134). Values of 5 percent diameter offset dowel bearing strength (F_e) required for these equations were estimated from the specific gravity values of the test material using equations approximately equivalent to those used for bolts (see Commentary for 8.2.1 - Yield Mode Equations). Yield mode design values for the test configurations were compared to those obtained from the original methodology (equations C9.3-1 and C9.3-2) to verify there was a reasonably stable relationship between the two for the range of joint configurations available (114).

Reexamination of the original lag screw research (134) showed that although the F_3 factor (the adjustment for length of lag screw in the main member) in the original lag screw equations was related to ultimate load or strength of the joint, the proportional limit load (approximately one-fourth the ultimate) was unaffected as long as the total length of penetration (shank as well as threaded depth) of the screw in the main member was at least five times the shank diameter, or $5D$ (114,117). In view of the fact that previous design values were keyed to proportional limit rather than ultimate joint loads, the position was taken that the yield mode equations would be implemented in the 1991 edition and compared with previously developed design values assuming that the full design value is developed if the length of the screw (shank plus threaded portion less length of tapered tip) in the main member is at least $8D$, regardless of species specific gravity; and that proportionate design values are achieved for penetrations between a minimum of $4D$ and $8D$. These criteria are in agreement with the penetration requirement in the 1988 draft standard of Eurocode No. 5 (45,114).

To establish adjustment factors which would reduce yield mode equation values to the design value levels used in previous editions of the Specification, the ratios of yield mode design value to design value based on previous methodology (modified by the new penetration criteria) were determined for a wide range of lag screw joint configurations made with both wood and steel side members. An average ratio was developed for each of the seven yield mode conditions, one for Mode I_s and three each for Modes III and IV. Rather than include three equations for each of the latter two modes in the Specification, it was assumed that Mode III consisted only of yielding of the threaded portion of the screw in the main member and that Mode IV consisted only of yielding of the shank portion of the screw in the side member and of the threaded portion of the screw in the main member (117). It was found that this simplification could be accomplished, while obtaining approximately the same overall average ratio of yield mode design value to previous design value as that resulting from use of three equations for each Mode, by assuming a constant ratio of yield moment of the threaded portion to yield moment of the shank of 0.75 (114,117). The yield moment ratio (R_m) for the screw appears in the selected behavioral equations for Modes III_s and IV (114,117) as shown below.

Mode I

$$P = D\, t_s\, F_{es} \qquad \text{(C9.3-3)}$$

Mode III_s

$$P = \frac{k D\, t_s\, F_{em}}{(2 + R_e)} \qquad \text{(C9.3-4)}$$

$$k = -1 + \sqrt{\frac{2(1+R_e)}{R_e} + \frac{2R_m F_{yb}(2+R_e)D^2}{3F_{em}t_s^2}}$$

Mode IV

$$P = D^2 \sqrt{\frac{F_{em}F_{yb}(1+R_m)}{3(1+R_e)}} \qquad \text{(C9.3-5)}$$

where:

R_e = F_{em}/F_{es}
t_s = thickness of side member
D = unthreaded shank diameter of lag screw
F_{em} = dowel bearing strength of main member
F_{es} = dowel bearing strength of side member
R_m = ratio of yield moment of threaded portion to yield moment of shank

Yield Mode Design Equations

Substituting 0.75 for R_m in the foregoing behavioral equations for Modes III_s and IV and adding the conversion factors relating yield mode design values to previously published design values gives the lag screw parallel to grain lateral design value (Z) equations given in 9.3.2 of the Specification. The factors $4K_\theta$, $2.8K_\theta$ and $3K_\theta$ in the denominators of Equations 9.2-1, 9.2-2 and 9.2-3, respectively, are the adjustments that convert yield mode design values based on 5 percent diameter offset dowel bearing strength to the level of proportional limit based design values tabulated in the 1986 and earlier editions of the specification. For parallel to grain loading, K_θ equals one. For perpendicular to grain loading, K_θ equals 1.25 for a connection with one member loaded parallel to grain and one member loaded perpendicular to grain.

Dowel bearing strength values (F_e) used in the lag screw yield mode equations are given in Table 9A for all structurally graded lumber species. The values also apply to glued laminated timber. The values in Table 9A have been established using the same dowel bearing strength equations used for bolts (see Commentary for 8.2.1 - Yield Mode Equations). For perpendicular to grain loading, the dowel strength equation is entered with the shank diameter of the lag screw.

A bending yield strength, F_{yb}, of 45,000 psi may be used for common lag screws having a shank diameter of 3/8 inch or larger. For smaller diameter screws, use of higher yield strengths may be appropriate (see Appendix I and Tables 9.3A and 9.3B). The yield mode equations are applicable only to connections in which the total penetration of the lag screw (shank and threaded portion) in the main member is at least four times the shank diameter ($4D$), excluding the length of the tapered tip, and the minimum thread length is that specified for the diameter in Appendix L. This Appendix provides standard shank and root diameters and total, thread and tapered-tip lengths for different screw sizes. Tapered-tip lengths are calculated as 0.866 the root diameter.

It is to noted that when the length of the threaded portion of the lag screw is greater than the standard threaded portion length given in Appendix L of the Specification, the root diameter rather than the shank diameter should be used as D in the yield mode equations if the boundary between the shank and threaded portion of the screw falls within the cleat or side member.

For each joint configuration, the nominal design value, Z, for each yield mode is calculated to determine the limiting value for the connection. In most cases, Mode III_s or IV will be the limiting case. For a member loaded at an angle to grain, the lag screw yield mode equations are entered with a dowel bearing strength, $F_{e\theta}$, calculated in accordance with Equation 9.3-4, a form of the standard bearing angle to grain formula (see Appendix J). Design values for lag screws acting at an angle to grain have been based on this equation using allowable lag screw parallel and perpendicular to grain design values as the reference design value levels since the 1944 edition (see Commentary for 8.2.1 - Member Loaded at an Angle to Grain).

Tabulated Wood-to-Wood Design Values. Lag screw design values given in Table 9.3A assume the threaded portion of the screw is located completely in the main member, the total penetration of the screw in the main member is a minimum of $8D$ (excluding the length of the tapered tip), and screws of standard diameters, threaded lengths and other dimensions (see Appendix L) are used. Values also are based on lag screw bending yield strength values of 45,000 psi for screws of 3/8 inch and larger diameter, 60,000 psi for 5/16 inch diameter and 70,000 psi for 1/4 inch diameter. The values assumed for the screw sizes less than 3/8 inch diameter are those estimated from tests of common wire nails of the same diameter (see Appendix I). It is the responsibility of the designer to assure that the lag screws specified and used qualify for tabulated design values.

Two lateral design values for perpendicular to grain loading are shown in Table 9.3A: one for lag screw connections with the side member loaded perpendicular to grain and the main member loaded parallel to grain

($Z_{s\perp}$); and one for a connection with main member loaded perpendicular to grain and the side member loaded parallel to grain ($Z_{m\perp}$).

Comparison of 1991 and Earlier Edition Values. Lag screw design values given in the 1991 edition cover a greater range of side member geometries than those given in earlier editions. Because of the simplifications made in the yield mode equations and the averaging procedures used to adjust yield mode lag screw design values to design values previously tabulated, new design values are both higher and lower than those given for the same joint configurations in the earlier editions. This is shown by the comparisons in Table C9.3-1. The penetration depth factor, C_d, shown in this table, applicable to the 1991 tabulated values, is the adjustment for less than full design value penetration ($8D$) of the screw in the main member (see 9.3.3 of Specification and foregoing Commentary). Washer thickness of 1/8 inch for 1/2 inch and larger diameters screws and 0 inch for smaller diameters screws were assumed in calculating values of C_d. Adjustments for penetration depth are embedded in the values tabulated in previous editions (see Equations C9.3-1 and C9.3-2).

In terms of the design value ratios for the joint configurations compared, lag screw design values for wood-to-wood connections based on 1991 edition provisions average 22 percent and 25 percent higher for parallel to grain loading and perpendicular to grain loading, respectively, than those tabulated in the 1986 edition. The overall higher design values for parallel to grain loading ($Z_{//}$) are a result of the procedure used to translate yield limit design values to the level of proportional limit based design values tabulated in previous editions and to the equations used to establish dowel bearing strength values. This procedure included considering ratios of yield limit and previous design values for both joints with wood and with steel side members when establishing a uniform conversion factor for each yield mode equation (see Commentary for 9.3.1 - Yield Mode Equations). In the case of perpendicular to grain loading ($Z_{\perp}$), the overall higher level of design values in the 1991 edition reflects the effect of the equation used to establish the dowel bearing strength values for perpendicular to grain loading in Table 9A. It is to be noted that lag screw perpendicular to grain design values tabulated in earlier editions of the Specification were based on application of procedures originally developed for bolts rather than on tests of lag screw joints under perpendicular to grain loading. The yield mode equations provide a fully rationalized basis for evaluating the interactions of member bearing strength, member thicknesses, fastener diameter and fastener strength.

Table C9.3-1 - Comparison of 1991 and 1986 NDS Wood-to-Wood Single Shear Lag Screw Lateral Design Values

Side Member Thickness in.	Lag Screw L in.	Lag Screw D in.	Penetration Depth Factor C_d (1991)	Lag Screw Lateral Design Value, lbs $Z_{//}$ 1991	$Z_{//}$ 1986	$Z_{//}$ Ratio	$Z_{m\perp}$ 1991	$Z_{m\perp}$ 1986	$Z_{m\perp}$ Ratio
Southern pine:									
1-1/2	4	1/4	1.000	230	170	1.35	180	170	1.06
		3/8	0.760	319	250	1.28	228	190	1.20
		1/2	0.516	366	290	1.26	217	190	1.14
	6	1/4	1.000	230	230	1.00	180	220	0.82
		3/8	1.000	420	420	1.00	300	320	0.94
		1/2	1.000	710	600	1.18	500	390	1.28
2-1/2	7	1/2	1.000	750	650	1.15	520	420	1.24
		3/4	0.646	1085	850	1.28	704	470	1.50
	9	1/2	1.000	750	830	0.90	520	540	0.96
		3/4	0.979	1645	1350	1.22	1067	740	1.44
		1	0.711	1820	1660	1.10	1180	830	1.42
Spruce-Pine-Fir:									
1-1/2	4	1/4	1.000	200	130	1.54	150	130	1.15
		3/8	0.760	281	180	1.56	198	140	1.41
		1/2	0.516	294	210	1.40	206	140	1.47
	6	1/4	1.000	200	210	0.95	150	200	0.75
		3/8	1.000	370	370	1.00	260	280	0.93
		1/2	1.000	570	430	1.33	400	280	1.43
2-1/2	7	1/2	1.000	650	460	1.41	430	300	1.43
		3/4	0.646	879	610	1.44	575	330	1.74
	9	1/2	1.000	650	740	0.88	430	480	0.90
		3/4	0.979	1331	960	1.39	871	530	1.64
		1	0.711	1500	1190	1.26	939	590	1.59

For joints made with two different species, tabulated design values for the species with the lower dowel bearing strength may be used in lieu of using the yield mode equations of 9.3.1 with the appropriate dowel bearing strength for each species.

9.3.2-Wood-to-Metal Connections

9.3.2.1 In previous editions, design values for lag screw joints made with metal side plates were established as 1.25 times the value for a wood-to-wood joint of equivalent configuration as determined from Equation C9.3-1 or C9.3-2 (134). Metal side plates were assumed to be 1/2 inch thick and resultant values were considered applicable to side plates of lesser thickness.

For thicker side plates, tabulated design values were required to be reduced for the lesser penetration of the lag screw.

Under the methodology of the 1991 edition, lag screw design values for joints made with metal side plates are determined using the Mode III_s and Mode IV equations for wood-to-wood joints in 9.3.1 using a dowel bearing strength, F_{es}, applicable to the metal used in the side plates (see Appendix I) and the actual thickness of the plate as the side member thickness. As previously noted (see Commentary for 9.3.1 - Background), the factors used to relate yield mode design values to proportional limit based design values tabulated in previous editions were based on lag screw joints made with both wood and metal side plates. Thus Equations 9.3-2 and 9.3-3 apply to joints with metal as well as wood side plate when the appropriate input variables are used.

The lag screw design values for joints made with steel side plates given in Table 9.3B assume the same strength lag screws as those used for Table 9.3A, a dowel bearing strength of 58,000 psi for 1/4 inch steel (ASTM A36) side plates, and a dowel bearing strength of 45,000 psi for steel plates less than 1/4 inch. The latter value is the tensile strength for ASTM A446, Grade A galvanized sheet steel. It is to be noted from Table 9.3B that, for constant screw diameter and steel strength, design values based on the yield mode equations decrease as steel plate thickness decreases. Previous methodology recognized no effect of plate thickness below 1/2 inch.

Comparison of 1991 and Earlier Edition Values. Differences in 1991 and earlier edition design values for wood-to-metal lag screw joints are illustrated in Table C9.3-2. The 1991 design values are for joints made with 1/4 inch side plates. The 1986 values apply to joints made with 1/2 inch or thinner side plates. The values of C_d less than 1.000 in Table C9.3-2 are the adjustments applied to 1991 tabulated design values when there is less than full design value penetration ($8D$) of the screw in the main member (see 9.3.3 of Specification and foregoing Commentary). Joints were assumed made without washers.

The average design value ratios for the configurations compared show 1991 design values for metal-to-wood connections were 2 percent lower and 16 percent higher for the parallel and perpendicular to grain loading cases, respectively, than the comparable 1986 design values. The higher overall design values for the perpendicular to grain comparisons reflect the effects of the equation used to establish dowel bearing strengths for perpendicular to grain loads in Table 9A (see

Table C9.3-2 - Comparison of 1991 and 1986 NDS Wood-to-Metal Single Shear Lag Screw Lateral Design Values

Steel Side Member Thickness in.	Lag Screw L in.	Lag Screw D in.	Penetration Depth Factor C_d (1991)	Lag Screw Lateral Design Value, lbs $Z_{//}$ 1991	$Z_{//}$ 1986	$Z_{//}$ Ratio	$Z_{m\perp}$ 1991	$Z_{m\perp}$ 1986	$Z_{m\perp}$ Ratio
Southern pine:									
1/4	4	1/4	1.000	310	240	1.29	230	180	1.28
		3/8	1.000	510	480	1.06	350	290	1.21
		1/2	0.859	697	610	1.14	447	320	1.40
	6	3/8	1.000	510	550	0.93	350	330	1.06
		1/2	1.000	810	950	0.85	520	490	1.06
		3/4	0.875	1452	1500	0.97	840	660	1.27
	8	1/2	1.000	810	980	0.83	520	510	1.02
		3/4	1.000	1660	2130	0.78	960	940	1.02
		7/8	1.000	2220	2480	0.90	1240	1030	1.20
	10	5/8	1.000	1190	1550	0.77	720	740	0.97
		3/4	1.000	1660	2200	0.75	960	970	0.99
		1	1.000	2870	3680	0.78	1540	1470	1.05
Spruce-Pine-Fir:									
1/4	4	1/4	1.000	280	210	1.33	190	160	1.19
		3/8	1.000	450	340	1.32	290	210	1.38
		1/2	0.859	619	440	1.41	369	230	1.60
	6	3/8	1.000	450	490	0.92	290	300	0.97
		1/2	1.000	720	760	0.95	430	400	1.08
		3/4	0.875	1295	1070	1.21	709	470	1.51
	8	1/2	1.000	720	880	0.82	430	460	0.93
		3/4	1.000	1480	1560	0.95	810	690	1.17
		7/8	1.000	1980	1770	1.12	1030	740	1.39
	10	5/8	1.000	1060	1380	0.77	610	660	0.92
		3/4	1.000	1480	1970	0.75	810	870	0.93
		1	1.000	2550	2640	0.97	1300	1050	1.24

Commentary for 9.3.1 - Yield Mode Equations, Comparison).

9.3.2.2 (See Commentary for 7.2.3)

9.3.3-Penetration Depth Factor, C_d

The penetration depth factor provides for reduced design values when the length of penetration of the lag screw in the main member, both shank and threaded portion, is less than eight times the shank diameter ($8D$). The full proportional limit design value of lag screw joints of any species is considered developed when this penetration depth occurs (see Commentary for 9.3.1 - Background, 1991 Edition). Penetrations down to 50 percent or $4D$ of the full design value penetration depth are allowed if tabulated design values or yield mode equation design values are reduced proportionately.

The penetration depth of the lag screw in the main member is calculated as the length of the lag screw (ℓ) minus the sum of the thickness of the side member (t_s), the thickness of any washer used (w) and the length of the tapered tip of the screw (E), or $[\ell-(t_s+w+E)]$. Lag screw dimensions, including thread and tapered tip lengths, are given in Appendix L. Consistent with the basis of lag screw design values published in previous editions, a washer thickness of 1/8 inch for screw diameters of 1/2 inch and larger and 0 inch for smaller diameter screws may be assumed.

Examples of the use of the C_d factor to adjust design values for less than full penetration are shown in Tables C9.3-1 and C9.3-2 and related Commentary.

9.3.4-End Grain Factor, C_{eg}

Use of two-thirds the perpendicular to grain lag screw lateral design value for screws inserted in the end grain of the main member (62) has been a provision of the Specification since the 1944 edition. When design values for this case are based on the yield mode equations of 9.3.1, the dowel bearing strength of the main member is assumed equal to the perpendicular to grain bearing strength of the species from Table 9A.

Because of the tendency of the member to split under lateral loading, structural lag screw connections in end grain surfaces should be avoided (62,66). Lag screws in end grain surfaces particularly should not be subjected to combined withdrawal and lateral loading.

9.3.5-Combined Lateral and Withdrawal Loads

In the 1977 through the 1986 editions, the Specification provided that lag screws subjected to combined lateral and withdrawal loads be analyzed separately for the resistance of the screw to each load. The results of recent lag screw tests (115) showed that withdrawal load components did not reduce lateral load capacity when maximum joint loads are considered. However, when joint resistance was evaluated at the design load level by expressing the strength of the joint loaded at any angle to the surface as the lesser of the proportional limit load divided by 1.875 (2.25/1.2) or the maximum load divided by 4.167 (5/1.2), an interaction of the load components was observed with larger diameter screws at load angles less than 45° (115). Use of these alternative design load bases is required because lag screw lateral design values are based on proportional limit joint loads whereas withdrawal design values are based on maximum joint loads. The factors of 1.875 and 4.167 are the adjustments used to convert the two types of test values to allowable levels (see Commentary for 9.2.1 and 9.3.1 - Background).

To account for the interaction observed in the new lag screw tests, Equation 9.3-6 has been introduced in the 1991 edition for determining the allowable design value of lag screws subject to combined lateral and withdrawal loads. This equation, a form of the bearing angle to grain equation (see Appendix J), is

$$Z_\alpha' = \frac{(W'\,p)\,Z'}{(W'\,p)\cos^2\alpha + Z'\sin^2\alpha} \qquad \text{(C9.3-6)}$$

where:

Z_α' = allowable design value for lag screw loaded at angle to the surface of main member

Z' = lateral design value for lag screw connection

W' = withdrawal design value for lag screw connection per inch of penetration

p = length of thread penetration in the main member

α = angle between wood surface and direction of applied load

The length of penetration of the threaded portion of the screw in the main member excludes the length of the tapered tip and includes the reduction in penetration resulting from the use of a washer under the screw head.

Equation C9.3-6 will give generally conservative design values for load angles greater than 45°. Equation C9.3-6 can also be used to determine the allowable design value of lag 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 C9.3-1.

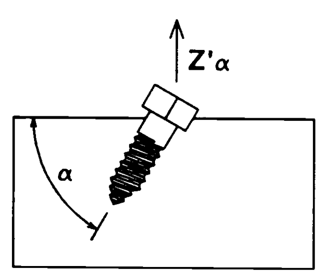

Figure C9.3-1 Combined Lateral and Withdrawal Load for Lag Screw Inserted at an Angle to Wood Surface

9.4-PLACEMENT OF LAG SCREWS

9.4.1-Geometry Factor, Edge Distance, End Distance, Spacing

Application of the same positioning requirements for lag screws as those for bolts has been a provision of the Specification since the 1944 edition. The similarity of the performance characteristics of the two types of fasteners was recognized in the original lag screw research (134) and the use of edge distance, end distance and spacing criteria for bolts with lag screws was specifically recommended (62). Lag screw tests conducted on Douglas-fir joints in 1963 confirmed that a $4D$ spacing between lag screws in a row was more than sufficient to develop the full proportional limit load capacity of the joint (102).

9.4.2-Multiple Lag Screws

The group action factor, C_g, has been applied to lag screw joints containing two or more screws in a row (screws aligned in the direction of the load) since the factor was first introduced in 1973.