# 11.4 Combined Lateral and Withdrawal Loads

## 11.4.1 Lag Screws and Wood Screws

When a lag screw or wood screw is subjected to combined lateral and withdrawal loading, as when the fastener is inserted perpendicular to the fiber and the load acts at an angle, $\alpha$, to the wood surface (see Figure 11F), the adjusted design value shall be determined as follows (see Appendix J):

$$Z_\alpha' = \frac{(W'p)Z'}{(W'p)\cos^2\alpha + Z'\sin^2\alpha} \qquad (11.4\text{-}1)$$

**where:**

$\alpha$ = angle between wood surface and direction of applied load

p = length of thread penetration in main member, in.

## 11.4.2 Nails and Spikes

When a nail or spike is subjected to combined lateral and withdrawal loading, as when the nail or spike is inserted perpendicular to the fiber and the load acts at an angle, $\alpha$, to the wood surface, the adjusted design value shall be determined as follows:

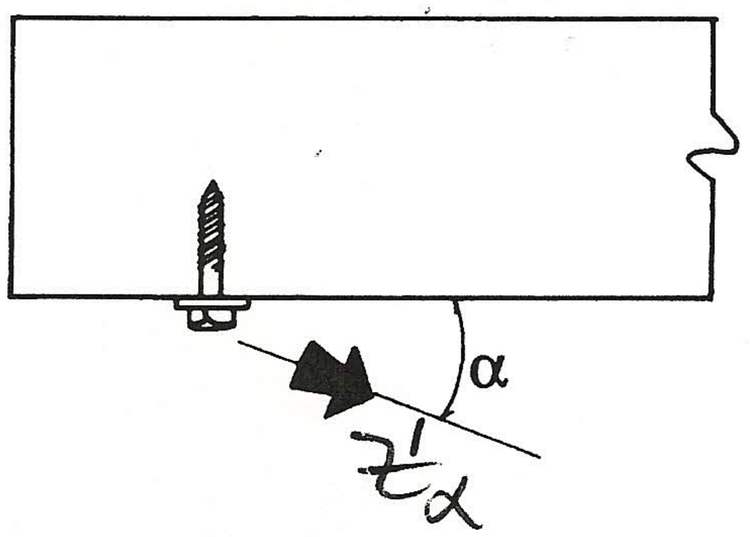
$$Z_\alpha' = \frac{(W'p)Z'}{(W'p)\cos\alpha + Z'\sin\alpha} \qquad (11.4\text{-}2)$$

**where:**

$\alpha$ = angle between wood surface and direction of applied load

p = length of penetration in main member, in.

**Figure 11F Combined Lateral and Withdrawal Loading**




# 11.5 Adjustment of Reference Design Values

## 11.5.1 Geometry Factor, $C_\Delta$

11.5.1.1 When D < 1/4", $C_\Delta$ = 1.0.

11.5.1.2 When D ≥ 1/4" and the end distance or spacing provided for dowel-type fasteners is less than the minimum required for $C_\Delta$ = 1.0 for any condition in (a), (b), or (c), reference design values shall be multiplied by the smallest applicable geometry factor, $C_\Delta$, determined in (a), (b), or (c). The smallest geometry factor for any fastener in a group shall apply to all fasteners in the group. For multiple shear connections or for asymmetric three member connections, the smallest geometry factor, $C_\Delta$, for any shear plane shall apply to all fasteners in the connection. Provisions for $C_\Delta$ are based on an assumption that edge distance and spacing between rows of fasteners is in accordance with Table 11.5.1A and Table 11.5.1D and applicable requirements of 11.1.

**Table 11.5.1A Edge Distance Requirements [1,2]**

| Direction of Loading | Minimum Edge Distance |
|---|---|
| Parallel to Grain: | |
| when $\ell/D \le 6$ | 1.5D |
| when $\ell/D > 6$ | 1.5D or ½ the spacing between rows, whichever is greater |
| Perpendicular to Grain:[2] | |
| loaded edge | 4D |
| unloaded edge | 1.5D |

1. The $\ell/D$ ratio used to determine the minimum edge distance shall be the lesser of:
   (a) length of fastener in wood main member/D = $\ell_m/D$
   (b) total length of fastener in wood side member(s)/D = $\ell_s/D$
2. Heavy or medium concentrated loads shall not be suspended below the neutral axis of a single sawn lumber or structural glued laminated timber beam except where mechanical or equivalent reinforcement is provided to resist tension stresses perpendicular to grain (see 3.8.2 and 10.1.3).

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### C11.3.7 Asymmetric Three Member Connections, Double Shear

Conservatively, the Specification requires the use of minimum side member bearing length and minimum dowel diameter in the calculation of design values for asymmetric three member connections. Inherent in this calculation is the assumption that the load to each side member is equivalent. Where other load distributions occur, more complex analysis may be needed.

### C11.3.8 Multiple Shear Connections

The Specification requires evaluation of each individual shear plane using the yield limit equations of NDS 11.3.1 and then assigning the lowest value to the other shear planes. Interior members should be checked for the combined loading from the adjacent shear planes to ensure that sufficient bearing capacity exists (such as would exist in a double shear connection limited by Mode $I_m$).

### C11.3.9 Load at an Angle to Fastener Axis

Two member connections in which the load acts at an angle to the axis of the fastener are checked using the component of the load acting at 90° to the axis and member thicknesses equal to the length of the fastener in each member measured at the centerline of the fastener (see NDS Figure 11E). Reference design values for connections in which the load acts at an angle to the fastener axis are based on the yield limit equations of NDS 11.3.1. The lowest value of $Z$ obtained, using $t_m$ and $t_s$ equal to the length of fastener in each member, divided by the cosine of the angle of intersection of the two members is the maximum reference design value for the connection.

The adequacy of the bearing area under washers and plates to resist the component of force acting parallel to the fastener axis can be checked using adjusted compression design values perpendicular to grain, $F_{c\perp}'$.

### C11.3.10 Drift Bolts and Drift Pins

Reference lateral design values for drift bolts or pins (181) are 75 percent of the reference design value for common bolts of the same diameter to compensate for the absence of head, nut, and washer. End distance, edge distance, and spacing requirements, and group action adjustments that are applicable to bolts, are also applicable to drift bolts and drift pins.

## C11.4 Combined Lateral and Withdrawal Loads

### C11.4.1 Lag Screws and Wood Screws

Results of lag screw tests indicated that loading at an angle to the fastener axis to induce lateral and withdrawal components did not reduce the maximum connection capacity. However, when joint resistance was evaluated at the design load level, an interaction of the load components was observed with larger diameter screws at load angles less than 45° (87). Analysis at design load level was performed due to the differences in design level to maximum capacity ratios for lateral and withdrawal. NDS Equation 11.4-1 can also be used to determine the reference 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 perpendicular to the fastener axis.

### C11.4.2 Nails and Spikes

It is assumed that current adjustments for toe-nailed connections address the effects of combined lateral and withdrawal loading and do not require further modification.

Research on the effects of combined lateral and withdrawal loading on nailed connections (37) involved tests of Engelmann spruce, Douglas fir, and red oak single shear connections made with 8d common nails. Nail penetration depths of 6, 10, and 14 diameters into the main member and load angles of 0°, 90°, and six intermediate directions were investigated. Two tests were conducted at each load angle. The interaction equation found to best describe maximum connection load results for each species and penetration depth was of the form:





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$$P = \frac{(1 + K \sin 2\alpha)(W'pZ')}{(W'p)\cos\alpha + (Z')\sin\alpha} \qquad \text{(C11.4.2-1)}$$

**where:**

P = maximum load at angle to grain, $\alpha$

W′p = maximum load at 90° (withdrawal load perpendicular to grain per inch of penetration in the main member times the penetration depth)

Z′ = maximum load at 0° (lateral load)

$\alpha$ = angle between wood surface and direction of applied load, and

K = factor based on least squares analysis of test data for each species-penetration group

The average value of K for the six species and penetration groups evaluated was 0.535, and ranged from 0.151 to 1.406. Average K values by species were 0.432, 0.864, and 0.309 for Douglas fir, Engelmann spruce, and red oak, respectively. When K is conservatively assumed to equal 0, Equation C11.4.2-1 reduces to NDS Equation 11.4-2 or, in another format the following:

$$\frac{R_W}{W'p} + \frac{R_Z}{Z'} \le 1 \qquad \text{(C11.4.2-2)}$$

**where:**

$R_W$ = connection withdrawal force, and

$R_Z$ = connection lateral force.

# C11.5 Adjustment of Reference Design Values

## C11.5.1 Geometry Factor, $C_\Delta$

C11.5.1.1 For fasteners with diameters less than 1/4", no reduction for geometry is specified.

C11.5.1.2 For fasteners with diameters equal to or greater than 1/4", the geometry factor provides a proportionate reduction of reference design values for less than full end distance or less than full spacing distance. The lowest geometry factor for any fastener applies to all other fasteners in that same connection, not just to the end fastener or a pair of fasteners in a row. It should be noted that further reductions may be necessary when checking stresses in members at connections (see NDS 10.1.2).

The requirement that fastener design values for multiple shear plane connections or asymmetric three member connections be based on the application of the lowest geometry factor for any shear plane to all fasteners in the joint assumes that the total joint capacity is proportional to the number of shear planes.

**Edge Distance:** Requirements in NDS Table 11.5.1A for parallel to grain loading of 1.5*D* or the greater of 1.5*D* or 1/2 the spacing between rows for $\ell/D$ greater than 6, and for loaded edge - perpendicular to grain loading of 4*D* are based on early research (146). The unloaded edge perpendicular to grain minimum of 1.5*D* is a good practice recommendation.

NDS Section 11.5.1 does not provide specific guidance on edge distance requirements for loads applied at angles other than 0° and 90°, nor does it provide specific geometry factors for reduced edge distances.

The ratio of the fastener length in side member to fastener diameter, $\ell/D$, in NDS Table 11.5.1A is based on the total thickness of both wood side members when connections of three or more wood members are involved. For connections involving metal main or side members, only the $\ell/D$ ratio for the wood members are considered for determination of edge distance requirements in this section. Metal parts must still be designed per NDS 10.2.3.

Avoidance of heavy or medium suspended loads below the neutral axis of a beam was added as a result of several reported field problems involving structural glued laminated timber beams subject to a line of concentrated loads applied through bolted hangers or ledger strips attached in the tension zone or at the bottom edge of the beam. Concentrated loads less than 100 pounds and spaced more than 24" apart may be considered a light load condition.

For perpendicular to grain connections, the member is required to be checked for shear in accordance with NDS 3.4.3.3 using a reduced depth, $d_e$, equivalent to the beam depth, *d*, less the distance from the unloaded edge of the beam to the center of the nearest fastener.

**End Distance:** Requirements in NDS 11.5.1.2(a) and NDS Table 11.5.1B for parallel to grain loading are based on early recommendations (146). For tension loads (fasteners bearing toward the member end), the minimum end distances of 7*D* for softwoods and 5*D* for hardwoods for $C_\Delta$ = 1.0 were established by test. For compression loads (fasteners bearing away from the member end), the minimum end distance of 4*D* for $C_\Delta$ = 1.0 was based on the minimum spacing of fasteners in a row for $C_\Delta$ = 1.0 (146). End distances for angle to grain tension loadings