Design Lag Screwed Wood Connections With Spreadsheet

Course Content

INTRODUCTION

The complete design of a wood structure includes the design of connections between the various structural members. The integrity of the load path depends on the strength of the attachment between pieces. The designer has a choice of several "dowel-type" connectors (nails, screws, lag screws, bolts, pins) as well as a variety of devices such as connector plates and pre-engineered metal connectors. Lag screws (lag bolts) are often used in situations where it is not practical or possible to use bolts. This could be in a situation where the nuts would be inaccessible or where the bolt would be too long to be practical. In a sense, the threaded portion of the lag screw secures it to the wood replacing the nut of a regular bolt.   Lag screws may be loaded in withdrawal, laterally, or in a combination of the two. A properly fabricated lag screw connection can carry a significant load.

Specific loads can be assigned to lag screwed connections based on several variables. Load calculations are quite complex and lend themselves well to the use of a spreadsheet. This course discusses the design of lag screwed wood connections and includes the Excel© 2003 spreadsheet, LAGUP©, with five examples of its use. The spreadsheet is designed for stand alone use for many common situations requiring only information provided in the following discussion or the spreadsheet itself. It is assumed that the student is familiar with the use of spreadsheets. Traditional (English) units and the allowable stress design (ASD) approach are used.

The design of wood member connections is complicated, in part, because of the variability of wood. Dozens of species are used for structures, and the relevant properties vary within and between species. Also, the structural properties within a single piece of wood vary significantly depending on the direction of the grain.

Engineering properties of wood products intended for structural use are readily available. The American Forest & Paper Association has published several manuals including the National Design Standard ANSI/AF&PA NDS-2001 (Reference 1) that provide information relevant for wood structural design, including connector design. Technical information for "engineered" lumber products such as laminated veneer lumber (LVL) and I joists is available from manufacturers. References used for this course are given at the end of this discussion. These and similar sources provide additional useful information.

WOOD PROPERTIES RELEVANT TO CONNECTOR DESIGN

The following is a brief description of several properties or descriptors of wood that are relevant to lag screw design.

Species – The species refers to the biological kind of tree from which the wood is obtained. Most wood used for structural purposes is called "softwood" which means it comes from cone bearing (coniferous) trees. This includes several sub-species of pine

and fir as well as dozens of other commonly used species. Less commonly used is "hardwood" lumber which comes from leaf bearing (deciduous) trees. Examples of these are oak and maple. The terms "softwood" and "hardwood" can be misleading because some "softwoods" such as southern yellow pine are harder than some "hardwoods" such as cottonwood. Nearly all wood used for structures in the U.S.A. comes from trees that grow by adding layers (rings) to the outside of the tree (exogenous growth). The rate of this ring growth varies from season to season and from species to species. The density of the wood depends to a large extent on the nature of the growth.

Density/Specific Gravity – Weight density is arguably the most important wood property affecting connector design. Weight density is expressed in the number of pounds per cubic foot of dry wood. It is converted into specific gravity by dividing by the weight density of water as illustrated following. Wood that weighs 35 lbs/ft^3 dry has a specific gravity of .56 as shown below.

$$35 \text{ lbs/ft}^3 / 62.4 \text{ lbs/ft}^3 = .56$$

Published specific gravities usually are an average for an entire species and are typically given to two significant digits. The National Design Specification publication (Ref. 1, p.74) is one source of values. The spreadsheet, LAGUP©, provides a table of specific gravities for some common species.

Grade – Agencies have been organized to provide grading rules for commercially useful wood species. Based on these rules, lumber is sorted into grades with reliable structural properties. Even within one grade of one species there may be a large range in any given engineering property so the assigned design values are conservative.

Moisture Content – Wood may contain varying amounts of water. It may be in "cells" (open pores) that would otherwise contain air or it may be in the cell walls. Moisture content (M.C.) is expressed as a percentage and is calculated by dividing the weight of water present in a specimen by the weight of the dry specimen.   It could vary from above 100% to 0%. A sample that weighs 40 grams and is completely dried to 35 grams had a moisture content of:

$$(40 \text{ grams} - 35 \text{ grams}) / 35 \text{ grams} = 14\% \text{ moisture content.}$$

Lumber is typically dried in air or by kiln from the "green" condition when it is harvested to a "dry" condition for use. A typical range of moisture content for "dry" structural lumber as used is about 6% to 19% with 19% M.C. serving as the break point between dry and wet lumber. (Ref. 2, p. 186).   The moisture content of wood changes in response to its environment. This is associated with volume changes that differ in different directions within the wood. The effects of moisture content and its possible variation throughout the life of a structure require careful consideration. It may affect the selection of connector material (zinc plated, galvanized, stainless steel, etc.), the detailing (hole size and layout) as well as the design value per connector. Adjustments to design values for a variety of reasons including damp or wet conditions of use are discussed later.

Grain – The grain of wood refers to the make-up and orientation of the cells that compose the material. The configuration of most of the cells can be compared to a

bundle of straws standing upright. The direction along the length of a tree and therefore along the length of a piece of lumber is called parallel to grain. The relevant strength value for lag screw design is highest in that direction. The direction at right angles to the tree length radially in any direction is called perpendicular to grain. The relevant strength value for lag screw design is significantly lower in that direction. The strength values at angles of grain between parallel and perpendicular are at intermediate values and are calculated by the Hankinson Formula to be given later. The grain direction is not always in perfect alignment with the length of a piece of lumber (cross grain) and may be interrupted by various other defects (knots, splits, etc.). These strength reducing characteristics are accounted for in the grading of the lumber.

A connector placed in the face or edge of a piece of lumber is in "side grain"; a connector in the end of a piece of lumber is in "end grain." A connector can carry more load in side grain. End grain loading is given a zero value for some situations. Figure 1 illustrates various aspects of grain direction. The red loads shown are parallel to the surfaces of the structural member but at various angles to the grain of the structural member.   The yellow loads shown are at angles to the wood surface. The spreadsheet to be illustrated in this course can be used for both types of loads.
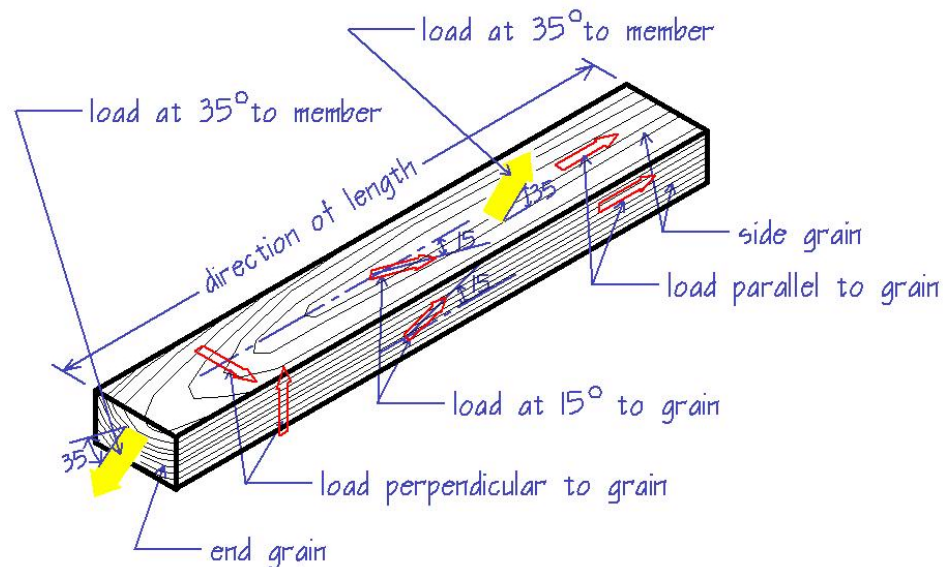

Figure 1. Wood Grain and Load Directions

Engineering Properties - The wood strength parameter that controls lag screw loading is the "dowel bearing strength", F_e, in psi, which relates to the allowable bearing stress of the wood and is a function of angle of load to grain and the lag screw (or "dowel") size. The calculation of F_e is based on wood specific gravity, G, and lag screw shank diameter, D, as follows (Ref. 3, p.25):

$F_{e\parallel}$ is dowel bearing stress parallel to grain; $F_{e\perp}$ is dowel bearing stress perpendicular to grain.

$$F_{e\parallel} = 11200G \qquad F_{e\perp} = 6100G^{1.45}/D^{.5}$$

Dowel bearing strengths at other angles to grain are calculated using the Hankinson formula:

$$F_{e(\theta)} = F_{e\parallel}\, F_{e\perp}/(F_{e\parallel}\sin^2 \theta + F_{e\perp}\cos^2 \theta)$$

where θ is the angle of load to grain.   Values are rounded to the closest 50 psi. Thus, $F_{e\parallel}$ for wood with a G of .56 = 11200(.56) = 6250 psi for lag bolts sizes ¼" thru 1."
For the same wood and a 3/8" lag bolt $F_{e\perp} = 6100(.56)^{1.45}/(.375)^{.5} = 4300$ psi.
$F_{e(15)}$ for a 3/8" lag bolt $= (6250)(4300)/\{(6250)(.259)^2 + (4300)(.966)^2\} = 6050$ psi.

Formulas apply to lag bolt of diameters ¼" to 1 1/4" inclusive. Reference 3, p.15, gives a table of calculated dowel bearing strengths. The spreadsheet is set up to use either specific gravities, some of which are supplied, or dowel bearing strengths.
    Load Duration Factor - The capacity of wood to support a given load depends on how long the load will be in place. The basic allowable stresses are modified or "adjusted" by multiplying by the appropriate factor. Consideration must be given to all load combinations to determine the controlling situation. The addition of a load of short duration may not control the design since the allowable stresses can be increased. This is illustrated below. The equation for calculating duration factor (after Ref. 2, p.8) is:

$$C_D = (1.7512)(T^{-.04635}) + .29575 \quad \text{where T is time in seconds.}$$

The factors given in Table 1 are for commonly encountered situations.

Table 1.   Load Duration Factors, $C_D{}^*$ (Ref. 3, p.8)

Maximum Load Duration	C_D	Typical Design Load
Permanent	.9	Dead Load
10 years	1.0	Occupancy Live Load
2 months	1.15	Snow Load (when appropriate)
7 days	1.25	Construction Load
10 minutes	1.6	Wind/Earthquake/Impact

  *Not applied to compression stress perpendicular to grain, $F_{C\perp}$, or modulus of elasticity, E (Ref.1, p.26).

Using the information from Table 1 and the wood of G = .56 with wind load controlling:

$$F_{e\parallel} = 1.6\,(6250) = 10000 \text{ psi}$$

Suppose, however, the following loads:
           Dead Load   = 2400 pound and
           Occupancy Live Load = 3600 pounds and
           Wind Load   = 2000 pounds
The dead load, which might be alone, has an allowable stress of (.9)(6250) = 5650 psi.

The dead load plus the occupancy live load has an allowable stress of (1)(6250) = 6250 psi. The total load has an allowable stress of (1.6)(6250) = 10000 psi since the total load is of short duration because of the wind. The controlling load can be found by taking the largest of the following ratios: 2400/.9 = 2670, (2400 + 3600)/1.0 = 6000, (2400 + 3600 + 2000)/1.6 = 5000. Dead load plus occupancy live load control. Wind load may be neglected in this instance and C_D = 1.0.

       Group Action Factor – The design value for more than one laterally loaded lag screw is not a simple multiple of the number of lag screws used and the value for one alone. A group action factor, C_g, is calculated based on the number of lag screws in a row and the relative stiffnesses of the members bolted together. The stiffness depends on member cross section area and modulus of elasticity. The provided spreadsheet includes moduli for some common species; reference 4, pp. 31-38 includes a long list. Thirty million (30000000) psi may be used for steel and 57000 times the square root of the ultimate compression strength for concrete. Tables of group action factors for some conditions are in reference 3, pp. 9-10.

The formula for calculating C_g uses the following definitions as it relates to lag screws:

       Row – a series of connectors parallel to the load.

       Side Member – the member holding the shank of the lag screw.

       Main member – the member holding the threaded end of the lag screw.

       See Figures 2 and 3 for illustrations. In the unusual case of a three member joint the side members form the outsides and the main member is between.

Gross cross section areas are used in the formulas to follow except when members are loaded perpendicular to grain. In that case, the area used is the product of the member thickness and the fastener group width (out to out of centers of rows).   When one line of lag screws is used the area is the product of the member thickness and the minimum parallel to grain spacing of the lag screws. The formula was developed on the assumption that all connectors in the joint are the same size. The formula for C_g follows (after Ref 1, p.60):

$$C_g = Q(1+ R_{EA})/((1-m)(P)) \qquad \text{wherein}$$

$Q = m(1-m^{2n})$ $P = n\{(1+ R_{EA}m^n)(1+m)-1+m^{2n}\}$

$m = u – (u^2-1)^{.5}$ $u = 1+.5\lambda s(1/E_m A_m + 1/E_s A_s)$

$\lambda = 180000D^{1.5}$ for wood to wood connections

$\lambda = 270000D^{1.5}$ for steel to wood connections

D = bolt diameter

E_m = modulus of elasticity of main member

E_s = modulus of elasticity of side member

A_m = area of main member

A_s = area of side member(s)

R_{EA} = the smaller of $E_s A_s/E_m A_m$ or $E_m A_m/E_s A_s$

n = number of fasteners in a row s = bolt center spacing within a row

For design, the use of the group action factor requires repetitive passes since the number of lag screws is unknown until the connection is designed.

Geometry Factor/Spacings – Lag screw spacings must be at least as large as those given in Table 2 for full load value. If smaller, the capacity is reduced by the geometry factor, C_Δ. C_Δ is the ratio of the actual spacing and the spacing for $C_\Delta = 1$ (Ref. 1, pp. 76-78). The spacings in red are the absolute minimum even with a load reduction.
In the table, D is the shank diameter and L is the smaller of the length of the lag screw in the side member and the length of the lag screw in the wood main member. For loading at an angle to the fastener, further calculations for adequate spacing are necessary.

Table 2. Lateral Loaded Lag Screw Spacing Required for $C_\Delta = 1$ (Ref. 1, pp.76-78)

	∥ to Side Grain Minimum	⊥ to Side Grain Minimum	Withdrawal in End Grain
Edge Distance	L/D ≤ 6 1.5D L/D >6 Greater of 1.5D or ½ spacing between rows	Loaded Edge 4D Unloaded Edge 1.5D	1.5D
End Distance	Compression 4D 2D Tension Softwood 7D 3.5D Hardwood 5D 2.5D	Softwood 4D Hardwood 4D	4D
In A Row	4D 3.0D	Required spacing for attached members 3.0D	4D
Between Rows	1.5D 1.5D	L/D ≤ 2 2.5D 2<L/D<6 (5L+10D)/8 L/D ≥ 6 5D	4D

Figures 2 and 3 illustrate spacing dimensions. In Figure 2: "a" is end spacing, "b" is spacing in a row, "c" is edge spacing, and "d" is spacing between rows for both the main and side members. The load is parallel to grain for both members. In Figure 3, "a" is end spacing, "b" is spacing in a row, "c" is edge spacing, and "d" is spacing between rows for the side member. For the main member, "a" is edge spacing, "b" is spacing in a row, "d" is spacing between rows, and "e" is a loaded edge spacing. The main member is loaded perpendicular to grain and the side member is loaded parallel to grain. The spreadsheet provides for the use of the geometry factor, but does not calculate it. The use of staggered bolts is beyond the scope of this course.
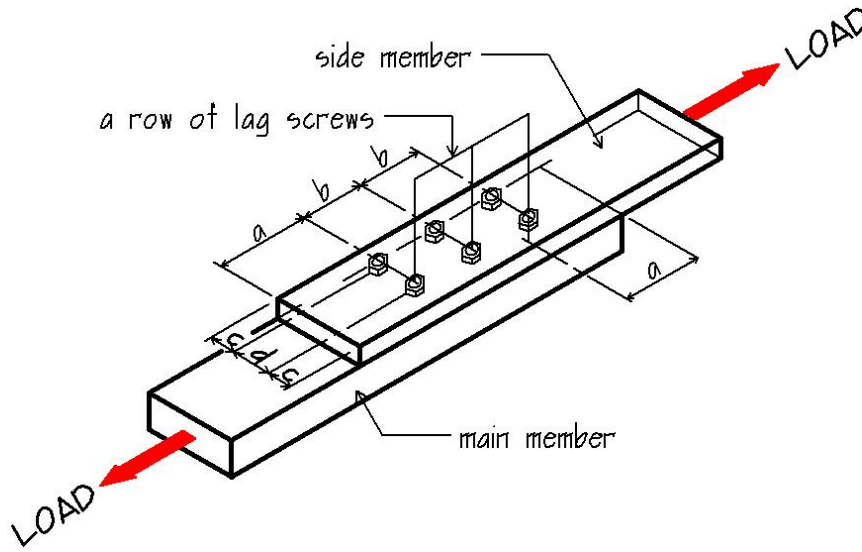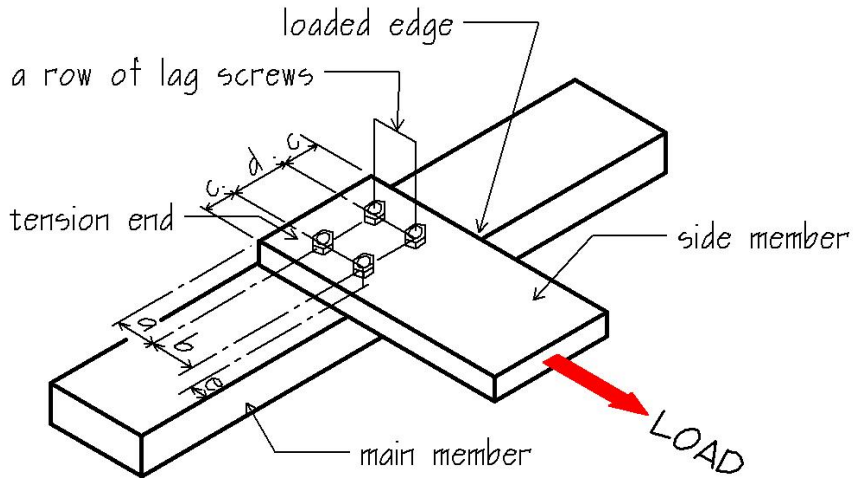
Figure 2. Lag Screw Spacing and Loading

Figure 3. Lag Screw Spacing and Loading

Moisture and Temperature Factors – Two other factors that may affect connection strength are given in Table 3. The wet service factor, C_M, depends on the moisture content of the wood at the time of fabrication and in use. $C_M = .4$ applies if more than a single row of lag screws is used and is used when lumber is assembled "green" and dries in use. The temperature factor, C_t, depends on both temperature and the in-use moisture condition. For temperatures below 100F, $C_t = 1.0$.

Table 3. Moisture and Temperature Factors (Ref. 3, pp.6-10)

Moisture Content		C_M	C	C_t
At Fabrication	In Use		$100 < T \leq 125$	$125 < T \leq 150$
$\leq 19\%$	$\leq 19\%$	1.0	.8	.7
$>19\%$	$\leq 19\%$	.4 lateral	.8	.7

		1.0 withdrawal		
Any	>19%	.7	.7	.5

Pressure treatments with preservatives or fire retardant chemicals may require allowable stress adjustments. That information should be obtained from the treatment company.

       <u>End Grain Factors</u> - Lag screws have smaller capacity in end grain than in side grain. This is accounted for by applying the end grain factors, C_{eg}. For withdrawal loads, $C_{eg} = .75$; for lateral loads $C_{eg} = .67$.

       <u>Penetration Depth Factor (Ref. 2, pp. 121-122)</u> - For lateral loads, a minimum depth of penetration, p, equal to 8 times the shank diameter, D, is required for the full design value. In a two member connection, this penetration is into the main member; in a three member connection, it is into the far side member. Otherwise, the penetration depth factor, $C_d = p/8D$. The minimum penetration for any design value is 4D. Penetration depth may be on the threaded and unthreaded part of the lag screw but does not include the tip of the screw. Penetration depth factor does not apply to withdrawal loads. A table of standard lag screw dimensions is given on page 36 of reference 3. See Figure 4 for standard nomenclature. Lag screw dimensions are built into the spreadsheet.

COMBINING FACTORS

       All factors relevant to a design situation are used. Thus, several factors may be multiplied for a given condition. If, for example, a member with a basic allowable stress of 1200 psi is subject to both construction load and moisture the allowable stress is:

$$(1200 \text{ psi})(1.25)(.7) = 1050 \text{ psi}$$

The 1.25 is C_D from Table 1 and .7 is C_M from Table 3. If conditions are called "normal," the adjustments factors that are entered by the spreadsheet user are all 1.0. This does not include the group action factor which is calculated by the spreadsheet.

LAG SCREW PROPERTIES RELEVANT TO WOOD DESIGN

       The bending yield strength of the lag screw, F_{yb}, may be a factor in determining a connection capacity. Reference 1, p. 160, uses the following values for ordinary lag screws: for diameters $\geq 3/8$", $F_{yb} = 45000$ psi; for diameters = 5/16", $F_{yb} = 60000$ psi; for diameter = ¼", $F_{yb} = 70000$ psi. While tension failure of a lag screw is unlikely, the stress should be checked and compared to the allowable. A value of $F_t = 20000$ psi is used in the spreadsheet. Lag screws made from higher strength materials such as stainless steel have higher values of bending yield stress and allowable tensile stress. It is the designer's responsibility to specify the minimum properties of the steel.

       Standard lag screws consist of a hex or square head like a bolt head, a smooth shank, a coarse thread and a tapered tip. See Figure 4 below. The shank length is consistent for a given lag screw length, but the length of the tip varies with diameter.
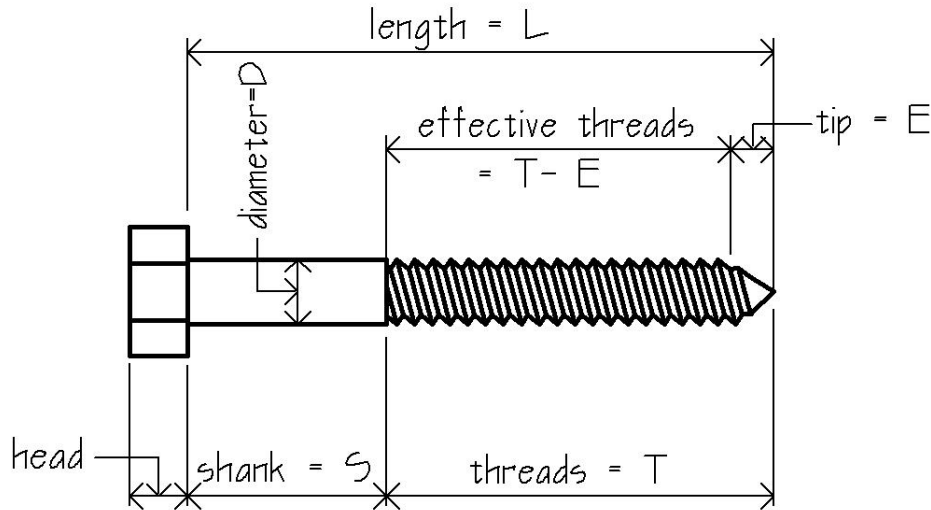
Figure 4. Standard Lag Screw Nomenclature

        Some lag screws (not "standard") are threaded for the full length. For those, and whenever threads occur at the shear plane, the diameter at the base of the threads (root diameter) is used in the calculations (Ref. 2, p.119).

        The proper installation of lag screws in either withdrawal or lateral loading typically requires a pilot hole drilled to two different diameters. The hole for the shank is drilled at the shank diameter and length and the hole is continued for the rest of the length of the lag screw at a reduced size. The recommended sizes for the threaded portion are based on the shank diameter, D, and the specific gravity, G, of the wood as follows: for $G > .6$, 65% to 85% of D; for $.5 < G \le .6$, 60% to 70% of D; for $G \le .5$, 40% to 70% (Ref. 1, p.66). Lead or pilot holes are not required for lag screws of 3/8" or smaller diameter if they are loaded primarily in withdrawal in wood of $G \le .5$. The use of lubrication to facilitate insertion of the lag screw does not affect its allowable load. Lag screws are to be screwed in, not driven in. When washers are used with lag screws the thickness of the washer must be considered in calculating depth of penetration.

LOAD APPLICATION

Loads may be applied laterally (sideways) or in withdrawal (direct pull). Single shear (two member) lateral loads are illustrated in Figures 2 and 3. Double shear (three member) lateral loads are illustrated in Figures 5 and 6. These loads are resisted by shear in the lag screws and dowel bearing on the members. In Figures 2 and 5, the loads are parallel to grain (or 0 degrees to grain) in both main and side members. In Figure 3, the load is parallel to grain in the side member and perpendicular to grain in the main member. In Figure 6, the load is parallel to grain in the side members and at θ degrees to grain in the main member. Three member joints are included in this discussion for completeness, but the use of bolts in this type connection is much more practical if it can be done.
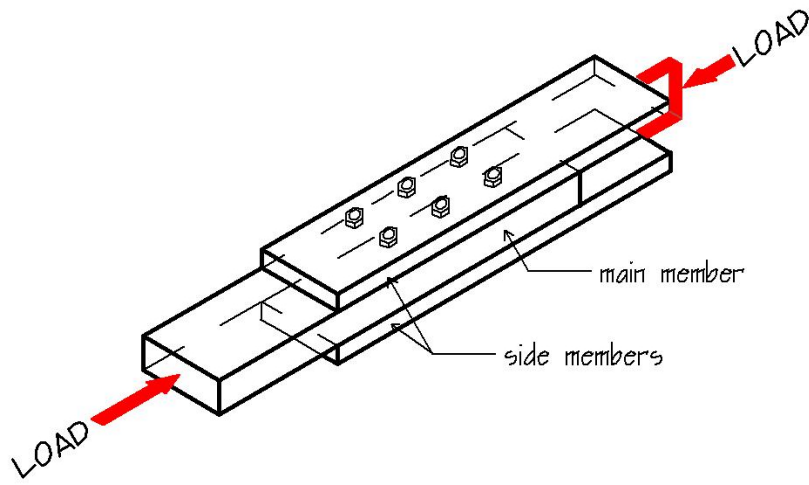
Figure 5. Lateral Loading
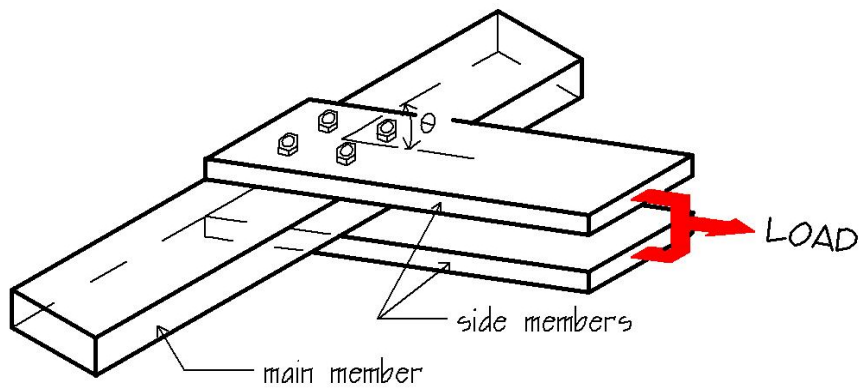
Figure 6. Lateral Loading

Lag screws also have the capacity to carrying load in direct withdrawal in either end or side grain as illustrated in Figure 7.
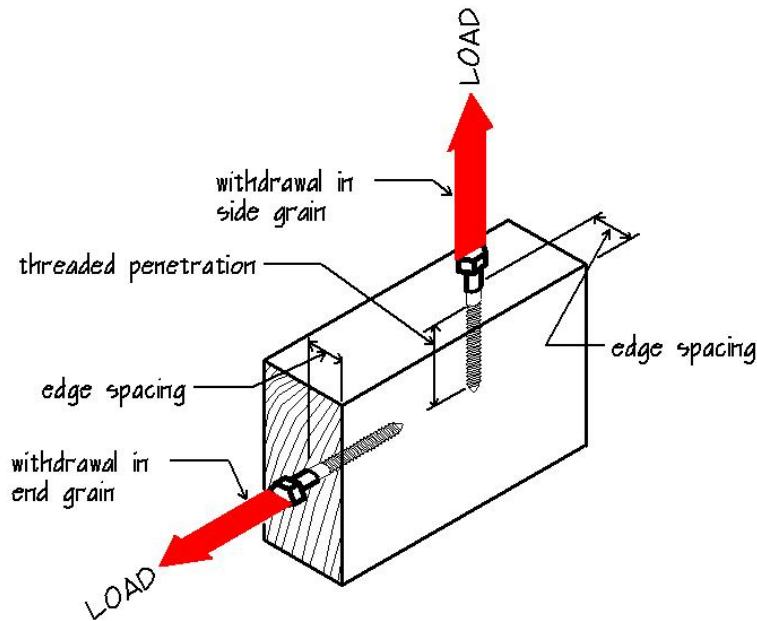
Figure 7. Withdrawal Loading

Loads may be at an angle other than 0^0 (withdrawal) and 90^0 (lateral) to the axis of the lag screw as shown in Figure 8. This is a combination of withdrawal and lateral loading. In Figure 8, the lag screw with Load B is inserted at an angle, β, and the load is parallel to the surface. The threaded penetration is measured perpendicular to the load (Ref. 1, p. 72). The lag screw with Load C is perpendicular to the surface but the load is at an angle, α, to the surface. If the angles are equal, the calculations are identical.
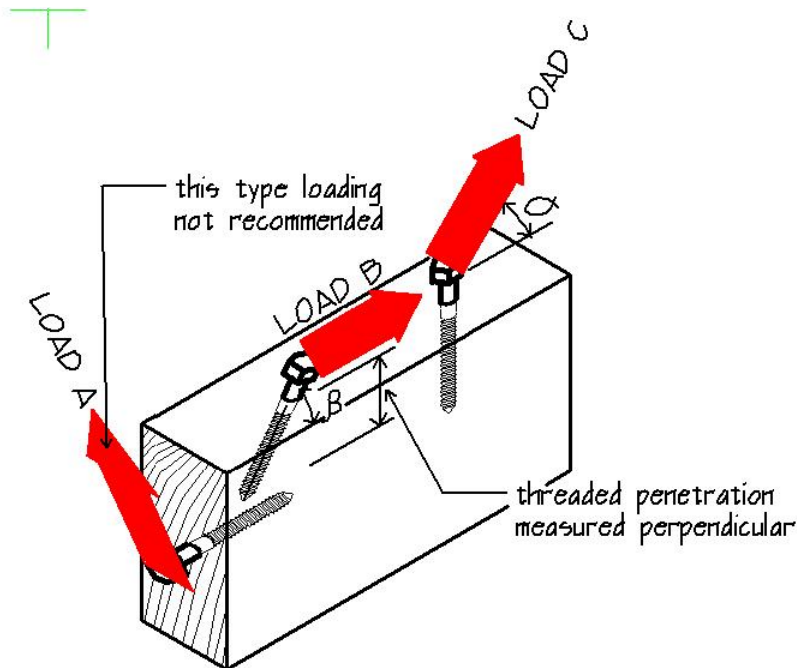
Figure 8. Combined Withdrawal and Lateral Loading

STEEL SIDE PLATES

Steel side plates are accommodated by using the same formulas that are used for wood side plates except F_{es} = 87000 psi is used in the failure mode formulas described below. The formulas in the spreadsheet are based on the use of A36 steel. The adjustment factors described above are used with wood, not steel. The Manual of Steel Construction allows the use of a 1.33 factor for wind or seismic loads (Ref 5, p.5-30). The tensile strength of the steel side plates is calculated by the spreadsheet.

FAILURE MODES AND EQUATIONS (Ref. 1, pp.71-72, 159)

Lateral Loads - There are three possible failure modes for the typical single shear (two member) wood to wood connection. These are shown in Figure 9. Only the last two failure modes apply to steel to wood connections. Formulas have been developed for the basic allowable load for each failure mode. Design involves calculating the value of each failure mode and selecting the lowest value. The formulas do not apply if there are not side members. The diameter, D, may be the shank diameter or the root diameter depending on the relationship of the threads and the members (Ref. 1, p. 75).
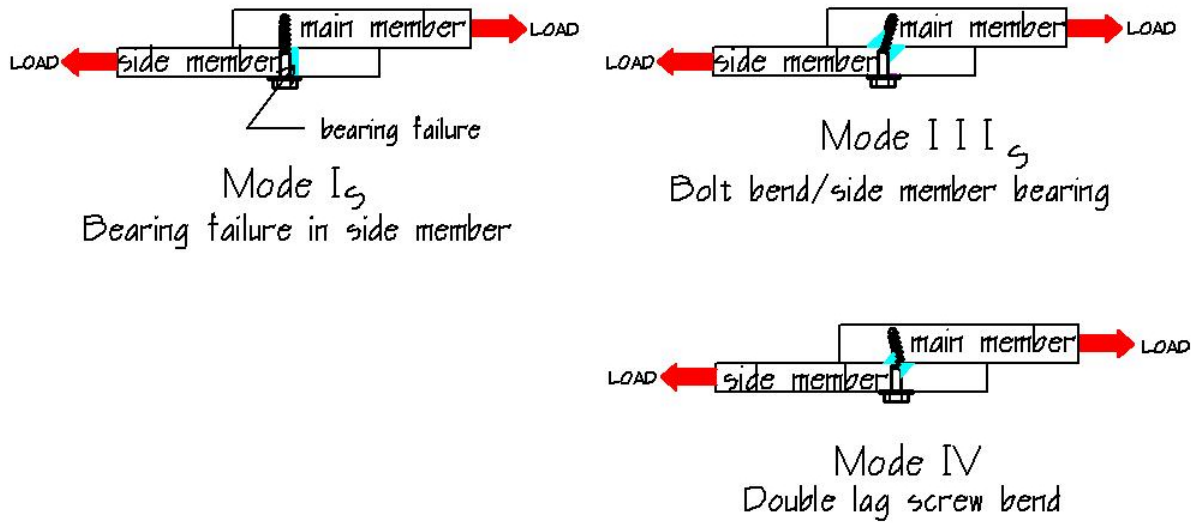
Figure 9. Lag Screw (Single Shear) Joint Failure Modes

Nomenclature: D = diameter (shank or root) F_{yb} = dowel bending yield strength (psi)
  $R_e = F_{em}/F_{es}$
  $K_\theta = 1 + .25(\theta/90)$ where θ is maximum angle to grain for any member
  Ls = dowel bearing length (penetration) in the side member (inches)
  F_{em} = dowel bearing strength of main member (psi)
  F_{es} = dowel bearing strength of side member (psi)
  Z = the allowable for a given failure mode

$$k = -1 + [2(1 + R_e)/R_e + \{2F_{yb}(2 + R_e)D^2\}/(3F_{em}L_s^2)]^{.5}$$

Single shear Mode I_S : $Z = DL_sF_{es}/4\ K_\theta$

Single shear Mode III_S : $Z = kDL_sF_{em}/\{(2 + R_e)\ 3.2\ K_\theta\}$

Single shear Mode IV: $Z = (D^2/3.2K_\theta)\{2F_{em}F_{yb}/3(1 + R_e)\}^{.5}$

The load factors relevant to lateral loads are C_D, C_g, C_Δ, C_M, and C_t.

Withdrawal Loads – The formula, per inch of threaded penetration, for withdrawal loads, W, perpendicular to side grain is given following (Ref. 2, p. 116). G is the specific gravity and D is the lag screw shank diameter. The tip of the lag screw is not included in the thread length.

$$W = 1800G^{1.5}D^{.75}$$

The load factors relevant to withdrawal loads are C_D, C_{eg}, C_d, C_M, and C_t. Minimum spacing requirements are given in Table 5.

Table 5. Spacing Requirements for Withdrawal Loaded Lag Screws (Ref. 1, pp. 78)

	Minimum Spacing
Edge Distance	1.5D
End Distance	4D
In A Row	4D
Between Rows	4D

Allowable tensile stress at the lag screw root diameter should be checked.

Combined Lateral and Withdrawal Loads (Ref. 2, p. 122) – The formula for determining allowable load, Z_α', at an angle, α, between the wood surface and the lag screw is:

$$Z_\alpha' = W'pZ'/(W'p\cos^2\alpha + Z'\sin^2\alpha)$$

W' is the factored (adjusted by load factors) withdrawal load
Z' is the factored (adjusted by load factors) lateral load
p is the length of threaded penetration measured perpendicular to the member

Combined lateral and withdrawal in end grain as illustrated by Load A in Figure 8 should be avoided (Ref. 1, p. 72).

MEMBER FAILURE IN TENSION

The capacity of a joint may be controlled by the allowable load on the main member or the side member. Members could be in bending, tension, or compression. For example, in Figure 3 the side member is in tension and the main member is in bending. In Figure 2, both members are in tension. In Figure 5, members are in compression. Regardless of calculated lag screw capacity, the load should not exceed the strength of the wood. Allowable tension load is the product of the net cross section area at the critical section and the allowable tensile stress. The net cross section area is the gross area reduced by the cross section removed by the lag screw holes.
Wood basic allowable tensile stresses are subject to modification by multiplying by appropriate factors as is the case with stress associated with lag screws. The duration of load factors, C_D, are the same. The temperature factor C_t = .9 if the temperature is greater than 100F degrees. An additional factor applied to allowable tensile stresses for wood, is the size factor C_f, given in Table 6.

Table 6. Tensile Stress Size Factors* (Ref.4, p.30)

Nom.Width	2,3,4	5	6	8	10	12
Factor	1.5	1.4	1.3	1.2	1.1	1.0

*This factor is included in the basic allowable stress for southern pine.

The tensile stresses for a few species, obtained from Reference 4, pp.31-38, are included in the spreadsheet. There is no group action factor or geometry factor as with lag screws. Member compression failure at the joint is not usually a problem. Checking bending is beyond the scope of this course. The spreadsheet determines allowable tension load based on net section across a set of holes. It does not apply for staggered bolt patterns and is limited to tension side members. Hole diameter sizes are assumed to be the same size as the lag screw. For example, if the side member in Figure 2 is a nominal 2x8 and the lag screws are 5/8" diameter the net area is:

$$(1.5 \text{ in})(7.25 \text{ in}) - 2(1.5 \text{ in})(.625 \text{ in}) = 9.00 \text{ sq. in.}$$

The "2" in the equation refers to the number of lag screws across the grain, not the number in a row. If the member is No. 1 Western Cedar, and the load is caused by snow, and other factors are normal, the allowable load based on the member is:

$$(425 \text{ psi})(1.15)(1.2)(1.0)(1.0)(9.00 \text{ sq. in.}) = 5280 \text{ pounds.}$$

The 425 psi came from the table on the spreadsheet, the 1.15 is C_D from Table 1, the 1.2 is C_f from Table 4, and the 1.0's are C_M and C_t from Table 3.

USING THE SPREADSHEET

The Excel© 2003 spreadsheet, LAGUP©, has the appropriate formulas embedded and provides some useful technical data. These are in protected cells so that they will not be inadvertently changed. Data for other species and grades can be obtained from references 3 and 4 or similar sources. Information provided by the user is entered into yellow or turquoise colored unprotected cells. An unprotected light yellow "Job Notes" pad is also provided. Results of the calculations are provided in red colored cells. Insofar as possible, the nomenclature used in the foregoing explanation is used in the spreadsheet. Many of the cells have explanatory notes attached. The spreadsheet works well to try alternate design solutions. Lateral loading is limited to two member (single shear) connections. The main member is wood; the side member may be wood or steel. Example problems follow with explanations. Example Problem 1 is entered into the spreadsheet.

Example Problem 1: Use a connection like that shown in Figure 2.
                   Side member is S4S 2x10 No.1 Doug Fir-Larch`
                   Main member is S4S 3x10 No.1 Doug Fir-Larch
                   3/8" x 4" mild steel lag screws at 3" spacing in a row
                   Load is snow load; other factors are normal.
The values entered into the various spreadsheet cells are shown in Table 7.

Table 7. Spreadsheet Entries for Example Problem 1.

*inactive, could be blank or any value

Cell	E24	E25	E26	E27	E28	E29	E30	E31	E32	E33	E34	E35
entry	L	s	g	w	s	.375	4.0	*	*	45000	1.5	2.5

Cell	E36	E37	E38	E39	E40	E41	E42	M34	M35	M37	M38	E66
entry	.5	.5	0	0	0	90	.125	*	*	*	*	6

Cell	E67	E68	E69	E72	K67	K68	K69	K70	K71	K72	K73	E85
entry	1.15	1	1	1	2	3	3.0	1.7	1.7	23.12	13.87	675

Cell	E86	E87	E88	E89	K85	K86
entry	675	1.1	1.1	1.0	9.25	9.25

The answer provided based on the lag screws is 1020 pounds based on Yield Mode III$_s$.
The answer provided based on main member tension is 15850 pounds, and based on the
side member tension is 9470. Therefore, the lag screw capacity controls.

Example Problem 2: Use a connection like that shown in Figure 3.
                    Side member is rough 2x10 No.1 Western Cedar
                    Main member is rough 3x8 No.2 Doug Fir-Larch
                    1/4" x 5" mild steel lag screws at 3.5" spacing in a row,
                    5" between rows
                    Normal loading and conditions.
The values entered into the various spreadsheet cells are shown in Table 8.

Table 8. Spreadsheet Entries for Example Problem 2.

*inactive, could be blank or any value

Cell	E24	E25	E26	E27	E28	E29	E30	E31	E32	E33	E34	E35
entry	L	s	g	w	s	.25	5.0	*	*	70000	2	3

Cell	E36	E37	E38	E39	E40	E41	E42	M34	M35	M37	M38	E66
entry	.36	.5	0	90	0	90	.125	*	*	*	*	4

Cell	E67	E68	E69	E72	K67	K68	K69	K70	K71	K72	K73	E85
entry	1	1	1	1	2	2	3.5	1.7	1.0	15.00	20.00	575

Cell	E86	E87	E88	E89	K85	K86
entry	425	1.2	1.1	1.0	8.00	10.00

The 15.0 entered in cell K72 was determined by:
                    3" thick x 5" fastener group width = 15.0 sq. in.
The values entered in cells E85 and E87 are not used by the spreadsheet in this case.

The answer provided based on the lag screws is 280 pounds based on Yield Mode IV. The answer provided based on side member tension is 8880 pounds. Therefore the lag screw capacity controls.

Example Problem 3: Use a connection like that shown in Figure 10 following.
            Side members (splice plates) are ¼" by 8" steel
            Main member is rough 3x12   No.1 Red Oak
            Use 1/2" x 3" mild steel full threaded lag screws at 3" spacing
            in a row.
                Wind loading and moist conditions.
The values for one splice plate are entered into the various spreadsheet cells are shown in Table 9.

 Table 9. Spreadsheet Entries for Example Problem 3.

   *inactive, could be blank or any value

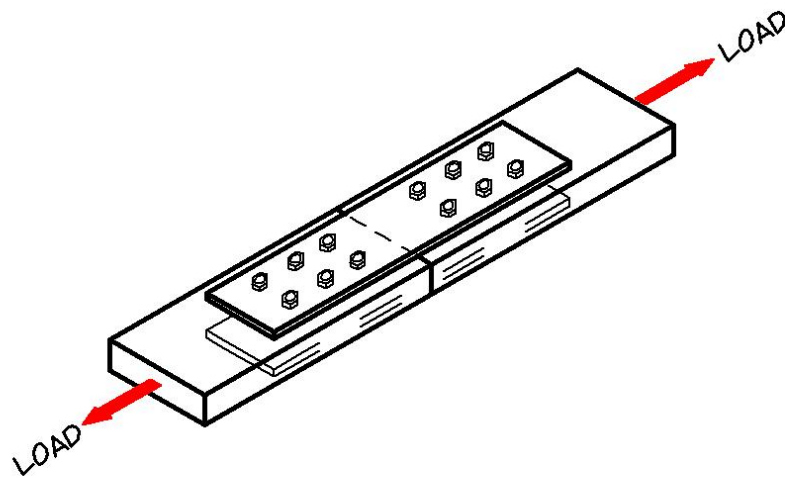| Cell	E24	E25	E26	E27	E28	E29	E30	E31	E32	E33	E34	E35
entry	L	s	g	s	f	.50	3.0	*	*	45000	.25	3.0
Cell	E36	E37	E38	E39	E40	E41	E42	M34	M35	M37	M38	E66
entry	*	.67	0	0	0	90	.125	*	*	*	*	6
Cell	E67	E68	E69	E72	K67	K68	K69	K70	K71	K72	K73	E85
entry	1.6	.7	1	1	2	3	3.0	1.3	30	36.00	2.00	500
Cell	E86	E87	E88	E89	K85	K86						
entry	28700	1.0	*	1.0	12.00	8.00						

Figure 10. Steel Splice Plates on Wood

There are six lag screws "in the joint" used in the spreadsheet, not twelve lag screws, and there are three lag screws in a row, not six.

The answer provided based on the lag screws is 2270 pounds based on Yield Mode III$_s$. The answer provided based on the main member tension is 11680 pounds. The steel side plate has a tension capacity of 50230 pounds. Therefore, the lag screw capacity controls. With adequate lag screw spacing, a similar splice plate could be installed on the back of the joint and nearly double the joint capacity since the capacity is dominated by the lag screw strength. If the area of both side plates (4.00) is used in cell K74 the group action factor given is .99. If both sides of the joint are accessible it is better to use bolts.

Example Problem 4: Use a connection like that shown in Figure 7 (side grain).
　　　　Use one 5/8" x 6" mild steel lag screw with 3 1/2" penetration into side grain of southern pine.
　　　　Long term (dead) load controls. Other conditions normal.
The values entered into the various spreadsheet cells are shown in Table 10.

Table 10. Spreadsheet Entries for Example Problem 4.

*inactive, could be blank or any value

Cell	E24	E25	E26	E27	E28	E29	E30	E31	E32	E33	E34	E35
entry	w	s	*	*	*	.625	*	3.5	*	*	*	*
Cell	E36	E37	E38	E39	E40	E41	E42	M34	M35	M37	M38	E66
entry	*	.55	*	*	*	*	*	*	*	*	*	1
Cell	E67	E68	E69	E72	K67	K68	K69	K70	K71	K72	K73	E85
entry	.9	1	1	1	*	*	*	*	*	*	*	*
Cell	E86	E87	E88	E89	K85	K86						
entry	*	*	*	*	*	*						

The withdrawal capacity of the lag screw is 1440 pounds.

Example Problem 5: Use a connection like Load C shown in Figure 8.

　　　　Use one 1/2" x 4" mild steel lag screw with 3" penetration into a 4" thick Douglas Fir-Larch main member using a ¼" thick steel side plate (not shown in Figure 8). Angle of load to wood surface is 60 degrees. Damp location, wind load.

The values entered into the various spreadsheet cells are shown in Table 11.

Table 11. Spreadsheet Entries for Example Problem 5.

*inactive, could be blank or any value

Cell	E24	E25	E26	E27	E28	E29	E30	E31	E32	E33	E34	E35
entry	c	s	g	s	s	.50	4	2.5	3.75	45000	.25	4
Cell	E36	E37	E38	E39	E40	E41	E42	M34	M35	M37	M38	E66
entry	*	.5	*	0	60	90	.125	*	*	*	*	1
Cell	E67	E68	E69	E72	K67	K68	K69	K70	K71	K72	K73	E85
entry	1.6	.7	1	1	1	1	*	*	*	*	*	*
Cell	E86	E87	E88	E89	K85	K86						
entry	*	*	*	*	*	*						

The answers provided for the lag screw is 800 pounds lateral load based on Yield Mode III$_s$ and 930 pounds withdrawal load. The combined (at the angle) load is 890 pounds. No width was given for the steel plate so no allowable tension load was given for it.

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