Design Bolted Wood Connections With Spreadsheet

Course Content

INTRODUCTION

The integrity of a structure under load depends on the structural members and the connections. Connection design is, therefore, an integral part of the design process. Bolts are one of the most important and common connectors and are used to attach wood members together in a variety of ways, as well as to attach wood to concrete or masonry. Specific loads can be assigned to bolted 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 bolted wood connections and includes the Excel© 2003 spreadsheet, BOLTUP©, with five examples of its use. The spreadsheet is designed for stand alone use for many common situations requiring only information provided in the discussion following 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 challenging, in part, because of the nature of wood. Dozens of species are used and the relevant structural properties of wood vary within a species and between species. Also, the structural properties within one piece vary significantly depending on the direction of the wood grain. Wood logs may be sawed and milled only (solid lumber) or may be manufactured into "engineered" wood products (glued-laminated, I joists, etc.) or otherwise reconstituted (plywood, oriented strand board, etc.). 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) which provide information relevant for wood structural design, including connector design. Reference 1 provides information for both sawed lumber and glued laminated timber. Technical information for "engineered" lumber products is available from the 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 connector design.

<u>Species</u> – 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. This course (and nearly all wood structures in this country) is limited to exogenous trees, those that grow by adding material to the outside in "rings." Density

varies from species to species which depends to a large extent on the ratio of spring growth and summer growth and the overall growth rate.

Density/Specific Gravity – Wood structural properties vary in large part because of density. Therefore, density is a fundamental parameter for connector design. English units are commonly used in the United States. Sometimes the number of pounds per cubic foot is used; other times the specific gravity is used. A typical value for dry softwood is 29 lbs/ft^3 which gives a specific gravity of .46 as shown below.

$$29\ lbs/ft^3 / 62.4\ lbs/ft^3 = .46$$

A specific value given usually represents an average for an entire species and is usually given to two significant digits as illustrated above. The National Design Specification publication (Ref. 1, p.74) uses the expression “Assigned Specific Gravity” with a table of values. The spreadsheet provides a table of specific gravities for some common species.

Grade – Grading agencies have been organized for various commercially useful wood species. The agencies have promulgated rules based on extensive testing by which wood is sorted into grades by humans or machines. Grading of structural lumber takes into account the many factors that affect structural properties. Basic structural design values are assigned for specific grades and species. Typical grades for lumber, in decreasing order, are “Structural,” “No. 1,” and “No. 2.” The number of grades varies from one grading agency (and species) to another. Even within one grade of one species there is a large range in a given engineering property so the assigned design values are conservative. Because they have similar properties, some species are grouped.

Moisture Content – Wood may contain varying amounts of water. It may be in “cells” (open pores) which 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 30 grams had a moisture content of:

(40grams-30 grams) /30 grams = 33% 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 the magnitudes of which differ in different directions within the wood. The effects of moisture content and its possible variation throughout the life of a structure require the use of proper connector material, careful detailing and the possible use of reduced design values. Connectors used in wet conditions should be galvanized or stainless steel. Bolt holes are slightly oversized and used at prescribed maximum and minimum spacings. 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. Generally, the strength parameters relevant to major connector design are highest in that direction. The direction at right angles to the tree length radially in any direction is called perpendicular to grain. The strength parameters relevant to major connector design are significantly smaller in that direction. Strength parameters 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. Connectors are typically used in "side grain," but, in some instances, they may be used in "end grain." 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. Strength parameters are higher in side grain. End grain loading is given a zero value for some situations. It is unlikely that a bolt would be used in end grain. Figure 1 illustrates various aspects of grain direction. Loads shown are parallel to the surfaces of the structural member but at various angles to the grain of the structural member. The spreadsheet to be illustrated in this course is limited to these kinds of "lateral" non-prying and non-withdrawal loads which are most likely to be relevant to bolted connections.

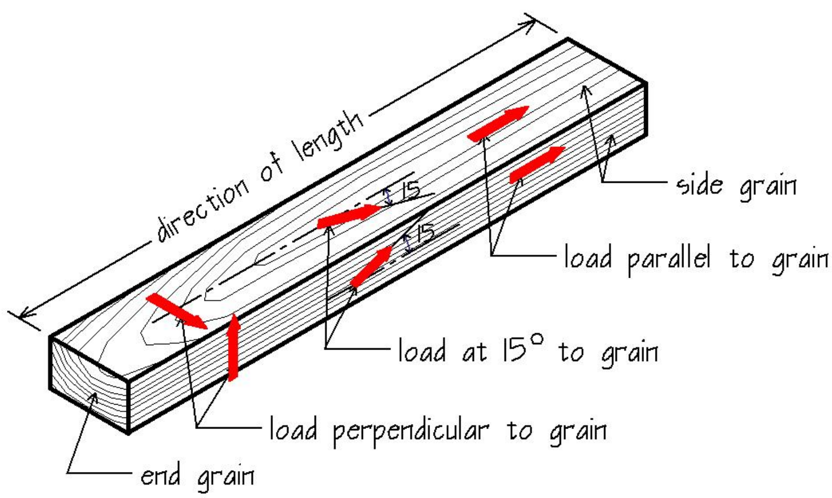

Figure 1. Wood Grain and Load Directions

Engineering Properties - The wood strength parameter that controls bolt 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 bolt (or "dowel") size. The calculation of F_e is based on wood specific gravity, G, and bolt diameter, D, as follows: $F_{e\|}$ is dowel bearing stress parallel to grain; $F_{e\perp}$ is dowel bearing stress perpendicular to grain.

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

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 .46 = 11200(.46) = 5150 psi for bolts sizes ¼" thru 1."

For the same wood and a ½" bolt $F_{e\perp} = 6100(.46)^{1.45}/(.50)^{.5} = 2800$ psi.

$F_{e(15)}$ for a ½" bolt $= (5150)(2800)/\{(5150)(.259)^2 + (2800)(.966)^2\} = 4850$ psi.

Bolt diameters are limited to between ¼" and 1" inclusive. Bolts with diameters up to 1½" were included in previous issues of the NDS and may be used at the discretion of the designer (Ref. 2, p. 97). 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. An equation for calculating duration factor is available (Ref. 2, p.8). 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 = .46 with wind load controlling:

$$F_{e\parallel} = 1.6\,(5150) = 8250 \text{ psi (rounded to closest 50)}$$

Suppose, however, the following loads:

Dead Load = 1000 pound and
Occupancy Live Load = 3000 pounds and
Wind Load = 1000 pounds

The dead load, which might be alone, has an allowable stress of (.9)(5150) = 4650 psi. The dead plus the occupancy live load has an allowable stress of (1)(5150) = 5150 psi.

The total load has an allowable stress of (1.6)(5150) = 8250 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: 1000/.9 = 1110, 4000/1.0 = 4000, 5000/1.6 = 3120. 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 bolt is not a simple multiple of the number of bolts used and the value for one bolt. A group action factor, C_g , is calculated based on the number of bolts in a row and the relative stiffnesses of the members bolted together. The stiffness depends on member cross section area and modulus of elasticity. Moduli of elasticity for various wood species are included in reference 4, pp. 31-38. The spreadsheet includes moduli for some common species; 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:

Row – a series of connectors parallel to the load.

Side Member(s) – in a two member connection the thinner of the members; in a three member connection the outer members.

Main member – in a two member connection the thicker of the two members; in a three member connection the middle member. If the members of a two member connection are of equal thickness either may be designated the main member.

See Figures 2 through 5 for illustrations.

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 bolts is used the area is the product of the member thickness and the minimum parallel to grain spacing of the bolts. The formula for C_g follows (after Ref 1, p.60):

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

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

$m = u - (u^2-1)^{.5}$ $\quad$ $u = 1+.5\lambda s(1/E_mA_m + 1/E_sA_s)$

$\lambda = 180000D^{1.5}$ 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_sA_s/E_mA_m or E_mA_m/E_sA_s

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

For design, the use of the group action factor requires repetitive passes since the number of bolts is unknown until the connection is designed. The spreadsheet is very useful for repetitive calculations.

Geometry Factor/Spacings – Bolt spacings must be adequate for full design values. Spacings less than those given in Table 2 require that the load value be reduced by the geometry factor, C_Δ. See reference 1, pp. 76-78 for this calculation.
In Table 2, D is the bolt diameter and L is the smaller of the length of the bolt in the main member and the total of the length of the bolt in the wood side members.

Table 2. Minimum Bolt Spacing for $C_\Delta = 1$ (Ref. 1, pp.76-78)

	$\parallel$ to Grain	$\perp$ to Grain
Edge Distance	$L/D \le 6$ 1.5D $L/D > 6$ Greater of 1.5D or ½ spacing between rows	Loaded Edge 4D Unloaded Edge 1.5D
End Distance	Compression 4D Tension Softwood 7D Hardwood 5D	Softwood 4D Hardwood 4D
In A Row	4D	Required spacing for Attached members
Between Rows	1.5D	$L/D \le 2$ 2.5D $2 < L/D < 6$ (5L+10D)/8 $L/D \ge 6$ 5D

Figures 2 and 3 illustrate bolt 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. Calculations of geometry factor and the use of staggered bolts is beyond the scope of this course.

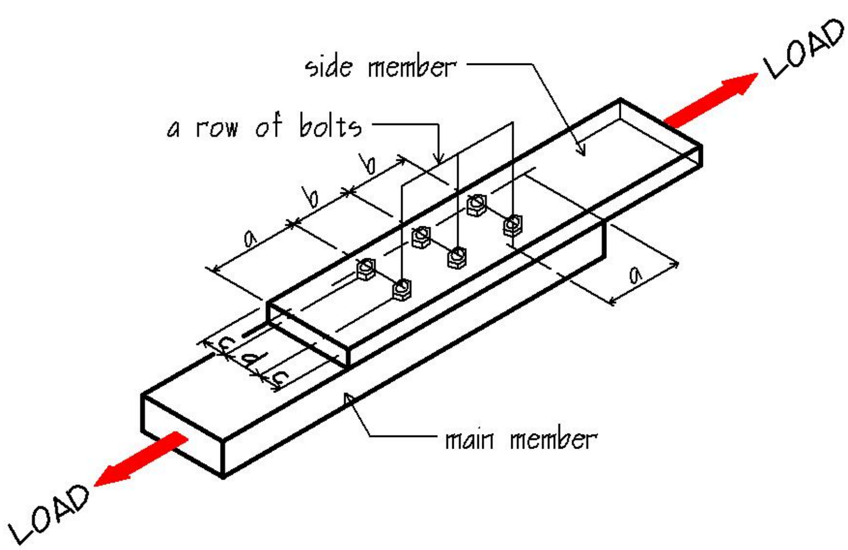

Figure 2. Bolt Spacing and Loading

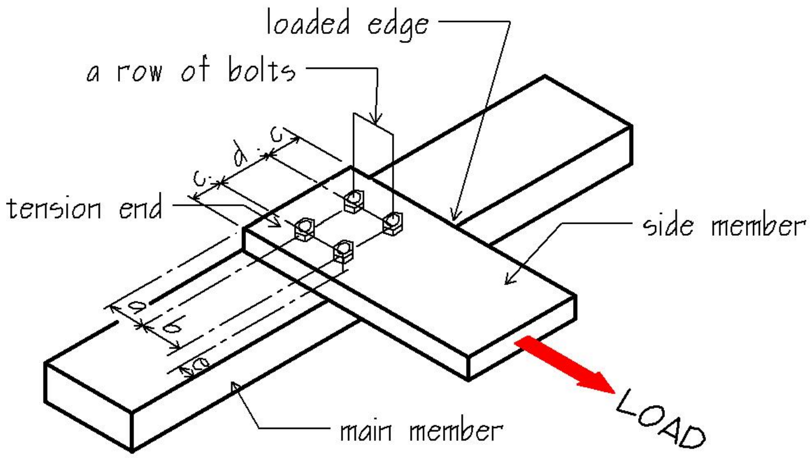

Figure 3. Bolt Spacing and Loading

Other Adjustment Factors – Two other things that affect bolted wood strength that may require adjustments to the basic design values 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 bolts 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_t	C_t
At Fabrication	In Use		$100<T\leq125$	$125<T\leq150$
≤19%	≤19%	1.0	.8	.7
>19%	≤19%	.4	.8	.7
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.

COMBINING FACTORS

All factors that are 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 1000 psi is subject to construction load and moisture concurrently, the allowable stress is:

$$(1000 \text{ psi})(1.25)(.7) = 875 \text{ psi}$$

Where 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.

BOLT PROPERTIES RELEVANT TO WOOD DESIGN (Ref. 2, p. 97)

The bending yield strength of the bolt, F_{yb}, may be a factor in determining a connection capacity. F_{yb} is taken as the average between the yield stress and the ultimate tensile stress of the bolt steel. (Ref. 2, p.100) For A307 bolts it is 45000 psi; for Grade 2 bolts it is 48000 psi. For higher strength bolts (e.g., stainless steel, Grade 5, Grade 8 and A325) the yield strengths and ultimate tensile strengths are considerably higher and the connection capacity may be higher.

The nut is usually tightened enough to bring the washers into firm bearing on the wood, but the values calculated by the NDS procedures also apply to "loose" nuts. Threads are allowed in shear planes, but it is better to avoid it if practical. It is recommended that bolt diameters range from ¼" to 1." Larger diameter (1 ¼" and 1 ½") bolts were included in previous NDS publications. They are not prohibited, but are to be used at the designer's discretion if fabrication is carefully done. Bolt holes are drilled with diameters over-sized by 1/32" for smaller bolts and over-sized by 1/16" for larger bolts. In the spreadsheet, it is assumed that holes are over-sized by 1/16."

LOAD APPLICATION

This course and the spreadsheet provided deals with loads applied parallel to the members as is shown in Figures 1 through 5. These are called "lateral" loads and are resisted by shear in the bolts and dowel bearing on the member. This is in contrast to "withdrawal" loads which are along the axis of the bolt and to combined lateral and withdrawal loads at some value between parallel and perpendicular to the bolt axis. In a two member joint, as illustrated in Figures 2 and 3, the bolts are in single shear. In a three member joint, as illustrated in Figures 4 and 5, the bolts are in double shear. In Figures 2 and 4, 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 5, the load is parallel to grain in the side members and at θ degrees to grain in the main member.

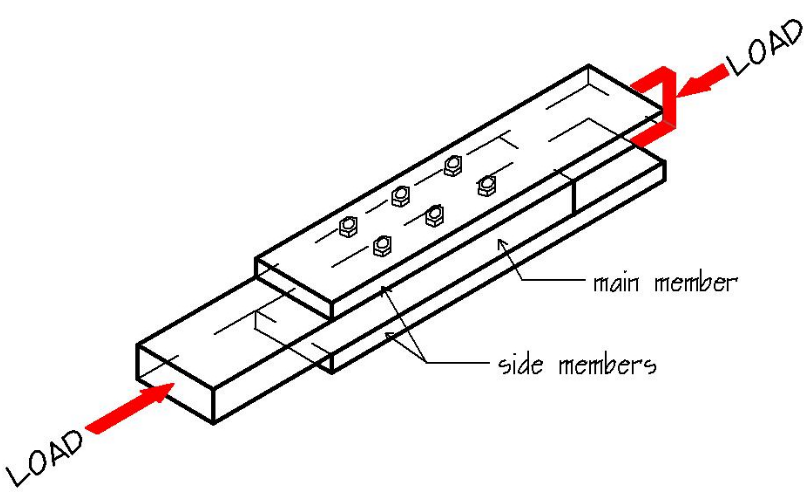

Figure 4. Lateral Loading

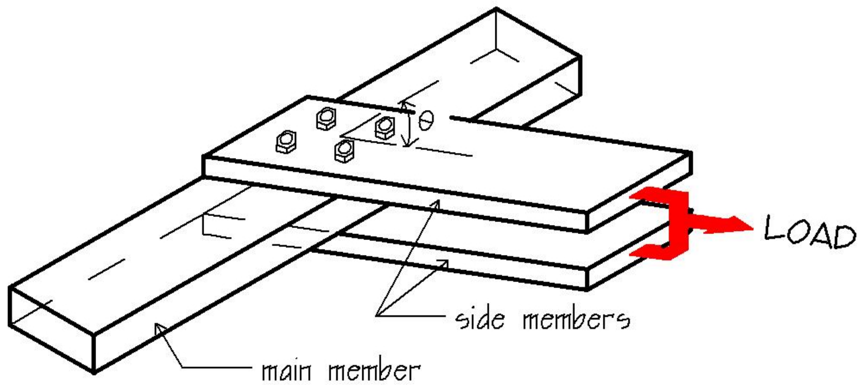

Figure 5. Lateral Loading

Bolts may connect more than three members. In that case, each member pair is analyzed as a two member joint and the total joint capacity is the product of the weakest member pair and the number of shear planes.

STEEL SIDE PLATES

Steel side plates are accommodated by using the same formulas that are used for wood side plates except F_{es} = 58000 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 6, p.5-30). The tensile strength of the steel side plates are calculated by the spreadsheet.

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

There are six possible failure modes for a single shear (two member) connection and four possible failure modes for a double shear (three member) connection. These are shown in Figures 6 and 7. 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.

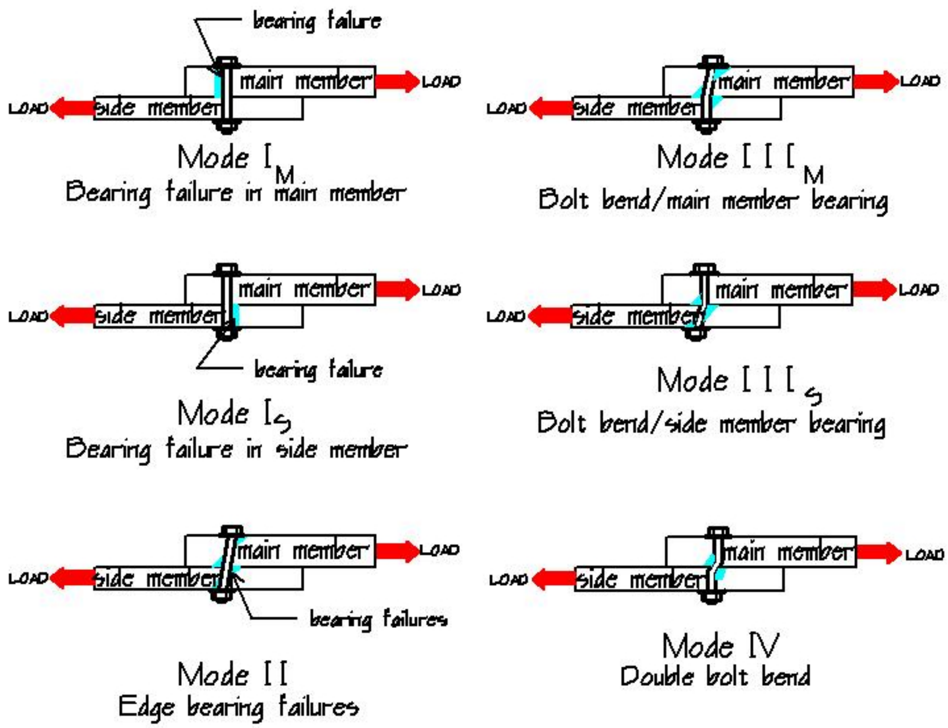

Figure 6. Two Member (Single Shear) Bolted Joint Failure Modes

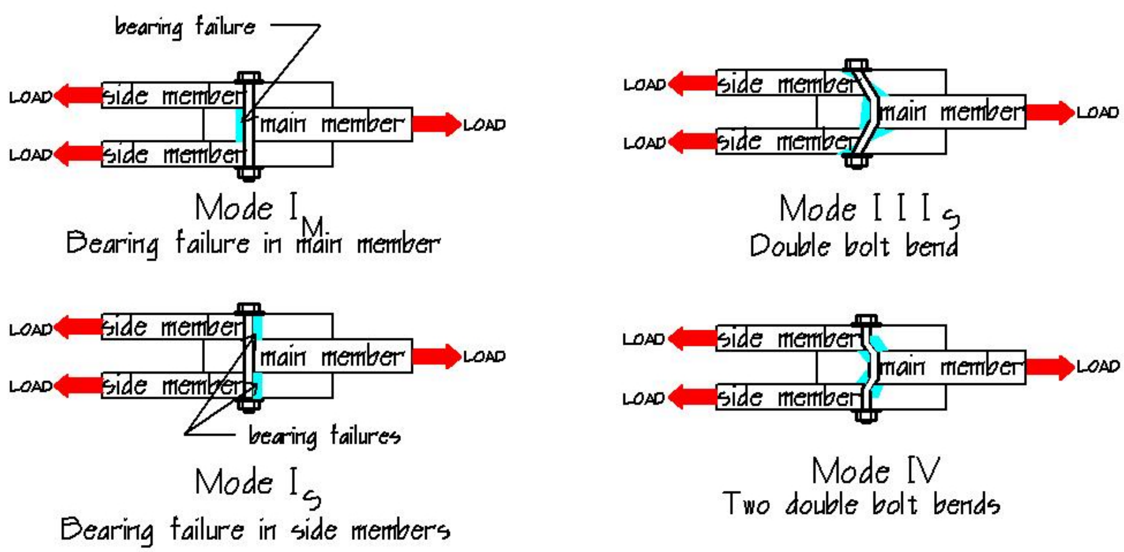

Figure 7. Three Member (Double Shear) Bolted Joint Failure Modes

Nomenclature: D = diameter (inches) F_{yb} = dowel bending yield strength (psi)
$R_e = F_{em} / F_{es}$ $R_t = L_m / Ls$
$K_{\theta} = 1+.25(\theta/90)$ where θ is maximum angle to grain for any member
L_m = dowel bearing length in main member (inches)
Ls = dowel bearing length in one 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

$$k_1 = [\{R_e + 2 R_e^2 (1+R_t+ R_t^2) + R_t^2 R_t^3\}^{.5} - R_e(1 + R_t)]/(1 + R_e)$$

$$k_2 = - 1 + [2(1 + R_e) + \{2F_{yb}(1 + 2 R_e)D^2\}/(3F_{em}L_m^2)]^{.5}$$

$$k_3 = - 1 + [2(1 + R_e)/R_e + \{2F_{yb}(2 + R_e)D^2\}/(3F_{em}L_s^2)]^{.5}$$

Single shear Mode I_M : $Z = DL_mF_{em}/4 K_{\theta}$

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

Single shear Mode II : $Z = k_1DL_sF_{es}/3.6 K_{\theta}$

Single shear Mode III_M : $Z = k_2DL_mF_{em}/\{(1 + 2R_e)3.2 K_{\theta}\}$

Single shear Mode III_S : $Z = k_3DL_sF_{em}/\{(2 + R_e) 3.2 K_{\theta}\}$

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

Double shear Mode I_M : $Z = DL_mF_{em}/4 K_{\theta}$

Double shear Mode I_S : $Z = 2DL_sF_{es}/4 K_{\theta}$

Double shear Mode III_S : $Z = 2k_3DL_sF_{em}/\{(2 + R_e) 3.2 K_{\theta}\}$

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

CONNECTING WOOD TO CONCRETE OR MASONRY

The formulas given above can be used to calculate the capacity of the wood member in wood to concrete or wood to masonry connections by using the following values and the single shear mode formulas (Ref. 5, pp. 15.18, 15.19). The concrete or masonry becomes the main member with L_m = bolt embedment length in the concrete or masonry and F_{em} = 6000 psi provided the ultimate compressive strength of the concrete or masonry is ≥ 2000 psi. Reference 3, p. 20, contains a table of values for one condition. Stress adjustment factors apply to the wood (Ref. 3, p. 20). Reference 1 does not address the exact procedure for calculating variables for the group action factor, C_g. The author's approach is given in example problem 4.

MEMBER FAILURE

The capacity of a joint may be controlled by the allowable load on the main member or side members. 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, members are in tension. In Figure 4, members are in compression. Regardless of calculated bolt 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 bolt holes. Wood basic allowable tensile stresses are subject to modification by multiplying by appropriate factors as is the case with stress associated with bolts. 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 4.

Table 4. 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 bolts. 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 bolt holes. It does not apply for staggered bolt patterns and is limited to tension members and two and three member connections. Hole diameter sizes are assumed to be 1/16" bigger than the bolt size. For example, if the side member in Figure 2 is a nominal 2x8 and the bolts are 5/8" diameter the net area is:

$$(1.5 \text{ in})(7.25 \text{ in}) - 2(1.5 \text{ in})(.6875 \text{ in}) = 8.81 \text{ sq. in.}$$

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

$$(425 \text{ psi})(1.15)(1.2)(1.0)(1.0)(8.81 \text{ sq. in.}) = 5170 \text{ pounds.}$$

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. The answer is rounded to the closest 10 pounds.

USING THE SPREADSHEET

The Excel© 2003 spreadsheet, BOLTUP©, 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. At least one of the members must be wood (not steel side members with masonry main members). Adequate bolt spacing is assumed. Example problems follow with explanations. Example Problem 1 is entered into the spreadsheet.

Example Problem 1: Use a connection like that shown in Figure 4.
Side members are S4S 2x10's No.2 Doug Fir-Larch
Main member is S4S 3x10 No.1 Doug Fir-Larch
3/4" A307 bolts at 3" spacing in a row
Load is snow load

The values entered into the various spreadsheet cells are shown in Table 5.

Table 5. Spreadsheet Entries for Example Problem 1.

*inactive, could be blank or any value

Cell	E21	E22	E23	E24	E25	E26	E27	E28	E29	E30	E31	E32
Value	g	d	w	w	.75	45000	1.5	2.5	.50	.50	0	0
Cell	M27	M28	M30	M31	E52	E53	E54	E55	K52	K53	K54	K55
Value	*	*	*	*	6	1.15	1.0	1.0	2	3	3.0	1.7
Cell	K56	K57	K58	E69	E70	E71	E72	E73	K69	K70		
Value	1.6	23.1	27.8	675	575	1.1	1.1	1.0	9.25	9.25		

The answer provided based on the bolts is 16490 pounds based on Yield Mode III_s. The answer provided based on main member tension is 16280 pounds, and based on the side member tension is 16640. Therefore, the wood main member tensile 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
3/4" A307 bolts at 3.5" spacing in a row, 5" between rows
Normal loading

The values entered into the various spreadsheet cells are shown in Table 6.

Table 6. Spreadsheet Entries for Example Problem 2.

*inactive, could be blank or any value

Cell	E21	E22	E23	E24	E25	E26	E27	E28	E29	E30	E31	E32
Value	g	s	w	w	.75	45000	2.0	3.0	.36	.50	0	90
Cell	M27	M28	M30	M31	E52	E53	E54	E55	K52	K53	K54	K55
Value	*	*	*	*	4	1.0	1.0	1.0	2	2	3.5	1.6
Cell	K56	K57	K58	E69	E70	E71	E72	E73	K69	K70		
Value	1.0	15.0	20.0	575	425	1.2	1.1	1.0	8.00	10.0		

The 15.0 entered in cell K57 was determined by:

3" thick x 5" fastener group width = 15.0 sq. in.

The answer provided based on the bolts is 2200 pounds based on Yield Mode II. The answer provided based on the member tension is 7830 pounds. Therefore the bolt capacity controls.

Example Problem 3: Use a connection like that shown in Figure 8 following.
Side members (splice plates) are ¼" by 8" steel
Main member is rough 3x12 No.1 Red Oak
7/8" A307 bolts at 3 1/2" spacing in a row. Wind loading.

Table 7. Spreadsheet Entries for Example Problem 3.

*inactive, could be blank or any value

Cell	E21	E22	E23	E24	E25	E26	E27	E28	E29	E30	E31	E32
Value	g	d	s	w	.875	45000	.25	3.0	*	.67	0	0
Cell	M27	M28	M30	M31	E52	E53	E54	E55	K52	K53	K54	K55
Value	*	*	*	*	6	1.6	1.0	1.0	2	3	3.5	1.3
Cell	K56	K57	K58	E69	E70	E71	E72	E73	K69	K70		
Value	30.0	36.0	4.0	500	21600	1.0	*	1.0	12.0	8.00		

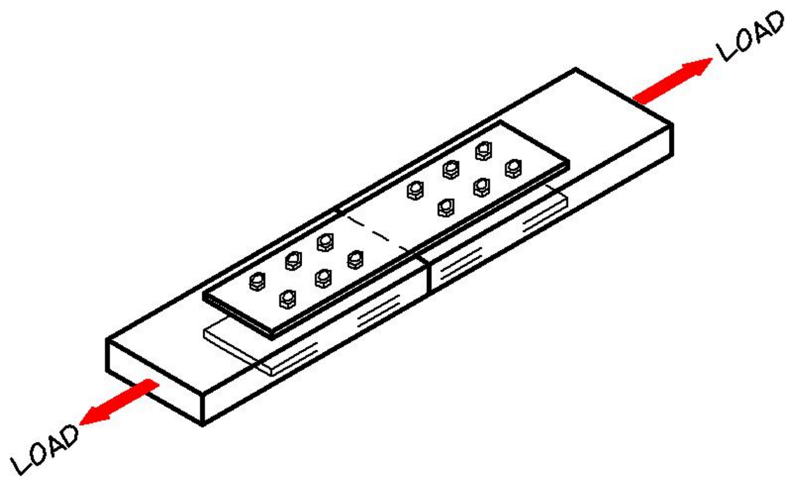

Figure 8. Steel Splice Plates on Wood

There are six bolts "in the joint" used in the spreadsheet, not twelve bolts, and there are three bolts in a row, not six. The value for steel bearing was entered automatically.

The answer provided based on the bolts is 45560 pounds based on Yield Mode III_s. The answer provided based on the main member tension is 24300 pounds. The steel side plates have a tension capacity of 66150 pounds. Therefore the wood tension member capacity controls.

Example Problem 4: Connect a pressure treated #2 southern pine 2x4 bottom plate to the edge of a 3000 psi concrete slab with A307 ½" anchor bolts at ends and at 48" o.c. Assume a 4" bolt embedment and 12' long plates. Load is wind load creating shear.

Table 8. Spreadsheet Entries for Example Problem 4.

*inactive, could be blank or any value

Cell	E21	E22	E23	E24	E25	E26	E27	E28	E29	E30	E31	E32
Value	g	s	w	m	.50	45000	1.5	4.0	.55	*	0	0
Cell	M27	M28	M30	M31	E52	E53	E54	E55	K52	K53	K54	K55
Value	*	*	*	*	4	1.6	.9	1.0	1	4	48	3.1
Cell	K56	K57	K58	E69	E70	E71	E72	E73	K69	K70		
Value	1.7	99	5.25	*	825	*	1.5	1.0	*	3.5		

The value for concrete bearing was entered automatically. The .9 in cell E54 was a judgment call based on pressure treatment. Depending on the preservative treatment method, this could have been 1.0. The value in cell K55 is the modulus of elasticity of 3000 psi concrete = $(57000)(3000)^{.5}$. The value in cell K57, "the area of the main member," is a judgment call. The final answer is not very sensitive to this number as long as it is relatively large.

The answer provided based on the bolts is 2130 pounds based on Yield Mode III_s. The answer provided based on side member tension is 8720 pounds. Therefore, the bolt capacity controls.

Example Problem 5: Use a connection like that shown in Figure 5 except use one 1" diameter A307 bolt. Side members are S4S 2x6's with $F_{e\parallel}$ = 5250 psi, $F_{e\perp}$ = 2050 psi, F_t = 450 psi and E = 1100000 psi. The main member is a S4S 2x10 with $F_{e\parallel}$ = 5700, $F_{e\perp}$ = 2300 psi, F_t = 750 psi and E = 1300000 psi. □ is 75° "Normal" loading.

Table 9. Spreadsheet Entries for Example Problem 5.

*inactive, could be blank or any value

Cell	E21	E22	E23	E24	E25	E26	E27	E28	E29	E30	E31	E32
Value	b	d	w	w	1.0	45000	1.5	1.5	*	*	0	75
Cell	M27	M28	M30	M31	E52	E53	E54	E55	K52	K53	K54	K55
Value	5250	2050	5700	2300	1	1.0	1.0	1.0	1	1	*	*
Cell	K56	K57	K58	E69	E70	E71	E72	E73	K69	K70		
Value	*	*	*	750	450	1.1	1.3	1.0	9.25	5.5.		

When only one bolt is used the group adjustment factor is set to 1.0 so several of the cells are not relevant.

The answer provided based on the bolt is 740 pounds based on Yield Mode I_m. The answer provided based on side member tension is 7790 pounds. Therefore, the bolt capacity controls.

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6. American Institute of Steel Construction, 1989, *Manual of Steel Construction, 9th Edition*, Chicago, Illinois.