Wood: Mechanical Fasteners

The strength and stability of any structure depends heavily on the fasteners that hold its parts together. One prime advantage of wood as a structural material is the ease with which wood structural parts can be joined together using a wide variety of fasteners: nails, staples, screws, lag screws, bolts, and various types of metal connectors. For the utmost rigidity, strength, and service each fastener type requires careful design. General requirements for moisture content, location, spacing, and fabrication in the design of joints should be checked with design manuals (American Forest and Paper Association 1997, American Society of Civil Engineers (ASCE) 1995, Beyer *et al.* 1998).

1. *Nails*

The nail is the most common mechanical fastener used in wood construction. There are many types, sizes, and forms of nails, including common, box, annularly threaded, cement-coated, and galvanized.

Withdrawal resistance of a nail shank from a piece of wood depends on material density, nail diameter, penetration depth, and surface condition of the nail. For bright, common wire nails driven into the side grain of dry wood or green wood that remains wet, many test results have shown that the maximum withdrawal load is given by the empirical equation

$$p_w = 54.1G^{5/2}DL \qquad (1)$$

where p_w is the maximum load (N), L is the depth (mm) of penetration of the nail in the member holding the nail point, G is the specific gravity of the wood based on ovendry weight and volume at 12% moisture content, and D is the nail diameter (mm) (Anonymous 1999).

The yield theory approach is used to determine the lateral strength of a dowel-type connection, assuming sufficient edge and end distances (ASCE 1996). The yield theory describes a number of possible yield modes that can occur in a dowel-type connection (Fig. 1). Mode I is a wood-bearing failure in either the main or side member; mode II is a rotation of the fastener in the joint without bending; modes III and IV are combinations of wood-bearing failure and one or more plastic hinge yield formations in the fastener. The yield strength of these different modes is determined from a static analysis that assumes the wood and the dowel are both perfectly plastic. It further assumes that no axial force is transmitted along the length of the dowel.

The yield mode that results in the lowest load for a given geometry is the theoretical connection yield load. Typically for nails, the single shear yield expression applies. Modes I_m and II are not considered in nail and spike connections. The single shear yield mode equations (Table 1) are entered with the dowel-bearing strength, the dimensions of the wood members, the bending yield strength, and fastener diameter. The dowel-bearing strength of the wood is determined experimentally by compressing a dowel into a wood member. For nails, bearing strength is assumed to be independent of grain orientation and nail diameter.

Additional factors that affect the withdrawal and lateral load carried include type of nail point, type of shank, length of time the nail remains in the wood, surface coatings, and moisture content changes in the wood.

2. *Staples*

Pneumatically driven staples have been developed with various modifications in points, shank treatment and coatings, gauge, crown width, and length. Most factors that affect the withdrawal and lateral loads of nails similarly affect the load on staples. Thus, Eqn. (1) and the yield theory are used to predict the withdrawal

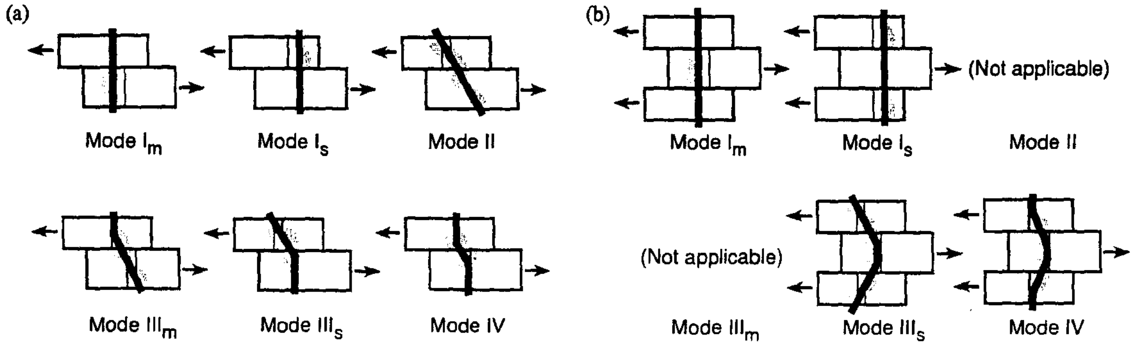

Figure 1
Various combinations of wood-bearing and fastener-bending yields for (a) two-member connections and (b) three-member connections.

Table 1
Yield theory expressions for single shear nail and double shear bolted connections.

Mode	Lateral strength (Z) for two-member nailed joint	Lateral strength (Z) for three-member bolted joint
I_s	Dt_sF_{es}	$\frac{2Dt_sF_{es}}{K_\theta}$
I_m		$\frac{Dt_mF_{em}}{K_\theta}$
III_m	$\frac{k_1DpF_{em}}{1+2R_e}$	
III_s	$\frac{k_2Dt_sF_{em}}{2+R_e}$	$\frac{2k_2Dt_sF_{em}}{(2+R_e)K_\theta}$
IV	$D^2\sqrt{\frac{2F_{em}F_{yb}}{3(1+R_e)}}$	$\frac{2D^2}{K_\theta}\sqrt{\frac{2F_{em}F_{yb}}{3(1+R_e)}}$

Definitions
D Dowel diameter (mm)
F_{em} Dowel-bearing strength of main member (MPa)
F_{es} Dowel-bearing strength of side member (MPa)
F_{yb} Bending yield strength of dowel (MPa)
K_θ $= 1+\theta/360$
P Penetration of nail or spike into main member (mm)
t_s Thickness of side member (mm)
t_m Thickness of main member (mm)
Z Lateral yield strength for single fastener (N)
θ Angle of load to grain (degrees)
R_e $= F_{em}/F_{es}$
k_1 $= -1+\sqrt{2(1+R_e)+\frac{2F_{yb}(1+2R_e)D^2}{3F_{em}p^2}}$
k_2 $= -1+\sqrt{\frac{2(1+R_e)}{R_e}+\frac{2F_{yb}(2+R_e)D^2}{3F_{em}t_s^2}}$

load and lateral load, but to date verification tests have not been conducted.

Along with the immediate performance, other factors such as corrosion, sustained performance under service conditions, and durability in various uses should be considered when evaluating the relative usefulness of a stapled connection.

3. Screws

Both wood screws and tapping screws are used in wood construction and are available in a wide range of materials and head types. The maximum withdrawal load p_q (N) for wood screws inserted in the side grain of seasoned wood may be expressed as

$$p_q = 108G^2DL \qquad (2)$$

where D is the screw shank diameter (mm) and L is the penetration length (mm) of the threaded part of the screw. This equation is applicable for screw lead holes with a diameter of about 70% of the root diameter of the threads in softwoods, and about 90% in hardwoods. Withdrawal resistance of tapping screws is generally 10% greater when compared with wood screws of similar diameter and threaded length.

Lateral screw strength is determined by single shear yield theory expressions similar to that for nail design. Screw expressions only consider mode I, III, and IV failures. Dowel-bearing strength values are based on the same established values for nails.

4. Lag Screws

Maximum withdrawal load p_r (N) for lag screws from seasoned wood is given by

$$p_r = 125G^{3/2}D^{3/4}L \qquad (3)$$

Lag screws require lead holes that vary from about 40% to 85% of the root diameter, depending on the wood density.

Lateral lag screw strength is determined by the single shear yield theory similar to the prrocedure for bolts. Yield modes I, III, and IV may occur. The dowel-bearing strength values are based on the same parallel-and perpendicular-to-grain density equations that are used to establish values for bolts.

5. Bolts

The yield theory approach is used to determine the lateral strength of single-bolted connections, assuming sufficient edge and end distances (ASCE 1996). Edge and end distances ensure that the wood will not split or tear and will only fail in bearing, Unlike the previous connections, bolted connections are designed for both single and double shear applications (Fig. 1). The yield strength of these different modes is determined from a static analysis that assumes the wood and bolt are both perfectly plastic. The yield mode that results in the lowest yield load for a given geometry is the theoretical connection yield load. Equations corresponding to the yield modes for three-member joints have been developed (Table 1). The nominal single-bolt value is dependent on the joint geometry (thickness of main and side members), bolt diameter and bending yield strength, dowel-bearing strength, and direction of load to the grain. The equations are also valid for various load-to-grain directions by adjusting the dowel-bearing strength for grain orientations with the F_{em}, F_{es}, and K_{θ} parameters (see Table 1). The lowel-bearing strength of the wood members is determined from tests that relate species density, grain orientation, and dowel diameter to bearing strength. Additional factors that affect lateral load carried include the number of bolts and moisture content changes in the wood.

6. Multiple-fastener Joints

When fasteners are used in rows parallel to the direction of loading, total joint load is unequally distributed among fasteners in the row, and theoretically the two end fasteners carry a majority of the load. Simplified elastic methods of analysis have been developed to predict the load distribution among the fasteners in a row. These analyses indicate that the load distribution is a function of the extensional stiffness of the joint members, the fastener spacing, the number of fasteners, and the single-fastener load-deformation characteristics. Actual load distribution in field-fabricated joints is difficult to predict because of fastener misalignment, spacing variations, and variability of the single-fastener load-deformation characteristics.

7. Metal Connectors

Many specialty-type connectors are made for use in wood construction. These include devices such as framing anchors, joist and beam anchors, and rafter anchors. These connectors generally require nails to attach them to the wood and are thus subject to the same variables that affect nailed joints.

Metal plate connectors, commonly called truss plates, have become a popular means of joining wood members, especially in trussed rafters and joists. These connectors transmit loads by means of teeth, plugs, or nails, which vary from manufacturer to manufacturer. Plates are usually made of light-gauge galvanized steel and have an area and shape necessary to transmit the forces on the joint. Basic strength values for plate connectors are determined from load-slip curves from tension tests of two butted wood members joined with two plates. The manufacturers of these plates are responsible for establishing their design values and methods of use following industry-established standards.

See also: Wood: Density; Wood: Strength and Stiffness ; Wooden Structures

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