

Technology Profile



**Value
to
Wood**

TP-03-06W
March 2004



Figure 1. Timber frame using connections with wooden pegs

Mechanical Connections in Heavy Timber Construction

When constructing timber structures, it is important that structural members such as beams, columns, and trusses be designed to carry the specified loads, because no chain is stronger than its weakest link. It is equally important that the connections joining these members be carefully designed. A connection must be able to transfer the load and its effects from one member to the other within acceptable deformation limits. Adequate connection behaviour is especially important for structures built in seismically-active regions where inappropriate connection design can lead to structural collapse during a major

earthquake. The introduction of various wood products to the market has increased the opportunities for wood use in various structural applications, thereby increasing the importance of connections as structural components.

Connection types

There is a wide variety of mechanical fasteners available on the market, ranging from wooden pegs (Figure 1), to modern custom-made welded assemblies for joining large wood members. Common connectors can be divided into three categories: dowel-type, surface-type and bearing-type. Dowel-type connectors (nails, spikes, staples, bolts, pins and screws) are generally cylindrically shaped connectors that penetrate deep into the wood and transfer the load between

members by a combination of wood-bearing and connector-bending. Surface-type connectors (punched metal plates, tooth plates and timber rivets) combine the dowel-type action with that of the metal plates with which they are used, so they can collect and transfer the load near the surface of the member. Bearing-type fasteners (split rings, tooth rings and shear plates) are designed to transfer the forces relying solely on the shear- or bearing-resistance of wood.

The earthquake phenomenon

The response of a timber structure during an earthquake is the result of an energy transfer process. When the earthquake waves reach the structure, seismic energy is introduced into the building, which causes the building to move laterally, thus introducing horizontal seismic



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forces on the structure. If the structure is able to withstand the generated forces and is able to dissipate the seismic input energy by means of material damping, friction, or connection deformation without major damage, it will be able to withstand the earthquake.

Wood properties related to connection performance

The physical properties of wood depend on its complex internal structure, natural variability and density. The strength and stiffness properties of wood vary with the orientation of the applied load relative to the wood fibres, which causes the mechanisms of failure to vary accordingly. Tension failures, either parallel- or perpendicular-to-grain, and shear failures tend to be brittle; compression perpendicular-to-grain failures are ductile and therefore preferable for use in seismically-active areas. The ultimate strength of wood under load decreases with time. This fact, and the high strength-to-weight ratio of timber, are major contributors to the satisfactory performance of timber buildings in past earthquakes. Ductile (highly deformable) connections are usually best suited for seismically-active areas where connections that stress the wood in tension perpendicular-to-grain are not desirable.

Nails and Spikes provide a simple and quick way of connecting timber members in construction. Common nails are available with smooth, spiral or ring shanks. By shear mode, nails are ductile connectors capable of resisting many cycles of seismic loading. Nails are most commonly used in wood-frame shear walls, the main lateral load resisting system in North American platform-frame residential construction. Numerous static, cyclic and shake table tests on nailed shear walls showed their favorable energy dissipating characteristics and superior seismic performance. Large displacements can be achieved in nailed connections without failure. Increased nailing density (smaller spacing) in nail connections can lead to formation of a brittle "block-tearing" failure mode and reduced load capacity.



Figure 2. Bolted connections used in heavy timber construction

Bolted connections are frequently used in heavy timber frames (Figure 2). They are placed in pre-drilled holes in the wood members that are normally 1 to 2 mm larger than the bolt shank diameter. Washers are useful in bolted connections as they spread the compression load by the tightening of

the bolts over the face of the wood member. Seismic behaviour of bolted connections is influenced by wood properties, bolt slenderness (member width to bolt diameter ratio), connection end distance, and fastener spacing parallel- and perpendicular-to-grain. The connection capacity increases if the end distance,

edge distance and the spacing between the bolts increase. If the number of bolts in the connection increases, the ultimate load per bolt decreases. Small diameter (slender) bolts tend to behave more like nails or dowels as their shaft can bend without inducing wood fracture, thus exhibiting ductile behaviour and relatively large energy dissipation. When slender bolts yield, they also allow for better redistribution of the load among all the fasteners in the connection, resulting in improved load sharing. When larger diameter bolts are used, the inelastic behaviour and energy dissipation of the connection depends on the embedding behaviour of the wood alone, which often leads to brittle failures.

Steel dowels are cylindrical steel rods, generally with a smooth surface, available in diameters from 6 to 30 mm. They are inserted into predrilled holes of the same diameter as the rod. The yielding capacity of the dowel, in combination with the bearing strength of the surrounding wood, provides high ductility and good energy dissipation characteristics under cyclic loads. Best seismic behaviour is obtained when slender dowels are used with a relatively large spacing between them. Joints with stocky dowels or small spacing tend to fail in a brittle mode before large deformations are reached, and should be avoided in active seismic areas. Dowels can also be used with inside steel shear plates creating aesthetically-pleasing connections that can be very effective in construction of heavy timber frames (Figure 3).



Figure 3. Steel dowel connection

Timber rivets, also known as glulam rivets, are high-strength nail-type fasteners developed in Canada for use in heavy timber construction (Figure 4). Although they are made of high-strength steel, they are pliable enough to provide very ductile connections.



Figure 4. Glulam rivets used in heavy timber construction

Capacity of a riveted connection is governed either by rivet yielding or a wood failure mode. The rivet yielding failure mode, where the rivets bend and yield while the wood under their shanks fails in crushing, is the desirable failure mode for seismic applications. Rivet spacing usually controls the failure mode. Larger spacing results in a rivet yielding failure mode, while smaller spacing leads to brittle wood failures, usually in the form of block-shear around a group of rivets.

Connections with glued-in rods have potential for use in timber construction. Usually, holes are drilled in the end-grain of a glulam or structural composite lumber member, parallel to the member length. Steel rods are then placed into the holes and fixed using a structural glue. A comprehensive research program was undertaken in New Zealand to determine the static and seismic behaviour of these connections (Madsen, 2000). Some of the connections investigated during the research program were found to be less efficient (Figure 5a) due to the reduction of the strength at the joint as a consequence of the holes drilled through the beam. Best results were obtained with connections

using steel brackets and glued-in rods (Figure 5b). Several buildings have already been designed and built in New Zealand with this connection type.

Lag screws are threaded fasteners with a square or hexagonal head that are placed in the wood members with a wrench. Both lag and wood screws provide lateral and withdrawal resistance. Lag screws have lower lateral load resistance when compared to bolts of the same diameter, but they have an advantage when significant bolt length is required, or when the access to one side of the connection is restricted. The resistance of lag screws generally increases with the length of the embedded thread portion into the wood member. Their strength properties are less sensitive to changes in wood moisture than most other similar fasteners. The seismic behaviour of lag screws is influenced by the slenderness of the fastener, its material properties and the wood properties.

Split rings and shear plates are used to transfer relatively large loads in heavy timber or glulam members. These connectors transfer shear either between the faces of two timber members or between a timber member and a metal side plate. In split rings, the ring is split so that it can be fitted into a circular groove on the meeting face of each timber member. The grooves are cut with a special tool and are of a slightly larger diameter than the unfitted connector, so the split usually opens when the ring is sprung into the groove. The split also allows the gap to close if the timber shrinks, or to open further if the wood swells, ensuring that the timber and steel are always kept in contact with each other. A bolt through the center of the ring is introduced to simply hold the joint together while the split ring transfers the load. Care must be taken to ensure that the bolt is the proper size since it is an integral part of the connection assembly.

Shear plates can be used singly to connect wood to steel, or be paired back-to-back to connect wood members. Typical wood-to-metal applications occur at purlin-to-beam, column-to-foundation, arch peak, and steel gusset connections. Grooves for shear plates must also be precision machined by special tools, which recess the

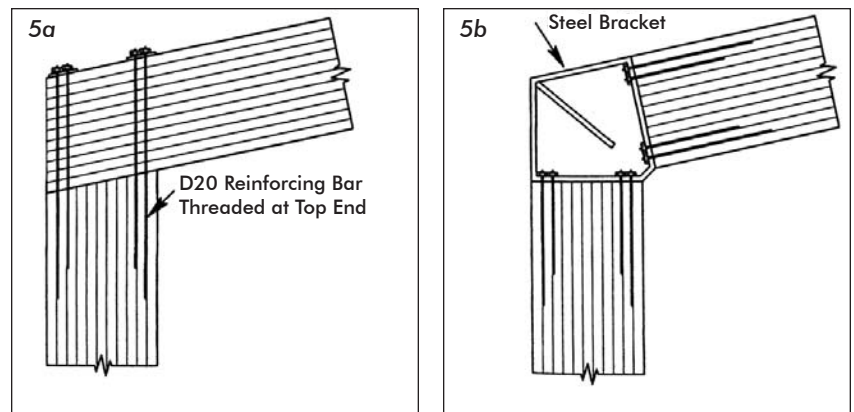


Figure 5. Connection configurations that utilize glued-in rods in glulam (Madsen, 2000)

wood so that the shear plates sit flush with the surface. The brittle nature of connections made with split rings and shear plates should be accounted for in seismic applications.

Concluding remarks

Connections in heavy timber construction are one of the most important but least understood components. Connections provide continuity to the members, and strength and stability to the structural system. This overview provides basic information on characteristics of the most commonly used mechanical fasteners in heavy timber construction and their behaviour when subjected to earthquake loads.

References

CWC 2004. Canadian Wood Council web site: www.cwc.ca.

Madsen, B., 2000. Behaviour of timber connections. Timber Engineering Ltd., North Vancouver, B.C., 2000.

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