



Portland Jetport, Portland, Maine
Architect: Gensler

Southern pine glulam was chosen for this 40,000-sf roof because of its ability to span long distances with minimal need for intermediate supports.

Connection Options for Wood-Frame and Heavy Timber Buildings

Effective solutions provide strength, stiffness, stability and ductility

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The use of wood as a structural material continues to grow far beyond traditional applications, such as single-family homes and buildings up to four stories. Although recent attention has focused on the possibility of wood high-rises, wood's cost-effectiveness, versatility and light carbon footprint are already making it a material of choice for an expanding range of building types—from innovative public, educational and corporate structures that utilize mass timber products as their main architectural expression, to five-story (and higher) multi-family projects built with dimension lumber using long-established techniques. An essential element common to all of these buildings is effective connections.

In wood buildings, effective connections provide strength, stiffness, stability and ductility in addition to providing a continuous load path to the foundation. They are critical to building performance—under regular loads, and especially during extreme

events such as hurricanes and earthquakes. According to post-disaster surveys, structural failures during these events are often due to faults in connection design or assembly.

This continuing education course provides an overview of connection options for modern wood structures, both light wood-frame and heavy timber (see glossary). It covers mechanical connections—including dowel, shear and metal connector plates with integral teeth—and joinery connections, as well as proprietary connections that are in many ways supporting the current surge in innovative wood design. Proper selection and installation, and ways to avoid potential problems, are also discussed.

WOOD CONNECTION BASICS

To determine the most appropriate connection for a given application, it is necessary to understand certain fundamentals, starting with the terminology. In this continuing education course,

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Learning Objectives

After reading this article, you should be able to:

1. Describe the basic categories of mechanical and joinery connections for modern wood structures, and their application in both light wood-frame and heavy timber construction.
2. Examine the wide range of connection options available today, from traditional joinery methods to widely used fasteners and connectors to the innovative proprietary connection systems that are enabling longer wood spans, higher walls and taller buildings.
3. Apply practical and technical design guidance to ensure effective performance of connections in wood structures.
4. Discuss key considerations for selection and installation of connections, for best performance and to avoid potential problems.

To receive AIA/CES credit, you are required to read the entire article and pass the test. Go to ce.enr.com for complete text and to take the test for free.

This course also qualifies for Professional Development Hours (PDH): Submit a certificate of completion for PDH credit to your state licensing board. Check your state licensing board for all laws, rules, regulations and continuing education requirements.

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Table 1: Example of Comparative Design Values

No. 2 Douglas-Fir Larch 2x or 4x	Parallel to Grain	Perpendicular to Grain
Compression Design Value (psi*)	775	625
Tension Design Value (psi)	575	No published values
Dowel Bearing Strength for ¼-in.-dia fastener (psi)	5,600	4,450

*Pounds per square inch

a connection encompasses all of the components that attach one part of a building element to another, be it wood to wood, wood to steel or wood to another material. Within the connection are connectors and/or fasteners. Metal hangers, column bases and many other products fall within the category of connectors. Fasteners include (among others) nails, screws, timber rivets and bolts. These products do the ultimate work of fastening the elements of a connection, either with additional connectors (such as hangers) or on their own.

Several characteristics of wood are also relevant to overall connection behavior.

First, wood is anisotropic, meaning it has different strength properties in different directions: longitudinal (strong), tangential (weaker) and radial (weakest).

- ▶ Wood is stronger in compression and tension parallel to grain versus perpendicular to grain; the former is the preferable way of designing wood connections. However, this is not always practical or possible.
- ▶ While wood is weaker in compression perpendicular to grain, this is the most common way to transfer loads in construction. The most common loads are gravity loads, and the typical way to transfer them is in bearing—thus reliance on the compression perpendicular to grain properties of wood. Fasteners and connectors are required to transfer other loads, such as wind uplift and the lateral loads caused by occasional wind and seismic forces to provide a continuous load path to the foundation.

While capacities are more limited when wood is loaded in compression perpendicular to grain (versus parallel to grain), the limits for bearing conditions on the surface of wood members are deformation-based, not strength-based, and published design values can be increased for smaller bearing areas. Accordingly, dowel bearing strengths are higher relative to compression parallel

or compression perpendicular to grain values. However, dowel bearing strengths perpendicular to grain are lower relative to dowel bearing strengths parallel to grain for larger diameter (less than ¼ in.) fasteners (see Table 1).

- ▶ Wood is weakest when tension is applied perpendicular to grain. This should be avoided—which is why there are no published design values for tension perpendicular to grain.

Second, wood connections are stronger when the load is spread over a number of fasteners. Large concentrated loads should be avoided unless designed not to exceed the wood’s strength capabilities (e.g., net tension and shear). Spreading the load also builds in a degree of redundancy, which is useful in high-wind or seismic events. To accomplish this, designers are advised to:

- ▶ Use small fasteners (less than ¼ in. dia).
- ▶ Use multiple fasteners when possible.
- ▶ Keep the scale of fasteners relative to the size of wood members being connected.

Third, as with other building materials, wood moves in response to environmental conditions. The main driver for this movement in wood is moisture. Allowances must be made to accommodate potential shrinkage and swelling, particularly in connections. (See *Moisture Effects* on page 6.)

CONNECTION TYPES

There are two major types of connections used in wood buildings: mechanical and joinery (sometimes referred to as carpentry). Within these categories are many variations, and thus a wide range of options to accommodate virtually any building design.

WOOD BUILDING SYSTEMS: A GLOSSARY

The terms for different types of wood building systems can be confusing, and the way they are used also varies slightly in different parts of the world. Following is a brief glossary of terms as they are used in this course:

LIGHT-FRAME WOOD CONSTRUCTION

is characterized by vertical and horizontal structural elements formed by a system of repetitive wood framing members. Framing is made from standard sizes of 2x and 3x dimension lumber, and vertical supports are more numerous than with other wood building systems. In addition to low-rise buildings, four-story Type V buildings and five-story Type III buildings are commonly light-frame wood construction.

MASS TIMBER CONSTRUCTION

uses large prefabricated wood members made from cross laminated timber (CLT) or structural composite lumber (e.g., laminated veneer lumber, laminated strand lumber, parallel strand lumber) for wall, floor and roof construction. Nail laminated timber, another form of mass timber construction, has been utilized for over 20 years. It includes vertical 2x sawn lumber, nail laminated together to create a solid wood floor system. Glued-laminated timber (glulam) can also be used in beam and column applications.

TIMBER-FRAME

describes the structural configuration of a broad category of systems, including post-frame, post-and-beam, and heavy timber braced frame. It is characterized by the use of members (typically larger than 4x6) arranged in two-dimensional frames at a consistent interval throughout a building.

HEAVY TIMBER

relates to fire resistance and is specifically defined as a construction type—Type IV—within the 2015 International Building Code (IBC). Buildings with mass timber and timber-frame systems can be used within the heavy timber category if the minimum sizes specified for Type IV construction are met.

Photos: Josh Partee Photography



Designed by Path Architecture, Radiator is one of the first five-story timber-frame office buildings to be built in Portland, Ore., since the early 1900s. Fabricated steel bucket-style connectors with bolts were utilized for glulam beam-to-beam connections.

Mechanical Connections

Mechanical connections used in wood buildings can be classified into three major categories: dowel, metal connector plates with integral teeth, and shear. There are also a number of proprietary connections that combine characteristics of each of these types.

Dowel-type fasteners. Wood members connected with dowel-type fasteners are probably the most common mechanical connection type because they are effective at transferring loads while also being relatively simple and efficient to install. They come in many forms and their strength properties can be calculated using the *National Design Specification® (NDS) for Wood Construction*. Nails are generally used when loads are relatively light, as in multi-family and light commercial buildings. Staples can be used in place of nails, but equivalent capacities need to be determined as the NDS doesn't publish design values for staples. Screws may be more satisfactory than nails under certain conditions (such as exposure to moisture) since they have less tendency to work loose and generally have high wind withdrawal resistance under severe wind events. Timber rivets are a high-strength dowel-type fastener used in conjunction with specially fabricated metal plates.

Dowelled connections transfer the force

between members through a combination of dowel bearing and bending of the dowel fastener.

► Nails come in many types (e.g., box nail, common nail, rink shank, sinker, cooler), as well as multiple pennyweights (the NDS tabulates 6d to 60d). There are also proprietary nails unique to specific manufacturers. Due to the variety of nails available, pennyweight, type, diameter and length should be specified.

For flooring, APA – The Engineered Wood Association recommends using a glued-nailed system, as described in the *Engineered Wood Construction Guide*. In this system, glue is used to attach sheathing to the substrate member, whether lumber or an I-joist, to minimize squeaks and increase stiffness due to T-beam action. All nailing must be completed before glue sets. Gluing is not recommended for bonding wall or roof sheathing to framing because it leads to reduced ductility. Although adhesives may be used in Seismic Design Categories A, B and C, with a reduced R=1.5, their use is prohibited in Seismic Design Categories D, E and F.

► Bolt design values are tabulated in the NDS for five diameters (½ in., ⅝ in., ¾

3 x 0.265 Boat Nail

3 x 0.128 Bright Box Nail

2-7/8 x 0.113 Box Nail

3 x 0.128 Casing Nail

2-7/8 x 0.120 Cooler Nail

2-7/8 x 0.120 Sinker Nail

2-7/8 x 0.135 Corker Nail

3 x 0.148 Common Nail

3 x 0.113 Finish Nail

3 x 0.135 Flooring Nail, Deformed

This chart shows 10 nails, all referred to as 10d, and each with potentially different performance characteristics. Thus, specifying a 10d nail is not clear.

in., ⅞ in. and 1 in.). Diameters greater than 1 in. are not permitted as they can initiate localized stresses in the wood member, which can cause splitting or other brittle wood failures. Bolts are inserted in pre-drilled holes ⅓ in. to ¼ in. larger than the bolt diameter. A common mistake is not leaving enough room for installation of nuts



Modern Computer Numerically Controlled (CNC) connections provide the ability to fabricate joints with precision. This is especially useful when fabricating joints on large members with complex shapes.

or tightening with a wrench or other torque device.

► Lag screws are typically used when it isn't possible to use a nut as required for bolts or when withdrawal capacity is required. They are inserted into pre-drilled holes. The clearance hole for the shank (unthreaded portion of the lag screw) should be the same diameter as the shank, while the lead hole for the threaded portion is a variable percentage of the shank diameter based on the wood's specific gravity. Because lag screws can be fully threaded, the NDS assumes fairly conservative design values which are based on the smaller "root" diameter of the fastener. Higher lateral capacities for lag screws can be calculated if the designer can ensure the threads are far enough from the shear plane. For more information, see the American Wood Council (AWC) publication, *Application of Technical Report 12 for Lag Screw Connections, Design Aid No. 1*.

► Timber rivets are high-strength steel nails typically hot-dipped galvanized, with a flattened oval shank section and a wedge-shaped head. When driven through the pre-drilled steel plate and into the timber, the tapered heads wedge tightly in the holes. Rivets must be driven with the long axis parallel to the wood grain. An excellent way to spread the load with multiple fasteners, they can be used as an alternate to a large number of bolts, resulting in a connection with greater ductility and resilience.

Metal connector plates with integral multiple rows of teeth partially penetrate the wood members and are used primarily with fabricated lightweight wood trusses. With these connections, loads are transferred

near the surface of the wood member.

Shear connectors, sometimes referred to as bearing connectors, are typically used to accommodate heavier loads. They include split rings, shear plates and toothed shear plates. They are usually made from cast iron or light metals, and are capable of transmitting the load relying solely on bearing and shear resistance of the wood in

ONLINE CALCULATOR

The American Wood Council offers a free online connection calculator (www.awc.org), which allows users to calculate capacities for single bolts, nails, lag screws and wood screws per the 2005 NDS. Both lateral (single and double shear) and withdrawal capacities can be determined. Wood-to-wood, wood-to-concrete and wood-to-steel connections are possible.

the direction parallel or perpendicular to the grain. They can be used to connect wood to wood members or wood to steel, and may be concealed or visible.

Profiling using special machining tools, split rings are usually fitted in a circular groove on the meeting side of the timber members. The split in the steel rings allows the gap in the ring to close or open if the wood members shrink or swell to ensure that the wood members and split ring remain in contact. A bolt is installed through the center to hold the joint assembly together. In connections with shear plates, grooves must be precision machined with special tools, which recess

the wood so the shear plates sit flush with the surface. Typically, shear plates and split ring connections have brittle wood failure modes and should be avoided in structures located in high seismic regions unless the designer employs elastic seismic design.

Proprietary connections. Some of the most innovative connection systems are proprietary—that is, produced exclusively by one manufacturer or designed specifically for one building. This area has seen considerable growth in recent years, with connection systems and products developed for use in larger and more complex buildings being designed to take advantage of wood's economic, aesthetic and environmental benefits.

Custom-fabricated structural framing connections, for instance, provide a single-piece connection between two framing members. They generally consist of bent or welded steel, carrying load from the supported member (through direct bearing) into the supporting member (by hanger flange bearing, fastener shear or a combination of the two).

Pre-engineered metal connectors are commonly used in all types of wood construction. Traditional fasteners like nails, bolts and rivets, as well as generic types of pre-engineered metal connectors such as metal hangers, are reliable and widely used, but have some limitations in large, multi-story buildings that newer proprietary systems are designed to overcome. Newer systems, for example, are often concealed, which makes them fire-resistant if they are sufficiently below the wood surface. They can be designed for use in multiples without reducing the strength of the wood, and they can be designed to be either stiffer or more flexible, depending on the application.

Photo: Gensler, 2015 WoodWorks Wood Design Award, Matthew Millman Photography



At the Jackson Hole Airport in Jackson, Wyo., embedded steel knife plates with structural screws provide load transfer at brace-to-beam connections.

One example of a proprietary product that's becoming widely used—especially in cross laminated timber (CLT) and glulam structures (see sidebar on page 8)—is the self-tapping or self-drilling screw. A number of manufacturers in North America, Europe and Japan produce them with different features and in many shapes and sizes. They have enhanced hardness for higher lateral load capacity and come in various capacities for different applications. The main advantage is that they can be driven into wood without pilot holes, using a regular handheld power drill. This lessens the risk of mistakes in the field and improves efficiency and reliability.

Pre-engineered connectors are manufactured by component manufacturers, which have exhaustive catalogues of products that suit various applications. Categories, in addition to the ones previously mentioned, include framing anchors, hold-down devices, straps and ties. Many components are fabricated using formed sheet metal, increasing in thickness as loads increase. Specific nailing and fastening requirements are provided by the manufacturers and must be rigorously followed to develop full connection capacity.

Reference design values for mechanical connections are provided in various sources. The NDS contains reference design values for dowel-type connections such as nails, bolts, lag screws, wood screws, split rings, shear plates, drift bolts, drift pins and timber rivets.

Design values for proprietary connectors are provided in code evaluation reports.

Joinery

Traditional joinery connections (also known as carpentry connections) are typically created by cutting notches, holes and tongues in connected members so they interlock—such as with mortice/tenon and scarf joints. In these types of connections, forces are in principle transferred in compression/bearing. Interlocked connections in tension require wood or metal pins or keys to prevent separation. Tension connections are often kept to a minimum, and in some cases metal straps and bolts are provided to achieve better connections, mainly for long-span roof trusses in historic structures. In a properly designed joinery connection, there is sufficient interlocking, tightening of connections and friction due to the self-weight and supplementary support from walls, buttresses and adjacent buildings to design for both gravity and lateral forces associated with wind or seismic events.

While fairly common in single-story homes, commercial and recreational structures, joinery connections are seldom used for modern, multi-story heavy timber buildings. One reason is the fact that these connection systems demand highly developed skills usually associated only with experienced carpenters. Such connections are also labor intensive which makes them

uneconomical for industrial production.

Although joinery parts can be produced with great speed and precision using Computer Numeric Controlled (CNC) technology, this approach is not as widely used in North America as it is in Japan and Western Europe. Here, mechanical connections dominate primarily because they can be made without expensive equipment and assembled with relative ease on site.

One of the benefits of joinery-type connections is that they're often made entirely of wood. If the connection is exposed to moisture and drying, the change in dimensions of the wood parts will be similar. In a wood/steel connection subject to the same moisture/drying, there may be a differential change between the wood and steel.

AVOIDING POTENTIAL PROBLEMS

Notching

Although notching is an essential technique in traditional joinery, and may be required in the field for a number of reasons, any field notches or holes that are not properly made, or that deviate from approved drawings, may significantly reduce the capacity of even a properly designed member. The NDS provides guidance on notching, and the wood industry has produced extensive technical notes with recommendations related to the size of notches appropriate for different materials. With glulam, for example, end notching is limited to $\frac{1}{10}$ the depth of the member or 3 in., whichever is less. When a notch is used, designers should consider driving a lag screw or self-tapping screw in 6–8 in. from the bearing going up past the neutral axis. If a crack were to develop, the screw will keep it from progressing down the length of the beam and acts as a transverse reinforcement.

Moisture Effects

Wood expands and contracts as a result of changes in its equilibrium moisture content (EMC). Expansion in the direction parallel to grain in a wood member is minimal; however, change in the direction perpendicular to grain can be considerable and must be accounted for in connection design and detailing. The common rule-of-thumb is that wood will experience a 1% change in the radial or tangential direction for every 4% change in moisture content. A nominal 2x12, for example, can decrease in depth through shrinkage by just under $\frac{1}{4}$ in. as it changes from 18% to 10% EMC.

Photo: Crescent Communities



Crescent Terminus
Atlanta, Ga.
Architect: Lord Aeck Sargent

In designing connections, it is important to design and detail the connection such that the member's shrinkage is not restrained. Otherwise, shrinkage of the wood member can cause excessive tension perpendicular-to-grain stresses and splitting may occur. Specific issues related to shrinkage include:

Beam-to-column connections:

Continuous full-depth side plates can cause problems because they restrain wood shrinkage and may cause splitting. **Solution:** Smaller discontinuous side plates transmit forces and allow wood movement.

Beam-to-beam connections: For beam hangers, fasteners placed near the top of the supported beam can restrain wood shrinkage and may cause splitting. **Solution:** Fasteners placed near the bottom of the supported beam can minimize the effects of shrinkage while top tabs provide lateral restraint.

Beam-to-wall connections: If bolts are placed high on the beam, or high and low,

tension perpendicular to grain stresses may cause splitting. **Solution:** Bolts near the bottom of the beam, preferably with slotted holes, allow for wood shrinkage. (A variety of pre-engineered connections are available with pre-drilled slotted holes.)

Another issue related to moisture is exposed end grain. This can result in checking and possible decay, even in low-rainfall climates. **Solutions:** Redirect water flow around the connection. Use preservative-treated or natural decay-resistant wood products. (If preservative-treated wood is used, preservative treatment needs to be applied after all field cuts.) Use end caps and flashing. Allow for air flow and drying—e.g., by detailing drain holes or slots in box-type connectors or maintaining a gap of at least 1/2 in. between wood and concrete or masonry construction.

SELECTION AND INSTALLATION

Ensuring that structural connectors perform as intended involves a number of considerations for both the designer and installer. In the ASD/LRFD Manual, AWC

highlights them as follows:

Wood Members

Specific details related to the wood members being connected will have an impact on the capacity of the connection. The following are important considerations regarding the wood members themselves:

- ▶ The species of wood must be the same as that for which the connector was rated by the manufacturer. Manufacturers test and publish allowable design values only for certain species of wood. For other species, consult with the connector manufacturer.
- ▶ The wood must not split when the fastener is installed. A fastener that splits the wood will not provide enough capacity for the design load. If wood tends to split, consider pre-boring holes using a diameter not exceeding 3/4 of the nail diameter. Pre-boring requirements for screws and bolts are provided in the NDS.
- ▶ Regarding shrinkage, most connectors

are manufactured to fit common dry lumber dimensions. Other dimensions may be available from the manufacturer.

- ▶ Where built-up members (multiple members) are installed in a connector, the members must be fastened together prior to installation of the connector so they act as a single unit.
- ▶ The dimensions of the supporting member must be sufficient to receive the specified fasteners. Most connectors are rated based on full penetration of all specified fasteners. Refer to the connector manufacturer for other situations.
- ▶ If a connection is designed to transfer load by bearing, the bearing capacity of the wood members should be evaluated.
- ▶ Local stresses in connections using multiple fasteners should be checked to ensure adequacy. Where a fastener group is composed of closely spaced fasteners loaded parallel to grain, the capacity of the fastener group may be limited by wood failure at the net section or tear-out around the fasteners caused by local stresses. One method for determining local stresses is provided in Appendix E of the NDS.

Connectors

The condition of the connector is critical to how it will perform. The following are important items regarding the connector:

- ▶ Connectors may not be modified in the field unless noted by the manufacturer. Bending steel in the field may cause fractures at the bend line, and fractured steel will not carry the rated load.
- ▶ Modified connectors may be available from the manufacturer. Not all modifications are tested by all manufacturers. Contact the manufacturer to verify loads.
- ▶ In general, all holes in connectors should be filled with the nails specified by the manufacturer. Contact the manufacturer regarding optional nail holes and optional loads.
- ▶ Different environments can cause corrosion of steel connectors. Always evaluate the environment where the connector will be installed. Connectors are available with different corrosion

resistances. Contact the manufacturer for availability.

Fasteners

Most wood connections rely on fasteners to transfer the load from one member to the other. Therefore, the choice and installation of the fasteners is critical to the performance of the connection. The following are important considerations:

- ▶ All fasteners specified by the manufacturer must be installed in accordance with the manufacturer’s installation recommendations to achieve the published value.
- ▶ The size of fastener specified by the manufacturer must be installed.
- ▶ The fastener must have at least the same corrosion resistance as the connector.
- ▶ Bolts must generally be structural quality bolts, equal to or better than ANSI/ASME Standard B18.2.1.
- ▶ Bolt holes must be a minimum of 1/32 in. and a maximum of 1/16 in. larger than the bolt diameter.
- ▶ Fasteners must be installed prior to loading the connection.
- ▶ Power-driven fasteners may deflect and injure the operator or others. Nail tools may be used to install connectors, provided the correct quantity and type of nails are properly installed in the manufacturer’s nail holes. Nail tools with nail hole-locating mechanisms should be used. Follow the nail tool manufacturer’s instructions and use the appropriate safety equipment.

DESIGN GUIDANCE FOR EFFECTIVE CONNECTIONS

Connections obviously need to provide the structural strength necessary to transfer loads. As discussed above, well-designed connections also mitigate potential adverse effects of moisture ingress. Finally, well-designed connections minimize the potential for excessive tension perpendicular to grain stresses—under design conditions as well as those related to unusual loading conditions. Chapter 10 of the

ASD/LRFD Manual provides details for a variety of design configurations (e.g., beam-to-concrete or masonry wall connections and beam-to-beam connections). Many begin with a brief discussion of the pertinent design challenges. For example:

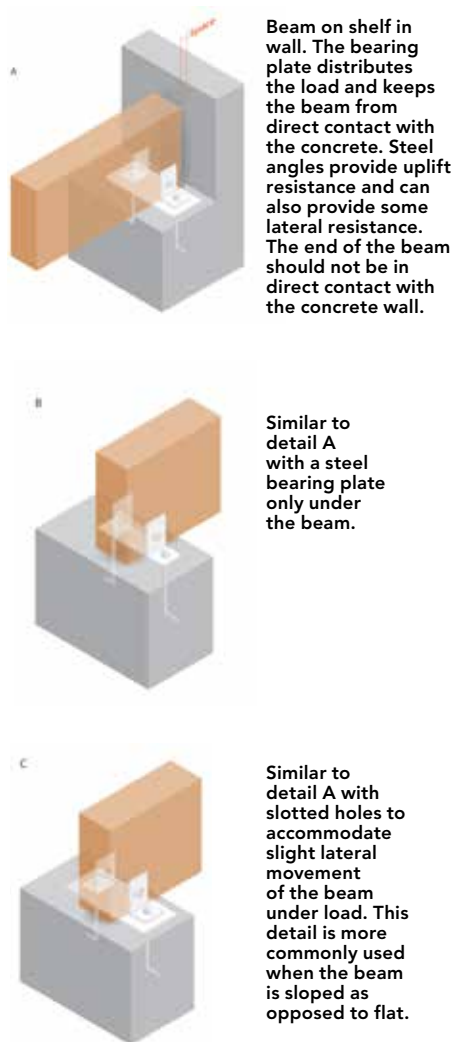
Beam-to-Concrete or Masonry Wall Connections

Design concept: Concrete is porous and “wicks” moisture. Good detailing never permits wood to be in direct contact with concrete.

FIVE STORIES AND HIGHER

With the exception of height, the outward appearance of mid-rise wood-frame buildings has not changed a lot over the years; however, the quality and precision

Source: American Wood Council



CROSS LAMINATED TIMBER

Cross laminated timber (CLT) is an engineered wood building system, part of a new product category known as mass timber. CLT is made from several layers of solid-sawn or structural composite lumber, stacked crosswise (usually at 90-degree angles) and glued together on their wide faces. This cross lamination provides dimensional stability, strength and rigidity, which is what makes CLT a viable alternative to concrete, masonry and steel in many applications. It can be used for an entire building, as both the lateral and vertical load resisting system, or for select elements such as the roof, floors or walls.

There are numerous resources available to designers interested in connections related specifically to CLT and other mass timber products. These include the U.S. CLT Handbook, which is available as a free download at www.thinkwood.com, and the 2015 NDS available from the American Wood Council.

Common connections for CLT assemblies include wall-to-foundation, wall-to-wall (straight or junction), floor-to-floor, wall-to-floor, and wall-to-roof. Panels may be connected to each other with half-lapped, single or double splines made from engineered wood products, while metal brackets, hold-downs and plates are used to transfer forces. Mechanical fasteners may be dowel-type (e.g., nails, screws, dowels, bolts) or bearing-type (e.g., self-drilling or self-tapping screws).

In Europe, self-tapping screws are used extensively for the connection of CLT panels. Benefits include ease of installation, high lateral and withdrawal capacities, ability to take combined axial and lateral loads and the fact that, most of the time, they don't require pre-drilling. Glued-in rods are also becoming increasingly popular both in mainstream heavy timber construction and, increasingly, for CLT. This is being driven by recent developments in CNC machining technology, wood materials and the desire for a high level of prefabrication to reduce assembly time and cost.

of design and construction has increased considerably. Connection-related design aspects that are more critical in a five- or six-story wood-frame building include accommodating greater dead, live, wind and seismic loads, which increase with the additional height.

Going from four to six floors, for example, increases the gravity loads by 50% but lateral forces due to wind or seismic forces may actually double.

While the size and capacity of connections might change and designers may use more specialized, high-capacity connectors, the connectors themselves are largely the same as they are for any light wood-frame building—nails, bolts and lag screws used with and without proprietary connectors.

Continuous tiedown systems are often used in multi-story wood shear wall construction for resisting wind or seismic overturning loads.

HEAVY TIMBER CONSTRUCTION

Heavy timber construction utilizes many of the standard connections described above, including bolted connections, timber rivets, split rings and shear plates. Innovative proprietary connections are also widely used, and today's designers have a tremendous range of options. Innovative examples include, among many others, grid plates and concealed kerf plates with self-drilling dowels. Where fire endurance is required, connectors and fasteners shall be protected from fire exposure. Some methods of providing protection include wood, fire-rated gypsum board or fire resistant coatings.

Because heavy timber buildings lend

themselves to innovative design, many require custom connections to arrive at the sensitive balance between safety, efficiency, serviceability and aesthetics.

Traditional heavy timber details are available in the publications, *Heavy Timber Construction Details* by AWC and *Glulam Construction Details (Form T300)* by APA – The Engineered Wood Association. These details are consistent with the construction requirements outlined in IBC section 2304.10. They are representative of those you would find in existing historic buildings, and are useful when retrofitting or restoring historic structures.

Additional Resources:

- *National Design Specification (NDS) for Wood Construction*, American Wood Council
- *ASD/LRFD Manual for Engineered Wood Construction, Chapter 10 – Mechanical Connections*, American Wood Council
- *DES310: The Wood Connection Session* (e-course), American Wood Council, APA – The Engineered Wood Association, Canadian Wood Council, Wood Truss Council of America
- *Technical Note: Glulam Connection Details*, 2007, APA – The Engineered Wood Association
- *U.S. CLT Handbook*, 2013, FPInnovations
- *Structural Design in Wood*, Stalnak & Harris, Kluwer Academic Publishers



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