



David Barber, ME, PEng
CHM Fire

Scott Breneman, PhD, PE, SE
WoodWorks – Wood Products Council

Fire Design of Mass Timber Connections

Requirements and Compliance Strategies

Introduction

This paper introduces the design of mass timber connections for fire resistance. It is intended for architects and engineers with limited experience in this type of connection design and describes pathways for compliance under the International Building Code (IBC), connection types, and methods for determining a fire-resistance rating (FRR). References are to the 2024 IBC and may be applicable to other editions.

For a more comprehensive look at the fire design of mass timber buildings, see the WoodWorks publications, *Fire Requirements for Mass Timber Elements: Code Applications, Construction Types, and Fire Ratings* and *Fire Design of Mass Timber Structural Members: Demonstrating Fire-Resistance Ratings of Mass Timber Products*.

Fire-Resistance Ratings and Connections

A fire-resistance rating is a quantified measure of how long a building component or assembly—such as a wall, floor, beam, or column—can continue to function when subjected to a controlled fire exposure. Established through laboratory tests following standards like ASTM E119 Standard Test Methods for Fire Tests of Building Construction and Materials and UL 263 Standard for Fire Tests of Building Construction and Material, FRRs reflect the component or assembly's ability to resist heat, prevent flame and hot gas passage, and, when applicable, support applied loads for a defined period, typically expressed in hours. The tests simulate fire conditions using a standard time-temperature curve, and tested assemblies are required to meet performance thresholds for structural stability and thermal protection. These ratings are essential standardized benchmarks in building codes, guiding design decisions to improve occupant safety and limit fire damage.

IBC Section 704 provides FRR requirements specific to structural members. This section does not explicitly mention connections; however, it states that the FRR of a structural member “shall not be less than the ratings required for the fire-resistance-rated assemblies supported by the structural members.” For connections between fire-resistance-rated structural members, the connection needs fire protection that achieves at least the same FRR as the supported member(s).

Other sections of the IBC have FRR requirements that apply to structural members based on aspects of the project such as construction type (Table 601), occupancy separations (Section 508), dwelling unit separations (Section 420.1), and support of horizontal assemblies (Section 711).

If a connection has a fire protection requirement, the two main paths for demonstrating fire resistance of the connection assembly are the same as for structural members: testing and approved analytical methods.



Fire-Resistance Testing

IBC Section 703.2.1

Fire-resistance testing of mass timber connection assemblies has been undertaken by researchers and connection manufacturers to support 1-hour, 2-hour, and 3-hour FRRs. Tests by researchers are performed to advance modeling and prediction methods, while tests by connection manufacturers give engineers, architects, contractors, and authorities having jurisdiction (AHJ) an efficient process for understanding and demonstrating the fire resistance of specific connection assemblies.



Photo: David Barber

FIGURE 1: CLT floor panel being lifted off the test furnace following an ASTM E119 fire test

ASTM E119 and UL 263 can both be used to demonstrate IBC compliance. These standards are used to test the FRR of load-bearing and non-load-bearing components and assemblies, including beam, column, wall, floor, and roof assemblies in both combustible and noncombustible construction. Assemblies with connections are not specifically included in the test standards, so researchers and manufacturers developing new tests must coordinate with the testing facility to define how to meet the intent of the standard, including the loading and structural support configuration.

When using a fire-resistance test as the basis for demonstrating an FRR, the following details need to be confirmed:

- Fire testing has been completed to ASTM E119 or UL 263 requirements.
- The fire-tested assembly matches that of the proposed project detailing.
- The fire test was completed with an applied load that is consistent with the proposed project forces.

- Details such as fire seals in gaps, screw type, and timber species are consistent with the proposed project.
- All fire test limitations have been reviewed and understood.

The fire-tested assembly must be constructed in a way that is similar to the assembly in the building project. Variations may be allowed; however, they need to be reviewed by the project team and relevant product manufacturer and approved by the AHJ.

Another relevant test standard is the Canadian CAN/ULC S101 Standard Methods of Fire Endurance Tests of Building Construction Materials. Because this standard uses the same fire exposure as ASTM E119, mass timber connections that pass a CAN/ULC S101 test are considered to have equivalent fire resistance. Some test reports state compliance of a single test with both standards. However, use of a fire test report stating compliance with only ULC S101 is subject to approval of the AHJ.

For convenience, WoodWorks maintains a web-based inventory of completed mass timber fire-resistance tests in its [Mass Timber Fire & Acoustics Database](#). The database currently includes more than 20 fire-tested connection assemblies and will continue to grow.

Analytical Methods

IBC Section 703.2.2

The IBC allows an FRR to be demonstrated by analytical methods based on the same standard fire test protocols with five options listed in Section 703.2.2. For mass timber connections, option (3)—calculations in accordance with Section 722—is frequently suitable.

The pathway to show fire resistance is as follows:

1. Section 703.2.2(3) refers to calculations meeting Section 722 Calculated Fire Resistance.
2. Section 722.1 establishes the methods to calculate the fire resistance of structural materials.
3. For exposed wood members, Section 722.1(4) references Chapter 16 of the American Wood Council's (AWC's) National Design Specification® (NDS®) for Wood Construction.

Chapter 16 of the NDS provides a standardized method for determining the FRR of exposed timber members using calculations based on the established charring behavior of wood.

When exposed to the standard fire conditions of ASTM E119 or similar fire test protocols, timber chars at a predictable rate. The charred timber and a thin adjacent layer at an elevated temperature provide no structural capacity. The depth of the impacted material can be predicted by the char models in NDS Chapter 16 and the structural capacity of the remaining unaffected timber checked against the design load.

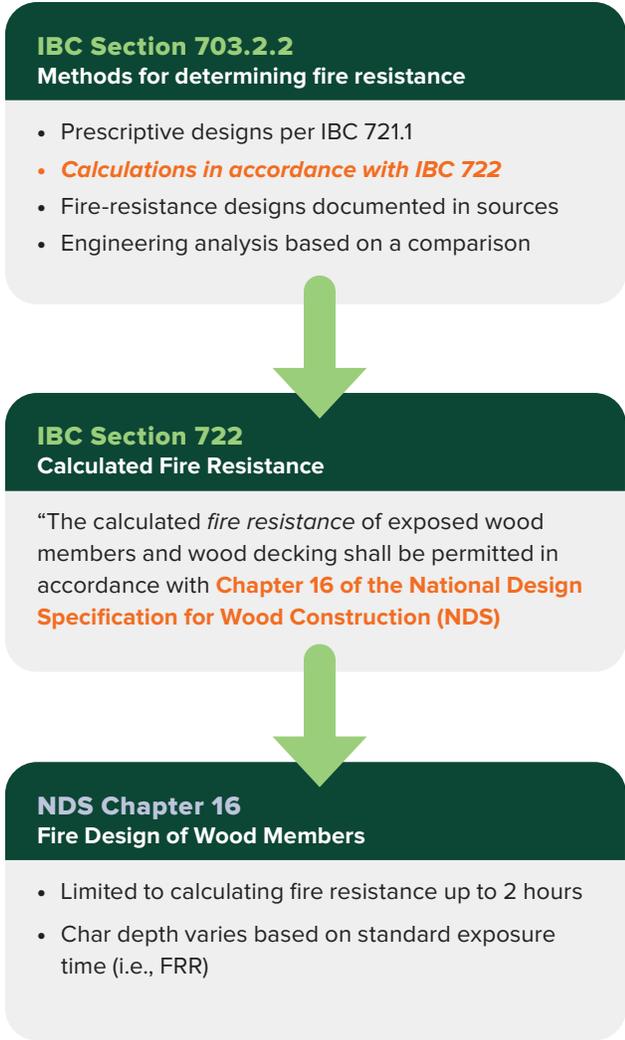


FIGURE 2: Code path for demonstrating fire resistance using calculations

This method of calculated FRR applies to many timber elements as described in the WoodWorks paper, *Fire Design of Mass Timber Structural Members: Demonstrating Fire-Resistance Ratings of Mass Timber Products*.

NDS Section 16.5 extends the calculated method to connections with details provided in AWC’s Fire Design Specification for Wood Construction (FDS). It states:

Structural wood connections, including connectors, fasteners, and portions of wood members included in the connection design, shall be protected from fire exposure for the required fire resistance time in accordance with the FDS. Protection shall be provided by wood, fire-rated gypsum board, other approved materials, or a combination thereof. Fasteners attaching wood protection shall not be required to be protected.

The analytical methods in the FDS can be used to calculate the fire protection of a connection, whether provided by timber, Type X gypsum board, insulation, or a combination.

Where an analytical method is being used to justify the fire resistance of a connection, the approval path should be reviewed with the AHJ.

Timber Connections in Types IV-A/IV-B/IV-C
IBC Section 2304.10.1

Types IV-A, IV-B, and IV-C construction are sometimes referred to as the ‘tall mass timber’ construction types because they allow buildings up to 18, 12, and nine stories (respectively). The IBC requires timber connections in these structures to meet additional requirements, as follows:

2304.10.1 Fire protection of connections.

Connections used with fire-resistance-rated members and in fire-resistance-rated assemblies of Type IV-A, IV-B, or IV-C construction shall be protected for the time associated with the fire-resistance rating. Protection time shall be determined by one of the following:

- 1. Testing in accordance with Section 703.2 where the connection is part of the fire resistance test.*
- 2. Engineering analysis that demonstrates that the temperature rise at any portion of the connection is limited to an average temperature rise of 250°F (139°C), and a maximum temperature rise of 325°F (181°C), for a time corresponding to the required fire-resistance rating of the structural element being connected. For the purposes of this analysis, the connection includes connectors, fasteners, and portions of wood members included in the structural design of the connection.*

Where the FRR is determined by a fire-resistance test following IBC Section 703.2.1, item (1) of 2304.10.1 is met, and the temperature rise requirements of 2304.10.1(2) do not need to be calculated. Passing a loaded fire-resistance test is sufficient without measuring the internal temperature of the relevant timber and connectors.

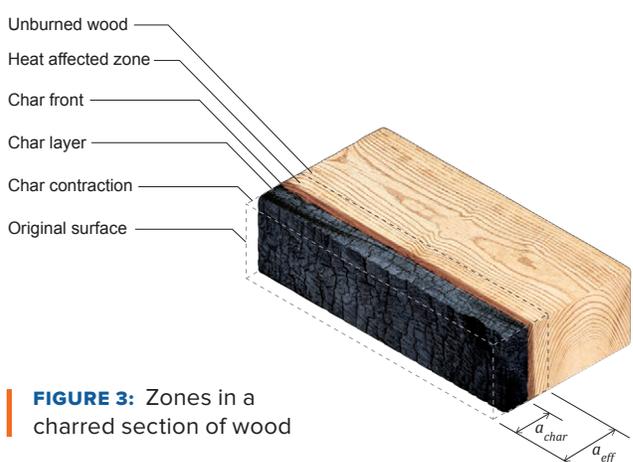


FIGURE 3: Zones in a charred section of wood



Photo: David Barber

FIGURE 4: Completion of a Simpson Strong-Tie ASTM E119 fire test for a glulam beam-to-column connection

When using an analytical method to demonstrate fire resistance following IBC Section 703.2.2, Section 2304.10.1(2) provides additional temperature limits for mass timber connections. These limits are applicable to the metal connector(s), fasteners, and timber directly connected to the metal connector(s). To meet these requirements, FDS Section 3.6 provides methods to calculate thermal separation, which can also be used to demonstrate that the connection has adequate protection to meet the required temperature rise limits. This protection can be provided with timber, Type X gypsum board, or insulation.

When using the calculated method for connection assemblies in other construction types (not Type IV-A, IV-B, or IV-C), the temperature rise criteria from Section 2304.10.1(2) and thermal separation calculations in the FDS can be used as guidance for the connectors and fasteners.

Mass Timber Panel Connections

This section describes options for connecting mass timber panels in floor, roof, and wall assemblies, along with details for achieving fire resistance. Panels may be connected to each other or to other structural elements, either combustible or noncombustible, such as a cross-laminated timber (CLT) floor connecting to a beam or shaft wall. One of the advantages of mass timber is that structural elements can be left exposed and this is often the case for panels, which means they need to provide fire resistance without noncombustible protection on the exposed side. However, they can also be hidden from view and fully or partially protected with applied gypsum board.

Panel-to-Panel Connections

There are a variety of panel-to-panel connections, with the single surface spline and half lap being two of the most popular (Figure 5).

When a CLT floor or wall is exposed to fire, charring will reduce the panel depth (thickness), resulting in greater deflections. With long enough exposure, the charring leads to structural failure (because the reduced depth has inadequate strength to resist the applied loads) or burn-through at a connection. Burn-through can be exacerbated by small gaps between panels at the connection, which provide a faster path for the passage of hot gases and flames than through the panel itself. Unprotected CLT panel-to-panel butt connections do not perform well in fire as the connection is not effective at preventing the movement of hot gases. In a surface spline connection, a plywood spline often functions as draftstopping on the non-fire side and can perform adequately.



Photo: David Barber

FIGURE 5: Five-ply CLT panels connected with a surface spline (left) and half-lap connection (right)



Photo: VXR Media Group

FIGURE 6: Connected CLT panels viewed from the underside
Ascent, New Land Enterprises, Korb + Associates

Failure through increased temperature rise on the non-fire side is not typically an issue for CLT panels away from the panel connection.

The method to demonstrate an FRR of a panel-to-panel connection may be different than the method to demonstrate the structural fire resistance of the panel itself.

A CLT connection must be effectively sealed. Possible sealants include fire-rated intumescent (expanding) caulk or tape in the connection, a concrete topping layer, or regularly fastened sheathing such as plywood or noncombustible boards on the non-fire-exposed side.

FDS Section 3.2.3 Char Penetrations at Intersections and Abutting Edges can be used to calculate the FRR of a CLT connection. For example, a single top-side plywood spline at least 3/8-inch thick in a CLT floor connection meets the draftstopping requirements of FDS Section 2.5.3.1. If the gap between panels is at most 1/8 inch, then the char penetration model of FDS Section 3.2.3.2 applies to the connection. If the impact of panel deformations based on loading and support conditions accelerates the opening

of the gaps during fire exposure, additional considerations or detailing may be needed.

Similarly, glue-laminated timber (GLT), nail-laminated timber (NLT), and dowel-laminated timber (DLT) panels are typically installed with wood structural panel (WSP) sheathing applied to the top surface. Among its purposes, the sheathing serves as a draftstop, preventing air penetration through small gaps between the individual laminated pieces of timber in NLT and DLT and at the larger gaps between panels.

Floor-to-Wall Connections

Where mass timber floor panels connect to concrete, masonry, or mass timber walls that run vertically past the floor, the connection is often a ledger constructed from a steel angle or timber. The ledger detail must be designed to provide fire resistance to support the floor given the applied loads. When the floor acts as a fire-rated separation (horizontal assembly), the detail must also be designed to prevent hot gases and flames from moving between floors. Because there are very few fire tests available on ledgers, fire resistance is typically demonstrated through analytical methods using applied protection.



Photos: David Barber

FIGURE 7: CLT panel-to-panel connections after a fire test, including surface spline (left) and half-lap (right)



Photo: KK Law courtesy naturallywood.com

FIGURE 8: CLT panel supported on a steel angle ledger

Where CLT floors intersect exterior walls, WoodWorks offers guidance through the article, [*Exterior Walls in Mass Timber Buildings – Part 2: Common Floor-to-Wall Details*](#).

Connections Located on a Beam

Where the panel-to-panel connection is located centrally over a timber beam, the beam can provide effective timber cover for the connection and thus its required fire resistance. If the timber cover provided by the beam is adequately sized (i.e., the connection will not be exposed to fire), this type of connection can be a butt connection. The designer must also check the edge distance of the fasteners and the bearing area to ensure adequate support in the fire design condition.

Adhesives or Sealants at Panel Intersections

IBC Section 703.7 includes a requirement for the use of sealants or adhesives at abutting panel edges, as well as at the intersection of mass timber elements and fire-rated elements of construction Types IV-A, IV-B, and IV-C. These requirements are intended to prevent airflow through such intersections, where it could degrade the thermal separation and fire containment. For more information, see the WoodWorks article, [*Sealants and Adhesives at Intersecting Mass Timber Members*](#).

Mass Timber Framing Connections

The most common structural form for a mass timber building is post and beam, with glue-laminated timber (glulam) columns and beams supporting mass timber floor panels. In this type of system, connections are required for each beam connecting to a beam, beam connecting to a column, and column connecting to a column. Primary beams connected to columns are referred to as girders and secondary beams connected to girders are purlins.

Most mass timber framing elements are connected in one of two ways: timber bearing on timber or metal connectors. Metal connectors come in a variety of forms but generally consist of metal plates, brackets, or hangers.

These are typically coupled with dowels, bolts, or screws (often proprietary self-tapping screws due to their ease of construction).

As noted, the fire resistance of a timber connection assembly is achieved with some form of protection. Protection applied around the connection can be either sacrificial wood or non-combustible protection such as Type-X gypsum board. Where the mass timber structural member is exposed, fire resistance is achieved by locating the structurally necessary portions of the connection within timber that has adequate strength and protection for the full fire duration.



Photo: David Barber

FIGURE 9: Glulam beam connecting into glulam girder with fully concealed connector

Timber-to-Timber Connections

Due to their simplicity, timber-to-timber connections have traditionally been used to attach beams to beams, beams to columns, and columns to columns. This includes timber dowels, timber cut-outs, intricate joinery, and timber-to-timber bearing—where one timber surface bears onto another (e.g., a beam on a column). Bearing connections are used frequently and, when properly sized, tend to be cost-effective.

For a timber-to-timber bearing connection, the capacity of the bearing area needs to be designed to resist the applied forces, based on the reduced cross-section of both members during a fire event. An assessment of the increased temperatures prior to the char layer forming is also required as this will reduce bearing strength both parallel and perpendicular to the grain. For bearing surfaces in the connection loaded perpendicular to the grain, the NDS and FDS require an increased depth of timber protection to account for reduced strength of the timber in bearing when exposed to fire (see FDS Section 3.3.1.4).

In timber-to-timber bearing connections, screws may be needed to maintain the structural integrity of the design by providing supplemental lateral and uplift resistance.



Photos: David Barber

FIGURE 10: Heavy timber beam-to-column connection (left) and modern beam-to-column connection with glulam girders bearing directly on a column (right)



Photos: Rothoblaas

FIGURE 11: Knife plate connectors installed on a column (left) and beam (right)



Photo: Simpson Strong-Tie

Embedded Knife Plate Connectors

Beam-to-beam, beam-to-column, and column-to-column connections often involve a steel or aluminum knife plate inserted into a pre-cut slot at the end of another timber member. The plate is secured with metal dowels, typically tight-fit smooth pins, bolts, or self-tapping screws, installed through the timber and plate. Knife-plate connections can achieve an FRR when the dowels are fully embedded within the timber and timber cover protects both the plate and dowels from fire exposure. The dowels in fire-rated connections are typically covered with wood plugs. (See Figure 13.)

FIGURE 12: Seated column-to-beam knife plate hanger

Failure of a knife plate connection can occur when the reduced cross-section of timber is unable to resist the stresses induced by the dowels. A connection may also fail if there is too large a gap between timber members and the base of the knife plate is not protected from elevated temperatures. In this scenario, the metal plate can conduct heat into the connection, resulting in premature failure of the metal or dowels.

Metal knife plate connectors have been fire-tested, though mostly under tension. The fire test results for tension connections should be used with caution when the proposed detail is a shear-and-bending connection, such as a beam support, because they do not replicate actual building conditions. When using calculated fire-resistance rating methods, the protective timber cover needs sufficient depth, including the char layer and heat-affected zone, which can be calculated per the NDS and FDS.

Gaps between connected timber members, such as the face of a column and end of a beam, need to be addressed in the fire design while also accounting for construction tolerances and timber shrinkage. Gaps of varying sizes can be sealed with an intumescent material located within the char zone of the connecting members, following the manufacturer's installation instructions and approved application of the product. Product selection should consider installation method, potential weather impacts, and the product's ability to expand and fire-seal the gap. Intumescent caulks may be easier to install; however, experience has shown that tapes can be more forgiving in adverse weather conditions and more likely to stay in position during assembly. It is important that the intumescent material not shift (or smear) as wood members are lifted and adjusted into place, for both fire performance and aesthetics.

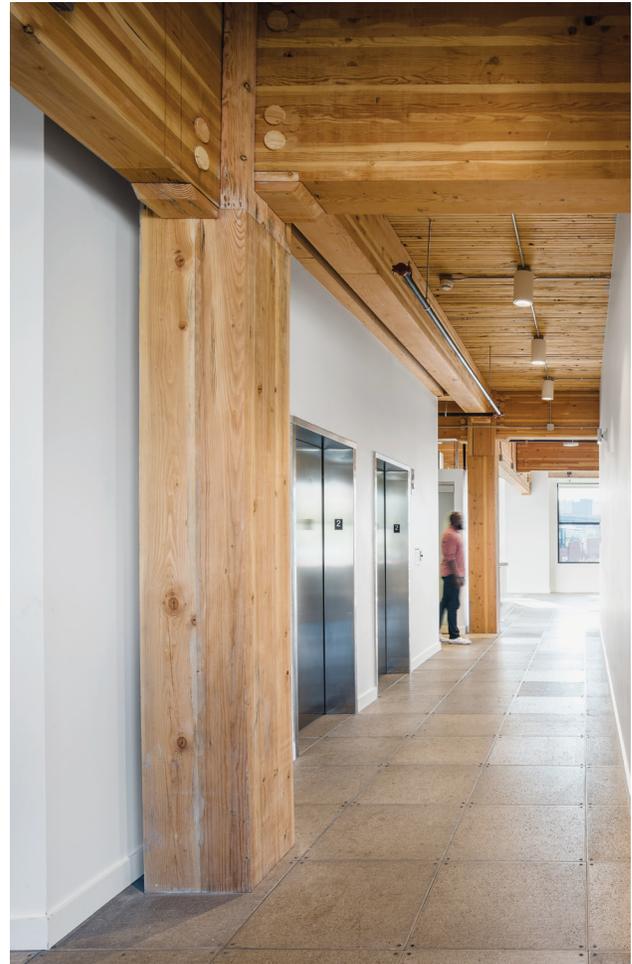


FIGURE 13: Steel connectors protected with timber cover at glulam beam
Clay Creative, Mackenzie Architects

What happens to a connector concealed within a mass timber element during a fire?

As the size of the mass timber element reduces due to cross-sectional charring, the induced stresses and deformations at the connection gradually increase, leading to eventual failure with long enough fire exposure. The structural capacity of a connection is also reduced when the elevated temperatures ahead of the char front reach the connector, reducing both metal connector and timber strength. Any exposed metal surface will accelerate transfer of heat into the timber, which is why this needs to be avoided. Fire resistance is influenced by the level of stresses in the connection, and a lower applied load will improve fire resistance when compared to the same connector fire-tested with a higher load.

External Metal Connectors

External metal connectors come in many forms, including custom fabricated steel plate hangers and buckets and commercial metal hangers. They are a simple method for connecting beams to beams and beams to columns. However, while simple to install, a connection that uses an external metal connector offers minimal fire resistance.

When exposed to fire, external metal plates, dowels, bolts, or screws conduct heat directly into the timber. Exposed steel starts to lose strength at temperatures around 750F (400C), which the standard fire test reaches within 10 minutes. Meanwhile, the dowels or bolts char the connection from within. For these reasons, external unprotected steel plates are not viable as fire-rated connections.

To achieve fire resistance, these types of connectors need to be encapsulated with Type X gypsum board, timber, or other specifically designed fire protection.

Where protection is provided with gypsum board, designers must consider the potential for gaps to form between the timber and board. As the timber is exposed to fire, the cross-sectional area will reduce in size while the gypsum board remains relatively fixed, resulting in gaps that expose the connection to fire. This can be addressed by fire-sealing the edges of the board with an intumescent product or a timber strip that penetrates past the end of the board into the connection. For more information, see FDS Commentary Figure C1-1.

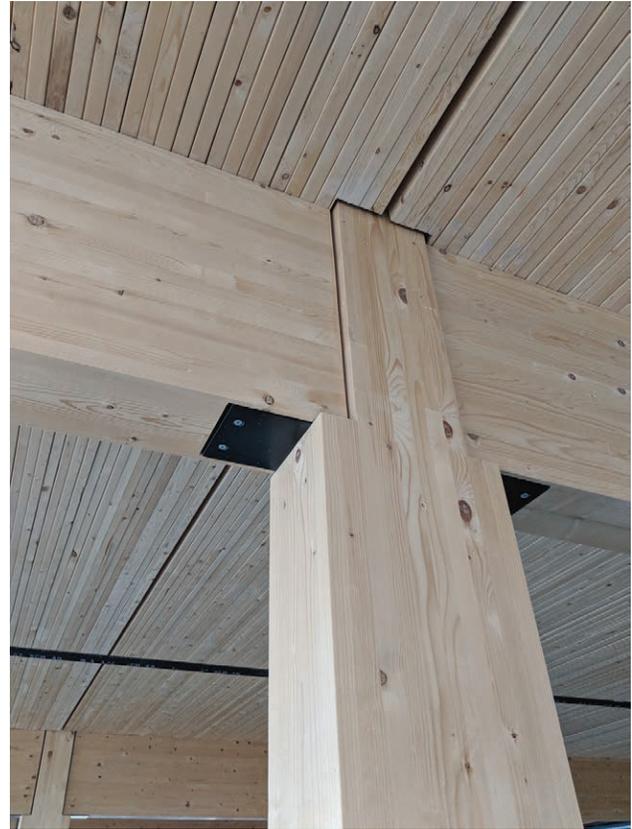


FIGURE 15: Unprotected exposed connections



FIGURE 14: Glulam beam supported an exterior steel bucket (left); primary glulam beam supporting secondary beam with exterior hanger (right)

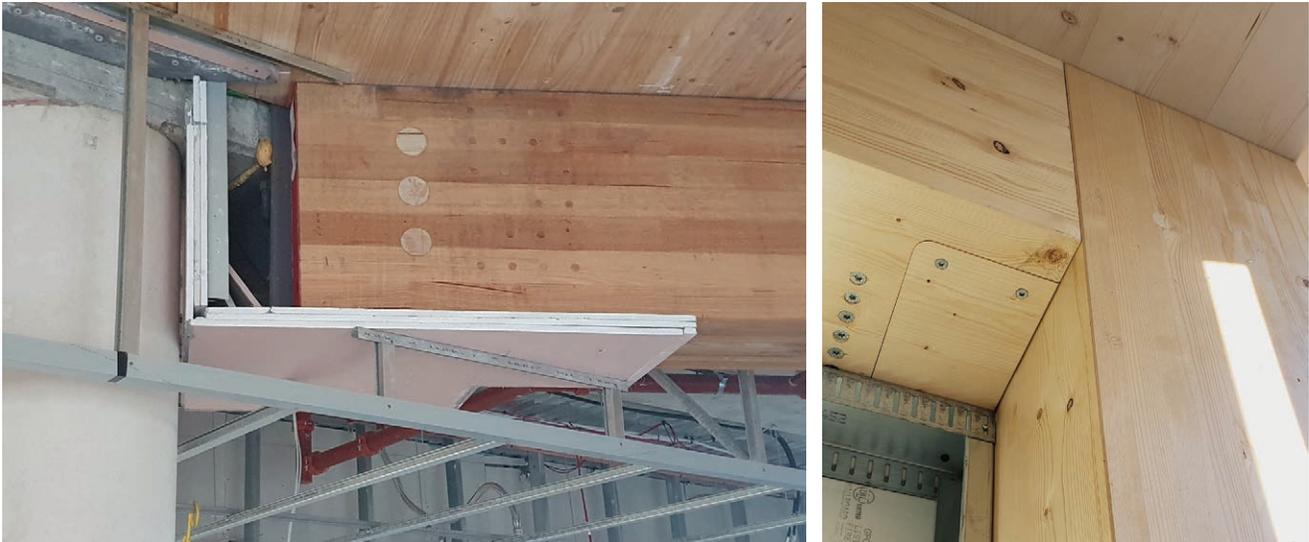


FIGURE 16: Fire-rated noncombustible board being constructed to protect an external steel connector supporting a glulam beam (left); metal connector covered with timber protection (right)

Can intumescent paint be used to protect metal connectors in a mass timber project?

Intumescent paints are a fire-protective coating used for structural steel but have limited application for mass timber connections. When heated to approximately 480-570F (250-300C), intumescent paints used for steel protection expand and create an insulative layer that reduces heat transfer into the underlying steel member. If applied to a steel connector in a mass timber connection, intumescent paint will offer some thermal protection to the steel component but may not protect the other components (e.g., timber in contact with a steel plate and fasteners into the timber). Such paints commonly start to protect the steel at around 480F, which is about the same time timber starts to char. Once fully expanded, the paint will typically limit the steel temperature to a range of 1000-1100F (538-593C). Any timber in contact with steel at these temperatures would have charred and no longer be structurally competent. Common intumescent paints also need up to 1 inch of space around the steel component for the paint to expand and provide insulation. Hence, if intumescent paint is being considered as a protection solution for a mass timber connection, the specific properties of the paint and its application need careful analysis to ensure its effectiveness.

Fully Concealed Metal Connectors

It is common to protect metal connectors from fire by fully concealing them within a timber element, thus using the timber as a protective cover. Often proprietary, these connections may involve one or two-part connectors, and have the advantage of off-the-shelf readiness for design, approval, and construction. Concealed metal connectors can be pre-installed to a beam or column at the fabrication facility and then easily and quickly assembled at the construction site.

A fully concealed metal connector can be designed to achieve any FRR, whether constructed from steel or aluminum. Note that load-carrying screws from the metal connector must be located within the protecting timber's unburnt wood zone to retain their withdrawal, shear, or bearing strength.

To achieve an FRR of 1 or 2 hours, the designer must carefully assess the protection of the timber cover. Failure can occur when the reduced timber cross-section within the char layers supporting the connector is unable to resist the stresses.

As with knife plate connectors, it is also important to consider gaps between the connecting timber members. Fully concealed metal connectors will typically create a gap between members once fitted in place, which will increase with normal timber shrinkage.

While concealed metal connectors can have protection designed using analytical methods, connection manufacturers are increasingly undertaking fire-resistance testing of connection assemblies with their products. Fire-tested connection assemblies may achieve an FRR with more efficient detailing than justified through calculations alone.



FIGURE 17: Concealed metal connectors typically create gaps between members that need to be considered (left); fully concealed steel beam-to-column connector, looking upwards to base of beam before installation of timber cover cap (right)

Project Design and Approvals

The most appropriate connections for a mass timber project meet multiple objectives, including finished appearance, structural capacity, pricing, ease of installation, and demonstrated fire resistance. The architect and structural engineer will typically consider options throughout the design, which continue to evolve based on input from the general contractor and/or mass timber installer (who may have preferred choices), a fire engineer/code consultant, and the AHJ.

Required Documentation

The initial connection design documentation consists of sketches and drawings coordinated between the architect and engineer, with the level of detail increasing through the project design phases. Proving fire resistance of a mass timber connection assembly requires documentation that is suitable for design, pricing, building approval, construction, and inspections.

If utilizing a fire-resistance test report from a connection manufacturer, the fire test criteria, tested parameters, and limitations need to be reviewed for consistency with the project. The report can then be submitted as part of the building permitting documentation, accompanied by supporting materials showing how the fire-resistance test aligns with the project design.

If using an analytical method to demonstrate fire resistance, it is recommended that a pre-submission meeting be held with the AHJ to discuss the method, details of the analysis, supporting documentation, and submission timing. The AHJ will confirm the process for submission and review as well as any additional documentation required as part of an engineering judgement or alternate materials and methods request (AMMR). Submissions when using the analytical method typically consist of a report that includes drawings and

sketches, referenced methods for calculations, and clear requirements for construction. It may also include fire-resistance test reports for similar connections.

Special Inspections

Special inspections required for mass timber connections will be included in the permitting documentation. The method(s) of inspection, what is inspected, and the regularity of inspections all need to be agreed upon prior to construction. Inspections will cover all components required for the connector to meet structural and fire demands, including the type of screw, number of screws, minimum edge distances for the connector components, and location and type of fire sealing product (among other things). Special inspections must be carried out by a qualified inspector approved by the AHJ.

For more information, see the WoodWorks paper, *Construction Quality Assurance on Mass Timber Projects: Inspection and Observation*.

Conclusion

The [WoodWorks resource library](#) includes hundreds of technical resources for architects and engineers designing mass timber buildings. Regarding the fire design of connections, additional connection types, along with information on their load capacity, cost, and constructability, can be found in the [WoodWorks Index of Mass Timber Connections](#) and our collection of structural [CAD & Revit Details](#).



Refremem Photography, courtesy of GFA

619 Ponce / Jamestown / Handel Architects / StructureCraft

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