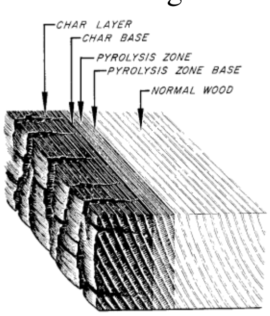
Timber Design Guide 2019-17

First Release:	July 2019	**Revised:**	
Prepared by:	Jim DeStefano, P.E., AIA, F.SEI		
Title:	Fire Resistance of Mass Timber Structures		

Introduction

There is a common misconception that timber structures perform poorly in a fire. While this may be true of unprotected light frame wood construction, it is certainly not true of timber structures, which actually perform better than unprotected structural steel. Even though timber is combustible, large timbers burn slowly and develop an insulating char layer on the surface. The char layer progresses slowly and protects the core of a timber from the heat of a fire, permitting the timber to continue to carry load.

When timber structures do eventually fail during a fire, they rarely fail suddenly. They sometimes give warning signs such as making loud cracking and hissing noises when a collapse is imminent. Timber connections with unprotected steel hardware, however, can fail suddenly without warning. Consequently, careful detailing of timber connections is crucial.



Mass timber is a type of construction that is inherently fire resistant, making it suitable for larger structures where light frame construction is not permitted by the building code. Mass timber elements may be sawn timbers, glulam timbers, or timber panels such as cross-laminated timber (CLT), nail-laminated timber (NLT), or dowel-laminated timber (DLT).

Building Code Requirements

When timber structures are used for single-family residences, the *International Residential Code (IRC)* does not require any fire-resistance rating of the structural elements. For non-residential and multi-family structures, however, the *International Building Code (IBC)* has very specific requirements for the fire-resistance rating of individual structural elements.

The *IBC* requires that a building be designated a particular "Type of Construction," commonly referred to as the "construction classification," and adhere to the fire-resistance requirements for that particular construction classification. The IBC identifies five general construction classifications with sub-categories of each. Type I construction is the most fire-resistant and Type V is the least fire-resistant. For a particular building use or occupancy, the IBC restricts the height and size of a building for each construction classification. The challenge is to select the construction classification for a particular project with the least onerous code requirements.

Construction Classification

Type I and Type II construction is limited to buildings with non-combustible structural elements such as protected structural steel or reinforced concrete. However, heavy timber is allowed for roof framing in Type IB, IIA, and IIB construction.

In Type III construction, all structural elements can be made of combustible materials, but the exterior walls must be non-combustible. There are no requirements for minimum sizes of wood members, so the floor and roof framing may be light wood framing or mass timber construction. Structural Insulated Panels (SIPs) can be used on the roof of a Type III building.

Type IV construction is "heavy timber" construction, also referred to as "mass timber." Minimum timber dimensions are stipulated in the code. For instance, floor beams must be 6x10s or larger and floor decking must be 3" nominal thickness.

In Type IV construction, the exterior walls must be non-combustible construction. CLT exterior walls are permitted if they are protected with fire-retardant-treated (FRT) plywood or gypsum board. Interior walls and partitions must have a 1-hour fire-resistance rating.

In Type IV construction, the code does not allow any concealed spaces in the floor or roof construction. The concealed space restriction can be very difficult to comply with. The 2021 IBC will allow concealed spaces provided they are sprinklered or protected.

The 2021 IBC will contain new expanded provisions for Type IV construction which will permit mass timber to be used on tall buildings up to 18 stories.

In Type V construction, combustible materials of any size can be used throughout the structure. As you might expect, only relatively small buildings meet the building height and size restrictions for Type V construction.

Fire-Resistance Ratings

The requirements for the fire-resistance rating of structural elements are contained in Table 601 of the *IBC*. For each construction classification, Table 601 stipulates minimum fire-resistance ratings for the primary structural frame, bearing walls, floor construction, and roof construction. The primary structural frame is defined as the columns and any beam or girder that connects to and braces the columns.

There are no fire-resistance rating requirements for brace members that resist only wind or seismic loads and do not support gravity loads.

For Type IV construction, Table 601 does not currently indicate specific fire-resistance rating requirements for structural timbers. The only requirements are that the timbers comply with the prescriptive minimum sizes. It is not uncommon to have some structural steel elements in a mass timber structure, but Table 601 gives no guidance on the fire-resistance rating of the steel members in Type IV. It is accepted practice to apply a 1-hour fire-resistance rating to structural steel beams and columns in a Type IV structure.

It is common practice to reference ASTM E119 (or UL263) fire test results listed by testing agencies such as Underwriters Laboratories (UL) to substantiate the fire-resistance rating of a particular structural element or assembly. Listed test results of beams and assemblies are categorized as either “restrained” or “unrestrained.” Wood construction is typically assumed to be unrestrained. Mass timber floor assemblies with CLTs secured to timber beams and girders is sometimes considered restrained.

There are a growing number of documented ASTM E119 fire tests that have been performed on CLT wall and floor assemblies with a variety of concrete floor toppings and gypsum board protective layers. In general, CLT wall and floor assemblies have performed well when tested. CLT panels manufactured with certain adhesives have demonstrated disappointing performance and those particular adhesives are no longer permitted in *ANSI/APA PRG 320-2018 Standard for Performance-Rated Cross-Laminated Timber*.

The fire-resistance rating of mass timber assemblies or elements is more commonly based on a structural mechanics-based analysis rather than on the listed results of an ASTM E119 fire test. Chapter 16 of the *AWC National Design Specification for Wood Construction (NDS)* has a procedure for calculating fire-resistance rating. The procedure is also described in *AWC*

Technical Report 10 – Calculating the Fire Resistance of Wood members and Assemblies (TR10).

The effective char depth on the timber is stipulated for different time intervals. For instance, the *NDS* stipulates that the effective char depth on a timber is 1.8” thick after 1 hour of fire exposure. It is then a simple matter of calculating the remaining section properties of a timber with 1.8” of wood removed from the exposed perimeter and determining if the reduced section is capable of supporting the applied gravity loads with a stress increase to convert allowable stress to ultimate stress. The design stress to member strength factor “K” is 2.85 for bending strength.

The fire-resistance calculation for a CLT panel is similar, except the stipulated effective char depths are a little different. Unless the spans are very short, a 5-ply CLT is needed if a fire rating is required, since there is not much left of a 3-ply CLT if the bottom ply is consumed.

For glulam timbers, it is necessary to modify the layup. Additional tension laminations are needed to compensate for the tension laminations lost to charring. Otherwise, the fire-resistance calculation needs to be based on the design stresses of a core lamination.

The effective char depth includes the predicted thickness of the char layer plus the heat-affected zone adjacent to the char layer. The heat-affected zone, also referred to as the pyrolysis zone, is approximately ¼” thick and is the region where the mechanical properties of the wood have been degraded by the heat of the fire.

When evaluating the residual strength of the reduced timber section, you do not need to apply full design loads. *ASCE/SEI 7* (section 2.5) stipulates a load combination for extraordinary events such as fire that combines dead load with 50% of the live load plus 20% of snow load. Wind and seismic loads do not need to be considered. Note the design examples in *TR10* are based on full live and snow loads which is overly conservative.

Protection of Connections

Timber connections need to have the same fire resistance as the members they are connecting. Section 16.3 of the NDS states:

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. Protection shall be provided by wood, fire-rated gypsum board, other approved materials, or a combination thereof.

Traditional mortise and tenon connections, in general, demonstrate reasonable fire resistance since their bearing surfaces are not compromised by the loss of the charred timber perimeter. Timber joints that rely on shallow bearing seats, however, have little fire resistance. For instance, a 1 ½” housing will have no bearing surface remaining when the effective char layer progresses to a depth of 1.8” and would need to be supplemented with a tusk tenon or concealed connection hardware.

Since steel bolts and steel connection hardware conduct heat readily, if the steel elements are not protected, the wood that they are in contact with can lose strength. *ASCE/SEI/SFPE 29-05 Standard Calculation Methods for Structural Fire Protection* states:

3.3.2.4 Connectors and Fasteners

Where 1-hour fire resistance rating is required, connections and fasteners shall be protected from fire exposure by 1.5 in. (38mm) of wood, 5/8 in. (16mm) Type X gypsum board, or other approved material.

Protecting the steel elements by embedding them within a timber so that they are protected with wood is usually the most practical approach. Any bolts carrying load need to be counterbored and plugged with a wood plug of sufficient thickness. Any bolts that are not necessary to support load do not necessarily need to be protected unless degradation of the wood around the bolts will compromise the connection.

Protecting timber connections with gypsum board is seldom an acceptable approach for an architecturally exposed timber structure.

Intumescent coatings qualify as “other approved material” for protecting exposed steel connection elements. When exposed to the heat of a fire, an intumescent coating will puff up and expand, creating an insulating barrier. Consequently, they should be applied only to exposed surfaces and should not be applied to surfaces in contact with a timber where they do not have room to expand.

There are no listed E119 fire tests for intumescent coatings applied to timber connection hardware. However, there are several E119 fire tests that have been documented for structural steel beams and columns. It is common practice to base the required intumescent coating thickness on a documented test of an unrestrained beam. For instance, UL design N-607 requires an intumescent coating with a dry film thickness (DFT) of 90 mils to achieve a 1-hour unrestrained beam rating. It typically requires multiple coats to achieve the required DFT. Consequently, intumescent coatings are often cost prohibitive if a fire-resistance rating greater than 1 hour is required.

Even though it is accepted practice to use intumescent coatings on timber connections, the practice is controversial. Results from limited fire tests suggest that an intumescent coating on exposed steel hardware may not significantly improve the fire-resistance of a timber connection. The intumescent coating does not deploy until the steel has reached 450 to 550 degrees F, but by then, the timber adjacent to the steel may have already lost significant strength. Additional research is needed.

Integrity

Fire-rated floor and wall assemblies need to prevent the passage of flames and hot gases. Openings and joints need to be detailed accordingly with appropriate fire-stopping materials.

CLT floor systems commonly have a concrete or poured gypsum topping which is effective at preventing breaching of the floor assembly at joints. If there is no such topping, fire-stop sealant may be needed at panel joints that do not fit tight.

Similarly, fire-stopping may be needed at CLT wall butt joints that do not fit tight.

References

CASE *Structural Engineer's Guide to Fire Protection* 2008

AWC *Technical Report No. 10 Calculating the Fire Resistance of Wood Members and Assemblies* 2018

ASCE/SEI/SFPE 29-05 *Standard Calculation Methods for Structural Fire Protection*

WoodWorks *Fire Design of Mass Timber Members* 2019