# Timber Design Guide 2025-17

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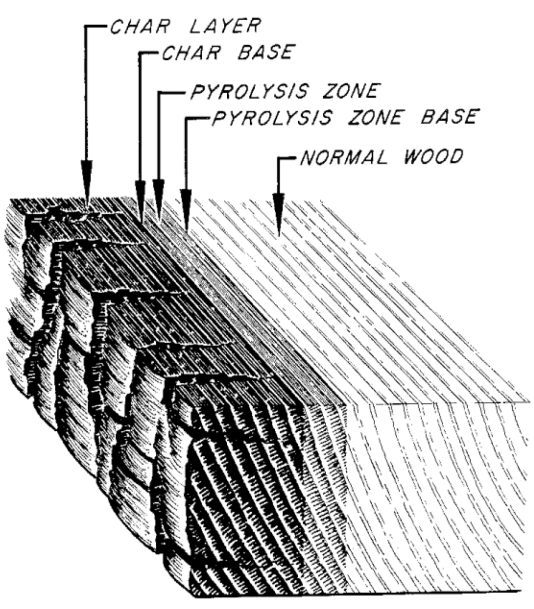
## Introduction

There is a common misconception that just because timber happens to be combustible, timber structures perform poorly in a fire. While this may be true of unprotected light wood frame construction, which burns like dry kindling, it is certainly not true of mass timber structures, which actually perform better than unprotected structural steel. Timber may be combustible, but 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 safely carry load.

When mass 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 and taller 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).

## Building Code Requirements

When timber structures are used for single-family residences, the *International Residential Code (IRC)* does not require any fire-resistance rating (FRR) 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 (FRR) 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 floor area 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.

While the building code analysis is normally performed by the project architect, it is crucial that the structural engineer take a more active role in the selection of the appropriate construction classification since there are structural implications.

## 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 I-B, II-A, and II-B 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-HT 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.

Types IV-A, IV-B, and IV-C made their debut in the *IBC-2021* in response to the Tall Wood initiative promoting mass timber for high-rise buildings. Type IV-A construction permits 18 story buildings, Type IV-B construction permits 12 story buildings, and Type IV-C permits up to 9 story buildings. This additional building height comes with a stiff penalty in the form of fire protection of timber elements with layers of gypsum wallboard (GWB). In Type IV-A buildings, all the mass timber elements must be covered with GWB, and in Type IV-B buildings, only 20%

of the ceiling area can have exposed mass timber. For buildings where exposed timber is an architectural feature, this can be devastating.

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 area limits for Type V construction.

## Fire-Resistance Ratings

The requirements for the fire-resistance rating (FRR) of structural elements are contained in Table 601 of the *IBC*. For each construction classification, Table 601 stipulates minimum FRRs 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 FRR requirements for brace members that resist only wind or seismic loads and do not support gravity loads.

For Type IV-HT construction, Table 601 does not indicate specific FRR 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 required FRR of the steel members in Type IV-HT. It is accepted practice to apply a 1-hour FRR to structural steel beams and columns in a Type IV-HT 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 and UL263 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 320-2019 Standard for Performance-Rated Cross-Laminated Timber*.

The fire-resistance rating (FRR) 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 or

UL263 fire test. Chapter 16 of the *AWC National Design Specification for Wood Construction (NDS)* has a procedure for calculating fire-resistance ratings (FRR). 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, Table 16.3.1 of the *NDS* stipulates that the effective char depth on a timber is 1.8” 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 an allowable stress increase to convert allowable stress to ultimate stress. The design stress to member strength factor “K” is 2.85 for bending.

The FRR calculation for a CLT panel is similar and the effective char depth is stipulated in Table 16.3.2 of the *NDS*. 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 has been consumed.

For glulam timbers, it is necessary to modify the lamination layup. Additional tension laminations are needed to compensate for the tension laminations lost to charring. Otherwise, the FRR 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 7-2022* (section 2.5) stipulates the load combination for extraordinary events such as fire that combines dead load with 50% of the live load plus 15% of snow load. Wind and seismic loads do not need to be considered. Note *TR10* suggests basing the analysis on full live and snow loads which is overly conservative.

## Protected Timbers

When timber elements are not intended to be exposed, FRRs can be achieved by covering the timbers with fire-resistant materials, usually gypsum wallboard (GWB). WoodWorks has published *Inventory of Fire Resistance Tested Mass Timber Assemblies & Penetrations* which lists fire tests that have been performed on protected and unprotected mass timber assemblies.

If there is no matching ASTM E119 or UL 263 fire tested assembly, ratings up to 1 hour can be analytically determined using the *Component Additive Method (CAM)*. Various fire protection materials are assigned a fire-resistance rating time, and these values may be added up for the components that make up the assembly. For instance, a single layer of 5/8" Type X GWB had an assigned fire-resistance of 40 minutes. If it can be demonstrated that a timber element can achieve a 20 minute rating based on char depth, adding a single layer of 5/8" Type X GWB to the fire side will result in a 1 hour fire rating. Very often, a 3-ply CLT can achieve a FRR this way.

## 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 char layer. Timber joints that rely on shallow bearing seats, however, have little fire resistance and need to be supplemented with 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 connection hardware by embedding it within a timber, so the steel is protected by wood, is usually the most practical approach. In some instances, it may be necessary to utilize firestopping materials at a timber connection to prevent excessive char penetration at the end of a timber.

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.

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 not to surfaces in contact with timber where they do not have room to expand.

There are no listed ASTM E119 or UL263 fire tests for intumescent coatings applied to connection hardware. However, there are several 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.

Even though it is common practice to use intumescent coatings on steel connection hardware, 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 wood 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, penetrations, and joints need to be detailed accordingly with appropriate firestopping 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, firestop sealant may be needed at panel joints that do not fit tight.

Similarly, firestopping may be needed at butt joints in CLT walls that do not fit tight.

## Conclusion

As mass timber has become more popular in recent decades, and is being utilized on larger and taller projects, fire resistance has become a significant structural consideration. It is no longer appropriate to simply delegate responsibility for fire safety to the project architect, structural engineers need to play a more dominant role.

## References

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

AWC *Fire Design Specification for Wood Construction (FDS)* 2022

AWC *Technical Report No. 10 Calculating the Fire Resistance of Wood Members and Assemblies* 2021

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

WoodWorks *Fire Design of Mass Timber Members* 2023