Fire-Resistive Design of Exposed Timber Structures

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Timber has been successfully used to construct fire-safe buildings in the United States, Canada and Europe for more than a century. And there are good reasons for that:

- When exposed to elevated temperatures, the mechanical properties of timber offer significant advantages over other structural alternatives.
- In a fire, timber forms a self-insulating char layer which provides protection for the unburned portion.
- Timber members do not expand appreciably when heated, and retain a substantial amount of strength when exposed to the extreme temperature levels that commonly occur in building fires.
- Heated steel tends to expand and loses a significant portion of its stiffness, causing steel columns and beams to collapse, even though steel is often defined as non-combustible. This can result in damage to other structural elements, potentially leading to building collapse.

No building material is "fireproof." The goal of fire-resistive design is to provide the proper building materials and protection based on the use of the structure. The fuel load within the structure must be considered as well, as it can pose an increased fire threat in proportion to the types of materials stored in the building. Modern building codes account for: 1) the type of structure; 2) the anticipated use of the building; and 3) the number of occupants the building will house. The first priority in fire codes is to allow ample time and sufficient exit facilities for the occupants to escape. Next, the structure should retain its stability long enough for fire-fighting personnel to combat the fire. Finally, the protection of the contents of the building and adjacent buildings need to be considered.

There are three recognized methods of addressing these priorities using timber construction. Timber members can be protected from fire exposure by enclosing them within a fire-resistant assembly. There are many types of wall, floor, floor-ceiling and roof-ceiling assemblies available for use. For purposes of this discussion, however, we will restrict our consideration to fire-resistive design of *exposed* timber members. There are two code-approved methods of achieving a level of fire protection for timber structures with exposed members. Heavy Timber Construction, the older of the two methods, is included in the codes based on a long history of satisfactory performance. The newer method, One-Hour Fire-Resistive Construction, is based on calculating the capacity of timber members exposed to fire. The One-Hour Fire-Resistive methods have been verified by testing members in accordance with the fire testing requirements of ASTM E-119.

Method One: Heavy Timber Construction

Many large mill buildings were destroyed by fire in the 1800s, resulting in sizable losses to the insurance carriers. Heavy Timber Construction was originally developed by the insurance industry to reduce their liability in the mill industries in the eastern United States. This building method utilized large timber members arranged appropriately to eliminate sharp protruding edges, concealed spaces and gaps in construction, where the heated vapor could pass through the structure. As mentioned earlier, timber will develop a char layer when exposed to fire, which insulates the inner portion of the member. In the absence of an outside fuel source, this char layer prevents oxygen from reaching the char front, resulting in the fire being extinguished in the member. By eliminating the sharp projections, this method provides fewer points of ignition. Concealed spaces are prohibited because they can hide smoldering embers which can later reignite the structure. The floor or roof system is constructed of multiple layers of boards arranged so that the hot vapors cannot pass through, thus keeping fresh oxygen from being delivered to the fire. Based on its successful utilization for more than 100 years, this construction method was adopted by both the International Building Code (IBC) in the U.S. and the National Building Code (NBC) in Canada.

In the code requirements for Heavy Timber Construction, the minimum sizes of the structural members are listed based on the location of the member. For example, the minimum size of a column carrying floor members is 8x8, and the minimum size of a floor beam is 6x10. For roof beams, the minimum size is a 4x6. These are nominal sizes for the members. For instance, the net size for a 4x6 is 3½"x5½" (89mm x 140mm). The requirements for floors and roof decks are also given in the code.

Figure 1. High school gymnasium with heavy timber roof. Notice the large main and secondary beams and 2 x 6 tongue and groove decking.

The 2007 IBC sees this method as so effective that it allows roofs to be constructed using Heavy Timber Construction in all buildings where One-Hour roof construction is permitted.

Timber connectors allowed by the building codes may also be used in the Heavy Timber Construction method. This includes wall boxes and fabricated metal connectors. These connectors have proven to be sufficiently resistant to fire so that no further protection is required. Refer to UBC section 605.6 for additional information on Heavy Timber Construction.

Figure 1A. This 1476 ft (450m) building is used to store potash, a chemical used in fertilizer. The glulam arches span 161 ft (49m) and are spaced at 32 ft (9.75m) on center. The glulam purlins are 3 $^{1/8}$" x 16 ½" (79mm x 419mm) and are spaced at 48" (1219mm) on center. The roof sheathing is 1$^{1/8}$" (28.6mm) thick plywood. This building classifies as Heavy Timber Construction.

Method Two-A: One-Hour Fire-Resistive Construction

In One-Hour Fire-Resistive Construction, every component of the building must meet the requirements of the ASTM E-119 fire test. In this test, a temperature-time curve is followed where the tested components are heated to 1600° F. Each component must be able to carry its design loading throughout the 60-minute test to be considered a One-Hour component. Timber members and all connections must offer the same protection. This can be accomplished by placing the connections within a One-Hour rated wall, protecting the connections with a minimum of 1½" (38mm) timber covering or by providing connections that are kerfed into the timber, leaving a minimum 1½" (38mm) covering. The bolts connecting the wood to the steel must be countersunk and plugged with 1½" (38mm) thick plugs. Additionally, the minimum nominal size of a timber member is 6" (152mm). For glued laminated (glulam) timbers, an additional tension lamination must replace a core lamination and the words, "Fire-Rated One Hour" must be stamped on the member.

In 1977, T. T. Lie, of the National Research Council of Canada, developed equations yielding the allowable time for timber members based on results of the required fire exposure. Lie calculated the reduced size of the timber members based on the observed char rate and the reduction of the strength of the member for the region beyond the char front. Next he adjusted the strength of the member from an allowable stress to the ultimate strength of the members. Finally, these relationships were combined to produce an equation that yields the time a given member can safely support the applied load. Lie developed equations for beams and columns with three and four sides exposed to fire. Refer to UBC Standard 7-7 for the equations used in this method.

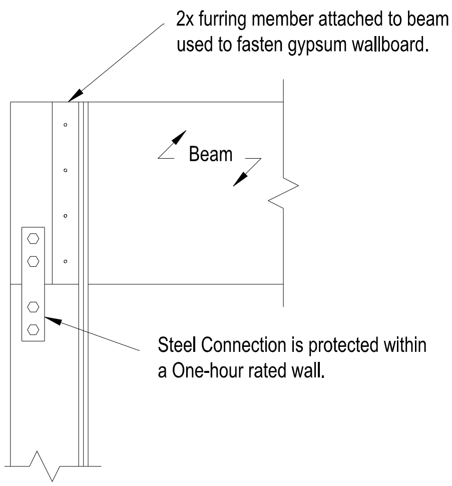

Figure 2. Steel Connection Protected by One-hour Fire rated wall

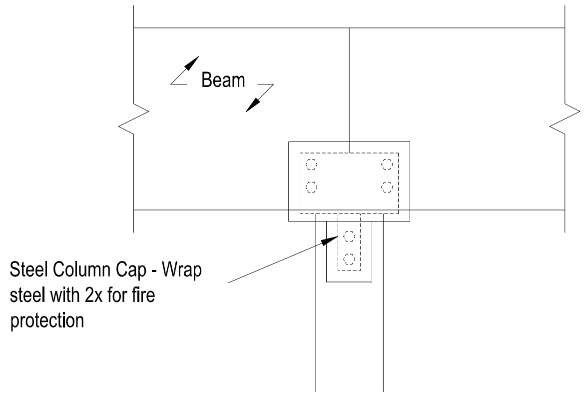

Figure 3. Steel Connection Protected by 2x wood covering

Method Two-B: AWC Technical Note #10

In 2001, the American Wood Council (AWC) developed a revised method of designing fire-rated timber members. This method is described in the AWC Technical Note #10. Using the same assumptions as Lie in regard to reducing the member section and converting from the allowable strength to the ultimate capacity of the member, this method calculates an effective char rate based on the length of time a member is exposed to fire. Tests have shown that the rate of char declines with increased time of exposure due to the insulating effect of the char layer. However, where Lie's method calculated an allowable time of exposure for a given member size, the newer method allows the designer to calculate the allowable capacity of the member based on the reduced member size, using the average ultimate strength of the member.

The allowable stresses given in the National Design Specification for Wood Construction (U.S.) are based on the Working Stress Design method. These values have been reduced from the measured ultimate stresses for wood. In order to apply this method of calculating the fire resistance of a timber member, the designer must calculate the ultimate stress for the member by multiplying the allowable stress by an adjustment factor that accounts for the variation of the material and other adjustments.

Accepted by the latest U.S. building codes, this method allows the design of bending members, columns, tension members and members subjected to combined bending and axial load. It also provides a method for designing timber decks for a One-Hour fire rating, and for checking members for more than a One-Hour fire rating. Refer to AWC technical note #10 for further information.

Figure 4. Birchwood Community Church in Anchorage, Alaska. These glulam arches were sized to achieve a one-hour rating. The roof-ceiling assembly will have two layers of 5/8" (16mm) gypsum wallboard attached to the bottom of the roof joists. The steel connections will be covered with 2x wood blocking.

Conclusion

The slow-burning characteristics of large timber members have long been recognized as an advantage in designing fire-safe buildings. The U.S. and Canadian building codes recognize two methods of achieving fire safety using exposed timber members. Heavy Timber Construction, with a long history of successful performance, uses a prescriptive method of specifying minimum sizes of members to obtain a fire-resistive design. One-Hour Fire-Resistive Construction uses the observed char rate of timber exposed to fire to calculate the size of timbers necessary to meet the code-required protection. These methods give building designers the necessary tools to incorporate the beauty of exposed timber members into a fire-resistive structural framing system.