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WOOD DESIGN & BUILDING

Fire-Resistive Design of Exposed Timber Structures

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DES800-A Fire-Resistive Design of Exposed Timber Structures

Description:
Timber has been successfully used to construct fire-safe buildings in the United States, Canada and Europe for more than a century. No building material is "fireproof." One goal of fire-resistive design is to provide the proper building materials and structural fire protection, based on the use of the structure. The combustibility of the structure is often a primary consideration, however it is recognized that the greatest fire threat lies with the types of materials stored in the building. This course covers several different methods where timber construction may be used to address fire safety priorities.

Learning Objectives:

After reading this article, you should be able to:

1) Be able to define important goals of fire-resistive design.
2) Be able to discuss how timber can be used successfully to provide fire resistance for buildings.
3) Be able to identify and describe the different methods of addressing fire resistance in wood buildings.
4) Be able to recall important IBC and NBCC code requirements for Heavy Timber Construction.

To receive credit, you are required to read the entire article and pass the test. Go to http://awc.org/education/ecourses for complete text and to take the test for free.

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 that provides protection for the unburned portion.
- Timber beams and columns 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.

No building material is "fireproof." The goal of fire-resistive design is to provide the proper building materials and structural fire protection, based on the use of the structure. The combustibility of the structure is often a primary consideration, however it is recognized that the greatest fire threat lies with 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 primary priority related to fire safety in building codes is to allow ample time and sufficient exit facilities for the occupants to escape. Next, most structures are required to be designed to retain their stability long enough for fire-fighting personnel to perform their duties, which relates both to helping to evacuate occupants and reducing the probability of harm to persons as well as fighting the fire to reduce the probability of economic loss due to damage to the building or adjacent buildings.

There are several recognized methods for addressing these priorities with timber construction. Timber members can be protected from fire exposure by enclosing them within a fire-resistant assembly. There are many types of fire-resistive wall, floor, floor-ceiling and roof-ceiling timber assemblies available for use. For purposes of this article, however, we are limiting our consideration to the fire-resistive design of exposed timber members. In North America, there are two code-approved methods of achieving the required 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 fire performance and is elaborated through descriptive and prescribed details (minimum dimensions and arrangements) for beams columns, arches, and floor and roof elements. The newer method, which in the U.S. is termed *One-Hour Fire-Resistive Construction*, is based on calculating the capacity of timber members exposed to fire. The calculation methods have been verified by testing members in accordance with the fire testing requirements of ASTM E-119 (in Canada, ULC S-101).

High school gymnasium with heavy timber roof. Notice the large main and secondary beams and 2 x 6 (38 x 140 mm) tongue and groove decking.

Method One: Heavy Timber Construction

Many large mill buildings were destroyed by fire in the 1800s, resulting in sizable losses to the insurance carriers. The concept of *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) that 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, which retards the further degradation of the timber member.

By eliminating the sharp projections, this method provides fewer points of ignition on the timber elements. Concealed spaces are prohibited because they can hide smoldering embers, which can later reignite the structure. The floor or roof system is typically constructed of thick layers of lumber or panel products or multiple layers of boards arranged so that the hot vapors or fire cannot pass through.

Based on its successful utilization for more than 100 years, this construction method has been recognized by both the International Building Code (IBC) in the U.S. and the National Building Code of Canada (NBCC).

In the U.S., the 2006 IBC included provisions, based on this method being so effective, to allow roofs to be constructed using *Heavy Timber Construction* in all buildings where 'one-hour'

In the IBC and NBCC code requirements for *Heavy Timber Construction*, the minimum sizes of the structural members are listed based on the location of the member. For example, in the IBC, the minimum size of a column carrying floor members is 8 x 8, and the minimum size of a floor beam is 6 x 10. For roof beams, the minimum size is a 4 x 6. These are the nominal sizes listed in the IBC for the timber members. For instance, the net size for a 4 x 6 is 3½ in. x 5½ in. (89mm x 140mm). The requirements for floors and roof decks are also given in the codes. In the NBCC, minimum actual dimensions (in millimeters) are stated.

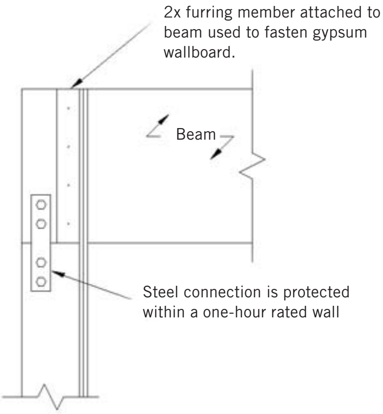
This 1476-ft. (450m) building is used to store potash, a chemical used in fertilizer. The glulam arches span 161 ft. (49m) and are spaced at 32 ft. (9.75m) on center. The glulam purlins are 3 ⅛ in. x 16 ½ in. (79mm x 419mm) and are spaced at 48 in. (1219mm) on center. The roof sheathing is 1 ⅛-in. (28.6mm) thick plywood. This building design qualifies as *Heavy Timber Construction*.

roof construction is permitted. In Canada, in the 1985 NBCC, provisions were included that allowed for roofs of *Heavy Timber Construction* on all buildings, regardless of area or minimum fire resistance requirements, where the building height is not more than two storeys and the building is sprinklered.

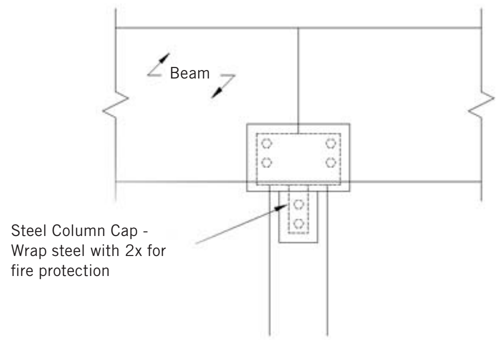
Timber connectors allowed by the building codes may also be used in the *Heavy Timber Construction* method. This includes wall boxes and fabricated metal connectors. These connectors have proven to be sufficiently resistant to fire so that no further protection is required. Refer to IBC section 602.4 and NBCC, Division B, Article 3.1.4.6 for additional information on *Heavy Timber Construction*.

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

In the U.S., 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-in. (38mm) timber covering or by providing connections that are kerfed into the timber, leaving a minimum 1½-in. (38mm) covering. The bolts connecting the wood to the steel must be countersunk and plugged with 1½-in. (38mm) thick plugs. Additionally, the minimum nominal size of a timber member is 6 in. (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.



STEEL CONNECTION PROTECTED BY ONE-HOUR FIRE-RATED WALL



STEEL CONNECTION PROTECTED BY 2X WOOD COVERING

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.

In Appendix D of Division B of the NBCC, similar design equations are described that can be used to determine the fire resistance rating of glulam beams and columns.

Method Two-B: AWC Technical Report #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 Report #10 and has been incorporated into Chapter 16 of the National Design Specification (NDS) for Wood Construction (U.S.). 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 Report #10 for further information.

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 ⅝-in. (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.