FIRE RESISTANCE

Introduction

In the *National Building Code of Canada (NBCC)*[1] "fire-resistance rating" is defined in part as: "the time in minutes or hours that a material or assembly of materials will withstand the passage of flame and the transmission of heat when exposed to fire under specified conditions of test and performance criteria…"

Fire Resistance Ratings

Standard Fire Test Methods

The test and acceptance criteria the NBCC refers to are contained in a standard fire test method, CAN/ULC-S101, *Standard Method of Fire Endurance Tests of Building Construction and Materials*, published by ULC Standards.

Horizontal Assemblies

Horizontal assemblies such as floors, ceilings and roofs are tested for fire exposure from the underside only. This is because a fire in the compartment below presents the most severe threat. For this reason, the fire-resistance rating is required from the underside of the assembly only.

The fire-resistance rating of the tested assembly will indicate, as part of design limitations, the restraint conditions of the test. When selecting a fire-resistance rating, it is important to ensure that the restraint conditions of the test are the same as the construction in the field. Wood-frame assemblies are normally tested with no end restraint to correspond with normal construction practice.

Vertical Assemblies

Partitions or interior walls required to have a fire-resistance rating must be rated equally from each side, since a fire could develop on either side of the fire separation. They are normally designed symmetrically. If they are not symmetrical, the fire-resistance rating of the assembly is determined based on testing from the weakest side. For a loadbearing wall, the test requires the maximum load permitted by design standards be superimposed on the assembly. Most wood-stud wall assemblies are tested and listed as loadbearing. This allows them to be used in both loadbearing and non-loadbearing applications. Most steel-stud wall assemblies are tested and listed as non-loadbearing because they are used primarily in non-loadbearing applications in noncombustible buildings.

Loadbearing steel-stud wall assemblies typically use studs of a heavier gauge steel than non-loadbearing studs to be able to support the load. The heavier gauge stud reacts differently when exposed to fire and withstands the tendency for studs to twist and distort when exposed to heat. Loadbearing and non-loadbearing steel stud wall listings are not interchangeable because the properties of the studs in these assemblies are not the same. Listings for loadbearing wood stud walls can be used for non-loadbearing cases since the same studs are used in both applications.

Loading during the test is critical as it affects the capacity of the wall assembly to remain in place and serve its purpose in preventing fire spread. The strength loss in studs resulting from elevated temperatures or actual burning of structural elements causes deflection. This deflection affects the capacity of the protective wall membranes (gypsum board) to remain in place and contain the fire. The fire-resistance rating of loadbearing wall assemblies is typically lower than that of a similarly designed non-loadbearing assembly.

Exterior walls only require rating for fire exposure from within a building. This is because fire exposure from the exterior of a building is not likely to be as severe as that from a fire in an interior room or compartment. Because this rating is required from the inside only, exterior wall assemblies do not have to be symmetrical.

Alternative Fire Test Methods

The NBCC permits the authority having jurisdiction to accept results of fire tests performed according to other standards. Since test methods have changed little over the years, results based on earlier or more recent editions of the CAN/ULC-S101 standard are often comparable.

The primary US fire-resistance standard, ASTM E119, is very similar to the CAN/ULC-S101 standard. Both use the same time-temperature curve and the same performance criteria. Fire-resistance ratings developed in accordance with ASTM E119 are usually acceptable to Canadian officials. Whether an authority having jurisdiction accepts the results of tests based on these standards depends primarily on the official's familiarity with them.

Availability of Test Results

Testing laboratories and manufacturers also publish information on proprietary listings of assemblies which describe the materials used and assembly methods.

A multitude of fire-resistance tests have been conducted over the last 70 years by North American laboratories. Results are available as design listings or reports through:

- APA
- Intertek
- QAI Laboratories
- PSF Corporation
- Underwriters' Laboratories of Canada
- Underwriters' Laboratories Incorporated

In addition, manufacturers of construction products publish results of fire-resistance tests on assemblies incorporating their proprietary products (for example, the Gypsum Association's *GA-600 Fire Resistance Design Manual*[2]).

NBCC Table A-9.10.3.1.A. and Table A-9.10.3.1.B

The NBCC contains generic fire-resistance rating information for wood assemblies and members. This includes fire and sound resistance tables describing various wall and floor assemblies of generic building materials that assign specific fire-resistance ratings to the assemblies. Over the last two decades a number of large research projects were conducted at the National Research Council of Canada (NRCC) on light-frame wall and floor assemblies, looking at both fire resistance[3] and sound transmission. As a result, the 2010 NBCC has hundreds of different wall and floor assemblies with assigned fire-resistance ratings and sound transmission ratings. These results are published in the NBCC Table A-9.10.3.1.A. Fire and Sound Resistance of Walls and NBCC Table A-9.10.3.1.B Fire and Sound Resistance of Floors, Ceilings and Roofs. Not all assemblies described were actually tested. The fire-resistance ratings for some assembles were extrapolated from fire tests done on similar wall assemblies.

The listings are useful because they offer off-the-shelf solutions to designers. They can, however, restrict innovation because designers use assemblies which have already been tested rather than pay to have new assemblies evaluated. Listed assemblies must be used with the same materials and installation methods as those tested.

Alternative Methods for Determining Fire Resistance

The previous section on fire-resistance ratings deals with the determination of fire-resistance ratings from standard tests. Alternative methods for determining fire-resistance ratings are permitted as well.

The alternative methods of determining fire-resistance ratings are contained in the NBCC, Division B, Appendix D, Fire Performance Ratings. These alternative calculation methods can replace expensive proprietary fire tests. In some cases, these allow less stringent installation and design requirements such as alternate fastener details for gypsum board and the allowance of openings in ceiling membranes for ventilation systems.

Section D-2 in NBCC, Division B, Appendix D includes methods of assigning fire-resistance ratings to:

- wood-framed walls, floors and roofs in Appendix D-2.3. (Component Additive Method);
- solid wood walls, floors and roofs in Appendix D-2.4.; and,
- glue-laminated timber beams and columns in Appendix D-2.11.

Component Additive Method

The most practical alternative calculation method includes procedures for calculating the fire-resistance rating of lightweight wood-frame wall, floor and roof assemblies based on generic descriptions of materials. This component additive method (CAM) can be used when it is clear that the fire-resistance rating of an assembly depends strictly on the specification and arrangement of materials for which nationally recognized standards exist.

The assemblies must conform to all requirements in NBCC, Division B, Appendix D-2.3. Wood and Steel Framed Walls, Floors and Roofs.

Fire Resistance of Solid Wood Assemblies

While the information currently contained in Appendix D-2.4. addresses more historic construction techniques, there has been some resurgence in the use of such assemblies, and the information can be particularly useful when repurposing historic buildings.

Calculating Fire Resistance of Glulam Timbers

NBCC, Division B, Appendix D also includes empirical equations for calculating the fire-resistance rating of glue-laminated (glulam) timber beams and columns, in Appendix D-2.11. These equations were developed from theoretical predictions and validated by test results.

Large wood members have an inherent fire resistance because:

- the slow burning rate of large timbers, approximately 0.6 mm/minute under standard fire test conditions; and,
- the insulating effects of the char layer, which protects the unburned portion on the wood.

These factors result in unprotected members that can stay in place for a considerable time when exposed to fire. The NBCC recognizes this characteristic and allows unprotected wood members, including floor and roof decks, that meet the minimum sizes for heavy timber construction to be used both where a 45-minute fire-resistance rating is required and in many noncombustible buildings.

The calculation method in Appendix D determines a fire-resistance rating for glulam beams and columns based on exposure to fire from three or four sides. Using this approach, the fire-resistance rating (FRR) in minutes of glulam beams and columns is:

$$FRR = 0.1fB\left[4 - 2\frac{B}{D}\right]$$

for beams exposed to fire on 4 sides,

$$FRR = 0.1fB\left[4 - \frac{B}{D}\right]$$

for beams exposed to fire on 3 sides,

$$FRR = 0.1fB\left[3 - \frac{B}{D}\right]$$

for columns exposed to fire on 4 sides,

$$FRR = 0.1fB\left[3 - \frac{B}{2D}\right]$$

for columns exposed to fire on 3 sides,

where,

f = the load factor shown in Figure 1 to compensate for partial loading;

B = the full dimension of the smaller side of the beam or column in mm before exposure to fire, as shown in Figure 2;

D = the full dimension of the larger side of the beam or column in mm before exposure to fire as shown in Figure 2.

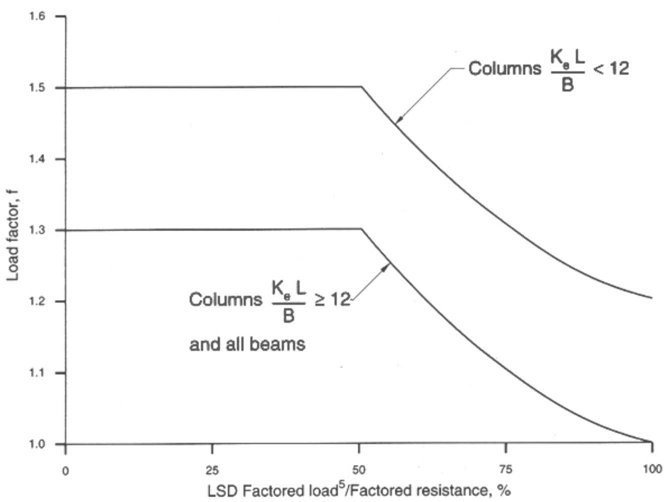

Figure 1. Load factor for glulam fire-resistance calculations (NBCC, 2010)

Notes:

1. *Ke = Effective length factor*
2. *L = Unsupported length of a column in mm*
3. *B = Smaller side of a beam or column in mm (before fire exposure)*
4. *LSD = Limit States Design*
5. *In the case of beams, use factored bending moment in place of factored load.*

The formula for columns or beams which may be exposed on three sides applies only when the unexposed face is the smaller side of a column; no experimental data exists to verify the formula when a larger side is unexposed. If a column is recessed into a wall or a beam into a floor, as shown below, the full dimensions of the structural member are used in the formula for exposure to fire on three sides.

Comparisons of the calculated fire-resistance ratings with experimental results show the calculated values are very often conservative.

A designer may determine the factored resistance for a beam or column by referring to CSA Standard O86-09 Engineering Design in Wood or the 2010 Canadian Wood Council's Wood Design Manual.

An example of fire-resistance calculation of glulam beam is shown below.

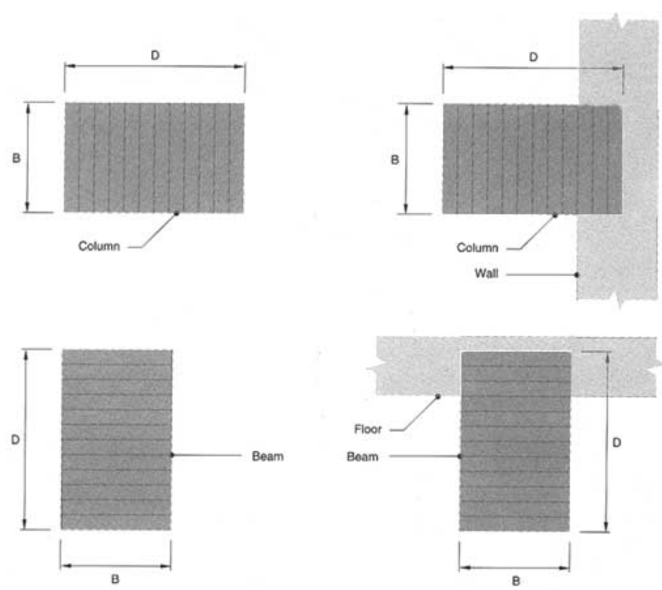

Figure 2. Glulam exposure cases (NBCC, 2010)

Further information on the calculation of fire resistance of heavy timber members is available in the American Wood Council's publication *Technical Report 10: Calculating the Fire Resistance of Exposed Wood Members (TR10)*[4]. [Note that this document is not currently referenced in the NBCC.]

Example

Determine the fire-resistance rating of a glulam beam exposed on three sides having dimensions of 175 x 380 mm and with a factored bending moment equal to 80 percent of its bending moment resistance.

B = 175mm D = 380mm

From Figure 1, f=1.075 for a beam designed to carry a factored load producing 80 percent of factored bending moment resistance.

$$t = 0.1fB \left[4 - \frac{B}{D}\right]$$

$$t = 0.1 \times 1.075 \times 175 \times \left[4 - \frac{175}{380}\right]$$

Total fire-resistance rating = 66.6 minutes

This beam could be used to support a one-hour fire-resistance-rated wood-frame floor assembly.

More detailed information on the fire-resistance test, CAN/ULC-S101, and the NBCC provisions related to fire-resistance rating requirements can be found in Chapter 5 of CWC's *Fire Safety Design in Buildings*.

As well, the 2015 edition of the CSA O86 Standard *Engineering Design in Wood* includes a new informative Annex B that provides a method to calculate fire-resistance ratings for large cross-section wood elements, such as beams and columns of glued-laminated timber, solid-sawn heavy timber and structural composite lumber.

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[1] National Building Code of Canada, National Research Council, Ottawa, ON, 2010.
[2] http://www.gypsum.org/products/publications/fire-resistance-design-manual-ga-600-12/
[3] Fire-resistance testing reports:

- Sultan, M.A., Séguin, Y.P., and Leroux, P.; "IRC-IR-764: Results of Fire Resistance Tests on Full-Scale Floor Assemblies", Institute for Research in Construction, National Research Council Canada, May 1998.
- Sultan, M. A., Latour, J. C., Leroux, P., Monette, R. C., Séguin, Y. P., and Henrie, J. P.; "RR-184: Results of Fire Resistance Tests on Full-Scale Floor Assemblies - Phase II", Institute for Research in Construction, National Research Council Canada, March 2005.
- Sultan, M.A., and Lougheed, G.D.; "IRC-IR-833: Results of Fire Resistance Tests on Full-Scale Gypsum Board Wall Assemblies", Institute for Research in Construction, National Research Council Canada, August 2002.

[4] www.awc.org