3.1.3 Timber

When attention is given to all details, the fire resistance of a wood member or assembly depends on three items:

1. performance of its protective membrane (if any)
2. extent of charring of the structural wood element, and
3. load-carrying capacity of the remaining uncharred portions of the structural wood elements.

In recent years, two fire resistance design procedures have gained U.S. and Canadian building code acceptance. Due to differences in the various codes, specifics need to be verified for a given code. In addition, other procedures and models have been proposed or are being developed.

3.1.3.1 Light Frame Assemblies

Gypsum board and plywood panelling are two common types of protective membrane, which is the first line of resistance in a fire in wood construction. The contribution of the protective membrane to the fire resistance rating of a light-frame assembly is clearly illustrated in the component additive calculation procedure.

The component additive calculation procedure is a method to determine conservatively the fire resistance ratings of load-bearing light-frame wood floor assemblies and of load-bearing and nonload bearing wall assemblies. With this procedure, one assumes that times can be assigned to the types and thicknesses of protective membranes and that an assembly with two or more protective membranes has a fire resistance rating at least that of the sum of the times assigned for the individual layers and the times assigned to the framing. The procedure was developed by the National Research Council of Canada. It has both U.S. and Canadian Code acceptance.

The times assigned to the protective membrane (Table 3.4), the framing (Table 3.5), and other factors (Table 3.6) are based on empirical correlation with actual ASTM E 119 tests of assemblies. The fire rating of an assembly is the sum of the appropriate items from Tables 3.4, 3.5, and 3.6. Depending on the codes, the rating for the assembly is limited to ether 60 or 90 minutes. The times given in Table 3.4 are based on the membrane's contribution to the total fire rating of the assembly. The times assigned to the protective membranes are not the "finish ratings:" of the material cited in test reports or listings. (A finish rating is defined as the time for an average temperature rise of 139°C or maximum rise of 181°C on the fire exposed side of the wood framing.)

There are minimum requirements for the membrane on the side not exposed to fire (Tables 3.7 and 3.8) in order to assure that the assembly does not fail because of fire penetration or heat transfer through assembly. Instead of being one of the combinations listed in Tables 3.7

TABLE 3.4. Time assigned to protective membranes.

Description of Finish	Time, minutes
⅜ inch Douglas fir plywood, phenolic bonded	5
½ inch Douglas fir plywood, phenolic bonded	10
⅝ inch Douglas fir plywood, phenolic bonded	15
⅜ inch gypsum board	10
½ inch gypsum board	15
⅝ inch gypsum board	20
½ inch Type X gypsum board	25
⅝ inch Type X gypsum board	40
Double ⅜ inch gypsum board	25
½ + ⅜ inch gypsum board	35
Double ½ inch bypsum board	40

Notes:
1. On wall, gypsum board shall be installed with the long dimension parallel to framing members with all joints finished. However, ⅝ inch Type X gypsum wallboard may be installed horizontally with the horizontal joints unsupported.
2. On floor/ceiling or roof/ceiling assemblies, gypsum board shall be installed with the long dimension perpendicular to framing members and shall have all joints finished.

TABLE 3.5. Time assigned to wood-frame components.

Description of Frames	Time, minutes
Wood studs, 16 inches on center	20
Wood joists, 16 inches on center	10
Wood roof and floor truss assemblies 24 inches on center	5

TABLE 3.6. Time assigned for additional protection.

Description of Additional Protection	Time, minutes
Add to the fire endurance rating of wood studs walls if the spaces between the studs are filled with rockwool or slag mineral wool batts weighing not less than ¼ lb./sq. ft. of wall surface.	15
Add to the fire endurance rating of non-load bearing wood stud walls if the spaces between the studs are filled with glass fiber batts weighing not less than ¼ lb./sq. ft. of wall surface	5

TABLE 3.7. Minimum requirement for the membrane on exterior face of walls (Any combination of sheathing, paper (if required) and exterior finish).

Sheathing	Paper	Exterior Finish
5/8 inch T&G lumber		Lumber siding
		Wood shingles and shakes
5/16 inch exterior grade plywood	Sheathing	1/4 inch ext. grade plywood
1/2 inch gypsum board	paper	1/4 inch hardboard metal siding,
		Stucco on metal lath
		Masonry veneer
None	None	3/8 inch ext. grade plywood

TABLE 3.8. Minimum requirement for flooring or roofing membranes.

Assembly	Structural members	Subfloor or roof deck	Finish flooring or roofing
Floor	Wood	1/2 inch plywood or 11/16 inch T&G softwood lumber	Hardwood or softwood flooring on building paper or Resilient flooring, parquet floor, felted-synthetic-fiber floor coverings, carpeting, or ceramic tile on 3/8 in. thick panel-type underlay; or Ceramic tile 1-1/4 in. mortar bed.
Roof	Wood	1/2 inch plywood or 11/16 inch T&G softwood lumber	Finish roofing material with or without insulation

and 3.8, the membrane on the side not exposed to fire (the outside) may be any membrane listed in Table 3.4 with a rated time of 15 minutes or greater.

3.1.3.2 One Hour Fire Resistive Exposed Wood Members

If timber structural members are exposed to fire, a char layer is formed at the exposed surface. The thickness of this layer grows continuously at an approximately constant rate. Because the char layer has practically no strength, the load carrying capacity of the member decreases. As the charring proceeds, a time will be reached when the uncharred part is reduced to a size at which the member can no longer support the load. By calculating the time it takes to reach the critical size, the fire resistance of the member can be determined. Such calculations have been carried out for glue laminated timber beams and columns exposed on three or four sides to fire, and simplified formulas have been derived for the prediction of their fire resistance (Lie 1977). According to these formulas, the fire resistance of glue-laminated timber beams and columns can be given as follows:

Beams heated on 4 sides

$$R = 2.54\, fB\, [4 - 2(B/D)] \tag{37}$$

Beams heated on 3 sides

$$R = 2.54\, fB(4 - B/D) \tag{38}$$

Columns heated on 4 sides

$$R = 2.54\, fB(3 - B/D) \tag{39}$$

Columns heated on 3 sides

$$R = 2.54\, fB(3 - B/2D) \tag{40}$$

where

R = the fire resistance of a beam or column (min)
B = the smaller side of a beam or column before exposure to fire (in.)
D = the larger side of a beam or column before exposure to fire (in.)

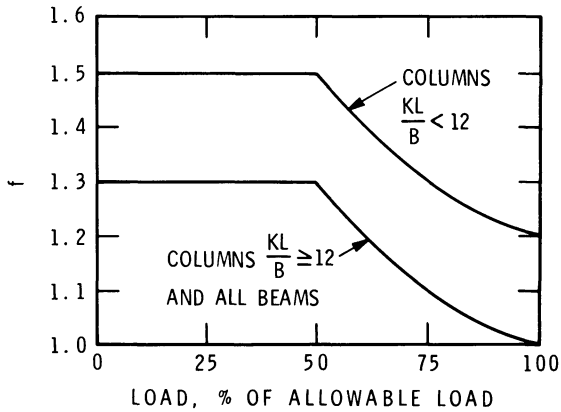


Figure 3.22—Factor f as a function of load for timber columns and beams.

f = factor taking into account the load and for columns the effective length as shown in Fig. 3.22
K = the effective length factor
L = the unsupported length of column (in.)

Equations 38 and 40 apply for the case where the unexposed face is the smaller side of the beam or column. Where one of the larger sides of a beam or column is not exposed to fire, conservative values of the fire resistance of the members can be obtained, using equation 37 for the beam and equation 39 for the column.

Note to formulas (37) to (40):

*The formulas are applicable for wood beam or column with minimum nominal dimension of 6 in. The net finish width for a nominal 6-in. glued laminated member is 5⅛ in.

The factor f depends on the load and, for columns, also on the effective length as shown in Fig. 3.22. If a load is applied that is lower than the allowable load the fire resistance of a member increases. The higher fire resistance of a member that is overdesigned is expressed by a higher value of f. With respect to fire, a member may be regarded as overdesigned if it is designed to resist accidental loads, such as seismic, wind and snow loads. The load on the beam or column may be assumed to be equal to the full specified dead load and live load plus 30% of the design snow load.

This procedure is contained within the Council of American Building Officials (CABO) Report No. NER-250 (National Evaluation Board 1984) and the supplement to the *National Building Code of Canada* (National Research Council of Canada 1990).

Connectors and fasteners relating to support of the member must be protected for equivalent fire-resistive construction. Where minimal 1-

hr fire endurance is required, connectors and fasteners must be protected from fire exposure by 1½ in. of wood, fire-rated gypsum board, or any coating approved for a 1 hour rating. NER-250 includes diagrams giving typical details of such protection.

There is often a high-strength tension laminate on the bottom of glued-laminated timber beams. As a result, it is required (NER-250) that a core lamination be removed, the tension zone moved inward, and the equivalent of an extra nominal 2-in.-thick outer tension lamination be added to ensure that there is still a high-strength laminate left after fire exposure.

3.2 FIRE RESISTANCES DETERMINED BY TESTING

Over the years, thousands of fire tests have been conducted on many types of materials and combinations of materials. Most of the tests were conducted to satisfy regulatory requirements. Very comprehensive documents containing fire test results for various structural members such as beams, columns, floors, roofs, walls and partitions are the *Fire Resistance Directory* (Underwriters Laboratories 1988), the *List of Equipment and Materials* (Underwriters Laboratories of Canada 1980), and that published by the American Insurance Services Group (1985). These documents are updated every year.

Other documents containing fire test results are more restrictive in that one inorganic material is used to provide fire resistance for the elements of the building. One such document is the *Fire Resistance Design Manual* (Gypsum Association 1978). Designs in this manual use gypsum products to provide fire resistance for walls, partitions, floor ceilings, columns, beams, and roof decks. Another document of the latter type is *Technical Note 16* on brick construction (Brick Institute of America 1974), that gives several designs using brick in combination with other materials.

Most of the information in the above mentioned documents are based on results of tests on building elements made with proprietary materials. Ratings for a large number of building elements made with generic materials are given in the NFPA *Fire Protection Handbook* (Fitzgerald 1986) and in the *National Building Code of Canada* (National Research Council of Canada 1990).

3.3 EXTENSION RULES AND GUIDELINES FOR FIRE RESISTANCE

In a test, the fire resistance of a building element is usually determined for one specific condition with regard to the factors that determine its fire performance, such as materials used in the specimen, its dimensions, load, etc. For any other condition, a new test is required which is a costly and time consuming method for determining fire resistance. By calculation of fire resistance, which can be carried out at a fraction of the time and cost involved in testing, the range of conditions for which the fire resistance can be determined can be considerably extended. A further extension of this range can be obtained by using experimentally or theoretically derived rules and guidelines that enable the interpretation of test or calculated results for conditions that differ from those in the test or calculation.

In the following, several extension rules and guidelines will be given for the assessment of the fire resistance of various building elements. The rules are for building elements made with steel, concrete, or timber, with or without protection. Only rules and guidelines will be given for variation in conditions that will produce equal or higher fire resistances than those under the conditions in the test or in the calculations. They are divided into guidelines that take into account the effect on the fire resistance (R) of the building element due to:

1) variation of material properties, or
2) variation of dimensions.

In addition, a number of generally valid rules will be given. In all cases, it is assumed that the variations do not introduce higher stresses in load bearing elements.

Where necessary, the rules and guidelines will be briefly explained. More information is given in *Fire Technology* (Harmathy 1965), in which the author introduced ten general rules for fire resistance. More information is also given in other sources, where the basis of several of the extension rules given below can be found (Stanzak and Lie 1973, Harmathy 1970, Lie 1978, Abrams and Gustaferro 1969, Gustaferro and Selvaggio 1967, and Lie 1972).

3.3.1 Definition of Terms

To facilitate the use of the rules and guidelines, definitions of a few often used terms will first be given before dealing with the rules.

Structural fire resistance: the ability of a construction to withstand the thermal effects of fire without loss of its load bearing function.

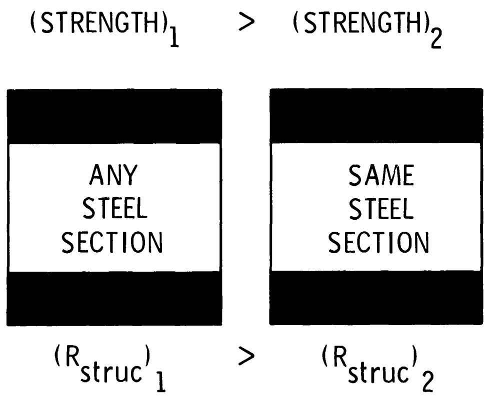
Thermal fire resistance: the ability of a fire separation to withstand the thermal effects of fire without excessive heat transmission through it.

Developed heated perimeter: for protected steel elements, the perimeter of the protection at the interface between steel and insulation (see Figs. 3.1–3.5, 3.7, 3.8). For unprotected steel elements, this perimeter is equal to the outer perimeter of the steel (see Figs. 3.6, 3.9). The developed heated perimeter is equal to the area per unit length of the steel element through which heat is supplied to the steel.

3.3.2 Variation of Material Properties

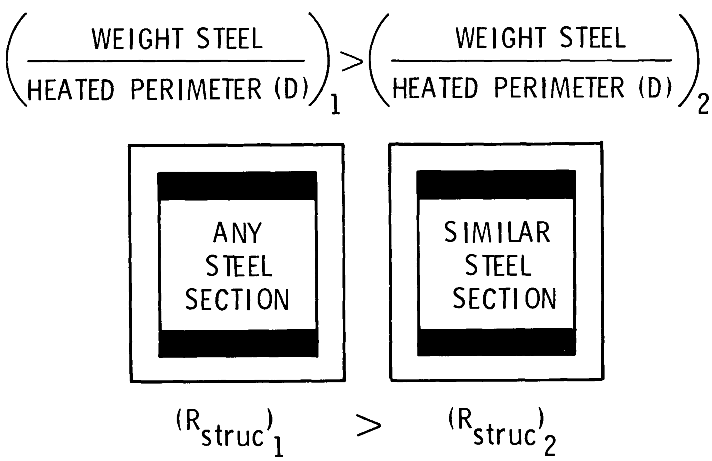
3.3.2.1 Steel

Guideline 1: The structural fire resistance of a protected or unprotected steel element may increase with the ratio of the strength of the steel to the load applied. (See Fig. 3.1, 3.2 and 3.5–3.9 for examples of these steel elements.)



NOTE: This may not be the case if other failure criteria apply.

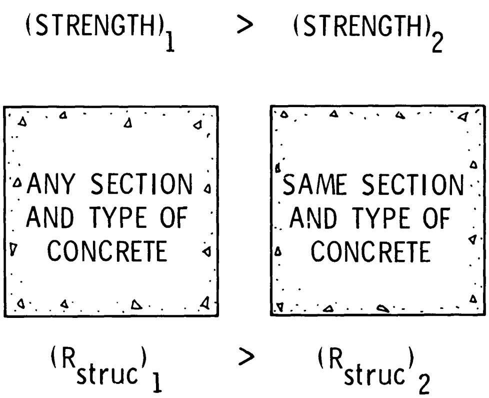
Guideline 2: The structural fire resistance of protected and unprotected steel elements increases with the ratio of the weight of the steel to the developed heated perimeter *D* (see Figs. 3.1, 3.2 and 3.5–3.9 for the developed heated perimeter *D* of various steel sections).



Explanation: If the weight of the steel is increased, more heat is needed to raise the temperature of the steel to the failure temperature. If the area through which the heat is supplied to the steel is increased, it will take less time to reach the failure temperature. This area is, for a unit length of the protected steel elements, equal to the developed heated perimeter *D*. Note that the accuracy of the above guideline is dependent upon the shape of the steel section. For example, for wide flange shapes and angles, the area through which heat is supplied to the steel is less than that corresponding to the developed heated perimeter *D*, because the fire exposed area is reduced between the flanges or legs. Therefore, the validity of the rule is restricted to similar shapes.

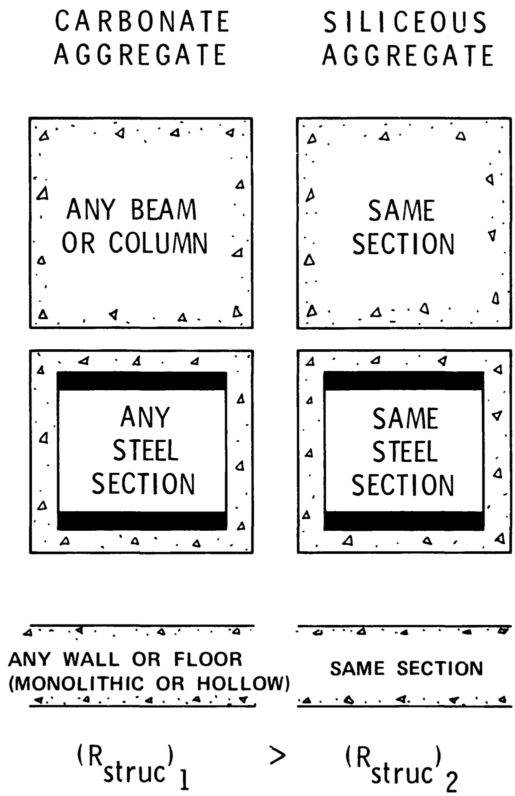
3.3.2.2 Concrete

Guideline 1: The structural fire resistance of a concrete building element increases with the strength of the concrete, if the same type of concrete is used.



Explanation: The fire resistance of concrete elements increases with the strength of the concrete if subjected to the same load. For a specific strength, siliceous aggregate concrete elements have lower fire resistances than carbonate aggregate concrete elements; and normal weight concrete elements often have lower fire resistances than lightweight concrete elements. Therefore the rule is only valid if the same type of concrete is used.

Guideline 2: The use of carbonate aggregate instead of siliceous aggregate is beneficial for the structural fire resistance of concrete or concrete protected building elements, if the strength of the concrete is not decreased.



Explanation: The thermal properties of carbonate aggregate concrete are more favorable than those of siliceous aggregate concrete from the point of view of heat transmission. Carbonate aggregate concrete is also more ductile than siliceous aggregate concrete.

Guideline 3: The use of carbonate aggregate instead of siliceous aggregate is beneficial for the thermal fire resistance of fire separating building elements.