FIRE RESISTANCE OF BUILDING ASSEMBLIES

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1.0 SCOPE

This document provides guidelines for estimating the fire endurance of existing building components and assemblies and information from which assemblies having a given fire endurance can be constructed. Fire endurance is the length of time during which a component or assembly continues to exhibit fire resistance. Fire resistance is a property of a component or assembly and is associated with either the ability to confine fire to its compartment of origin or to perform a given structural function.

Recommendations for fire endurance ratings can be found in FM Global Property Loss Prevention Data Sheets 1-3, 1-20, 1-22, the 7-series, and 8-series data sheets, and applicable building codes. The ratings given are in accordance with American Society for Testing and Materials (ASTM) E 119 (NFPA 251, UL 263), ASTM E 814 or acceptable modifications thereof. However, for a discussion of time-temperature curves used by other countries, see Section 12.

Unless noted as specific to high-strength concrete, the concrete-related recommendations in this data sheet are intended to apply to normal-strength concrete. Refer to Appendix A for definitions of normal- and high-strength concrete, and refer to Section 11 for recommendations specific to high-strength concrete.

The types of building materials and assemblies included in this data sheet are:

1. **Walls** subject to standard fire exposure (ASTM E 119) from one side and a hose stream, where applicable. (Note that a different rating may result for either side if the wall is not symmetrical. See later discussion.)

2. **Columns** subject to standard fire exposure from all sides.

3. **Floor-ceiling** or **roof-ceiling assemblies** subject to standard fire exposure from below.

4. **Fire-stop materials** for sealing around electrical and mechanical service penetrations through walls, ceilings and floors.

Some items *not* included are:

1. **Fire doors.** See the *Approval Guide*, a publication of FM Approvals.

2. **Protection of structural steel for storage areas.** See the applicable 8-series storage Loss Prevention Data Sheets and the *Approval Guide*.

3. **Undercoating** that allows a Class 2 insulated steel deck roof to meet the fire hazard requirements of Class 1 roof. See Loss Prevention Data Sheet 1-28R/1-29R, *Roof Systems* and the *Approval Guide*.

1.1 Changes

January 2012. The following changes were done for this revision:

1. Added recommendations for Autoclaved Aerated Concrete (AAC).

2. Added recommendations for double-wythe concrete masonry unit (CMU) walls, and CMU and concrete walls with fire-resistant finish materials such as plaster and gypsum board, with example problems.

3. Added recommendations for CMU cavity walls and hollow partition walls that contain foam plastic insulation.

4. Added recommendations and guidance for CMU % solid, face shell thickness, aggregate-based densities, and the fire-resistance benefits of grout-filled CMU.

5. Added recommendations to address high strength concrete (HSC) spalling and fire-exposed strength.

6. Added and revised recommendations for precast/prestressed (pc/ps) concrete and cast-in-place post-tensioned (pt) concrete - and new guidance for identifying the various types of concrete.

7. Added recommendations for fiber-reinforced polymer (FRP) rebar and externally-applied FRP reinforcing.

8. Added and revised recommendations regarding concrete cover for fire walls.

9. Added recommendations for heavy timber and glulam framing.

10. Added recommendations and guidance on ISO 834 and BS 476 time-temperature curves and fire tests.

11. Added background structural steel columns tested per the ASTM E119 fire test standard and the difference between the loaded and unloaded (limiting steel temperature) test options.

12. Added and revised guidance on fire-resistance rated glass and glazing.

13. Added guidance on firestopping and the T_{FM} rating in the FM Approval Guide.

14. Added an extensive glossary of terms.

2.0 THERMAL RESTRAINT

In fire tests of building elements, the element is considered restrained if the forces of expansion are resisted by forces external to the element. An element is considered unrestrained if it is free to expand and rotate at its supports.

In general, restrained elements or assemblies are capable of achieving greater fire endurance ratings than equivalent unrestrained elements or assemblies. This is due in large part to the different failure criteria for restrained and unrestrained elements in the various fire endurance tests. Consider an assembly that employs an *unrestrained* steel beam. According to ASTM E 119, test failure is determined to have occurred when either the average temperature in the steel beam has reached 1100°F (593°C) or the maximum temperature at any point in the steel beam has reached 1300°F (704°C). The elapsed time at which this occurs is the fire endurance rating.

For *restrained* assemblies, the same limiting temperatures are allowed at half the rated time or a minimum of 1 hour. The fire endurance rating is then the time at which the ultimate load capacity is exceeded or twice the time at which the temperature limits are reached, whichever is lower.

3.0 SPRAY-APPLIED FIRE PROTECTION COATINGS

A variety of coverings and coatings are available to limit the temperature of structural members in a fire. The two most basic categories of fire protection are membrane protection and direct application. Membrane protection refers to products that are used in such a way that they are independently supported from the surface they are protecting. This group includes batts, blankets and board stock. An example is boxing in with board stock materials like gypsum board. Direct applied protection refers to products that are applied directly to the substrate they are to protect. They generally are adhesively attached to the substrate. These coatings can be either troweled-on, formed and poured or spray-applied. An example is encasement in concrete, plaster, or gypsum.

A large variety of spray-applied coatings are available. However, they can generally be classified into three types:

- Mineral fiber
- Cementitious
- Intumescent

3.1 Mineral Fiber

Mineral fiber is molten volcanic rock that is spun into fine threads. The fibers are applied to the substrate by spraying with water. Tamping and the use of adhesives and sealers is usually optional.

Spray-applied mineral fiber fireproofing can be susceptible to damage. It can be removed manually or by accidental impact.

3.2 Cementitious

Cementitious coatings use cement and some type of aggregate. The type of cement (portland, gypsum, etc.) and the type of aggregate will determine the density and impact resistance of the material. It is cost-effective to use very lightweight aggregates since the material does not require significant compressive strength as does normal concrete. Therefore, the aggregates used are typically expanded minerals such as perlite and vermiculite or expanded plastics such as polystyrene.

3.3 Intumescent

Intumescent materials expand when exposed to the heat of a fire and form an insulating layer. Intumescents can be further classified as either paints or mastics.

3.4 Application

Prior to application of spray-applied fire resistive coatings, the substrate surface must be free of dirt, grease, oil and loose mill scale. Mill scale (dark gray color) need not be totally removed. Blast cleaning of the surfaces, although the most effective, is costly and normally not justified. However, it may be required for some proprietary systems. If this is the case, it would be indicated in the listing.

Cleaning with hand tools such as wire brushes is generally adequate. Priming or pre-painting is not normally required either. In fact, use of an incompatible paint may result in inadequate adhesion of the spray-applied fire protection to the surface.

4.0 BEAMS

4.1 Steel Beams

Steel beams may be tested and rated as part of an assembly or as individual members (beam-only tests). The difference can be significant in certain cases. In the beam-only tests, a more generic type roof/ceiling is used. The ratings developed from the assembly tests will be for specific roof/ceiling constructions. When steel beams of a different size are substituted for the beam in the listed design, the following formula can be used to determine the required thickness of **spray-applied fire protection** for the substitute beam:

English units

$$h_2 = h_1[(W_1/D_1)+0.6]/[(W_2/D_2)+0.6] \quad \text{(Eq. 1)}$$

SI units

$$h_2 = h_1[(W_1/D_1)+0.036]/[(W_2/D_2)+0.036] \quad \text{(Eq. 1)}$$

provided:

1. $W/D \geq 0.37$ (English units) or $W/D \geq 0.022$ (SI units)

2. $h \geq$ ⅜ in. (9.5 mm)

3. The unrestrained beam rating ≥ 1 hr.

where:

h = thickness of sprayed-on fireproofing material, inches (mm)
D = heated perimeter of the steel beam, inches (mm) (See Fig. 1)
W = weight of the steel beam, lb/ft (kg/m)
Subscript 1 refers to the ***design*** beam and coating thickness
Subscript 2 refers to the ***substitute*** beam and coating thickness

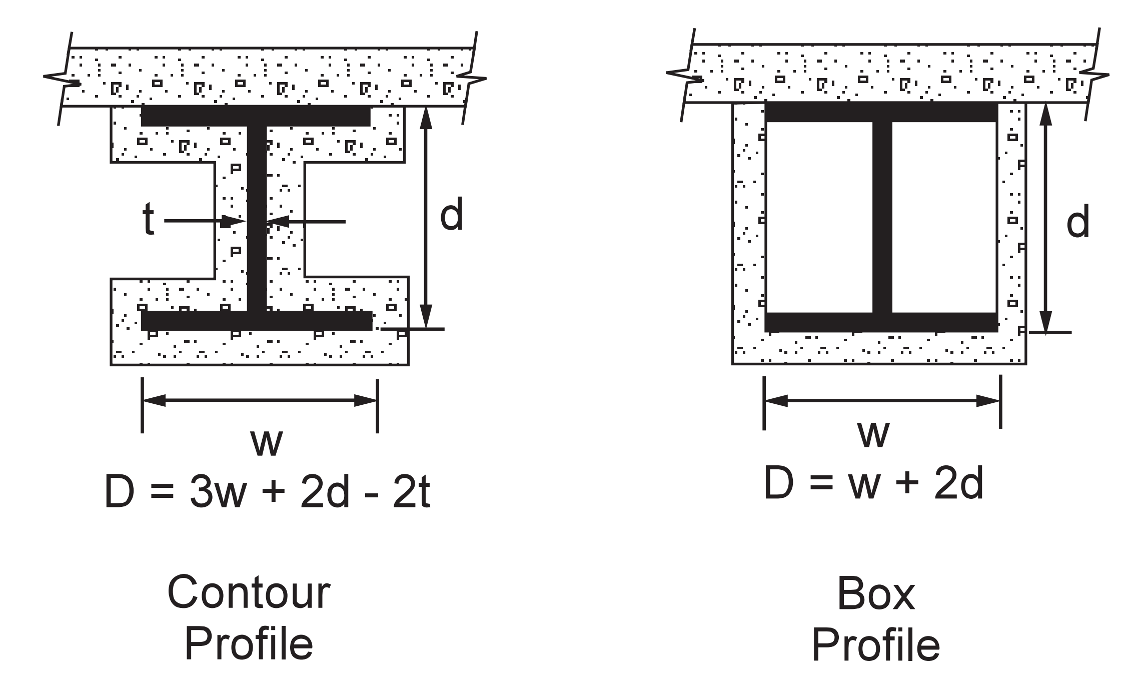


Fig. 1. Heated perimeters for beams

4.2 Concrete Beams

4.2.1 Reinforced Concrete Beams

The concrete cover for an individual steel reinforcing bar (rebar) is the minimum thickness of concrete between the surface of the rebar and the fire exposed surface of the beam. For beams in which several rebars are used, the cover is the average of the minimum cover of the individual bar. For corner bars (i.e., bars equal distance from the bottom and side), the minimum cover used in calculating the average should be half the actual minimum cover for the individual bar. The cover of an individual bar should not be less than ¾ in. (19 mm).

4.2.2 Prestressed Concrete Beams

The concrete cover for an individual tendon is the minimum thickness of concrete between the surface of the tendon and the fire exposed surface of the beam. For beams in which several tendons are used, the cover is the average of the minimum cover of the individual tendons. For corner tendons (i.e., tendons equal distance from the bottom and side), the minimum cover used in calculating the average should be half the actual minimum for the individual tendon. The cover of an individual tendon should not be less than 1 in. (25 mm).

When computing the cross-sectional area of a beam cast monolithically with the supported slab, the cross-sectional area of a section of slab equal to 3 times the average width of the beam can be included.

4.3 Timber and Glulam Beams

This section applies to heavy timber construction consisting of either solid timber or glued-laminated (glulam) beams.

All dimensions noted in this section are actual dimension, not nominal dimensions.

Heavy timber can provide some fire endurance without protective coatings or sheathing due to the insulating effect the charred wood provides to the underlying wood.

4.3.1 Minimum Beam Size

The minimum beam size is 5.5 in. (140 mm) wide x 9.5 in. (240 mm) deep.

4.3.2 Credited fire endurance of timber and glulam beams is limited to 60 minutes.

4.3.3 Only use 3-sided fire exposure to determine the fire endurance when the top side (width) of the beam has the same or better protection as noted for the timber connector and fasteners in Section 4.3.6.

4.3.4 Fire Endurance of Unprotected Timber Beams

Notation:
b = beam width (in. [mm])
d = beam depth (in. [mm])

Timber Beam Fire-Exposed on 4 Sides:

Fire Endurance (min.) = 3.3(b) [4-2(b/d)] ≤ 60 min. (English units) (Eq. 2)
Fire Endurance (min.) = 0.13(b) [4-2(b/d)] ≤ 60 min. (Metric [SI] units) (Eq. 2)

For example:

When b = 7.5 in., and d = 11.5 in.,
Fire Endurance = 3.3(7.5) [4-2(7.5/11.5)] = 67 min., but use 60 min.

Timber Beam Fire-Exposed on 3 Sides:

Fire Endurance (min.) = 3.3(b) [4-(b/d)] ≤ 60 min. (English units) (Eq. 3)
Fire Endurance (min.) = 0.13(b) [4-(b/d)] ≤ 60 min. (Metric [SI] units) (Eq. 3)

4.3.5 Fire Endurance of Unprotected Glulam Beams

Up to 1-hour fire endurance can be achieved by replacing at least one core lamination, which is at least 1.5-in. (38 mm) thick, with a tension lamination of equal to greater thickness in the tension zones of the glulam beam. Alternatively, an additional tension lamination of at least 1.5-in. (38 mm) can be added to the tension zones of the beam.

4.3.6 Connectors and Fasteners for Timber and Glulam Beams

Provide not less than 5/8-inch (16 mm) Type X gypsum board, 1.5-inch (38 mm) thick wood, or a material verified to be acceptable by fire-testing, to cover and protect connectors and fasteners for fire endurance ratings up to 1 hour.

5.0 COLUMNS

The fire endurance rating generally increases as the thickness of the steel increases for a steel column and as the cross-sectional area increases for a reinforced concrete column. However, in the case of reinforced concrete, the fire endurance is also dependent on the thickness of the concrete cover over the reinforcing steel.

5.1 Steel Columns

5.1.1 Spray-applied Protection

The fire endurance of steel columns protected by sprayed-on mineral fiber or cementitious fire proofing can be calculated using the formula:

English units

$$R = [C_1(W/D)+C_2]h \qquad \text{(Eq. 4)}$$

SI units

$$R = [C_1(17W/D)+C_2]h/25.4 \qquad \text{(Eq. 4)}$$

where:

R = fire endurance, ***minutes***
h = thickness of sprayed-on fireproofing material, inches (mm)
D = heated perimeter of the steel column, inches (mm) (See Fig. 2.)
W = weight of the steel column, lb/ft (kg/m)
C_1 & C_2 = material constants dependent on the type of fire proofing material.
For cementitious material, C_1 = 69 and C_2 = 31
For mineral fiber material, C_1 = 63 and C_2 = 42

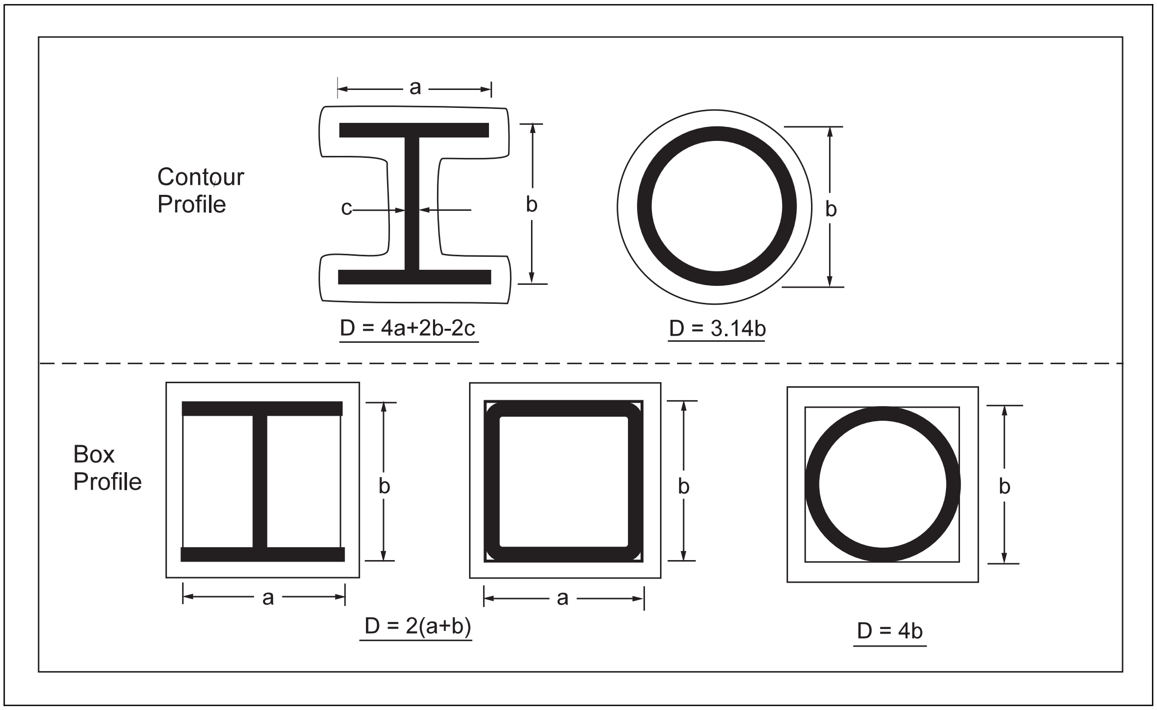


Fig. 2. Column profiles and heated perimeters, D.

Refer to FM Data Sheet 1-1, *Firesafe Building Construction and Materials*, for additional guidance.

5.1.2 Membrane Gypsum Board Protection

The fire endurance of steel columns boxed with gypsum wallboard can be calculated using the formulas:

English units

$$R = 2.17[h(W'/D)/2]^{0.75} \quad \text{(Eq. 5)}$$

SI units

$$R = 1.6[h(W'/D)/2]^{0.75} \quad \text{(Eq. 5)}$$

where:

R = fire endurance, *hours*
h = thickness of gypsum wallboard, inches (mm)
D = heated perimeter of the steel column, inches (mm) (See Fig. 2.)
W = weight of the steel column, lb/ft (kg/m)
W'= weight of the steel column and gypsum wall board protection, lb/ft (kg/m)

English units

$$W'=W+[50(hD)/144] \quad \text{(Eq. 6)}$$

SI units

$$W'=W+0.0008hD \quad \text{(Eq. 6)}$$

5.1.3 Concrete Encased Steel Columns

For concrete-encased steel columns, the fire-endurance ratings are affected by the thickness of the concrete protection and by the type of aggregates used in the concrete. Concrete containing limestone and dolomitic gravel aggregates has greater fire resistance than concrete containing siliceous aggregates. For protected steel columns, a rating of more than 4 hr is seldom required, and a concrete thickness of less than 2 in. (51 mm) is seldom practical.

5.1.4 Concrete-Filled Hollow Steel

Determine the fire endurance rating of hollow steel columns (e.g., pipe and structural tubing) with their core filled with unreinforced concrete should be determined in accordance with the following:

English units

$$R = [0.58a(f'_c+2.9)/(KL-3.28)]D^2(D/C)^{1/2} \quad \text{(Eq. 7)}$$

SI units

$$R = [a(f'_c+20)/(KL-1000)]D^2(D/C)^{1/2} \quad \text{(Eq. 7)}$$

Where:

R = fire endurance rating, hours
a = 0.07 for circular columns filled with siliceous aggregate concrete
0.08 for circular columns filled with carbonate aggregate concrete
0.06 for rectangular columns filled with siliceous aggregate concrete
0.07 for rectangular columns filled with carbonate aggregate concrete
f'_c = specified 28-day concrete compressive strength, ksi (MPa)
KL = column effective length, ft (m)
L = actual length, ft (m)
K = effective length factor. If unknown, assume 1.0 for columns supported at both ends and 2.0 for cantilevered columns.
D = outside diameter for circular columns and least outside dimension for rectangular columns, in. (mm)
C = compressive force due to unfactored dead load and live load, kips (KN)
1 kip = 1000 lb

The application of these equations is limited as follows:

1. The required fire endurance rating time should be ≤ 2 hours.

2. The specified concrete compressive strength should be ≥ 2.9 ksi (20 MPa) and ≤ 5.8 ksi (40 MPa).

3. The column effective length should be at least 6.5 ft (2.0 m) and no greater than 13.0 ft (4.0 m).

4. D should be at least 5.5 in. (140 mm) and no greater than 12 in. (305 mm) for rectangular columns or 16 in. (410 mm) for circular columns.

5. C should not exceed the design strength of the concrete core.

5.1.5 Plaster Protected Steel Columns

The ratings of Designs A to F in Table 1 were based on a W10 x 49 columns (10 x 10 in., [254 x 254 mm]; weighing 49 lb/ft or 73 kg/m). One test was repeated with a W6 x 20 (6 x 6 in., [152 x 152 mm]; weighing 20 lb/ft [30 kg/m]). The W6 x 20 column failed 10% sooner than the W10 x 49. The column Designs A to F in the test series used to prepare Table 1 were tested to failure. Failure occurred more than 10% later than the assigned endurance for ratings up to 3 hour, and at least 6% above the assigned endurance for the 4-hr ratings. **By relying on the overrun in the tests, Designs A to F in Table 1 can be used for all columns with a minimum flange thickness of 0.36 in. (9 mm)**.

The minimum thickness of protecting material (as shown on the sketches in Tables 1 and 2) is measured from the lath outward for metal lath and plaster types of protection, and from the face of the column outward for other types of protection. The ratings for the protected steel columns in Table 2 should not be used with net areas of metal and protecting material less than those given in the table.

The following references apply to the sketches in these tables and are applicable to Designs A to F in Table 1.

1. **Metal or rib lath.** No. 24 USS gage (0.58 mm). Unless otherwise noted, 3.4 lb/sq yd (1.8 kg/sq m).

   a. **Metal lath.** A self-furring, ⅜-in. (10 mm) expanded diamond-mesh lath. These metal-lath sections should be lapped 1 in. (25 mm) and tied 6 in. (152 mm) on centers.

   b. **Rib lath.** A small-mesh metal lath with ⅜-in. (10 mm) deep, heavy reinforcing ribs spaced approximately 4 in. (102 mm) on centers. Sections of this lath should be butted and held tightly against the column with No. 24 gage (0.58 mm), ½-in. (13 mm) wide bands.

2. **Steel corner bead.** To provide desirable plaster thickness on face of lath and protection for corners.

3. **Metal lath spacer.** To support metal lath 1¼ in. (32 mm) from column.

4. **Furring channel.** ¾-in. (19 mm) cold-rolled steel channel at about 2 ft (0.6 m) vertical spacings. Web of channel horizontal; bent around columns with ends lapped at least 3 in. (76 mm) and double tied.

5. **Gypsum wall board.** ½-in. (13 mm) thick.

6. **Wire.** No. 18 gage (1.21 mm) soft annealed galvanized wire fastened around the gypsum board 18 in. (0.46 m) on center vertically.

7. **Wire mesh.** 1 in. (25 mm) mesh, No. 17 gage (1.47 mm) over scratch coat.

8. **Perforated gypsum lath.** ⅜-in. (10 mm) lath applied in one or two layers.

9. **Plaster.** For fire protection.

   a. **Perlite plaster.** Scratch (base) coat 2 ft^3 (0.057 m^3) and brown finish coat 3 ft^3 (0.085 m^3) to 100 lb (45 kg) of fibered gypsum. Finish coat 1⁄16-in. (1.59 mm) thick.

   b. **Vermiculite plaster.** Scratch (base) coat 2 ft^3 (0.057 m^3) and brown (finish) coat 3 ft^3 (0.085 m^3) to 100 lb (45 kg) of fibered gypsum. Finish coat 1⁄16-in. (1.59 mm) thick.

   c. **Fireproofing cement.** A proprietary premixed cement, mixed with water to form a stiff plastic mix for plastering application.

   d. **Portland cement plaster.** Scratch (base) coat 2:1:8 and brown (finish) coat 2:1:10 (ratios are portland cement:lime:sand).

   e. **Gypsum sanded plaster.** 1 part gypsum to 3 parts sand.

Table 1. Fire Resistance of Plaster Protected Steel Columns

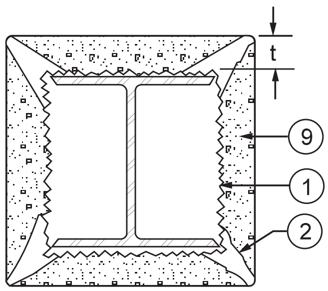
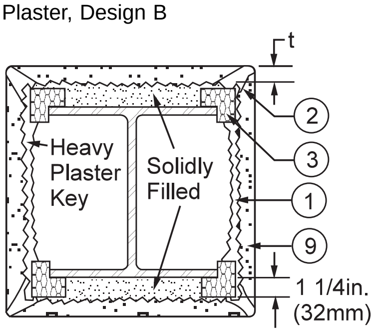
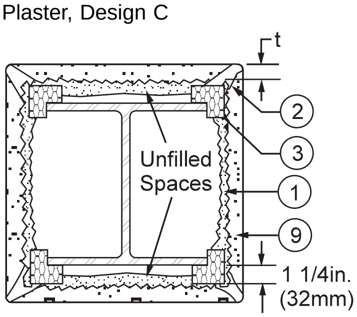
Type of Construction	*Minimum Thickness t, in. (mm)*	*Protecting Material*	*Fire Resistance, hr*
Plaster, Design A 	1¾ (44)	Vermiculite plaster	4
	1¾ (44)	Perlite plaster	4
	1⅜ (35)	Vermiculite plaster	3
	1⅜ (35)	Perlite plaster	3
	1¾ (44)	Portland cement plaster	3
	1 (25)	Perlite plaster	2
	1 (25)	Vermiculite plaster	2
	1 (25)	Portland cement plaster	1
Plaster, Design B 	1½ (38)	Vermiculite plaster	4
	1½ (38)	Perlite plaster	4
	1 (25)	Vermiculite plaster	3
	1 (25)	Perlite plaster	3
Plaster, Design C 	1 (25)	Perlite plaster	2
	1 (25)	Portland cement plaster	1
	¾ (19)	Sanded gypsum plaster	1

Table 1. Fire Resistance of Plaster Protected Steel Columns (cont'd.)

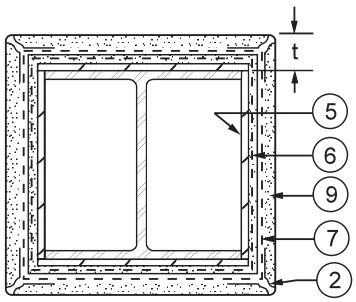
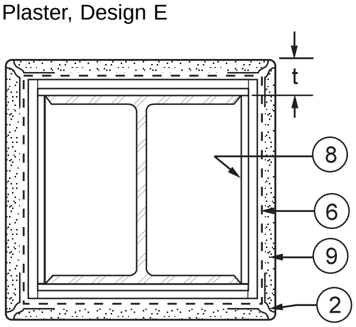
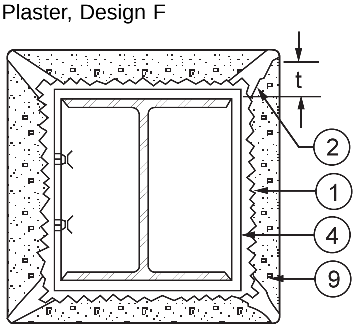
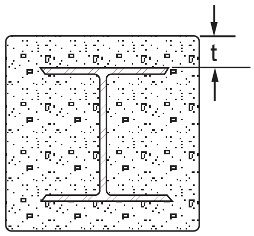
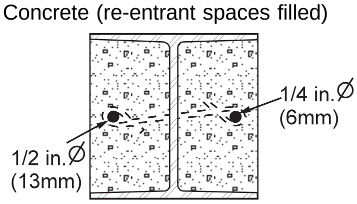
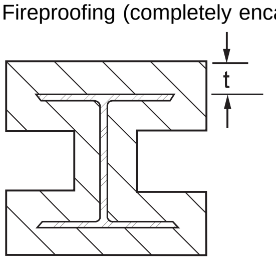
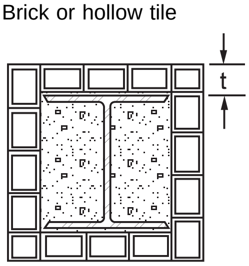
Type of Construction	*Minimum Thickness t, in. (mm)*	*Protecting Material*	*Fire Resistance, hr*
Plaster, Design D 	One Layer Gypsum Wallboard		
	2⅝ (67)	2⅛ in. (54 mm) perlite plaster over ½ in. (13 mm) gypsum board	4
	2 (51)	Two ¾ in. (19 mm) coats perlite	3
	Multiple Layers Gypsum Wallboard		
	2½ (64)	Two ¾ in. (19 mm) coats perlite plaster	4
	2½ (64)	Two ¾ in. (19 mm) coats vermiculite plaster	4
	2 (51)	1 in. (25 mm) perlite plaster	3
	2 (51)	1 in. (25 mm) vermiculite plaster	3
	1 (25)	2 layers gypsum wallboard with no plaster	1
	1½ (38)	3 layers gypsum wallboard with no plaster	1½
	2 (51)	4 layers gypsum wallboard with no plaster	2
Plaster, Design E 	Two Layers Perforated Gypsum Lath		
	2 (51)	2 coats vermiculite plaster, ⅝ in. (16 mm) scratch coat and ⅝ in. (16 mm) brown coat	3
	One Layer Perforated Gypsum Lath		
	1⅜ (35)	1 in. (25 mm) perlite plaster	2
	1⅜ (35)	1 in. (25 mm) vermiculite plaster	2
	1 (25)	⅝ in. (16 mm) layer gypsum board	1½
Plaster, Design F 	1½ (38)	Perlite plaster (Fill space between metal lath and flange of steel column)	4

Table 2. Fire Resistance of Protected Steel Columns

Type of Construction	*Minimum Thickness t, in. (mm)*	*Protecting Material*	*Minimum Area[1], in.^{2} (cm^2)*	*Fire Resistance, hr*
Concrete (completely encased) 	2 (51)	Concrete with calcareous aggregate	100 (645)	4
	2 (51)	Concrete with siliceous aggregate	100 (645)	3
	3 (76)	Concrete with siliceous aggregate	100 (645)	4
	2 (51)	Concrete with siliceous aggregate	144 (929)	4
Concrete (re-entrant spaces filled)  Note: Any type steel section with metal thickness at least 0.20 in. (5 mm) **Note:** Any type steel section with metal thickness at least 0.20 in. (5 mm)		Re-entrant spaced filled with a 1:6 or 1:2:4 concrete mixture, all aggregates, tied with vertical & horizontal ties.	60 (387)	¾
			35 (226)	½
Fireproofing (completely encased) 	1½ (38)	Vermiculite		2
	1⅞ (48)	Vermiculite		3
	2⅛ (54)	Sprayed gypsum plaster		3
	2½ (64)	Sprayed gypsum plaster		4
Brick or hollow tile 	4 (102)	Common brick	270 (1742)	7
	2 (51)	Common brick	180 (1161)	1¾
	2-3-4 (51-76-102)	Hollow tile (clay or shale) with wire mesh in horizontal joints, re-entrant space filled with concrete	225 (1452)	4
			220 (1419)	3½
			180 (1161)	3
			145 (935)	2½
			110 (710)	2
			80 (516)	1½

Note: 1. Minimum area is area of steel and protecting material. Deduct voids in hollow tile.

5.2 Concrete Columns

Refer to Table 3 and Table 4 for minimum concrete cover, and minimum dimensions of reinforced concrete columns of different aggregate types, for fire endurance ratings of 1 to 4 hours. The minimum dimensions of Table 4 do not apply to columns built into walls (i.e., pilasters) provided that:

1. The fire endurance of the wall is equal to or greater than the required fire endurance of the column;

2. Openings in the wall are protected; and

3. The main longitudinal reinforcement in the column has the minimum cover specified in Table 3.

Table 3. Minimum Concrete Cover for Reinforced Concrete Columns

Fire Endurance (Hours)	*Concrete Cover*	
	(in.)	(mm)
1	1.0	25
1.5	1.5	38
2	2.0	51
3	2.0	51
4	2.0	51

Notes:
1) Concrete cover is the clear cover to the main longitudinal reinforcing.
2) Concrete cover shown is for conventional reinforcement (rebar), regardless of aggregate type.
3) For prestressed (strand) or post-tensioned (tendon) columns, provide the same concrete cover as is recommended for walls in Table 7.2 for the needed fire endurance, but not less than the concrete cover in this table.

Table 4: Minimum Column Dimension for Reinforced Concrete Columns

Fire Endurance (Hours)	*Minimum Column Dimension**					
	Aggregate Type					
	Siliceous		Carbonate		Sand- Lightweight	
	(in.)	(mm)	(in.)	(mm)	(in.)	(mm)
1	8	203	8	203	8	203
1.5	9	229	9	229	8.5	216
2	10	254	10	254	9	229
3	12	305	11	279	10.5	267
4	14	356	12	305	12	305

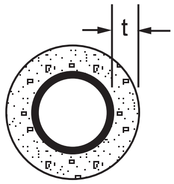
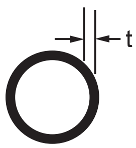
*Minimum column dimension is the minimum diameter for round columns, and the lesser of the cross-sectional dimensions for rectangular columns.

5.3 Cast Iron Columns

Refer to Table 5 for the fire endurance rating of cast iron columns. Cast iron columns with concrete fill in their core but no exterior fire protection coating will have a fire endurance rating of 1/2 hr or less, and unfilled and unprotected cast iron columns will have a fire endurance rating of 20 minutes or less, in theory. However, exposed cast iron columns may shatter if subjected to water spray after fire exposure. Therefore, for any reliable fire endurance rating, cast iron columns should be encased in fire resistant material.

The ratings for the columns in Table 5 should not be used with net areas of metal and protecting material less than those given in the table.

Table 5. Fire Resistance of Cast-Iron Columns

Type of Construction	*Minimum Thickness t, in. (mm)*	*Protecting Material*	*Minimum Area[1] $in.^2$ (cm^2)*	*Fire Rating, hr*
Encased with concrete 	2 (51)	Concrete 1:6 or 1:7 mix tied with not less than AWG No. 5 (4.6 mm) wire on 8 in. (203 mm) pitch	70 (452)	2
No exterior protection[2] 	0.60 (15)	Interior filled with concrete	35 (226)	½
	0.30 (8)	Interior filled with concrete	55 (355)	25 minutes
	0.60 (15)	Unfilled	12 (77)	20 minutes

Notes:
1. Minimum area refers to the area of solid material excluding inside the column if unfilled.
2. Cast iron columns with no exterior protection will have a useful fire resistance rating of ½ hr or less. If exposed to fire and then a hose stream, cast iron is likely to shatter from thermal shock.

5.4 Timber and Glulam Columns

This section applies to heavy timber construction consisting of either solid timber or glued-laminated (glulam) columns.

All dimensions noted in this section are actual dimension, not nominal dimensions.

5.4.1 Minimum Column Size 7.5 in. (190 mm) wide x 7.5 in. (190 mm) deep

5.4.2 Credited fire endurance of timber and glulam columns is limited to 60 minutes.

5.4.3 Only use 3-sided fire exposure to determine the fire endurance when one side of the column has the same or better protection as noted for the timber connector and fasteners in Section 5.4.5.

5.4.4 Fire Endurance of Unprotected Timber and Glulam Columns

Notation:
b = lesser column dimension (in. [mm])
d = greater column dimension (in. [mm])

Timber or Glulam Column Fire Exposed on 4 Sides:

Fire Endurance (min.) = $3.3(b)\ [3-(b/d)] \leq 60$ min. (English units) (Eq. 8)
Fire Endurance (min.) = $0.13(b)\ \{3-(b/d)] \leq 60$ min. (Metric [SI] units) (Eq. 8)

Timber or Glulam Column Fire Exposed on 3 Sides:

Fire Endurance (min.) = $3.3(b)\ [3-(b/2d)] \leq 60$ min. (English units) (Eg. 9)
Fire Endurance (min.) = $0.13(b)\ [3-(b/2d)] \leq 60$ min. (Metric [SI] units) (Eq. 9)

5.4.5 Connectors and Fasteners

Provide not less than 5/8-inch (16 mm) Type X gypsum board, 1.5-inch (38 mm) thick wood, or a material verified to be acceptable by fire-testing, to cover and protect connectors and fasteners for fire endurance ratings up to 1 hour.

6.0 WALLS AND PARTITIONS

Tables 6 through 10 give ratings for selected wall or partition constructions.

Fire resistance is sometimes less when combustible members are framed into the wall because the internal positioning reduces overall wall thickness. Heat is transmitted more rapidly through the smaller net wall thickness and could ignite combustible construction on the other side. If the combustible members are supported by pilasters and the wall thickness is not reduced, the full fire resistance of the wall is available.

Noncombustible members do not affect fire resistance when they are boxed in (not set in an open pocket). However, stability may be a problem. (See Data Sheet 1-22.)

6.1 Masonry Walls

The fire endurance of masonry walls depends on the type of material and the thickness of the wall, if it is solid. For hollow units, the term *equivalent thickness* is used. This is the thickness of a solid wall that could be made from the same amount of material in the hollow wall if the material were recast into a solid mass. The equivalent thickness may be computed using the following formula:

English units

$T_e = V/LH$ (Eq. 10)

SI units

$T_e = 1000V/LH$ (Eq. 10)

Where:

T_e = equivalent thickness, in. (mm)
V = net volume (gross volume less volume of voids), in^3 (cm^3)
L = length of masonry unit, in. (mm)
H = height of masonry unit, in. (mm)

Another method of calculating equivalent thickness if the percentage of solids is known, is to multiply the percent solids times the actual thickness of the masonry unit. The actual thickness is generally ⅜-in. (10 mm) less than the nominal thickness. For example, if it is known an 8 in. (203 mm) nominal thickness masonry unit is 60% solid, the equivalent thickness would be:

$T_e = (8 - 3/8) \times 0.60 = 7.625 \times 0.60 = 4.6$ in. English units

$T_e = (200 - 10) \times 0.60 = 190 \times 0.60 = 114$ mm SI units

Mortar joints are not considered in the computations. See Table 6 for ratings for equivalent thickness based on type of aggregate. Rated masonry units can be obtained with a laboratory certification of the equivalent thickness and the materials. Other masonry units may be rated by fire tests.

For a conservative field estimate of the fire endurance of an existing wall, twice the face shell thickness can be used as the equivalent thickness, T_e. If the aggregate is unknown, assume it is siliceous gravel.

Table 6. Masonry Walls

Material	*Thickness, in. (mm) and Construction Details*	*Fire Endurance with No Combustible Members Framed into Wall, hr*[1]
NOMINAL		
Brick (solid)	12 (300) all materials	10
	8 (200) sand and lime	7
	8 (200) clay and shale	5
	8 (200) concrete	6
	4 (100) clay and shale	1½
	4 (100) concrete and sand & lime	1½
Hollow Tile: Partition tile[2]	12 (300) (two 6 in. [150 mm] tiles)	4
	12 (300) (unknown number of cells)	3
	8 (200)	2
Concrete Masonry Unit: Unknown aggregate	16 (400)	4
	12 (300)	3
	8 (200)	1¾
EQUIVALENT THICKNESS		
Concrete Masonry Unit: Expanded slag or pumice aggregate	4.7 (119)	4
	4.0 (102)	3
	3.2 (81)	2
	2.1 (53)	1
Expanded clay, shale or slate aggregate	5.1 (130)	4
	4.4 (112)	3
	3.6 (91)	2
	2.6 (66)	1
Limestone, cinders, or air-cooled slag aggregate	5.9 (150)	4
	5.0 (127)	3
	4.0 (102)	2
	2.7 (69)	1
Calcareous gravel aggregate	6.2 (157)	4
	5.3 (135)	3
	4.2 (107)	2
	2.8 (71)	1
Siliceous gravel aggregate	6.6 (168)	4
	5.5 (140)	3
	4.4 (112)	2
	2.9 (74)	1

Notes:
1. Where combustible members frame into the wall, the fire endurance rating is governed by the thickness of solid material between the end of each member and the opposite face of the wall or between members set in from opposite sides.
2. Load-bearing hollow tile may be identified by its thicker walls. This tile will have a higher fire endurance rating than partition tile.

The following definitions apply to Table 6.

Siliceous gravels are grains or pebbles of quartz, chert, or flint.

Calcareous gravels are grains or pebbles of limestone and dolomite.

Cinders are residue of combustion.

Slag is the fused and vitrified matter separated during the reduction of a metal from its ore.

Expanded slag is cooled by pouring molten slag into water (as opposed to air cooled slag).

Expanded clay, shale or slate is produced by expanding the mined material in kilns. Vermiculites are in this category.

Pumice is the porous or spongy form of volcanic glass.

Refer to Table 6.1 to determine the equivalent thickness of typical 2-core (2-cell) concrete masonry units (CMU), which is the type used most often. If the type of CMU is unknown, and the % solid is unknown, assume that CMU is 2-core and use Table 6.1 to determine equivalent thickness.

Refer to Table 6.2 to determine the equivalent thickness of typical 3-core (3-cell) CMU. Only use Table 6.2 when the CMU is verified and documented to be 3-core CMU.

*Table 6.1 Equivalent Thickness and Minimum Face Shell Thickness of 2-Core Concrete Masonry Units**

Nominal Unit Thickness		*Actual Unit Thickness*		*Minimum Face Shell Thickness*		*Equivalent Thickness**		
(in.)	(mm)	(in.)	(mm)	(in.)	(mm)	(in.)	(mm)	*% Solid*
6	152	5.625	143	1.0	25	3.1	79	55
8	203	7.625	194	1.25	32	4.0	102	53
10	254	9.625	244	1.375	35	4.5	113	46
12	305	11.625	295	1.5	38	5.1	129	44
14	356	13.625	346	-	-	5.5	139	40
16	406	15.625	397	-	-	6.0	152	38

*Note: Equivalent thickness is approximate based on typical two-core concrete masonry units.

*Table 6.2 Equivalent Thickness and Minimum Face Shell Thickness of 3-Core Concrete Masonry Units**

Nominal Unit Thickness		*Actual Unit Thickness*		*Minimum Face Shell Thickness*		*Equivalent Thickness**		
(in.)	(mm)	(in.)	(mm)	(in.)	(mm)	(in.)	(mm)	*% Solid*
4	102	3.625	92	0.75	19	2.7	69	74
6	152	5.625	143	1.0	25	3.3	84	59
8	203	7.625	194	1.25	32	4.3	109	56
10	254	9.625	244	1.375	35	5.3	135	55
12	305	11.625	295	1.5	38	6.3	160	54

*Note: Equivalent thickness is approximate based on three-core concrete masonry units.

6.1.1 Masonry Walls with Gypsum Wallboard or Plaster Finishes

Refer to Tables 6.3 and 6.4 to determine the additional fire endurance provided by finish materials on masonry walls, with the following limitations:

- Where finishes are applied to the fire-exposed side or both sides of a masonry wall, the contribution to the fire endurance of the finish materials is limited to not more than the fire endurance of the masonry wall alone.
- The contribution to the fire endurance of the finish material on the non-fire exposed side of the wall is limited to one-half the fire endurance of the masonry wall alone.
- If either side of the masonry wall can be fire-exposed, and the finish is not the same on each side of the wall, then the fire endurance of the wall assembly must be calculated twice - with fire exposure at either side - and the credited fire endurance will be the lesser calculated fire endurance.

Table 6.3 Fire Endurance Assigned to Finish Materials on the Fire- Exposed Side of Masonry Wall

Thickness (in.)	*Time (min.)*[1]
Gypsum Board	
1/2 (13)	15
5/8 (16)	20
Type X Gypsum Board	
1/2 (13)	25
5/8 (16)	40
Portland Cement-Sand Plaster on Metal Lath	
1/2 (13)	10
3/4 (19)	20
1 (25)	30
Gypsum Sand Plaster on Metal Lath	
1/2 (13)	20
3/4 (19)	50
1 (25)	75
Portland Cement-Sand Plaster, Gypsum Sand Plaster, or Vermiculite or Perlite Aggregate Plaster Applied Directly to Masonry	
≤ 5/8 (16)	Add plaster thickness to the equivalent thickness of masonry.
> 5/8 (16)	Add plaster thickness of 5/8 in. (16 mm) to the equivalent thickness of masonry.

Notes:
1. Add the fire endurance of the finish material to the fire endurance of the masonry wall to obtain the fire endurance for the wall assembly.
2. For gypsum board or plaster used with steel furring channels: Space the furring channels not more than 24 in. (610 mm) apart and affix with masonry or concrete screws spaced not more than 12 in. (305 mm) apart. Space metal lath nails or screws not more than 12 in. (305 mm) apart along each furring channel.
3. For gypsum board attached directly to the masonry wall, use masonry or concrete screws spaced with 1 screw for each 2 ft^2 (0.18 m^2) of gypsum board.
4. Assume gypsum board is not Type X unless it can be verified.

Table 6.4 Factors for Finish Thickness on Non-Fire-Exposed Side of Masonry Wall

	Type of Masonry			
Finish Material	Solid Clay Brick	Concrete Masonry of Aggregate not otherwise included in this table or of unknown aggregate	Concrete Masonry of Expanded Shale, Expanded Slate, or Expanded Clay	Concrete Masonry of Expanded Slag or Pumice
Gypsum Board	3.0	2.5	2.25	2.0
Portland Cement-Sand Plaster, Lime Sand Plaster	1.0	0.75	0.75	0.5
Gypsum Sand Plaster	1.25	1.25	1.0	1.0
Vermiculite or Perlite Plaster	1.75	1.5	1.25	1.25

Notes:
1. Apply the factors in this table to the actual thickness of finish material on the non-fire- exposed side of the masonry wall to obtain the equivalent thickness of the type of masonry shown.
2. Add the equivalent thickness of masonry from the finish material to the equivalent thickness of masonry wall to obtain total equivalent thickness for determining the fire endurance of the wall assembly.
3. Do not credit any increase in fire resistance for finish materials affixed to hollow clay tile.

Example #1: Concrete masonry block (siliceous aggregate) wall with an equivalent thickness of 4.4 in. (112 mm). The fire endurance rating [R] without finishes is 2 hours (from Table 6).

a) Fire endurance rating with 1/2 in.(13 mm) Type X gypsum board affixed to the fire-exposed side only:

R = 2 hours + 25 minutes (from Table 6.3) = 2 hours, 25 min.

The fire endurance contribution of the Type X gypsum board (25 min.) does not exceed the fire endurance of the masonry wall alone (2 hours); therefore, the fire endurance rating is acceptable.

b) Fire endurance rating with 1/2 in.(13 mm) gypsum board affixed to the non-fire-exposed side only:

Gypsum board T_e = 1/2 in.(13 mm) x 2.5 (from Table 6.4) = 1.25 in. (32 mm)

Total T_e = 4.4 in. (112 mm) + 1.25 (32 mm) = 5.65 in. (144 mm)

From Table 6, the approximate fire endurance is 3 hours for siliceous aggregate CMU with an equivalent thickness of 5.5 in. (140 mm); therefore, say R = 3 hours.

The fire endurance contribution of the 1/2 in.(13 mm) gypsum board (1 hour) does not exceed one-half the fire endurance of the masonry wall alone (1/2 x 2 hr); therefore, the fire endurance rating is acceptable.

c) Fire endurance rating with 1/2 in. (13 mm) Type X gypsum board affixed to both sides of the wall:

The Type X gypsum board on the fire-exposed side adds 25 minutes to the fire endurance, while the gypsum board on the non-fire-exposed side adds approximately 1 hour; therefore, the fire endurance for the entire wall assembly is:

R = 2 hrs + 25 min. + 1 hr = 3 hrs, 25 minutes

The fire endurance contribution of the gypsum board affixed to both sides of the wall (25 min + 1 hr) does not exceed the fire endurance of the masonry wall alone (2 hr); therefore, the fire endurance rating is acceptable.

6.1.2 Multiple-Wythe Masonry Walls

6.1.2.1 For masonry walls where two wythes (two layers or two leafs), of masonry make up the wall assembly, and with no insulation between the wythes, the fire endurance of the wall assembly can be estimated based in the fire endurance of the two individual components as indicated in Table 6.5.

For example, if the fire endurance of one wythe is 1 hour, and fire endurance for the adjacent wythe is 1.5 hours, then the fire endurance for the double-wythe wall assembly is 4 hours.

Table 6.5 Fire Endurance of Double-Wythe Masonry Wall

Fire Endurance of Double Wythe Wall (Hours)						
Fire Endurance of Wythe 2 (Hours)	Fire Endurance of Wythe 1 (Hours)					
	0.5	1	1.5	2	2.5	3
0.5	1.6	2.4	3.1	3.7	4.4	5.0
1	-	3.2	4.0	4.8	5.5	-
1.5	-	-	4.9	5.7	-	-
Linear interpolation is acceptable for reasonable approximations.						

6.1.2.2 For multiple-wythe masonry walls with insulating material between the wythes (such as foamed plastic or cellular plastic insulation, or mineral or glass fiberboard) in a masonry cavity wall, it is the responsibility of the design professional or contractor to provide fire test results from a nationally recognized testing laboratory to document adequate fire endurance.

Do not use wall assemblies that contain foamed plastic insulation for MFL fire walls. Refer to Data Sheet 1-22, *Maximum Foreseeable Loss*, for additional information.

6.1.3 Crediting Core Fill for CMU

6.1.3.1 Do not credit flowable loose material, such as pea stone or vermiculite, to fill the hollow cores of CMU walls for the purposes of increasing fire endurance because these materials can flow from the cores where masonry face shells become cracked or damaged.

6.1.3.2 Grout-Filled CMU

Only credit the enhanced fire resistance of grout-filled CMU walls when all the cores are filled solid with cement grout.

For CMU made from siliceous or calcerous aggregates, and if all the cores are filled solid with cement grout, assume that the CMU is 100% solid and the equivalent thickness (T_e) is equal to the actual thickness of the siliceous or calcerous aggregate CMU for determining fire resistance.

For CMU made from aggregates other than siliceous or calcerous, and if all the cores are filled solid with cement grout, base the fire resistance of the wall on the method used in Section 6.1.1 and Table 6.4 by assuming that the equivalent thickness of the cement grout portion (based on % solid) is evaluated as Portland Cement-Sand Plaster on the non-fire-exposed side of the masonry wall.

6.1.4 Masonry Cover for Reinforcing

Cover for steel reinforcing (e.g., rebar) in masonry wall is provided by both the CMU face shell thickness and the cement grout in the reinforced cores. Refer to Section 6.2.3 and use the same recommended cover for load-bearing CMU walls as for concrete walls with siliceous aggregate.

6.2 Concrete Walls

The recommendations in this section apply to cast-in-place, site cast (e.g., tilt-up), and precast concrete.

6.2.1 Fire Endurance of Concrete Walls

Refer to Table 7 to estimate the fire endurance of concrete walls.

Table 7. Fire Endurance and Minimum Thickness of Concrete Walls

Concrete Aggregate Type	*Fire Endurance (Hours)*									
	1		1.5		2		3		4	
	Minimum Thickness									
	in.	mm	in.	mm	in.	mm	in.	mm	in.	mm
Siliceous	3.5	89	4.3	109	5.0	127	6.2	157	7.0	178
Calcerous	3.2	81	4.0	102	4.6	117	5.7	145	6.6	168
Lightweight	2.7	69	3.3	84	3.8	97	4.6	117	5.4	137
Note: Where combustible members frame into the wall, the fire endurance rating is governed by the thickness of solid concrete material between the end of each member and the opposite face of the wall or between members set in from opposite sides.										

6.2.2 Concrete Walls with Gypsum Wallboard or Plaster Finishes

Refer to Section 6.1.1, and use the same limitations (the fire endurance contribution of finish materials applied to masonry wall) for concrete walls.

Refer to Table 6.3 and use the same recommended additive fire endurance for concrete walls for finish materials applied to the fire-exposed side of the concrete wall. For finish materials applied to the non-fire-exposed side of a concrete wall, refer to Table 7.1.

Table 7.1 Factors for Finish Thickness on Non-Fire-Exposed Side of Concrete Wall

Finish Material	*Type of Aggregate used in Concrete*	
	Siliceous or Calcerous	Lightweight
Gypsum Board	3.0	2.5
Portland Cement-Sand Plaster, Lime Sand Plaster	1.0	0.75
Gypsum Sand Plaster	1.25	1.0
Vermiculite or Perlite Plaster	1.75	1.25

Notes:
1. Apply the factors in this table to the actual thickness of finish material on the non-fire- exposed side of the concrete wall to obtain the equivalent thickness of the type of concrete shown.
2. Add the equivalent thickness of concrete from the finish material to the equivalent thickness of concrete wall to obtain total equivalent thickness for determining the fire endurance of the wall assembly.

6.2.3 Concrete Cover

Provide concrete cover of steel reinforcement for walls as indicated in Table 7.2. If calcerous aggregate or lightweight aggregate concrete cannot be verified, assume the concrete is normal weight with siliceous aggregate.

Adequate thickness of concrete cover is dependent on two characteristics: the type of concrete (based on concrete density or type of aggregate), and the type of reinforcement the concrete cover is protecting.

Table 7.2 Minimum Concrete Cover of Steel Reinforcement for Fire Resistance of Concrete Walls

Type of Reinforcement	*Fire Resistance (Hours)*	*Minimum Concrete Cover*					
		Normal Weight Aggregate				Lightweight Aggregate	
		Siliceous		Calcerous			
		(inch)	(mm)	(inch)	(mm)	(inch)	(mm)
Rebar	1	3/4	19	1/2	13	1/2	13
	1.5	1	25	3/4	19	3/4	19
	2	1	25	3/4	19	3/4	19
	3	1 1/4	32	1 1/4	32	1 1/4	32
	4	1 3/4	44	1 1/2	38	1 1/4	32
P/S Strand or P/T Tendon	1	1 1/4	32	1	25	1	25
	1.5	1 1/2	38	1 1/2	38	1 1/4	32
	2	2	51	1 3/4	44	1 1/2	38
	3	2 1/2	64	2 1/4	57	2	51
	4	3	76	2 3/4	70	2 1/2	64

Notes:
(1) Concrete cover is to the main longitudinal reinforcement; not to ties or stirrups.
(2) Note that concrete cover prescribed by structural concrete codes/standards for normal (non-fire) durability may exceed the values in this table; the greater cover values shall govern.
(3) Rebar is hot-rolled steel reinforcing bar.
(4) P/S Strand is high-strength cold-drawn steel prestressing strand.
(5) P/T Tendon is high-strength cold-drawn steel post-tensioning tendon.

Note that concrete cover is the thickness of concrete measured from the face of the wall to the outer surface of the main longitudinal reinforcing closest to the face of the wall.

6.2.4 Multiple-Wythe Concrete Walls

6.2.4.1 For concrete walls of multiple-wythe or multiple layers such as concrete sandwich panels, follow the recommendations in Section 6.1.2.

For concrete walls where two wythes, or two layers, of concrete make up the wall assembly, the fire endurance of the wall assembly can be determined, similar to that of masonry walls, based in the fire endurance of the two individual components as indicated in Table 6.5.

6.2.4.2 For multiple-wythe concrete walls with combustible insulating material between the wythes (such as foamed or cellular plastic insulation), it is the responsibility of the design professional or contractor to provide fire test results from a reputable testing laboratory to document adequate fire endurance.

Do not use wall assemblies that contain foamed plastic insulation for MFL fire walls. Refer to Data Sheet 1-22, *Maximum Foreseeable Loss*, for additional information.

6.2.5 Precast Concrete Walls

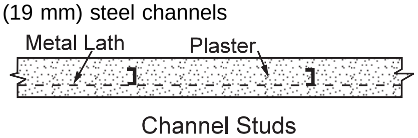
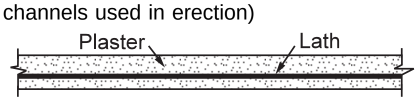
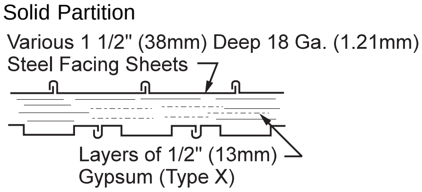
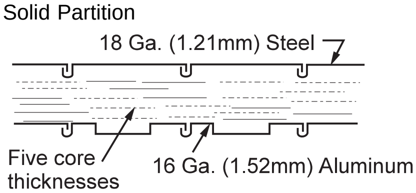
Precast concrete walls are made up of individual precast concrete units. The fire endurance rating of precast/prestressed concrete wall panels can be determined both by testing and analytical methods. Acceptable analytical methods are outlined in *"Design for Fire Resistance of Precast Prestressed Concrete"* published by the Prestressed Concrete Institute; however, do not credit foamed plastic, or cellular plastic, insulation (such as in a concrete sandwich panel) as enhancing or increasing the fire resistance rating of the wall.

Follow the recommendations in Section 6.2.4 for multi-wythe concrete walls.

6.3 Solid Partitions

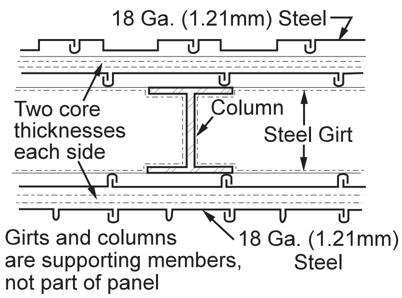
The fire endurance rating of various solid, nonbearing partitions can be found in Table 8.

Table 8. Solid Nonbearing Patitions

Construction	*Material and Thickness*	*Fire Endurance, hour*	*Added Resistance, Both Sides Plastered[1], hour*
Solid Partition, steel frame. Metal lath on ¾ in. (19 mm) steel channels 	1½ in. (38 mm) perlite gypsum	1	–
	2 in. (51 mm) fibered gypsum plaster	1¾	
	2 in. (51 mm) sanded gypsum 1:1½	1½	
	2¼ in. (57 mm) fibered gypsum plaster	2	
	2 in. (51 mm) Cement plaster	½	
	2½ in. (64 mm) sanded gypsum 1:1½ perlite or vermiculite	2	
	2½ in. (64 mm) fibered gypsum	2½	
Solid Partition. Lath only. (Temporary bracing channels used in erection) 	2 in. (51 mm) vermiculite or perlite plaster on ½ in. (13 mm) gypsum or metal lath	2	–
	1½ in. (38 mm) sanded gypsum on ½ in. (13 mm) gypsum or metal lath	1	
	1½ in. (38 mm) perlite or vermiculite on ½ in. (13 mm) gypsum or metal lath	1½	
Solid Partition 	4 layers ½ in. (13 mm) type X gypsum board[2]	2	–
	5 layers ½ in. (13 mm) type X gypsum board[2]	3	
Solid Partition 	5 layers ½ in. (13 mm) type X gypsum board	2½	–

Notes:
1. When plastered on both sides with ½ in. (13 mm) 1:3 gypsum-sand plaster.
2. Type X gypsum board denotes boards made with a specially formulated gypsum core that provides greater fire endurance than regular gypsum of equal thickness.
   Plaster thickness, referred to in the tables, is measured from the face of the metal lath to the exposed face of the plaster. Plaster proportions are given in the tables as weights of dry plaster to dry sand, the first ratio being for the scratch or base coat and the second for the brown or finish coat. Mixtures richer in plaster may be substituted for those given. Plaster noted as "neat" is to be taken as gypsum plaster containing no aggregate.
   Plasters often contain vermiculite or perlite lightweight aggregate. Mixtures containing either of these aggregates have a greater fire resistance than those containing sand. In the tables, the ratios following the plaster mix opposite these types of plaster indicate the number of cubic feet (0.028 m^3) of vermiculite or perlite per 100 pounds (45 kg) of fibered gypsum.

Table 8. Solid Nonbearing Partitions (cont'd.)

Construction	*Material and Thickness*	*Fire Endurance, hour*	*Added Resistance, Both Sides Plastered[1], hour*
Solid Partition 	2 layers ½ in. (13 mm) type X gypsum board on each side of steel column (column supports panel only)	3	–
	2 layers ½ in. (13 mm) type X gypsum board on each side of steel column (column part of building frame)	2	–
Solid Partition	2 layers each ¾ in. (19 mm) thick (actual) T&G boards, one side of wood studs, joints staggered	¼	–
	2½ in. (64 mm) gunite on reinforced mesh	½	
	2 in. (51 mm) solid gypsum blocks	1	
	3 in. (76 mm) solid gypsum blocks	3	
	3 in. (76 mm) gypsum blocks 70% solid	1	1
	4 in. (102 mm) gypsum partition blocks 70% solid	1	2
	5 in. (127 mm) solid gypsum partition blocks	4	2
	4 in. (102 mm) clay partition tile (1-cell)	¼	½
	4 in. (102 mm) cinder aggregate CMU 65% solid	1	1
	6 in. (152 mm) cinder aggregate CMU 60% solid	1¼	¾

Notes:
1. When plastered on both sides with ½ in. (13 mm) 1:3 gypsum-sand plaster.
2. Type X gypsum board denotes boards made with a specially formulated gypsum core that provides greater fire endurance than regular gypsum of equal thickness.
   Plaster thickness, referred to in the tables, is measured from the face of the metal lath to the exposed face of the plaster. Plaster proportions are given in the tables as weights of dry plaster to dry sand, the first ratio being for the scratch or base coat and the second for the brown or finish coat. Mixtures richer in plaster may be substituted for those given. Plaster noted as ''neat'' is to be taken as gypsum plaster containing no aggregate.
   Plasters often contain vermiculite or perlite lightweight aggregate. Mixtures containing either of these aggregates have a greater fire resistance than those containing sand. In the tables, the ratios following the plaster mix opposite these types of plaster indicate the number of cubic feet (0.028 m^3) of vermiculite or perlite per 100 pounds (45 kg) of fibered gypsum.

6.4 Hollow Partitions

6.4.1 It is the responsibility of the design professional or contractor to provide fire test results from a nationally recognized testing laboratory to document adequate fire endurance. Alternatively, refer to Table 9 and Table 10 for various hollow partition walls, or to the *ASTM E 119 Specification Tested* section in the *Approval Guide* for acceptable wall assemblies.

6.4.2 Where insulation is needed in hollow partition walls, use non-combustible insulation such as glass fiber or mineral fiber.

Table 9. Hollow Nonbearing Partitions

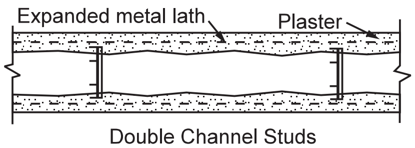
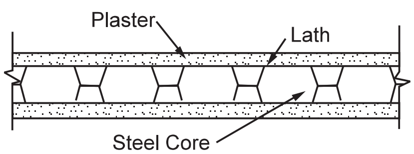
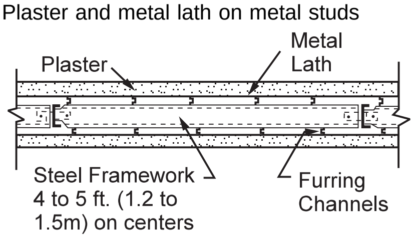
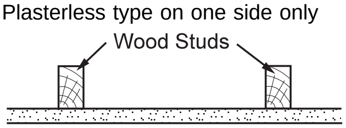
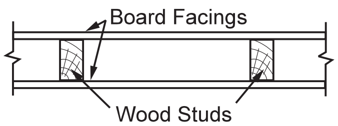
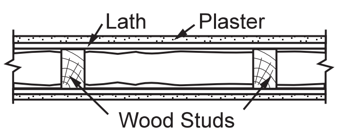
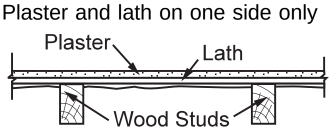
Construction	*Material and Thickness (each side)*	*Fire Resistance, hr*
Plaster and metal lath on metal studs 	1 in. (25 mm) neat gypsum	2½
	1 in. (25 mm) perlite gypsum	2
	1 in. (25 mm) sanded gypsum 1:½	2
	⅞ in. (22 mm) sanded gypsum 1:1½	1½
	⅞ in. (22 mm) portland cement 1:2-1:3	1
	¾ in. (19 mm) neat gypsum	1½
	¾ in. (19 mm) sanded gypsum 1:2	1
	¾ in. (19 mm) portland cement 1:2-1:3	½
Plaster and metal lath on cellular steel core 	¾ in. (19 mm) gypsum and sand plaster on metal lath on cellular steel core. (Core is not filled.) Use same rating for load-bearing partitions.	1
Plaster and metal lath on metal studs 	1 in. (25 mm) perlite gypsum	2
	1¾ in. (44 mm) vermiculite (¼:¾:¾)	5

Table 10. Stud Walls and Partitions, Bearing and Nonbearing [3]

Construction	*Material and Thickness (Each side or one side)*	*Fire Resistance, hr*	*Added Resistance, Partition Filled With Mineral Wool, hr*
Plasterless type on one side only	½ in. (13 mm) type X gypsum board	¼	
	⅝ in. (16 mm) type X gypsum board	⅓	
Plasterless type on both sides 	½ in. (13 mm) (actual) T&G sheathing boards	¼	¼
	¾ in. (19 mm) (actual) T&G sheathing boards	⅜	⅜
	¼ in. (6 mm) fir plywood	¼	½
	½ in. (13 mm) fiberboard (fire retardant treated)	½	
	⅜ in. (10 mm) type X gypsum board	½	
	⅜ in. (10 mm) type X gypsum board (2 layers)[1]	1	
	½ in. (13 mm) type X gypsum board[1]	¾	¼
	½ in. (13 mm) type X gypsum board (2 layers)[1]	1½	
	⅝ in. (16 mm) type X gypsum board[2]	1	
	⅝ in. (16 mm) type X gypsum board (2 layers)[2]	2	
	3⁄16 in. (5 mm) cement-asbestos board	⅙	½
	3⁄16 in. (5 mm) cement-asbestos board over ⅜ in. (10 mm) gypsum board	1	
	3⁄16 in. (5 mm) cement-asbestos board over ½ in. (13 mm) gypsum board[1]	1½	
Plaster and lath on both sides 	½ in. (13 mm) lime plaster, wood lath	½	¼
	½ in. (13 mm) sanded gypsum, wood lath	½	½
	¾ in. (19 mm) cement plaster on metal lath	½	
	¾ in. (19 mm) sanded gypsum on metal lath	1	½
	¾ in. (19 mm) neat gypsum plaster on metal lath	1½	
	1 in. (25 mm) portland cement plaster asbestos 3 lb (1.36 kg) per sack (42.6 kg) on metal lath	1	
	1 in. (25 mm) neat gypsum on metal lath	2	
	½ in. (13 mm) sanded gypsum on ⅜ in. (10 mm) plain or perforated gypsum lath	1	
	½ in. (13 mm) perlite or vermiculite plaster on ⅜ in. (10 mm) perforated gypsum lath	1½	
	1 in. (25 mm) perlite plaster on ⅜ in. (10 mm) perforated gypsum lath	2	
Plaster and lath on one side only	¾ in. (19 mm) vermiculite plaster on metal lath	⅜	
	9⁄16 in. (14 mm) perlite plaster on ⅜ in. (10 mm) perforated gypsum lath	½	

Notes:
1. For nonbearing partitions
2. Same with steel studs
T & G = Tongue and groove
3. For gypsum board applications, stagger the gypsum board joints of adjacent layers at least 12 in. (305 mm).

6.4.3 Type X Gypsum Board

Pure gypsum contains approximately 20% water within the calcium silicate crystal structure. When exposed to fire, it releases the water gradually which helps a board to resist fire. In Standard Time-Temperature fire tests this typically takes 10 minutes to vaporize the water from a ½ in. (13 mm) thick board. As the water vapor is released, gypsum board looses some of its strength. To maintain the board's integrity and to extend its fire resistance, glass fiber reinforcement is included in the manufacture of certain boards. In the USA these are referred to as *type X* gypsum wall boards.

ASTM C 36 defines *type X* gypsum board as any gypsum board that provides not less than 1 hr fire resistance for boards ⅝ in. (16 mm) thick, or not less than 3/4 hr fire resistance for boards ½ in. (13 mm) thick when applied on each side of wood studs 16 in. (406 mm) on center and tested in accordance with ASTM E 119.

Outside the USA manufacturers and standards organizations may not use the term *type X*. It is important to ensure when a locally manufactured gypsum board is being used, it is equivalent to the *type X* specified in FM Global data sheets. As various thicknesses are made, it is also important to provide at least the minimum thickness recommended in the loss prevention data sheet.

6.5 Wall Joints

Joints between wall panels must be protected. Some building codes may allow a lesser degree of protection than is afforded by the wall panel. For instance, a 4-hr fire rated panel wall may have openings protected with 3-hr rated fire doors. Based on the same logic, these codes allow the joints between panels to have a rating of only 3/4 that of the wall panels. The basis for this allowance is that there will generally be open space for personnel or vehicle traffic on either side of an opening and so it is less likely there will be combustibles to ignite. This does not apply for panel joints. Combustible storage may be placed directly against the wall at a joint. Therefore, FM Approvals **recommends the joint treatment have the same fire endurance rating as the wall panels**.

Fire tests of wall panel joints showed that fire endurance, as determined by temperature rise of 325°F (181°C) over the joint, is influenced by joint type, joint treatment, joint width, and panel thickness. A typical joint treatment is shown in Figure 3. Typically, a ceramic fiber blanket is used to provide the necessary fire endurance.

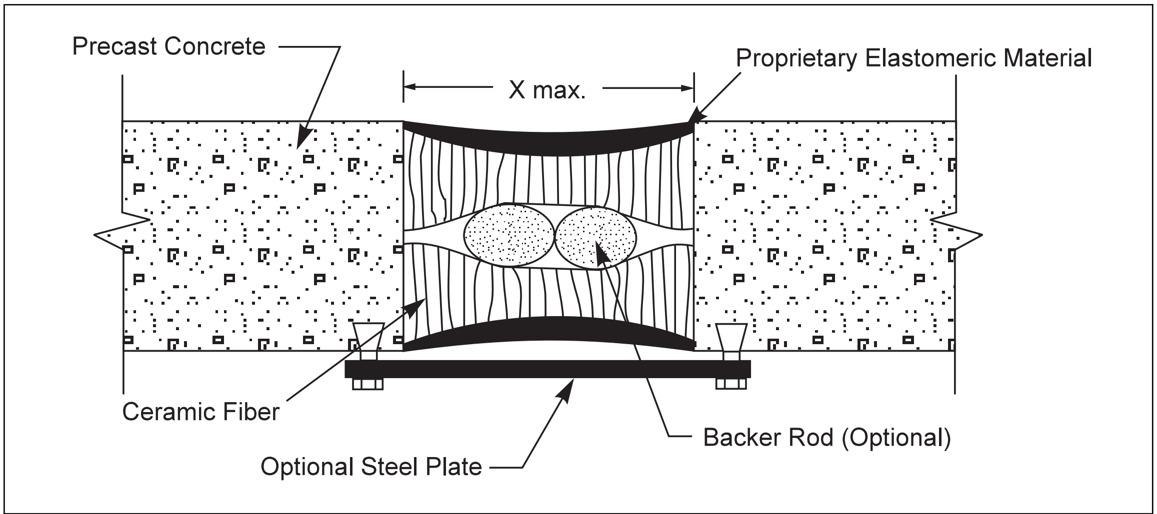


Fig. 3. Section view of proprietary fire-rated joint detail.

6.6 Autoclaved Aerated Concrete (AAC) Walls

AAC is provided in both block and panel units. AAC blocks generally have a maximum height of 8-in. (200 mm) and a maximum length of 24-in. (600 mm). AAC panel can be considered any AAC unit that exceeds the size restrictions of AAC block.

The dry weight density of AAC ranges from approximately 25 pcf (4.2 kN/m^3) to 50 pcf (8.4 kN/m^3) with corresponding compressive strengths of approximately 350 psi to 900 psi (2.4 MPa to 6.2 MPa).

6.6.1 Reference Material and Design Specifications and Standards

Use AAC block and AAC panels that comply with the requirements of nationally recognized material standards, such as ASTM C1452 (block) and ASTM C1386 (panel).

6.6.2 Fire Tests of AAC Walls

Use only AAC block and AAC panel fire wall assemblies that have been documented as passing a nationally accepted fire test, such as ASTM E 119 or UL 263, for the required fire endurance.

6.6.3 Minimum Requirements for AAC Walls

In addition to the recommendations in Sections 6.6.1 and 6.6.2, follow the recommendations in this Section as noted below:

6.6.3.1 For load-bearing walls, use AAC blocks and AAC panels that are:

a) not less than 5.9 in. (150 mm) thick where required fire endurance is 2 hours to 4 hours; or

b) not less than 3.9 in. (100 mm) thick where required fire endurance is less than 2 hours.

6.6.3.2 For non-load-bearing walls, use AAC blocks and AAC panels that are:

a) not less than 3.9 in. thick (100 mm) where required fire endurance is 2 hours to 4 hours; or

b) not less than 2.9 in. thick (75 mm) where required fire endurance is less than 2 hours.

6.6.3.3 For steel (non-prestressed) reinforcement in AAC blocks or panels, provide:

a) not less than 1.0-in. (25 mm) of AAC clear cover where fire endurance of 2 hours to 4 hours; or

b) not less than ¾-in. (19 mm) of clear cover where required fire endurance is less than 2 hours.

6.6.3.4 Provide AAC plain blocks and AAC panels that are solid AAC; or, for AAC reinforced blocks that are not solid AAC (e.g., U-block with horizontal reinforcement, or O-block with vertical reinforcement), ensure that not less than one-half the total wall thickness is AAC, with the balance of the wall thickness filled solid with cement-based grout.

6.6.3.5 Provide AAC block and AAC panel wall assemblies with thin-bed cement-based mortar on all joint surfaces.

6.6.3.6 Provide AAC block walls with staggered vertical joints (e.g., running bond or offset bond).

6.6.3.7 Provide AAC panel walls with staggered vertical joints except where the AAC panels are supported by, or mechanically attached to, structural members (such as reinforced concrete columns or beams) with adequate fire resistance ratings.

6.7 Fire-Rated Glazing

Glazing is often used in fire doors (door lites or vision panels) and fire walls (windows). Codes generally limit the size of individual glazing areas for fire doors and limit the aggregate glazing area for fire walls. The acceptance criteria of standard fire tests - such as UL 9 (NFPA 257) for window assemblies, or UL 10B and UL 10C (NFPA 252) for fire door assemblies - do not have limitations on the temperatures of the unexposed surfaces; that is, the acceptance criteria are based on a fire integrity rating alone, but not a fire insulating rating.

UL differentiates between the two general groupings of fire-rated glazing assemblies as:

- ″Fire-Protection-Rated Glazing Materials″ listed assemblies that are based on a fire integrity rating, but not an insulating rating (i.e., there is no limitation on temperatures on the unexposed surfaces, and a hose stream test is not required); and
- ″Fire-Resistance-Rated Glazing Materials″ listed assemblies that must meet UL 263 (ASTM E 119) and therefore must have not only adequate fire integrity but also an adequate fire-insulating rating, as well as adequate resistance to hose stream exposure where applicable (i.e., the same performance criteria as for fire-rated wall assemblies).

The International Building Code (IBC) has developed a marking system for fire-rated glazing, and those glazing assemblies that meet fire-resistance ratings for walls (tested to ASTM E 119 or UL 263), that include an adequate insulating rating, as well as adequate resistance to hose stream exposure where applicable, will carry a permanent ″W″ mark along with the fire endurance in minutes on the glazing. For example: a 2-hour fire-resistance-rated glazing assembly will carry a ″W-120″ permanent mark on the glazing.

There are three types of fire-rated glazing pertinent to the scope of this data sheet. They are:

a) Wired Glass

Minimum ¼-in. (6 mm) polished wired glass is routinely specified in fire doors and fire-rated partitions. Wired glass is made up of annealed glass and a mild steel wire mesh. The mesh pattern may be square, rectangular, diamond shaped or hexagonal. The wire mesh is normally centered in the glass. Wired glass has a fire protection rating for integrity (ability to remain in the frame to prevent tha passage of flame or hot gasses) of approximately 45 minutes. It has no appreciable insulating value and therefore no fire insulating rating.

In tests using the standard time-temperature curve of ASTM E 119, wired glass cracks within minutes of the start of the test. The wire mesh holds the fractured glass in place, preventing the passage of flame or gas. At approximately 45 minutes, the furnace temperatures exceed 1600°F (870°C) and the glass starts to become viscous and slumps out of the frame.

b) Fire-Resistant Glazing

This category includes monolithic borosilicate or calcium-silica tempered glass, ceramic glazing, and laminated glazing. These products do not have any embedded wire mesh. They may be listed by some third-party testing agency as having a fire protection rating ranging from 20 to 90 minutes. However, like wired glass, they do not meet the temperature rise limitations of ASTM E 119 (NFPA 251, UL 263) and therefore have no fire insulating rating. The fire protection rating refers only to the glazing's integrity rating and ability to meet criteria on the size of openings that develop.

c) Insulating Fire-Resistant Glazing

This category includes glazing materials that are intended to provide some insulating value. Proprietary products are available that consist of two or more layers of tempered glass separated by steel spacers. The cavity between the glass layers is typically filled with an aqueous gel or intumescent material.These gels and intumescent materials are transparent at ambient temperatures but become opaque when exposed to fire and thus become a barrier to radiation as well as being a thermal barrier. These products have been tested and meet the acceptance criteria of ASTM E 119. Therefore, these assemblies can be used as equivalently rated fire walls provided the construction details of the tested assemblies are followed in order to ensure the proper fire resistance rating is achieved; these details will include a maximum glazing area and maximum glazing width or height between the support framing for the tested assembly. This category of insulating fire-resistant glazing would be classified by UL to be ″Fire-Resistance-Rated Glazing Materials″. Fire endurance ratings of up to 3 hours are available.

When temperatures fall below 5°F (-15°C) or exceed 104°F (40°C), the insulating gel may become cloudy or opaque. Therefore, for exterior wall uses, additional exterior glazing protection designed to maintain the insulating fire-resistant glazing at acceptable temperatures may be necessary.

Refer to Data Sheet 1-20, *Protection Against Exterior Fire Exposure*, and Data Sheet 1-22, *Maximum Foreseeable Loss*, for recommendations regarding exterior walls, MFL subdivisions, and glazing for fire doors, respectively.

7.0 ROOF-CEILING ASSEMBLIES

Roof-ceiling assemblies are tested and rated as assemblies. All components of a given assembly must be provided (unless described as optional) for the assembly to attain the rating. Where there are openings or penetrations (HVAC grills, electrical fixtures, etc.), the listing will provide additional information or limitations on their protection. The rating is, of course, for the entire assembly. The assembly is tested with the underside of the ceiling exposed to the furnace and temperature rise readings are taken on the top surface of the roof.

Provide joint treatments with fire endurance ratings not less than the fire endurance rating needed for the roof-ceiling assembly.

8.0 FLOOR-CEILING ASSEMBLIES

Floor-ceiling assemblies are tested and rated as assemblies. All components of a given assembly must be provided (unless described as optional) for the assembly to attain the rating. The rating is for the entire assembly. The assembly is tested with the underside of the ceiling exposed to the furnace and temperature rise readings are taken on the top surface of the floor above.

Tables 11 through 16 give fire endurance ratings of commonly used floor constructions. The tabulated ratings are only for the types of construction illustrated or described. Where there are air-conditioning ducts, electric raceways, or other openings, the rating of the floor many depend upon the protection at the openings and not upon the floor construction itself. The membrane used in new wood floor constructions between the finished and rough flooring should preferably be an 11 lb/100 ft^2 (0.6 kg/m^2) glass fiber felt.

The principal factors affecting the fire endurance of prestressed concrete are the amount of concrete cover over the prestressing tendons and the cross sectional area of the member.

8.1 Provide joint treatments with fire endurance ratings not less than the fire endurance rating needed for the floor-ceiling assembly.

8.2 Refer to Table 7 to determine the minimum thickness of flat concrete floor slabs of uniform thickness, including cast-in-place, precast, precast/prestressed, and post- tensioned concrete, for the needed fire endurance rating. For floor-ceiling assemblies that are not flat concrete slabs of uniform thickness, refer to Tables 14, 15, or 16 for the fire resistance of various assemblies; or use an assembly that has been verified and documented by fire tests results performed by a nationally recognized testing lab to provide the needed fire endurance.

8.3 For precast/prestressed hollow-core plank, or other types of slabs with hollow cores or cells, use an equivalent thickness (T_e) based on the portion the cross-section that is solid concrete, similar to how T_e is calculated for CMU.

8.4 Use noncombustible insulating materials, such as lightweight insulating concrete, to fill the voids in hollow-core concrete plank and other voided slabs when additional thermal resistance is needed. Avoid the use of foamed plastic (cellular plastic) insulation in hollow core plank and other voided slabs unless adequate fire endurance has been verified and documented by fire tests results performed by a nationally recognized testing lab.

It is important that the fire-tested assembly accurately represent the as-built construction, particularly the details at the end conditions or boundary conditions.

8.5 Refer to Tables 14 and 15 for concrete cover of steel reinforcement for cast-in-place and precast concrete floors, respectively. For floor slabs not shown in Tables 14 and 15 (e.g., flat slabs of uniform thickness), refer to Table 7.2 to determine the concrete cover for the needed fire endurance. Alternatively, use a concrete cover based on a tested assembly as verified by fire test results.

Table 11. Fire Resistance of Plank-on-Timber Floors

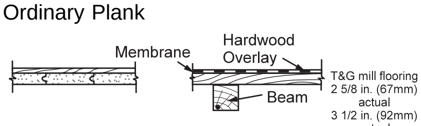
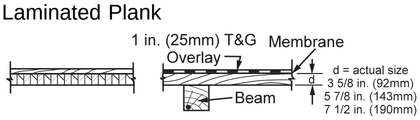
<table>
<tr><th colspan="2">Construction</th><th>Fire Resistance, hr:minutes</th></tr>
<tr><td rowspan="3">Ordinary Plank

</td><td colspan="2">Tongue & Groove mill flooring</td></tr>
<tr><td>2⅝ in. (67 mm) actual</td><td>0:45</td></tr>
<tr><td>3⅝ in. (92 mm) actual</td><td>1:00 (est.)</td></tr>
<tr><td rowspan="2">Laminated Plank

</td><td colspan="2">d = actual size</td></tr>
<tr><td>3⅝ in. (92 mm)</td><td>0:45</td></tr>
</table>

Table 12. Fire Resistance of Wood-Joisted Floors

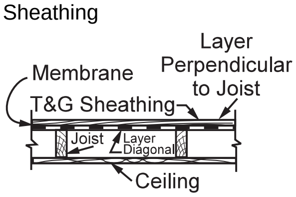
Construction	*Plaster Mix*		*Type of Ceiling*	*Fire Resistance, hr:minutes*
	Base Coat	*Finish Coat*		
Flooring to consist of two layers of 25/32 in. (10 mm) Tongue & Groove Sheathing	None		None	0:15
 	None		½ in. (13 mm) gypsum wallboard	0:25
	None		2 layers ⅜ in. (10 mm) gypsum wallboard	0:30
	None		½ in. (13 mm) type X gypsum wallboard	0:45
	None		2 layers ½ in. (13 mm) gypsum wallboard	1:00
	None		Same, with 1 in. (25 mm) wire fabric between	1:00
	None		⅝ in. (16 mm) type X gypsum board	1:00
	1:2	1:2	⅜ in. (10 mm) perforated gypsum lath and ½ in. (13 mm) sanded gypsum plaster	0:30
			Same, with ½ in. neat gypsum plaster	0:45
	1:4	1:2	Wood lath ⅝ in. (16 mm) lime plaster	0:30
	1:2	1:3	Wood lath ½ in. (13 mm) sanded gypsum plaster	0:35
	1:2	1:3	Metal lath fastened with 1¼ in. (32 mm) long, No. 11 gage (3.06 mm), ⅜ in. (10 mm) head, barbed roofing nails and ¾ in. (19 mm) sanded gypsum plaster	0:45
			Same, except fastened with 1½ in. (38 mm) long, No. 11 gage (3.06 mm), 7/16 in. (11 mm) head, barbed roofing nails	1:00
	1½-2:1	1½-3:1	Metal lath fastened with 1½ in. (38 mm) long No. 11 gage (3.06 mm), 7/16 in. (11 mm) head, barbed roofing nails and ¾ in. (19 mm) vermiculite plaster	1:45
	2½:1	3:1	⅜ in. (10 mm) gypsum lath and 1 in. (25 mm) wire mesh, ½ in. (13 mm) gypsum perlite plaster	1:30

Table 13. Fire Resistance of Steel-Joisted Floors

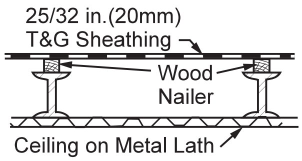
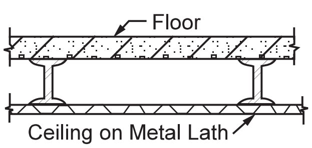
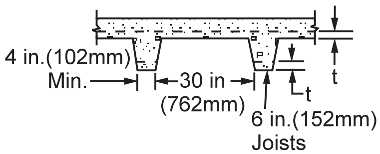
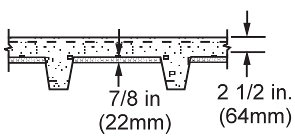
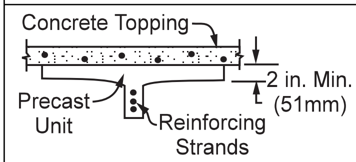
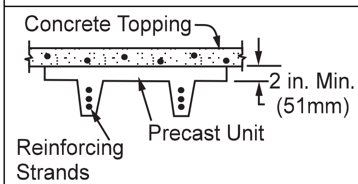
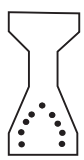
	Floor Construction	*Plaster Mix*		*Ceiling Construction (on metal lath except where otherwise noted)*	*Fire Resistance, hr:minutes*
		Base Coat	*Finish Coat*		
	1 layer sheathing	1:2	1:3	¾ in. (19 mm) sanded gypsum plaster	0:45
	2 layers sheathing	1:2	1:3	¾ in. (19 mm) sanded gypsum plaster	1:00
	2 in. (51 mm) reinforced concrete on metal lath	2:1	3:1	⅝ in. (16 mm) gypsum perlite on ⅜ in. (10 mm) perforated gypsum lath secured to furring channels	1:00
	2 in. (51 mm) reinforced concrete	1:2	1:3	¾ in. (19 mm) portland cement plaster or ¾ in. (19 mm) sanded gypsum	1:30
	2 in. (51 mm) precast reinforced gypsum tile	1:2	1:3	¾ in. (19 mm) portland cement plaster or ¾ in. (19 mm) sanded gypsum	1:30
	2½ in. (64 mm) reinforced concrete	1:2	1:3	¾ in. (19 mm) sanded gypsum plaster	2:00
	2½ in. (64 mm) reinforced concrete	1:2	1:2	1 in. (25 mm) sanded gypsum plaster	2:30
	2 in. (51 mm) reinforced concrete	2:1	3:1	1 in. (25 mm) neat gypsum plaster or ¾ in. (19 mm) gypsum vermiculite plaster	2:30
	2 in. (51 mm) precast reinforced gypsum tile with ¼ in. (mm) cement mortar finish	2:1	3:1	1 in. (25 mm) neat gypsum plaster or ¾ in. (19 mm) gypsum vermiculite plaster	2:30
	2½ in. (64 mm) reinforced concrete	2:1	3:1	1 in. (25 mm) neat gypsum plaster or ¾ in. (19 mm) gypsum vermiculite plaster	3:00
	2 in. (51 mm) precast reinforced gypsum tile with ½ in. (12 mm) cement mortar finish	2:1	3:1	1 in. (25 mm) neat gypsum plaster or ¾ in. (19 mm) gypsum vermiculite plaster	3:00
	2½ in. (64 mm) reinforced concrete	2:1	3:1	1 in. (25 mm) gypsum vermiculite plaster	4:00
	2 in. (51 mm) precast reinforced gypsum tile with ½ in. (13 mm) cement mortar finish	2:1	3:1	1 in. (25 mm) gypsum vermiculite plaster	4:00
	2 in. (51 mm) reinforced concrete		1:3	2 in. (51 mm) precast reinforced gypsum tile covered with ½ in. (13 mm) gypsum plaster	4:00

Table 14. Fire Resistance of Reinforced Concrete Floors

<table>
<tr><th>Construction</th><th>Slab Thickness, in. (mm)</th><th>t, Protection of Reinforcement[2], in. (mm)</th><th>Ceiling</th><th>Fire Resistance, hr</th></tr>
<tr><td rowspan="3">Reinforced concrete on cast-in-place or precast joists

</td><td>3
(76)</td><td>¾
(19)
slab
1½
(38)
joists</td><td>None</td><td>1</td></tr>
<tr><td>2
(51)</td><td>¾
(19)
slab and joists</td><td>¾ in.
(19 mm)
gypsum vermiculite[1]</td><td>3</td></tr>
<tr><td>3
(76)</td><td>¾
(19)
slab and joists</td><td>1 in.
(25 mm)
gypsum vermiculite[1]</td><td>4</td></tr>
<tr><td>Reinforced concrete with cementitious mixture protection

</td><td>2½
(64 mm)</td><td>¾
(19)</td><td>⅞ in.
(22 mm)
type MK vermiculite plaster</td><td>2</td></tr>
</table>

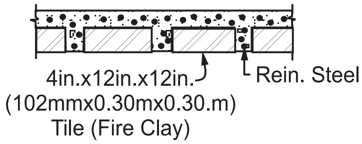
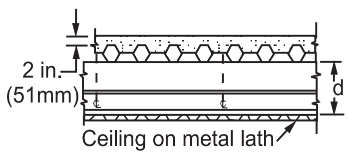
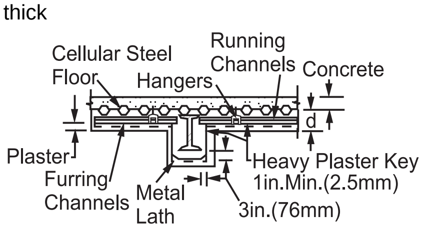
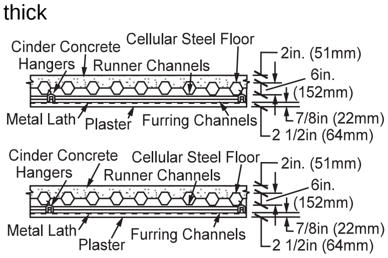
Notes:
1. Metal-lath-and-plaster ceiling. Slab thickened 2 in. (51 mm) where there is an underfloor duct system.
2. Measured from the surface of concrete to the bottom of reinforcement.

Table 15. Fire Resistance of Prestressed Concrete Units

<table>
<tr><th rowspan="2">Construction</th><th rowspan="2">Maximum Unit Width, ft (m)</th><th rowspan="2" colspan="2">Minimum Concrete Cover Over Wires, in. (mm)</th><th rowspan="2">Minimum Wire Spacing at Ends, in. (mm)</th><th colspan="2">Minimum Concrete Topping Over Unit, in. (mm)</th><th rowspan="2">Fire Resistance Rating, hr[1]</th></tr>
<tr><th>Normal Weight</th><th>Light-weight</th></tr>
<tr><td rowspan="2"></td><td>10
(3.05)</td><td colspan="2">1⅝ (41) bottom
2 (51) side</td><td>2
(51)</td><td>3-3¼
(76-83)</td><td></td><td>2</td></tr>
<tr><td>10
(3.05)</td><td colspan="2">1⅝ (41) bottom
2 (51) side</td><td>2
(51)</td><td></td><td>2½
(64)</td><td>3</td></tr>
<tr><td rowspan="2"></td><td>8
(2.44)</td><td colspan="2">1⅝ (41) bottom
1⅛ (29) side</td><td>2
(51)</td><td>3-3¼
(76-83)</td><td>2
(51)</td><td>2</td></tr>
<tr><td>4
(1.22)</td><td colspan="2">1½ (38) plus
1 (25)
sprayed
vermiculite</td><td>2
(51)</td><td></td><td></td><td>3</td></tr>
<tr><td rowspan="5">
Minimum Cross Sectional Area-168 in.^{2} (1084cm^2)</td><td rowspan="2"></td><td>Normal Weight</td><td>Light-Weight</td><td rowspan="2"></td><td rowspan="2">None</td><td rowspan="2">None</td><td rowspan="2">1</td></tr>
<tr><td>1
(25)</td><td>1
(25)</td></tr>
<tr><td></td><td>2
(51)</td><td></td><td></td><td>None</td><td>None</td><td>2</td></tr>
<tr><td></td><td>3
(76)</td><td>2
(51)</td><td></td><td>None</td><td>None</td><td>2½</td></tr>
<tr><td></td><td></td><td>3
(76)</td><td></td><td>None</td><td>None</td><td>3</td></tr>
</table>

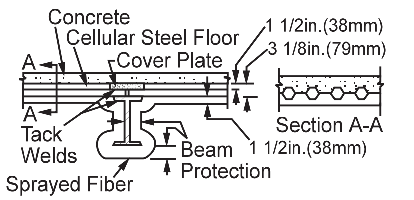
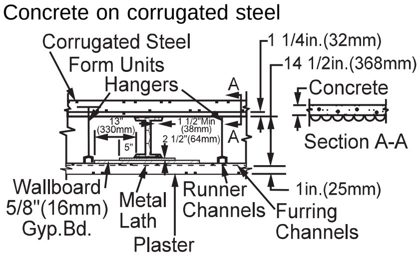
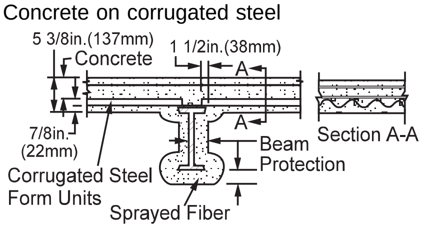
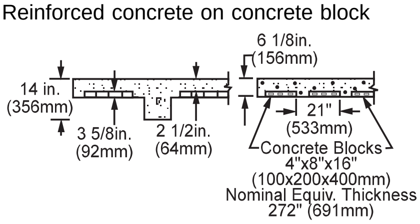
Note: 1. Where a lightweight aggregate concrete has been used, ratings may be increased 20%.

Table 16. Fire Resistance of Composite Floors

Construction	*Floor*	*Plaster Mix*		*Ceiling*	*Fire Resistance, hr*
		Base Coat	*Finish Coat*		
Reinforced concrete with tile fillers 	4 or 6 in. (102 or 152 mm) tile and 1½ in. or 2 in. (38 or 51 mm) concrete	–	–	None	1
	4 in. (102 mm) tile and 1½ in. (38 mm) concrete	–	1:3	⅝ in. (16 mm) sanded gypsum plaster	1½
	6 in. (152 mm) tile and 2 in. (51 mm) concrete	–	1:3	⅝ in. (16 mm) sanded gypsum plaster	2
Concrete on cellular steel floor on steel beams. Cellular section 3⅛ in. (79 mm) thick 	2 in. (51 mm) concrete, d=9 in. (229 mm)	2:1	3:1	1 in. (25 mm) neat gypsum on metal lath	4
	When d is less than 9 in. and more than 2 in. (51 mm), reduce time 1 hr.	2:1	3:1	1 in. (25 mm) gypsum perlite or vermiculite on metal lath	5
Concrete on cellular steel floor on steel beams. Cellular section 3⅛ in. (79 mm) thick 	2 in. (51 mm) perlite or vermiculite concrete, d=3 in. (76 mm)	2:1	3½:1	1 in. (25 mm) gypsum perlite or plaster and beam encased with same	4
	2 in. (51 mm) gravel concrete, d=4½ in. (114 mm)	–	–	1 in. (25 mm) sprayed asbestos fiber[1]	3
	Same	–	–	Beam rating: beam protected with 1 in. (25 mm) asbestos fiber[1]	2
	2½ in. (64 mm) gravel concrete, d=7¼ in. (184 mm)	2-2½:1	3-3¼:1	1⅛ in. (29 mm) total thickness: ⅝ in. (16 mm) gypsum vermiculite plaster and ½ in. (13 mm) vermiculite acoustic plaster, with beam encased with same	4
Concrete on cellular steel floor on steel beams. Cellular section 6 in. (152 mm) thick 	2 in. (51 mm) cinder concrete	2-2½:1	3-3½:1	⅞ in. (22 mm) vermiculite gypsum plaster on metal lath	4

Notes:
1. New applications may be illegal in some jurisdictions.
2. Poured monolithically with concrete beams.

Table 16. Fire Resistance of Composite Floors (cont'd.)

Construction	*Floor*	*Plaster Mix*		*Ceiling*	*Fire Resistance, hr*
		Base Coat	*Finish Coat*		
Concrete on cellular steel floor on steel beams. Cellular section 3⅛ in. (79 mm) thick 	2½ in. (64 mm) sand and limestone concrete	–	–	1⅞ in. (48 mm) sprayed asbestos fiber[1] and 3⅛ in. (79 mm) thickness around beam	4
	2½ in. (64 mm) gravel concrete	–	–	¾ in. (19 mm) sprayed asbestos fiber[1] and 2½ in. (64 mm) thickness around beam	3
	2½ in. (64 mm) gravel concrete	–	–	½ in. (13 mm) sprayed gypsum plaster	2
Concrete on corrugated steel 	3¼ in. (83 mm) sand and gravel concrete	2:1	3:1	1 in. (25 mm) gypsum vermiculite plaster on metal lath	4
	4 in. (102 mm) limestone air entrained concrete with reinforced concrete beams[2]	–	–	None	2
	3¼ in. (83 mm) sand and limestone concrete. Beam either reinforced concrete[2] or steel with 1 in. (25 mm) fibered gypsum	–	–	None	1
	2 in. (51 mm) gravel concrete	–	–	¾ in. (19 mm) perlite or vermiculite plaster on metal lath	2
	2 in. 951 mm) gravel concrete	–	–	⅞ in. (22 mm) perlite or vermiculite plaster on metal lath	3
Concrete on corrugated steel 	3¼ in. (83 mm) expanded slag concrete with negative moment reinforcement	2:1	–	⅜ in. (10 mm) gypsum perlite plaster on metal lath with 1½ in. (38 mm) perlite plaster on metal lath protection for beam	4
	3¼ in. (83 mm) sand and limestone concrete	–	–	⅞ in. (22 mm) sprayed asbestos fiber[1] with 2½ in. (64 mm) thickness of same material on beam	3
Reinforced concrete on concrete block 	4 in. (102 mm) lightweight aggregate concrete block with 2½ in. (64 mm) concrete slab	–	–	None	3

Notes:
1. New applications may be illegal in some jurisdictions.
2. Poured monolithically with concrete beams.

9.0 FIRE STOPS

Fire stops provide a fire resistant seal around electrical or mechanical service items that penetrate or pass through a fire rated wall or floor. To maintain the fire endurance rating of the wall or floor being penetrated, it is important that the fire stop material or system have a rating at least equal to that of the wall or floor. Refer to the *Approval Guide* for Approved designs.

A wide variety of fire stop products are available as penetration seals including caulks, putties, pillows, mastics, boards, silicone foams and cementitious slurries. Some of these materials form a char as they burn which insulates and protects the material behind it. Others have the ability to absorb heat or release moisture as they are subjected to fire. Others intumesce or swell when subjected to sufficient fire temperatures and expand to 2 to 10 times or more their initial volume.

Several factors may influence the performance of a penetration fire stop including type of fire stop material being used, the number, size and type of penetrating items, thickness of the barrier being penetrated and of course the thickness of the fire stop material.

Performance of a fire stop is measured by subjecting it to a standard time-temperature fire exposure and hose stream according to ASTM E 814 (or comparable standard). The time-temperature curve and hose stream pressure and duration in E 814 are identical to those required in E 119.

The E 814 standard allows for two ratings: an ***F*** rating (standing for fire) and a ***T*** rating (standing for temperature). To obtain an ***F*** rating, the fire stop must resist the passage of flame and hot gases and also the subsequent hose stream. The hose stream test is normally performed on a duplicate sample which has been subjected to fire exposure for ½ the rating period desired (but not more than 1 hour). The test sponsor may, however, elect to run the hose stream on the initial sample.

To obtain a ***T*** rating, the fire stop must meet the criteria listed above for an ***F*** rating, and in addition it must also limit the temperature rise on the unexposed side of the test assembly. As with E 119, temperatures are measured in E 814 at various locations on the unexposed side of the assembly including various points on the floor or wall, the face of the fire stop material and the penetrating item. The ***T*** rating indicates the minimum elapsed time before any temperature measured on the unexposed side of the assembly increases by more than 325°F (181°C) above its initial temperature.

Considerable difference of opinion exists in various sectors as to whether ***T*** ratings should be required over ***F*** ratings. The matter is currently under consideration by the various code groups.

Since a uniform procedure is lacking as to which rating should be used, FM Approvals *Standard for Firestopping* (Class 4990) determines the hourly ratings for its Approved fire stops in accordance with the criteria for a T_{FM}, which is similar to the ***T*** rating, but disregards the temperature measured by the thermocouple on the penetrating item itself. The limiting temperature is measured on the unexposed face of the fire stop material in the field of (and generally 1 in. [25 mm] away from the) penetrating item. This approach is discussed in the Appendix of ASTM E 814 and is felt to be a reasonable compromise since it allows somewhat more flexibility than the ***T*** rating but still yields a more conservative degree of protection than results from the ***F*** rating.

If the fire stop is installed in the wall or floor symmetrically, the rating applies from either direction. However, if the fire stop is not installed symmetrically, the rating applies only from the side which was exposed to the furnace.

10.0 FRP REINFORCEMENT SYSTEMS

This section applies to FRP (fiber-reinforced polymer or plastic) reinforcement systems consisting of aramid, glass, or carbon fibers embedded in a polymer matrix such as epoxy or vinyl ester resin.

10.1 FRP Rebar

Most rebar used in reinforced concrete or reinforced masonry construction is steel. However, occasionally FRP rebar is used for specialty applications; for instance, for occupancies with medical or scientific equipment that have sensitivity to metals such as steel rebar, or for occupancies and exposures that can be highly corrosive to steel rebar.

10.1.1 Only use FRP rebar for concrete or masonry when adequate structural performance for the required fire resistance has been documented by test results provided by a nationally recognized testing laboratory.

10.2 Externally-Applied FRP Reinforcement

Follow the manufacturer's recommendations for installation of the FRP reinforcement on concrete or masonry and for application of the fire-resistive coating.

Use externally-applied FRP reinforcement for concrete or masonry only when both of the following apply:

1) Provide a fire-resistive coating for the externally applied FRP reinforcement that will provide a fire resistance rating not less than the required fire resistance of the underlying concrete or masonry member; and that is compatible with the FRP reinforcement, as verified by test results provided by a nationally recognized testing laboratory.

2) Limit the strengthening of the FRP-reinforced concrete or masonry member to **25%** of the original strength (without FRP reinforcement) at ambient conditions. For example, if the axial design strength of a concrete column without externally-applied FRP reinforcement is 100,000 lbs (444 kN) at ambient conditions, then use an axial design strength of not more than 125,000 lbs (555 kN) for the concrete column with externally-applied FRP reinforcement at ambient conditions.

11.0 HIGH STRENGTH CONCRETE (HSC)

HSC can be treated and evaluated like normal-strength concrete for the purposes of fire resistance of construction, except for the following:

11.1 Spalling of HSC

HSC has been shown to be more susceptible to severe spalling during fire exposure than normal-strength concrete. Therefore, for HSC construction, use one or more of the following provisions, which have been demonstrated by fire testing to perform adequately without compromising fire resistance due to spalling:

a) Provide a proper HSC mix design.

b) Provide a fire-resistive covering or coating over the HSC.

c) Provide a continuous layer of 2-way steel wire between the reinforcing steel and the concrete surface.

11.2 Fire-Exposed Strength of HSC

For HSC with ambient compressive strength greater than 13,000 psi (90 MPa), it is the responsibility of the structural engineer of record to provide verification of adequate load-carrying capacity at fire-exposed temperatures for the required fire endurance.

For HSC used in high-rise buildings, refer to Data Sheet 1-3, *High-Rise Buildings,* for additional recommendations.

12.0 FIRE ENDURANCE TESTS AND STANDARDS

12.1 Fire Testing — General

Fire tests to determine the fire-resistive properties of construction materials and assemblies have been conducted since the late nineteenth century. Early tests were conducted in small buildings to test the walls and roofs of such structures. The first standard test procedure for rating fire endurance was developed in 1918, the result of extensive tests on building columns. The test program was sponsored by the National Bureau of Standards, the National Board of Fire Underwriters, and FM. This test procedure is now ASTM E 119 (NFPA 251, UL 263).

An estimate of the fire endurance of many materials and assemblies can sometimes be predicted by computation within the boundaries of existing test data. While progress continues to be made in this area, such procedures are not yet clearly established for all materials. The best policy is still to base ratings for most constructions on the standard fire test.

Important, large-scale test results are not the only consideration. Even the large-scale test specimens are small when compared with actual installations. The performance of a construction can be affected by dimensions, loading conditions, workmanship, and the arrangement of structural framing. A specific knowledge of the installation being rated, experience, and judgment are all necessary before a rating can be assigned.

12.2 The ASTM E 119 Fire Tests of Building Construction and Materials

Tests conducted in accordance with ASTM E 119 subject building assemblies to a standard time-temperature exposure (Fig. 4). This time-temperature curve was originally established for cellulosic material burning in a fire-resistive compartment with poor ventilation. Although building types and occupancies may have changed, the curve is still considered appropriate for most situations.

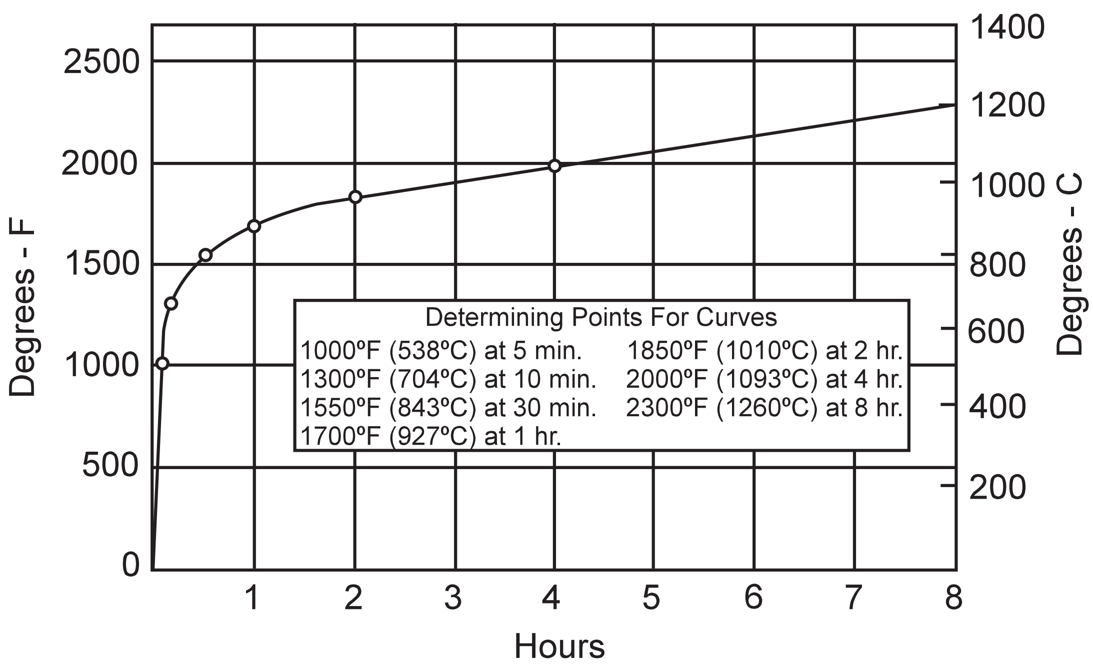


Fig. 4. ASTM E 119 standard time-temperature curve

Where the measured or anticipated rate of combustion is faster than that in the standard curve, a rough adjustment can be made by extending the duration of the standard fire. In practice this is done by finding the area under the time-temperature curve of the measured or anticipated fire. The base is generally taken as 68°F (20°C). A time is selected such that the area under the standard curve is equal to the area under the anticipated curve. This is an approximation that has been used for some time. Thus, a two-hour rated assembly may be recommended where the exposure is an ignitable liquid fire of, for example, 30 minute duration.

Comparisons have been conducted between the E 119 exposure and various alternative exposures such as a simulated hydrocarbon pool fire exposure. See Figure 5 for a comparison of the E119 time-temperature curve and an approximate time-temperature curve for a hydrocarbon pool fire. Two of the most commonly referenced simulated hydrocarbon pool fire exposure tests are ASTM E1529 (*Standard Test Method for Determining the Effects of Large Hydrocarbon Pool Fires on Structural Members and Assemblies*) and UL 1709 (*Rapid Rise Fire Tests of Protection Materials for Structural Steel*). ASTM E1529 applies to columns, unrestrained beams, and walls; UL 1709 applies only to steel columns.

Most fire tests of building assemblies are based on the ASTM E119 standard, or similar, fire tests. For evaluation and specification of building assemblies exposed to hydrocarbon pool fires, passive fire protection systems and fire endurance must be based on a hydrocarbon pool fire test similar to ASTM E1529 or UL 1709.

The ASTM E 119 standard defines the fire endurance rating as the elapsed time at which any of the following endpoint criteria occur:

- Structural failure, defined as the failure of the assembly to continue supporting the applied loads.

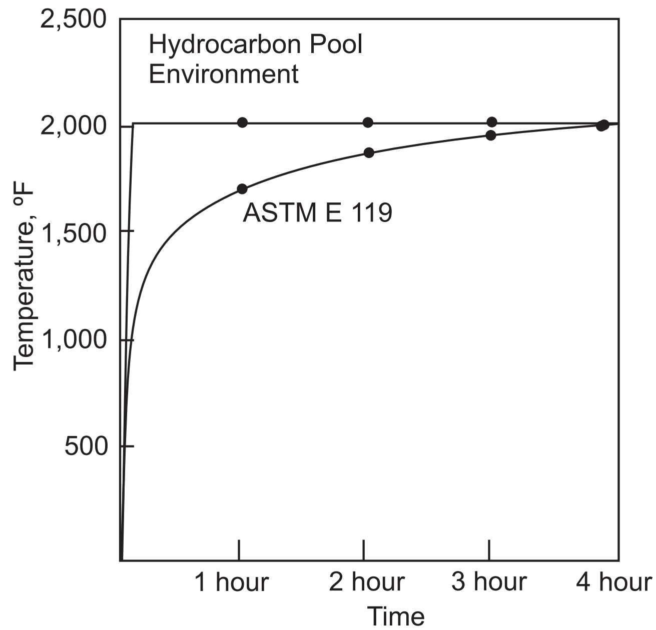


Fig. 5. Comparison of ASTM E 119 time-temperature curve with a hydrocarbon pool fire time-temperature curve

- The average temperature rise of the unexposed surface of the assembly exceeds 250°F (139°C) or the temperature rise recorded at any individual thermocouple reading exceeds 325°F (181°C).
- Passage of flames or gases hot enough to ignite cotton waste on the unexposed side of the assembly.
- Average steel temperature exceeds 1000°F (538°C) or any individual thermocouple reading exceeds 1200°F (649°C).

Wall assemblies are tested in a furnace by exposing one face of the wall to vertically oriented burners. Floor-ceiling or floor-roof assemblies are tested in a furnace with the burners in a pit below the assembly. Columns are tested in a vertical, cylindrical furnace or in a pit, with the exposure on all sides.

12.2.1 Walls

Walls are tested in the vertical plane furnace. A sample of the wall assembly, not less than 100 sq ft (9 sq m), and with neither dimension less than 9 ft (2.7 m), is placed on the face of the furnace. If the wall assembly is to be non-load-bearing, the sample is constructed within a frame that provides restraint at the top and bottom. If the assembly is to be load bearing, a load, calculated in accordance with the allowable provisions of the governing building code, is applied at the top or bottom of the assembly. The applied load is held constant throughout the test.

Shielded thermocouples monitor furnace temperatures near the exposed face of the sample. These temperatures must follow the standard time-temperature curve within set limits. This is accomplished by controlling the fuel and/or air supply. Thermocouples covered with standard pads to insulate them from ambient monitor temperatures on the face not exposed to the furnace (unexposed face).

Failure is generally determined by the temperature rise on the unexposed face. The failure point is reached when either the average reading of all thermocouples exceeds the initial temperature plus 250°F (139°C), or any individual thermocouple exceeds the initial temperature plus 325°F (181°C). Breaching or collapse would also indicate failure, but failure by temperature rise generally occurs first.

The assembly may also have been subjected to a hose stream test (required for durations of 1 hour or more). A standard hose stream is applied to the sample immediately after the fire test or to another duplicate sample that has been fire exposed for one-half the rating desired but not more than one hour. Failure in the hose-stream test is defined as development of an opening that allows a projection of water beyond the unexposed surface.

For load-bearing walls, the sample is cooled after the test and then subjected to twice the load used during the fire test.

For masonry walls the fire endurance may be determined using the equivalent thickness method described in section 6.1 and Table 6. Fire tests are not required for these ratings, since sufficient experience has been accumulated to have confidence in this method.

Some wall assemblies are not symmetrically constructed. Materials used on one face may be different from those used on the other face. The rating of such an assembly applies only to a fire on the face exposed to the furnace. The rating does not apply if the fire to be resisted occurs on the face not exposed to the furnace.

Two samples of asymmetrical walls are sometimes tested with each face being exposed individually in separate tests. The wall may be assigned two different ratings. For example, a wall assembly can have a 3 hr rating from one side and a 2 hr rating from the other side. Field installation must correspond to test orientation.

12.2.2 Columns

Originally, columns were tested in a vertical, cylindrical furnace. The fire tests were conducted on loaded columns with initial buckling as the failure criterion. Loading was calculated in accordance with the allowable provisions of a building code. This furnace was operated by the National Bureau of Standards.

Tests of steel columns are now run either in a furnace similar to the original, or in a pit furnace where several columns may be tested simultaneously. In either case, the column assemblies are exposed to the standard, time-temperature curve on all sides.

ASTM E119 (and UL 263) allows for two testing options for columns: (1) furnace test with the column loaded, and (2) furnace test without load on the column where acceptance is based on steel temperatures. The test based on steel temperatures is only allowed for structural steel columns where the fire-resistive coating or encasement is not designed to carry any load, which would apply to SFRM and gypsum board protection, but may not apply to concrete encasement of steel columns. The acceptance criteria for the column test without load is based on limiting the average steel temperature to 1000°F (538°C) and the single point steel temperature to 1200°F (649°C). For the loaded column test option, the load applied during the fire test is typically the design load prescribed in the nationally-recognized structural design standard or code. Where the testing option based on steel temperature is allowed for structural steel columns, it is more commonly used than the loaded column testing option.

Columns are not required to be subjected to a hose stream test after fire exposure.

12.2.3 Floors and Roofs

Floor and roof assemblies are tested over a pit furnace. The minimum area exposed to fire is 180 ft^2 (16 m^2) with neither dimension less than 12 ft (3.7 m). The assemblies may include a ceiling. Temperatures measured by shielded thermocouples located below the assembly must be controlled to follow the standard time-temperature curve. Failure generally is determined by temperature rise on the top surface of the assembly. This occurs when the average thermocouple temperature on the unexposed surface rises by more than 250°F (139°C) or any other thermocouple temperature exceeds 325°F (181°C) above the initial temperature.

For assemblies with wood members (above a ceiling), ignition of the wood constitutes failure even though surface temperatures may be below the allowable increase.

If the assembly has a suspended ceiling, fallout of the ceiling tiles will expose wood or bare steel to temperatures that will ignite the wood or produce critical temperatures in the steel.

Deflection is not a direct criterion for failure even though an assembly can deflect to the point that joints open or pieces fall out, accelerating failure by temperature rise. A hose stream test is not required after the fire exposure.

As noted previously, the fire endurance of prestressed concrete is primarily affected by the cross sectional area of the member and the amount of concrete cover over the prestressing wires. Generally, the concrete from which prestressed concrete members are made has a higher strength and somewhat better fire resistance than that used for standard reinforced concrete construction. The drawbacks associated with prestressed concrete are: a) the concrete is more susceptible to spalling which exposes the reinforcing wires; and b) the reinforcing wires are more susceptible to fire temperatures since they are cold-drawn, high carbon steel (instead of hot-rolled, low carbon steel normally used for reinforced concrete) and they are already under a high initial stress.

The fire endurance of members found to be inadequate can be increased by applying a cementitious or mineral fiber sprayed-on fire proofing material. Consult the manual *Design for Fire Resistance of Precast Prestressed Concrete* by the Prestressed Concrete Institute.

12.2.4 Beams

When steel or concrete beams are used in an assembly, they may be given a separate rating equal to or greater than that of the assembly. The rating is obtained by continuing the test beyond failure of the assembly from surface temperature rise.

Steel and concrete beams can obtain two types of ratings: an *unrestrained* rating can be assigned based on the steel beam or steel reinforcing in a concrete beam remaining below a set critical temperature; a *restrained* rating can be assigned based essentially on collapse. The restrained rating can be used when the ends of the beams are restrained against expansion.

Attention must be given to the deck used with a rated beam. According to ASTM E 119, a rated beam should be used with *"a floor or roof construction which has a comparable or greater capacity for heat dissipation from the beam than the floor or roof with which it was tested."* This can be interpreted to mean a floor or roof system with less insulation value or with a greater heat sink capacity. None of the assemblies listed in this standard has a separate beam rating. A hose stream test is not required after fire exposure.

12.2.5 Ceilings

ASTM E 119 contains a procedure for rating ceilings. The test is inclusive, so it will fit many situations (wood or steel framing, etc.). The test conditions and resultant data must be applicable to the assembly to be constructed. For example, if steel temperatures might govern, the test samples must be located where maximum temperatures will exist.

12.3 Nonstandard tests

ASTM E 119 contains restrictions on test procedure, including minimum size of sample and number of thermocouples.

Exploratory tests may be run with undersized samples, and samples with a nonstandard number and/or arrangement of thermocouples.

If results from a nonstandard test are to be used, a copy of the original laboratory report should be obtained and reviewed to determine if the test conditions are applicable to the end use of the assembly. For example, if fewer thermocouples were used than required by ASTM E 119, the test is not generally valid.

12.4 Other Fire Endurance Standards

Many countries have standards for establishing fire-endurance ratings by test, but these may differ from the standards mentioned in this data sheet in one or more respects. The British Standards Institution Standard BS 476: Part 20, Standard BS 476: Part 8 20 (BS 476-20: *Fire Tests on Building Materials and Structures - Method for Determination of the Fire Resistance of Elements of Construction [General Principles]*, is an example. Unlike the ASTM E119 fire test, BS 476-20 does not require a hose stream test for fire walls. BS 476 also allows for an alternate method, involving the measurement of gaps or fissures in the unexposed side of the assembly (rather than the ignition of cotton waste) under certain conditions, as a means of checking for the passage of flame or hot gases on the unexposed side of the assembly.

12.4.1 Standard Time-Temperature Curve

The time-temperature curves used by some countries are shown in Figure 6. With two exceptions, the effect of different curves on a given assembly will not be significant.

The results from the curve used by Japan will be high for assemblies tested for more than 3 hr. The results from the curve used in Russia will be high below 3 hr. That is, an assembly successfully tested for 4 or more hours according to the curve used in Japan may fail significantly when tested to other curves. An assembly successfully tested for 3½ hrs or less according to the curve used in Russia may fail significantly when tested to other curves.

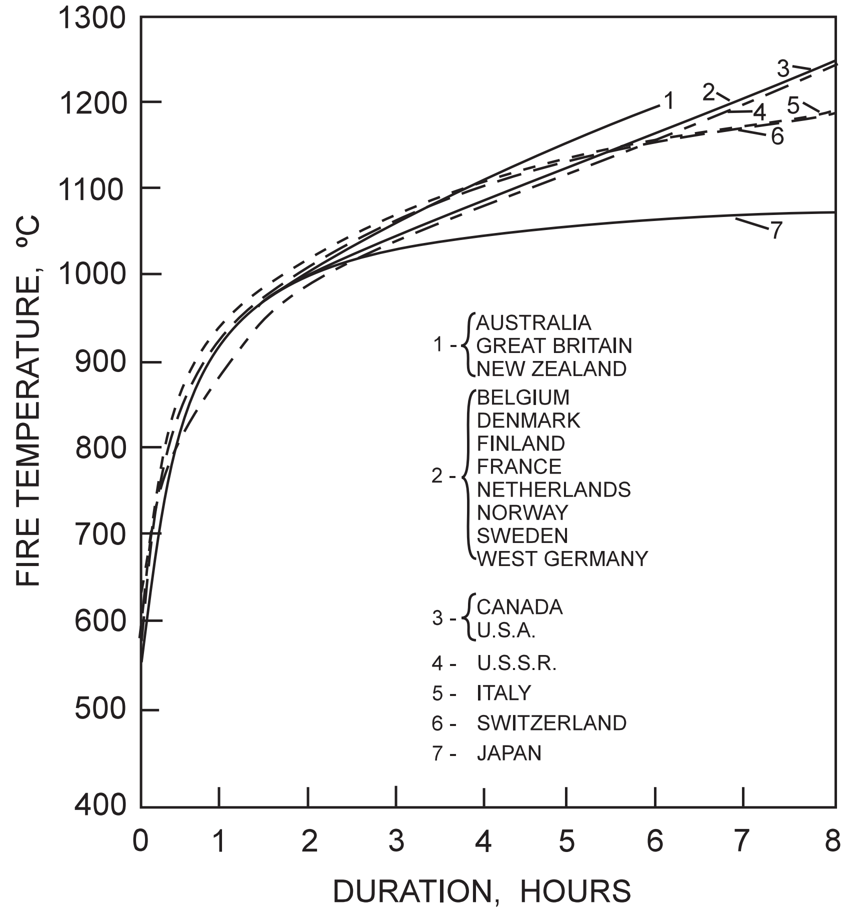


Fig. 6. Time-temperature curves used in various countries

BS 476-20 specifies a time-temperature curve that results in the following test furnace temperatures: 1069°F (576°C) at 5 minutes; 1252°F (678°C) at 10 minutes; 1548°F (842°C) at 30 minutes; 1733°F (945°C) at 1 hour; 1920°F (1049°C) at 2 hours; 2030°F (1110°C) at 3 hours; and 2107°F(1153°C) at 4 hours. Except for the 30-minute temperature, these furnace temperatures are slightly higher than those for ASTM E119, but the differences are not significant.

The International Standards Organization time-temperature curve for cellulosic building fires (ISO 834) is essentially the same as BS 476-20.

12.4.2 Sample Size

The size of the test sample may vary according to different standards. In some particular tests where heat transmission causes failure, the size may not be important. But if the failure is due to deflections (fire doors), drop-out of ceiling tiles, collapse of assembly, etc., the difference in size may mean the tests are not compatible.

12.4.3 Acceptance

The important differences between fire endurance standards are the time-temperature curves used and the sample sizes. For a specific assembly and end-use, however, other factors may also be important. Before accepting any assembly, the test report and the specific standard used in that test should be reviewed. The decision to accept or reject should be based on both the test and the end-use of that assembly.

Careful review is always necessary in accepting assemblies even though they may have been reportedly tested in accordance with ASTM E 119, E 814 or comparable test standard. (See Section 12.3, Nonstandard Tests.)

For example, some test furnaces are undersized. If the assembly tested is a masonry wall where heat transmission through the wall is the critical factor rather than expansion effects, the test data would be acceptable. If, however, the assembly was a metal sandwich panel, relative expansion of the components could lead to collapse. The test data for an undersized (nonrepresentative) sample should therefore not be used.

13.0 UNDERWRITERS LABORATORIES FIRE RESISTANCE DIRECTORY (ULFRD)

The ULFRD is a directory of listed assemblies that were tested in accordance with UL 263, *Fire Tests of Building Construction and Materials*. The standard is also known as ANSI A2.1, ASTM E 119 and NFPA 251. The ratings in the directory are expressed in hours and are applicable to floors, roofs, beams, columns and walls.

The designs are identified by a four digit alphanumeric design number. The prefix letter designates the group of construction, the first number designates the type of protection, and the final two numbers identify the particular design.

The prefix letters representing the various groups of constructions are listed below:

Prefix Letters	*Group of Construction*
A, B or C	Floor-Ceiling Designs — Concrete and (Cellular only) Steel Floor Units
D, E or F	Floor-Ceiling Designs — Concrete and Steel Floor Units
G, H or I	Floor-Ceiling Designs — Concrete and Steel Joists
J or K	Floor-Ceiling Designs — Concrete
L or M	Floor-Ceiling Designs — Wood Joist or Combination Wood and Steel Assemblies
N or O	Beam Designs — For Floor-Ceiling Assemblies
P, Q or R	Roof-Ceiling Designs
S or T	Beam Designs — For Roof-Ceiling Assemblies
U, V or W	Wall and Partition Designs
X, Y or Z	Column Designs

14.0 REFERENCES

There are other generic listings of fire resistive assemblies that can be of use in designing, estimating endurance of existing construction, or modifying existing construction. The following publications are such sources.

ASCE/SEI/SFPE 29-05 Standard Calculation Methods for Structural Fire Protection, American Society of Civil Engineers, 1801 Alexander Bell Drive, Reston VA 20191.

Design for Fire Resistance of Precast Prestressed Concrete, Fifth Second Edition, Prestressed Concrete Institute, 175 W. Jackson Boulevard, Chicago, IL 60604.

Design Guide 19, Fire Resistance of Structural Steel Framing, American Institute of Steel Construction, 1 East Wacker Drive, Suite 3100, Chicago IL 60601.

Fire Protection for Structural Steel in Buildings, Third Ed (2004), Association for Specialist Fire Protection (ASFP) 235 Ash Road, Aldershot, Hampshire UK GU124DD.

Eurocode 2: Design of Concrete Structures - Part 1-2: General Rules - Structural Fire Design (1992-1-2:2004), European Committee for Standardization (CEN), Management Centre, 36 rue de Stassart, Brussels, Belgium B-1050.

Fire Resistance Design Manual, Gypsum Association, 810 First Street NE, #510 Washington D.C. 20002.

Fire-Resistant Construction in Modern Steel-Framed Buildings, (second printing, September 1959), The American Institute of Steel Construction, Inc., 1010 Park Avenue, New York, NY 10017.

Fire Resistance Ratings, American Insurance Association, 85 John Street, New York, NY 10038.

Design for Fire Resistance of Precast Prestressed Concrete, Fifth Second Edition, Prestressed Concrete Institute, 175 W. Jackson Boulevard, Chicago, IL 60604.

Guidelines for Determining Fire Resistance Ratings of Building Elements, Building Officials and Code Administrators International, Inc., Country Club Hills, IL 60478.

SFPE Fire Protection Handbook, 2008 Edition, Section 6, Chapter 7, National Fire Protection Association, Batterymarch Park, Quincy, MA 02269.

For listings of Approved and specification-tested products, see the *Approval Guide*. Also, refer to the *Fire Resistance Directory* and the *Building Materials Directory* published by Underwriters Laboratories.

APPENDIX A GLOSSARY OF TERMS

Ambient conditions: Room temperature conditions (i.e., not fire exposed) where the air temperature is generally taken to be 68°F (20°C).

Autoclaved aerated concrete (AAC): AAC is made of Portland cement, fine aggregate, lime, and sometimes gypsum, with admixtures used to provide a high entrained air content. Air voids are typically visible on the surface of AAC. AAC is generally not used in exterior weather-exposed applications unless a weather-resistant coating is provided. AAC is provided in panels and blocks. AAC blocks are typically plain (not reinforced) and solid, although some hollow or voided blocks can be used to allow for horizontal reinforcement (e.g., rebar in O-block) or vertical reinforcement (e.g., rebar in U-block). AAC blocks are typically similar in size to CMU. AAC panels are typically precast and reinforced with steel wire, but are not prestressed. AAC joints are typically 1/16 in. (1.6 mm) to 1/8 in. (3.2 mm) rather than the standard 3/8 in. (9.5 mm) joints used for CMU construction. Most AAC has 10% to 30% of the density and compressive strength of normal strength concrete and concrete masonry.

Calcerous (or Carbonate) aggregate: an aggregate from calcium carbonate or magnesium carbonate-based stone such as marble, marl, limestone or dolomite.

Cast-in-place (CIP) concrete: Concrete that is cast (i.e., poured or placed) into formwork at its permanent position and location at the construction site.

Concrete compressive strength: The ultimate compressive strength of concrete as determined by crushing test cylinders. For comparison, concrete compressive strength based on test cubes will be approximately 20% to 25% greater than that that based on test cylinders.

Concrete masonry units (CMU): concrete blocks, which can be either hollow or solid, used in masonry construction. The cores or cells of hollow CMU are often filled solid with cement grout (once several courses of CMU are constructed) to obtain an adequate fire resistance rating.

Conventionally reinforced concrete: Concrete that is reinforced with rebar, where the rebar is not prestressed.

Face shell: The concrete masonry material that makes up the two exposed sides (two faces) of the concrete masonry unit.

Fiber reinforced polymer, or fiber reinforced plastic (FRP): Generally consisting of either aramid (AFRP), carbon (CFRP), or glass (GFRP) fibers embedded in a polymer matrix adhesive material such as epoxy.

Fire barrier: An assembly that can provide a barrier to flame and hot gas transmission from a fire (i.e., integrity), but is not an adequate thermal barrier (i.e., insulation) and may not provide a adequate barrier to fire radiation. Therefore, a fire barrier will not provide the same level of protection as a fire rated assembly. Some fire rated glazing may be adequate as a fire barrier but not necessarily as an adequate fire rated assembly due the lack of adequate performance as a thermal and fire radiation barrier.

Fire endurance [R]: The amount of time during which adequate fire resistance is exhibited.

Fire resistance: The ability or a member, component, or assembly to perform at fire-exposed conditions by providing adequate fire confinement (as a flame and hot gas barrier [fire integrity] and thermal barrier [fire insulation]), or retaining adequate load-carrying capacity.

Fire resistance rating [R]: See Fire Endurance.

Fire rated assembly: An assembly that provides adequate fire endurance.

Foamed Plastic (or Foam Plastic): Expanded plastic sometimes used as an insulating material in building assemblies for typical environmental and service temperatures.

High strength concrete (HSC) also known as High performance concrete: HSC generally has an ambient compressive strength of at least 6000 psi (41 MPa) and can be as much as 20,000 psi (138 MPa); as compared to normal strength concrete which has an ambient compressive strength of roughly 3000 to 5000 psi (21 to 34 MPa).

Insulation rating: the fire resistance rating of an assembly based on the limitation of temperature on the unexposed surfaces of the assembly.

Integrity rating: the fire resistance rating of an assembly based on the prevention of the passage of flame and hot gasses to the unexposed side of the assembly. Assemblies with an integrity rating - but without an insulating rating, or with an inadequate insulating rating - are not considered to have an adequate fire resistance rating.

Lightweight CMU: CMU with weight density less than 100 Lb/ft3 , which would include CMU made from expanded aggregates (clay, shale, slate, and slag) and pumice aggregate. Lightweight CMU will generally have better fire resistance per unit thickness than normal weight CMU.

Lightweight concrete: Concrete with a weight density of roughly 105 to 115 Lbs/ft^3 (16 to 18 kN/m^3). Lightweight concrete will generally have better fire resistance per unit thickness than normal weight concrete.

Load bearing wall (bearing wall): A wall that supports, in addition to its own weight, gravity loads from roof or floor framing. Where roof or floor framing rests on a wall, and there are no columns built into the wall, the wall is supporting the framing and is therefore a load bearing wall.

Masonry: Construction consisting of concrete blocks (CMU), clay bricks, or stones assembled with cement mortar joints binding the individual components together.

Medium weight CMU: CMU with weight density of 105 Lb/ft^3 [1680 kg/m^3] to 115 Lb/ft^3 [1840 kg/m^3] , which would include CMU made from cinder and air-cooled slag aggregate.

Non-load bearing wall: A wall that supports its own weight and no additional gravity load; although these walls can support lateral loads from wind or earthquake actions.

Normal weight CMU: CMU with weight density of 125 Lb/ft^3 [2000 kg/m^3] or greater, which would include CMU made from siliceous or calcerous aggregate. When the density of the CMU is unknown or cannot be verified, normal weight CMU is assumed for fire endurance purposes.
Normal weight concrete: Concrete with a weight density of roughly 145 Lbs/ft^3 (23 kN/m^3). When the density of the concrete is unknown or cannot be verified, normal weight concrete is assumed for fire endurance purposes.

Perlite: An expanded siliceous mineral that can be used as a lightweight aggregate in gypsum and cement plaster, and other fire resistive construction materials. Perlite is typically white or grayish white in appearance.

Pilaster: The portion of a wall that is thickened to project beyond the face or faces of the wall, often integrating a rectangular concrete or masonry column into a wall of the same material. A pilaster is often used to support a beam or girder (indicating the wall is a load-bearing wall); although a pilaster can also be used as a vertical strengthening element use to resist lateral loads (such as wind loads) in an exterior non-load-bearing wall with large vertical spans (large story heights). Some pilasters can be strictly decorative architectural elements and may provide no structural function.

Post-tensioned (PT) concrete: Concrete with reinforcing (typically high-strength steel tendon or cable) that is tensioned (stressed) only after the concrete has cured and hardened. The ends of the post- tensioned reinforcing are anchored into the concrete. There are two types of post-tensioned concrete: Bonded and Unbonded. Bonded PT concrete has the reinforcing located in a continuous corrugated plastic or metal duct embedded in the concrete, with the duct filled with cement grout - resulting in a continuous bond between the reinforcing, the grout, and the concrete. Unbonded PT concrete has reinforcing that is covered with plastic or paper sheathing filed with protective grease, with the sheathed reinforcing not bonded to the concrete except at its anchored ends. PT concrete is generally cast-in-place (known as cast- in-place/post tensioned [CIP/PT]).

Precast (PC) concrete: Concrete that is cast (i.e., poured or placed) into formwork and cured prior to transporting the concrete member to its location for erection - that is, concrete that is neither cast-in-place nor site-cast. PC concrete can be prestressed (precast/prestressed [PC/PS]), or conventionally reinforced with rebar.

Pretensioned concrete: see Prestressed Concrete.

Prestressed (PS) concrete: Concrete with reinforcing (typically high- strength steel strand or cable) that is stressed in tension prior to placement of the concrete in the formwork. Once the concrete cures and hardens, the tension on the reinforcing is released. The reinforcing is bonded to concrete encasement throughout its entire length. Prestressed concrete is typically precast.

Rebar: Reinforcing bars (or rods) typically of round cross-section, and generally made of steel unless noted otherwise. Rebar is embedded in either concrete or cement grout to strengthen concrete or masonry, respectively. Rebar is generally not prestressed, but has been used infrequently in older construction as prestressed reinforcement.

Reinforcing bar: see Rebar.

Siliceous aggregate: An aggregate from silica-based stone such as granite, basalt, chert or flint. Concrete and concrete masonry made with siliceous aggregate generally has the lowest fire resistive qualities of the common aggregate types. When the aggregate is unknown or cannot be verified, siliceous aggregate is assumed for fire endurance purposes.

Site-Cast Concrete: Concrete that is placed or cast and cured at the construction site but is then moved at the site for final erection. A tilt-up concrete wall panel is a common type of site-cast concrete. Tilt-up concrete panels will generally be larger than precast concrete panels. Site-cast and cast-in-place concrete made of the same type of aggregate will have similar fire resistance properties - except that site-cast concrete construction will generally have many more joints, which will require fire-stopping, than cast-in-place concrete.

Spray-applied fire resistive material (SFRM): A spray-applied (although some can also be trowel-applied) material used to provide or enhance fire resistance. SFRM is typically applied to structural steel, steel joists, and the underside of steel deck.

Tilt-up concrete: See Site-Cast Concrete.

Vermiculite: An expanded silicate-based mineral that can be used as a lightweight aggregate in gypsum and cement plaster, and other fire resistive construction materials. Vermiculite is typically brown or grayish brown in appearance.

Wythe: Used when describing widths, sections, or leafs of a masonry or concrete wall. For example, a masonry wall consisting of a single layer of CMU is a single-wythe wall. A masonry wall assembly with CMU and an attached clay brick masonry facade is an example of a double-wythe wall.

APPENDIX B DOCUMENT REVISION HISTORY

January 2012. The following changes were done for this revision:

1. Added recommendations for Autoclaved Aerated Concrete (AAC).

2. Added recommendations for double-wythe concrete masonry unit (CMU) walls, and CMU and concrete walls with fire-resistant finish materials such as plaster and gypsum board, with example problems.

3. Added recommendations for CMU cavity walls and hollow partition walls that contain foam plastic insulation.

4. Added recommendations and guidance for CMU % solid, face shell thickness, aggregate-based densities, and the fire-resistance benefits of grout-filled CMU.

5. Added recommendations to address high strength concrete (HSC) spalling and fire-exposed strength.

6. Added and revised recommendations for precast/prestressed (pc/ps) concrete and cast-in-place post-tensioned (pt) concrete - and new guidance for identifying the various types of concrete.

7. Added recommendations for fiber-reinforced polymer (FRP) rebar and externally-applied FRP reinforcing.

8. Added and revised recommendations regarding concrete cover for fire walls.

9. Added recommendations for heavy timber and glulam framing.

10. Added recommendations and guidance on ISO 834 and BS 476 time-temperature curves and fire tests.

11. Added background structural steel columns tested per the ASTM E119 fire test standard and the difference between the loaded and unloaded (limiting steel temperature) test options.

12. Added and revised guidance on fire-resistance rated glass and glazing.

13. Added guidance on firestopping and the T_{FM} rating in the FM Approval Guide.

14. Added an extensive glossary of terms.

January 1999. The January version of this data sheet supersedes the July 1977 version.

July 1977. Supersedes Handbook Chapter 6.