FIRE RESISTANCE RATINGS OF CONCRETE MASONRY ASSEMBLIES

Keywords: calculated fire resistance rating, columns, control joints, equivalent thickness, fire resistance ratings, fire walls, lintels, multi-wythe walls, specifications, steel column protection

INTRODUCTION

Concrete masonry is widely specified for fire walls and fire barriers because concrete masonry: is noncombustible, provides durable fire resistance, and is economical to construct.

Chapter 7 of the *International Building Code* (IBC) (refs. 2, 3) governs materials and assemblies used for structural fire resistance and fire-rated separation of adjacent spaces. Concrete masonry fire resistance ratings are determined using either prescriptive details and tables found in IBC Section 720 or calculations found in IBC Section 721. The technical content of these provisions corresponds to the provisions of *Code Requirements for Determining Fire Resistance of Concrete and Masonry Construction Assemblies*, ACI 216.1/TMS 216 (ref. 1) (hereafter referred to as the Standard). The 1997 edition of the Standard is referenced in the 2003 and 2006 IBC for concrete and masonry materials. The current edition of the Standard, published in 2007, contains only minor changes from the 1997 edition. IBC sections 721.3 through 721.5 are virtually identical to the provisions of the Standard.

This TEK is based on both the prescriptive details and tables as well as the calculated fire resistance procedure, which is practical, versatile and economical. The calculation procedure allows the designer virtually unlimited flexibility to incorporate the excellent fire-resistive properties of concrete masonry into the design. Included are methods for determining the fire resistance rating of concrete masonry walls, columns, lintels, beams, and concrete masonry fire protection for steel columns. Also included are assemblies composed of concrete masonry and other components, including plaster and gypsum wallboard finishes, and multi-wythe masonry components including clay or shale masonry units.

METHODS OF DETERMINING FIRE RESISTANCE RATINGS

The fire resistance rating of concrete masonry elements can be determined by:
- testing in accordance with ASTM E 119 (ref. 4),
- calculation, or
- properly validated computer modeling.

Of these, the calculation method is the most practical and most commonly used method of determining concrete masonry fire resistance ratings. The calculations are based on extensive research, which established relationships between physical properties of materials and the fire resistance rating. The calculation method is fully described in the Standard, and determines fire resistance ratings based on the equivalent thickness of concrete masonry units and aggregate types used in their manufacture.

Private commercial listing services provide an alternative to the calculation method. The listing service approach allows the designer to select a fire-rated assembly which has been previously classified and listed in a published directory of fire-rated assemblies. The listing service also monitors materials and production to verify that the concrete masonry units are and remain in compliance with appropriate standards. A premium is usually charged for units of this type. The system also is somewhat inflexible in that little variation from the original tested wall assembly is allowed including unit size, shape, mix design, ingredients, and even the plant of manufacture.

Testing is generally not practical due to the expense of the test and the time required to build, cure and test representative specimens.

CALCULATED FIRE RESISTANCE RATINGS

Background

The calculated fire resistance method is based on extensive research and testing of concrete masonry walls. Fire testing of wall assemblies is conducted in accordance with the *Standard Test Methods for Fire Tests of Building Construction and Materials*, ASTM E 119 (ref. 4) which measures four performance criteria, as follows:
- resistance to the transmission of heat through the wall assembly,
- resistance to the passage of hot gases through the wall, sufficient to ignite cotton waste,
- load-carrying capacity of loadbearing walls, and
- resistance to the impact, erosion and cooling effects of a hose stream on the assembly after exposure to the standard fire.

The fire resistance rating of concrete masonry is typically governed by the heat transmission criteria. From the standpoint of life safety (particularly for fire fighters) and salvageability,

Table 1—Fire Resistance Rating Period of Concrete Masonry Assemblies (refs. 1, 2, 3)

Aggregate type in the concrete masonry unit[C]	Minimum required equivalent thickness, in. (mm), for fire resistance rating, hours[A, B]													
	4	3¾	3½	3¼	3	2¾	2½	2¼	2	1¾	1½	1¼	1	¾	½
Calcareous or siliceous gravel	6.2	6.0	5.8	5.5	5.3	5.0	4.8	4.5	4.2	3.9	3.6	3.2	2.8	2.4	2.0
Limestone, cinders or unexpanded slag	5.9	5.7	5.5	5.2	5.0	4.8	4.5	4.3	4.0	3.7	3.4	3.1	2.7	2.3	1.9
Expanded clay, shale or slate	5.1	4.9	4.8	4.6	4.4	4.2	4.0	3.8	3.6	3.4	3.3	2.9	2.6	2.2	1.8
Expanded slag or pumice	4.7	4.5	4.4	4.2	4.0	3.8	3.6	3.4	3.2	3.0	2.7	2.5	2.1	1.9	1.5

[A] Fire resistance rating between the hourly fire resistance rating periods listed may be determined by linear interpolation based on the equivalent thickness value of the concrete masonry assembly.

[B] Where combustible members are framed into the wall, the thickness of solid material between the end of each member and the opposite wall face, or between members set in from opposite sides, must be at least 93% of the thickness shown.

[C] Minimum required equivalent thickness corresponding to the hourly fire resistance rating for units made with a combination of aggregates shall be determined by linear interpolation based on the percent by volume of each aggregate used in the manufacture.

this failure mode is certainly preferable to a structural collapse endpoint, characteristic of many other building materials.
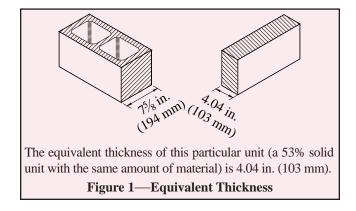
Fire testing of concrete masonry columns evaluates the ability of the column to carry design loads under standard fire test conditions.

Fire testing of a steel column protected by concrete masonry evaluates the structural integrity of the steel column under fire test conditions, by measuring the temperature rise of the steel.

Fire testing of concrete masonry beams and lintels evaluates the ability of the member to sustain design loads under standard fire test conditions. This is accomplished by ensuring that the temperature of the tensile reinforcement does not exceed 1,100 ºF (593 ºC) during the rating period.

Equivalent Thickness

Extensive testing has established a relationship between the fire resistance and the equivalent solid thickness of concrete masonry walls, as shown in Table 1. Equivalent thickness is essentially the solid thickness that would be obtained if the volume of concrete contained in a hollow unit were recast without core holes (see Figure 1). The equivalent thickness is determined in accordance with *Standard Methods of Sampling and Testing Concrete Masonry Units*, ASTM C 140 (ref. 5), and is reported on the C 140 test report. If the equivalent thickness is not known, but the percentage solid of the unit is, the equivalent thickness of a hollow unit can be determined by multiplying the percentage solid by the unit's actual thickness.

The equivalent thickness of a 100% solid unit or a solid grouted unit is equal to the actual thickness. For partially grouted walls where the unfilled cells are left empty, the equivalent thickness for fire resistance rating purposes is equal to that of an ungrouted unit. For partially grouted walls with filled cells, see the following section.

Loadbearing units conforming to ASTM C 90 (ref. 6) that are commonly available include 100% solid units, 75% solid units, and hollow units meeting minimum required face shell and web dimensions. Typical equivalent thickness values for these units are listed in Table 2.

Filling Cells with Loose Fill Material

If all cells of hollow unit masonry are filled with an approved material, the equivalent thickness of the assembly is the actual thickness. This also applies to partially grouted concrete masonry walls where all ungrouted cells are filled with an approved material.

Applicable fill materials are: sand, pea gravel, crushed stone, or slag that comply with ASTM C 33 (ref. 7) requirements; pumice, scoria, expanded shale, expanded clay, expanded slate, expanded slag, expanded fly ash, or cinders that comply with ASTM C 331 (ref. 8), perlite meeting the requirements of ASTM C 549 (ref. 9), or vermiculite complying with C 516 (ref. 10).

The equivalent thickness of this particular unit (a 53% solid unit with the same amount of material) is 4.04 in. (103 mm).

Figure 1—Equivalent Thickness

Table 2—Equivalent Thicknesses of Concrete Masonry Units, in. (mm)

Nominal width, in. (mm)	Based on typical hollow units[A]		Based on percent solid	
			(75%)	(100%)
4 (102)	2.7 (69)	[73.8]	2.7 (69)	3.6 (91)
6 (152)	3.1 (79)	[55.0]	4.2 (107)	5.6 (142)
8 (203)	4.0 (102)	[53.0]	5.7 (145)	7.6 (193)
10 (254)	4.5 (113)	[46.3]	7.2 (183)	9.6 (244)
12 (305)	5.1 (129)	[44.0]	8.7 (221)	11.6 (295)
14 (356)	5.5 (139)	[40.2]	10.2 (259)	13.6 (345)
16 (406)	6.0 (152)	[38.4]	11.7 (297)	15.6 (396)

[A] Values in brackets [ ] are percent solid values based on typical two-core concrete masonry units.

Wall Assembly Fire Ratings

The fire resistance rating is determined in accordance with Table 1 utilizing the appropriate aggregate type used in the masonry unit and the equivalent thickness.

Units manufactured with a combination of aggregate types are addressed by footnote B, which may be expressed by the following equation (see also the blended aggregate example, below):

$$T_r = (T_1 \times V_1) + (T_2 \times V_2)$$

where:

T_r = required equivalent thickness for a specific fire resistance rating of an assembly constructed of units with combined aggregates, in. (mm)

T_1, T_2 = required equivalent thickness from Table 1 for a specific fire resistance rating of a wall constructed of units with aggregate types 1 and 2, respectively, in. (mm)

V_1, V_2 = fractional volume of aggregate types 1 and 2, respectively, used in the manufacture of the unit (note that the clarification "dry-rodded volume" was added to the 2007 edition of the Standard, although this verbiage not included in the IBC)

Blended aggregate example:

The required equivalent thickness of an assembly constructed of units made with expanded shale (80% by volume), and calcareous sand (20% by volume), to meet a 3-hour fire resistance rating is:

From Table 1:

T_1 for expanded shale (3 hr rating) = 4.4 in. (112 mm)
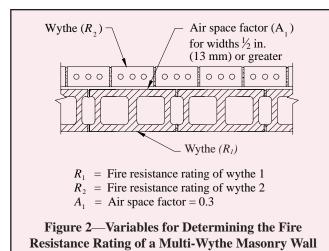T_2 for calcareous sand (3 hr rating) = 5.3 in. (135 mm)

$$T_r = (T_1 \times V_1) + (T_2 \times V_2)$$
$$T_r = (4.4 \times 0.80) + (5.3 \times 0.20) = 4.58 \text{ in. (116 mm)}$$

Multi-Wythe Wall Assemblies

The fire resistance rating of multi-wythe walls (Figure 2) is based on the fire resistance of each wythe and the air space between each wythe using the following equation:

$$R = (R_1^{0.59} + R_2^{0.59} + ... + R_n^{0.59} + A_1 + A_2 + ... A_n)^{1.7}$$

where:

$R_1, R_2,...R_n$ = fire resistance rating of wythe 1, 2,...n, respectively (hr).

R_1 = Fire resistance rating of wythe 1
R_2 = Fire resistance rating of wythe 2
A_1 = Air space factor = 0.3

Figure 2—Variables for Determining the Fire Resistance Rating of a Multi-Wythe Masonry Wall

$A_1, A_2,...A_n$ = 0.30; factor for each air space, 1, 2,...n, respectively, having a width of $^1/_2$ in. (13 mm) or more between wythes. Note that it does not matter which side is exposed to the fire.

For multi-wythe walls of clay and concrete masonry, use the values in Table 3 for the brick wythe in the above equation.

Reinforced Concrete Masonry Columns

The fire resistance rating of reinforced concrete masonry columns is based on the least plan dimension of the column as indicated in Table 4. The minimum required cover over the vertical reinforcement is 2 in. (51 mm).

Concrete Masonry Lintels

The fire resistance rating of concrete masonry lintels is determined based on the nominal thickness of the lintel and the minimum cover of longitudinal reinforcement (see Table 5). The cover requirements protect the reinforcement from strength degradation due to excessive temperature during the fire exposure period. Cover requirements may be provided by masonry units, grout, or mortar.

Table 3—Fire Resistance of Brick or Tile of Clay or Shale (ref. 1, 2, 3)

Material type	Minimum equivalent thickness[A] for fire resistance rating, in. (mm)			
	4 hr	3 hr	2 hr	1 hr
≥ 75% solid	6.0 (152)	4.9 (124)	3.8 (97)	2.7 (69)
Hollow units[B]	5.0 (127)	4.3 (109)	3.4 (86)	2.3 (58)
Hollow units[C]	6.6 (168)	5.5 (140)	4.4 (112)	3.0 (76)

[A] See *Equivalent Thickness* section for calculation.
[B] Unfilled hollow units.
[C] Grouted or filled according to the *Filling Cells with Loose Fill Material* section.

Table 4—Reinforced Concrete Masonry Columns (refs. 1, 2, 3)

Minimum column dimensions, in. (mm), for fire resistance rating of:			
1 hour	2 hours	3 hours	4 hours
8 (203)	10 (254)	12 (305)	14 (356)

Table 5—Reinforced Concrete Masonry Lintels Minimum Longitudinal Reinforcing Cover, in. (mm) (refs. 1, 2, 3)

Nominal lintel width, in., (mm)	Fire resistance rating			
	1 hour	2 hours	3 hours	4 hours
6 (152)	$1^1/_2$ (38)	2 (51)	[A]	[A]
8 (203)	$1^1/_2$ (38)	$1^1/_2$ (38)	$1^3/_4$ (44)	3 (76)
10 (254) or more	$1^1/_2$ (38)	$1^1/_2$ (38)	$1^1/_2$ (38)	$1^3/_4$ (44)

[A] Not permitted in the IBC. In the Standard, may be permitted with a more detailed analysis.

Control Joints

Figure 3 shows control joint details in fire-rated wall assemblies in which openings are not permitted or where openings are required to be protected. Maximum joint width is $\frac{1}{2}$ in. (13 mm). Although these details are not directly in the IBC, they are included by reference of the Standard.

In addition to these prescriptive fire resistance rated control joints, other control joints may be permitted in fire rated masonry walls. For example, the IBC and the Standard include provisions for ceramic fiber joint protection for precast panels, which are similar to concrete masonry walls in that both rely on concrete for fire protection, and both are governed by the ASTM E 119 heat transmission criteria. Using these provisions for an 8-in. (203-mm) concrete masonry wall with a maximum control joint width of $\frac{1}{2}$ in. (13 mm), a 1 in. (25 mm) length (measured perpendicular to the face of the wall) of ceramic fiber in the joint can be used in walls with fire resistance ratings up to 3 hours, while a 2 in. (51 mm) length can be used in the joints of a 4-hour wall (IBC Figure 721.2.1.3.1, ACI 216.1/TMS 216 Figure 2.7).
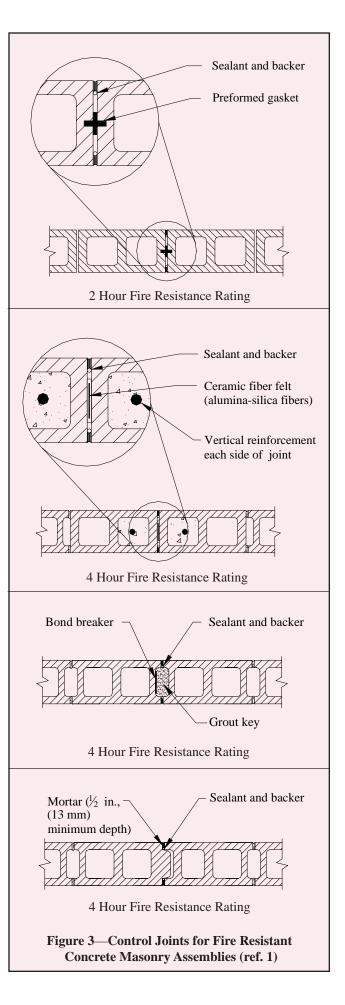
Steel Columns Protected by Concrete Masonry

The fire resistance rating of steel columns protected by concrete masonry, as illustrated in Figure 4, is determined by the following equation:
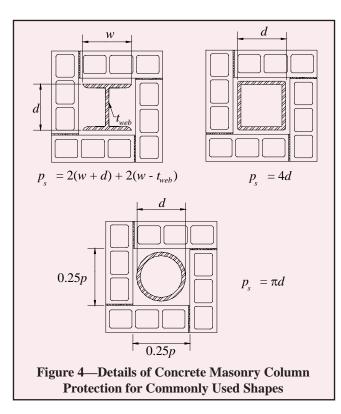
$$R = 0.17(W/D)^{0.7} + [0.285(T_e^{1.6}/K^{0.2})] \times [1.0 + 42.7\{(A_s/d_m T_e)/(0.25p + T_e)\}^{0.8}]$$
(English units)

$$R = 1.22(W/D)^{0.7} + [0.0018(T_e^{1.6}/K^{0.2})] \times [1.0 + 384\{(A_s/d_m T_e)/(0.25p + T_e)\}^{0.8}] \quad (SI)$$

where:

d_m = density of concrete masonry protection, pcf (kg/m^3)
D = heated perimeter of steel, in. (mm) (see Figure 4)
K = thermal conductivity of concrete masonry, Table 6, Btu/hr·ft·°F (W/m·C)
p = inner perimeter of concrete masonry protection, in. (mm)

Table 6—Concrete Masonry Conductivity (refs. 2, 3)	
Density, d_m pcf (kg/m^3)	Thermal conductivity[A], K Btu/hr·ft·°F (W/m·C)
80 (1,281)	0.207 (0.358)
85 (1,362)	0.228 (0.394)
90 (1,442)	0.252 (0.436)
95 (1,522)	0.278 (0.481)
100 (1,602)	0.308 (0.533)
105 (1,682)	0.340 (0.588)
110 (1,762)	0.376 (0.650)
115 (1,842)	0.416 (0.720)
120 (1,922)	0.459 (0.749)
125 (2,002)	0.508 (0.879)
130 (2,082)	0.561 (0.971)
135 (2,162)	0.620 (1.073)
140 (2,243)	0.685 (1.186)
145 (2,323)	0.758 (1.312)
150 (2,403)	0.837 (1.449)

[A] Thermal conductivity at 70 °F. °C = (°F-32)($\frac{5}{9}$)

2 Hour Fire Resistance Rating

4 Hour Fire Resistance Rating

4 Hour Fire Resistance Rating

4 Hour Fire Resistance Rating

Figure 3—Control Joints for Fire Resistant Concrete Masonry Assemblies (ref. 1)

Figure 4—Details of Concrete Masonry Column Protection for Commonly Used Shapes

$$p_s = 2(w + d) + 2(w - t_{web})$$

$$p_s = 4d$$

$$p_s = \pi d$$

R = fire resistance rating of the column assembly, hr.
T_e = equivalent thickness of masonry protection, in. (mm)
W = average weight of the steel column in lb/ft (kg/m)
Note: The Standard (ref. 1) replaces the first term in the above equation with $0.401(A_{st}/p_s)^{0.7}$ $(0.042(A_{st}/p_s)^{0.7}$ in SI), where A_{st} is the cross-sectional area of the steel column, in.² (mm²), and p_s is the same as D above. Both forms of the equation yield identical answers.

For more information on steel columns protected by concrete masonry, including tabulated masonry equivalent thickness values for various steel column sizes and fire resistance ratings, see TEK 7-6, *Steel Column Fire Protection* (ref. 11).

Table 7—Multiplying Factor for Finishes on Non-Fire-Exposed Side of Wall (refs. 2, 3)[A]

Type of finish applied to wall	Aggregate type in concrete masonry:	
	Siliceous or calcareous gravel	Limestone, cinders, unexpanded slag, or expanded shale, slate or clay
Portland cement-sand plaster	1.00	0.75[B]
Gypsum-sand plaster or gypsum wallboard	1.25	1.00
Gypsum-vermiculite or perlite plaster	1.75	1.50

[A] IBC values shown—note that in ACI 216.1/TMS 216, the categories for this table are slightly different.
[B] For portland cement-sand plaster ⅝ in. (16 mm) or less in thickness and applied directly to concrete masonry on the non-fire-exposed side, the multiplying factor is 1.0.

Effects of Finish Materials on Fire Resistance Ratings

In many cases, drywall, plaster or stucco finishes are used on concrete masonry walls. While finishes are normally applied for architectural reasons, they can also provide additional fire resistance. The IBC and the Standard make provision for calculating the additional fire resistance provided by these finishes.

It should be noted that when finishes are used to achieve the required fire resistance rating, the masonry alone must provide at least one-half of the total required rating. This is to assure structural integrity during a fire. The finish material must also be continuous over the entire wall.

Certain finishes deteriorate more rapidly when exposed to fire than when they are on the non-fire side of the wall. Therefore, two separate tables are required. Table 7 is applicable to finishes on the non-fire-exposed side of the wall, and Table 8 applies to finishes on the fire-exposed side.

For finishes on the non-fire-exposed side of the wall, the finish is converted to an equivalent thickness of concrete masonry by multiplying the thickness of the finish by the factor given in Table 7. The result is then added to the concrete masonry wall equivalent thickness, and used in Table 1 to determine the wall's fire resistance rating.

For finishes on the fire-exposed side of the wall, a time (from Table 8) is assigned to the finish. This time is added

Table 8—Time Assigned to Finish Materials on Fire-Exposed Side of Wall (refs. 1, 2, 3)

Finish description:	Time, min.
Gypsum wallboard	
⅜ in. (10 mm)	10
½ in. (13 mm)	15
⅝ in. (16 mm)	20
Two layers of ⅜ in. (10 mm)	25
One layer ⅜ in. (10 mm) and one layer ½ in. (13 mm)	35
Two layers of ½ in. (13 mm)	40
Type "X" gypsum wallboard	
½ in. (13 mm)	25
⅝ in. (16 mm)	40
Direct-applied portland cement-sand plaster	[A]
Portland cement-sand plaster on metal lath	
¾ in. (19 mm)	20
⅞ in. (22 mm)	25
1 in. (25 mm)	30
Gypsum-sand plaster on ⅜ in. (10 mm) gypsum lath	
½ in. (13 mm)	35
⅝ in. (16 mm)	40
¾ in. (19 mm)	50
Gypsum-sand plaster on metal lath	
¾ in. (19 mm)	50
⅞ in. (22 mm)	60
1 in. (25 mm)	80

[A] For the purposes of determining the contribution of portland cement-sand plaster to the equivalent thickness of concrete masonry for use in Table 1, use either the actual plaster thickness or ⅝ in. (16 mm), whichever is smaller.

to the fire resistance rating determined for the base wall and non-fire-exposed side finish, if any. The times listed in Table 8 are essentially the length of time the various finishes will remain intact when exposed to fire (i.e., on the fire-exposed side of the wall).

When calculating the fire resistance rating of a wall with finishes, two calculations are performed, assuming each side of the wall is the fire-exposed side. The fire rating of the wall assembly is the lower of the two. Note that there may be situations where the wall needs to be rated with the fire on only one side.

Installation of Finishes

Finishes that contribute to the total fire resistance rating of a wall must meet certain minimum installation requirements. Plaster and stucco are applied in accordance with the provisions of the building code without further modification.

Gypsum wallboard and gypsum lath are to be attached to wood or metal furring strips spaced a maximum of 16 in. (406 mm) on center. It must be installed with the long dimension parallel to the furring members and all horizontal and vertical joints must be supported and finished.

The Standard includes more detailed requirements for attaching gypsum wallboard, as follows. When installed with furring, it may be attached in one of two ways:
1) self-tapping drywall screws spaced a maximum of 12 in. (305 mm) and penetrating a minimum of $\frac{3}{8}$ in. (10 mm) into resilient steel furring channels running horizontally and spaced a maximum of 24 in. (610 mm) on center, or
2) lath nails at 12 in. (305 mm) on center maximum, penetrating $\frac{3}{4}$ in. (19 mm) into nominal 1 x 2 in. (25 x 51 mm) wood furring strips which are attached to masonry with 2 in. (51 mm) concrete nails spaced a maximum of 16 in. (41 mm) on center.

Note that the Standard also provides for gypsum wallboard attached using adhesives, by using a $\frac{3}{8}$ in. (10 mm) bead of panel adhesive placed around the perimeter of the wallboard and across the diagonals, and then secured with a masonry nail for each 2 ft^2 (0.19 m^2) of panel. It also allows $\frac{5}{8}$ in. (16 mm) Type "X" gypsum wallboard to be installed horizontally without being supported at the horizontal joints.

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