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Code Requirements for Determining Fire Resistance of Concrete and Masonry Construction Assemblies

An ACI / TMS Standard

Reported by Joint ACI / TMS Committee 216

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THE MASONRY SOCIETY

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FOREWORD

Fire resistance of building elements is an important consideration in building design. While structural design considerations for concrete and masonry at ambient temperature conditions are addressed by ACI 318 and ACI 530/ASCE 5/TMS 402, respectively, these codes do not consider the impact of fire on concrete and masonry construction. This standard contains design and analytical procedures for determining the fire resistance of concrete and masonry members and building assemblies. Where differences occur in specific design requirements between this standard and the aforementioned codes, as in the case of cover protection of steel reinforcement, the more stringent of the requirements shall apply.

Keywords: beams (supports); columns (supports); compressive strength; concrete slabs, fire endurance; fire ratings; fire resistance; fire tests; masonry walls; modulus of elasticity; prestressed concrete; prestressing steels; reinforced concrete; reinforcing steel; structural design; temperature distribution; thermal properties; walls.

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ACI 216.1-07 supersedes ACI 216.1-97, was adopted March 6, 2007, and published May 2007.

CHAPTER 1—GENERAL

1.1—Scope

This standard describes acceptable methods for determining the fire resistance of concrete building and masonry building assemblies and structural elements, including walls, floor and roof slabs, beams, columns, lintels, and masonry fire protection for structural steel columns. These methods shall be used for design and analysis purposes and shall be based on the fire exposure and applicable end-point criteria of ASTM E 119. This standard does not apply to composite metal deck floor or roof assemblies.

The primary intended use of this document is for determining the design requirements for concrete and masonry elements to resist fire and provide fire protection. Tolerance compliance to the provisions for concrete shall be based on information provided in ACI 117. Consideration for compliance to the provisions for masonry shall be based on the information provided in ACI 530.1/ASCE 6/TMS 602.

1.2—Alternative methods

Methods other than those presented in this standard shall be permitted for use in assessing the fire resistance of concrete and masonry building assemblies and structural elements if the methods are based on the fire exposure and applicable end-point criteria specified in ASTM E 119. Computer models, when used, shall be validated and supported by published material to substantiate their accuracy.

1.3—Definitions

The following definitions apply for this standard:

approved—approved by the building official responsible for enforcing the legally adopted building code of which this standard is a part, or approved by some other authority having jurisdiction.

bar, high-strength alloy steel—steel bars conforming to the requirements of ASTM A 722/A 722M.

barrier element—a building member that performs as a barrier to the spread of fire (for example, walls, floors, and roofs).

beam—a structural member subjected primarily to flexure, but also to axial loads.

blanket, ceramic fiber—mineral wool insulating material made of alumina-silica fibers and having a density of 4 to 8 lb/ft^3.

board, mineral—mineral fiber insulation board complying with ASTM C 726.

building code—a legal document that establishes the minimum requirements necessary for building design and construction to provide for public health and safety.

concrete, carbonate aggregate—concrete made with coarse aggregate consisting mainly of calcium carbonate or a combination of calcium and magnesium carbonate (for example, limestone or dolomite).

concrete, cellular—a low-density product consisting of portland-cement, cement-silica, cement-pozzolan, lime-pozzolan, lime silica pastes, or pastes containing a blend of these ingredients and having a homogeneous void or cell structure, attained with gas-forming chemicals or foaming agents. (For cellular concretes containing binder ingredients other than, or in addition to, portland cement, autoclave curing is usually employed.)

concrete, lightweight-aggregate—concrete made with aggregates conforming to ASTM C 330 or C 331.

concrete, normalweight—concrete made with aggregates conforming to ASTM C 33.

concrete, perlite—nonstructural lightweight insulating concrete having a density of approximately 30 lb/ft^3, made by mixing perlite aggregate complying with ASTM C 332 with portland cement slurry.

concrete, plain—structural concrete with no reinforcement or less reinforcement than the minimum amount specified in ACI 318 for reinforced concrete.

concrete, reinforced—structural concrete reinforced with no less than the minimum amount of prestressing tendons or nonprestressed reinforcement as specified by ACI 318.

concrete, semi-lightweight—Concrete made with a combination of lightweight aggregates (expanded clay, shale, slag, or slate, or sintered fly ash) and normalweight aggregates, having an equilibrium density of 105 to 120 lb/ft^3 in accordance with ASTM C 567.

concrete, siliceous aggregate—normalweight concrete having constituents composed mainly of silica or silicates.

concrete, structural—all concrete used for structural purposes, including plain and reinforced concrete.

concrete, vermiculite—concrete in which the aggregate consists of exfoliated vermiculite.

end-point criteria—conditions of acceptance for an ASTM E 119 fire test.

end-point, heat transmission—An acceptance criterion of ASTM E 119 limiting the temperature rise of the unexposed surface to an average of 250 °F for all measuring points or a maximum of 325 °F at any one point.

end-point, integrity—an acceptance criterion of ASTM E 119 prohibiting the passage of flame or gases hot enough to ignite cotton waste before the end of the desired fire-endurance period. The term also applies to the hose-stream test of a fire-exposed wall.

end-point, steel temperature—an acceptance criterion of ASTM E 119 defining the limiting steel temperatures for unrestrained assembly classifications.

end-point, structural—ASTM E 119 criteria that specify the conditions of acceptance for structural performance of a tested assembly.

endurance, fire—a measure of the elapsed time during which a material or assembly continues to exhibit fire resistance. As applied to elements of buildings with respect to this standard, it shall be measured by the methods and criteria contained in ASTM E 119.

fiberboard, glass—fibrous glass insulation board complying with ASTM C 612.

fiber, sprayed mineral—a blend of refined mineral fibers and inorganic binders.

fire resistance—the property of a material or assembly to withstand fire or provide protection from it. As applied to elements of buildings, it is characterized by the ability to confine a fire or, when exposed to fire, to continue to perform a given structural function, or both.

fire-resistance rating (sometimes called fire rating, fire-resistance classification, or hourly rating)—a legal term defined in building codes, usually based on fire endurance; fire-resistance ratings are assigned by building codes for various types of construction and occupancies, and are usually given in half-hour or hourly increments.

fire test—see **standard fire test**.

joist—a comparatively narrow beam, used in closely spaced arrangements to support floor or roof slabs (that require no reinforcement except that required for temperature and shrinkage stresses); also a horizontal structural member such as that which supports deck form sheathing.

masonry, plain—masonry in which the tensile resistance of masonry is taken into consideration and the resistance of the reinforcing steel, if present, is neglected.

masonry, reinforced—a material in which the masonry tensile strength is neglected and the effects of stress in embedded reinforcement are included in the design.

masonry unit, clay—solid or hollow unit (brick or tile) composed of clay, shale, or similar naturally occurring earthen substances shaped into prismatic units and subjected to heat treatment at elevated temperature (firing), meeting requirements of ASTM C 34, C 56, C 62, C 126, C 212, C 216, C 652, or C 1088.

masonry unit, concrete—hollow or solid unit (block) made from cementitious materials, water, and aggregates, with or without the inclusion of other materials, meeting the requirements of ASTM C 55, C 73, C 90, C 129, or C 744.

mastic, intumescent—spray-applied coating that reacts to heat at approximately 300 °F by foaming to a multicellular structure having 10 to 15 times its initial thickness.

material, cementitious—cements and pozzolans used in concrete and masonry construction.

material, vermiculite cementitious—cementitious material containing mill-mixed vermiculite to which water is added to form a mixture suitable for spraying.

reinforcement, cold-drawn wire—steel wire made from rods that have been rolled from billets, cold-drawn through a die; for concrete reinforcement of a diameter not less than 0.08 in. nor greater than 0.625 in.

standard fire exposure—the time-temperature relationship defined by ASTM E 119.

standard fire test—the test prescribed by ASTM E 119.

steel, hot-rolled—steel used for reinforcing bars or structural steel members.

strand—a prestressing tendon composed of a number of wires twisted about a center wire or core.

temperature, critical—temperature of reinforcing steel in unrestrained flexural members during fire exposure at which the nominal flexural strength of a member is reduced to the moment produced by application of service loads to that member.

tendon—a steel element such as strand, bar, wire, or a bundle of such elements, primarily used in tension to impart compressive stress to concrete.

wallboard, gypsum type "X"—mill-fabricated product, complying with ASTM C 36/C 36M, Type X, made of a gypsum core containing special minerals and encased in a smooth, finished paper on the face side and liner paper on the back.

1.4—Notation

A_1, A_2, and A_n = air factor for each continuous air space having a distance of 1/2 to 3-1/2 in. (13 to 89 mm) between wythes (nondimensional)

A_{ps} = cross-sectional area of prestressing tendons, in.^{2}

A_s = cross-sectional area of non-prestressed longitudinal tension reinforcement, in.^{2}

A_{st} = cross-sectional area of the steel column, in.^{2}

a = depth of equivalent rectangular concrete compressive stress block at nominal flexural strength, in.

a_θ = depth of equivalent concrete rectangular stress block at elevated temperature, in.

B = least dimension of rectangular concrete column, in.

b = width of concrete slab or beam, in.

b_f = width of flange, in.

c_c = ambient temperature specific heat of concrete, Btu/(lb/°F)

D_c = oven-dried density of concrete, lb/ft^3

d = effective depth, distance from centroid of tension reinforcement to extreme compressive fiber or depth of steel column, in.

d_{ef} = distance from centroid of tension reinforcement to most extreme concrete compressive fiber at which point temperature does not exceed 1400 °F, in.

d_ℓ = thickness of fire-exposed concrete layer, in.

d_{st} = column dimension, in.

°F = degrees Fahrenheit

f_c = measured compressive strength of concrete test cylinders at ambient temperature, psi

f'_c = specified compressive strength of concrete, psi

$f'_{c\theta}$ = reduced compressive strength of concrete at elevated temperature, psi

f_{ps} = stress in prestressing steel at nominal flexural strength, psi
$f_{ps\theta}$ = reduced stress of prestressing steel at elevated temperature, psi
f_{pu} = specified tensile strength of prestressing tendons, psi
f_y = specified yield strength of non-prestressed reinforcing steel, psi
$f_{y\theta}$ = reduced yield strength of non-prestressed reinforcing steel at elevated temperature, psi
H = specified height of masonry unit, in.
H_s = ambient temperature thermal capacity of steel column, Btu/(ft/°F)
h = average thickness of concrete cover, in.
k_c = thermal conductivity of concrete at room temperature, Btu/(h/ft/°F)
k_{cm} = thermal conductivity of concrete masonry at room temperature, Btu/(h/ft/°F)
L = specified length of masonry unit or interior dimension of rectangular concrete box protection for steel column, in.
l = clear span between supports, ft
M = moment due to full service load on member, lb-ft
M_n = nominal moment capacity at section, lb-ft
$M_{n\theta}$ = nominal moment capacity at section at elevated temperature, lb-ft
$M_{n\theta}^{+}$ = nominal positive moment capacity of section at elevated temperature, lb-ft
$M_{n\theta}^{-}$ = nominal negative moment capacity of section at elevated temperature, lb-ft
M_{x1} = maximum value of redistributed positive moment at some distance x_1, lb-ft
m = equivalent moisture content of the concrete by volume (percent)
p = inner perimeter of concrete masonry protection, in.
p_s = heated perimeter of steel column, in.
R = fire resistance of assembly, hours
R_0 = fire resistance at zero moisture content, hours
$R_1, R_2,...R_n$ = fire resistance of layer 1, 2,...n, respectively, hours
s = center-to-center spacing of items such as ribs or undulations, in.
T = specified thickness of concrete masonry and clay masonry unit, in.
T_e = equivalent thickness of concrete, concrete masonry and clay masonry unit, in.
T_{ea} = equivalent thickness of concrete masonry assembly, in.
T_{ef} = equivalent thickness of finishes, in.
t = time, min.
t_e = equivalent thickness of a ribbed or undulating concrete section, in.
t_{min} = minimum thickness, in.
t_{tot} = total slab thickness, in.
t_w = thickness of web, in.
u = average thickness of concrete between the center of main reinforcing steel and fire-exposed surface, in.
u_{ef} = an adjusted value of u to accommodate beam geometry where fire exposure to concrete surfaces is from three sides, in.
V_n = net volume of masonry unit, in.^{3}
W = average weight of the steel column, lb/ft
w = sum of unfactored dead and live service loads
w_c = density of concrete, lb/ft
w_{cm} = density of masonry protection, lb/ft^3
x_0 = distance from inflection point to location of first interior support, measured after moment redistribution has occurred, in.
x_1 = distance at which maximum value of redistributed positive moment occurs measured from: (a) outer support for continuity over one support; and (b) either support where continuity extends over two supports, in.
x_2 = in continuous span, distance between adjacent inflection points, in.
θ = subscript denoting changes of parameter due to elevated temperature
ρ = reinforcement ratio
ρ_g = ratio of total reinforcement area to cross-sectional area of column
ω_p = reinforcement index for concrete beam reinforced with prestressing steel
ω_r = reinforcement index for concrete beam reinforced with non-prestressed steel
ω_θ = reinforcement index for concrete beam at elevated temperature

1.5—Fire resistance determinations

The fire resistance of materials and assemblies shall be determined by one of the methods given in 1.5.1 to 1.5.4.

1.5.1 *Qualification by testing*—Materials and assemblies of materials of construction tested in accordance with the requirements set forth in ASTM E 119 shall be rated for fire resistance in accordance with the results and conditions of such tests.

1.5.2 *Calculated fire resistance*—The fire resistance associated with an element or assembly shall be deemed acceptable when established by the calculation procedures in this standard or when established in accordance with 1.2.

1.5.3 *Approval through past performance*—The provisions of this standard are not intended to prevent the application of fire ratings to elements and assemblies that have been applied in the past and have been proven through performance.

1.5.4 *Alternative methods*—The provisions of this standard are not intended to prevent the application of new and emerging technology for predicting the life safety and property protection implications of buildings and structures.

CHAPTER 2—CONCRETE

2.1—General

The fire resistance of concrete members and assemblies designed in accordance with ACI 318 for reinforced and plain structural concrete shall be determined based on the provisions of this chapter. Concrete walls, floors, and roofs shall meet minimum thickness requirements for purposes of

Table 2.1—Fire resistance of single-layer concrete walls, floors, and roofs

Aggregate type	Minimum equivalent thickness for fire-resistance rating, in.				
	1 hour	1-1/2 hours	2 hours	3 hours	4 hours
Siliceous	3.5	4.3	5.0	6.2	7.0
Carbonate	3.2	4.0	4.6	5.7	6.6
Semi-lightweight	2.7	3.3	3.8	4.6	5.4
Lightweight	2.5	3.1	3.6	4.4	5.1

barrier fire resistance. Concrete containing steel reinforcement shall additionally meet cover protection requirements in this chapter for purposes of maintaining fire resistance.

In some cases, distinctions are made between normalweight concrete made with carbonate and siliceous aggregates. If the type of aggregate is not known, the value for the aggregate resulting in the greatest required member thickness or cover to the reinforcement shall be used.

2.2—Concrete walls, floors, and roofs

Plain and reinforced concrete bearing or nonbearing walls and floor and roof slabs required to provide fire-resistance ratings of 1 to 4 hours shall comply with the minimum equivalent thickness values in Table 2.1. For solid walls and slabs with flat surfaces, the equivalent thickness shall be determined in accordance with 2.2.1. The equivalent thickness of hollow-core slabs or walls, or slabs, walls, or other barrier elements with surfaces that are not flat shall be determined in accordance with 2.2.2 through 2.2.4. Provisions for cover protection of steel reinforcement are contained in 2.3.

2.2.1 *Solid walls and slabs with flat surfaces*—For solid walls and slabs with flat surfaces, the actual thickness shall be the equivalent thickness.

2.2.2 *Hollow-core concrete walls and slabs*—For walls and slabs constructed with precast concrete hollow-core panels with constant core cross section throughout their length, calculate the equivalent thickness by dividing the net cross-sectional area by the panel width. Where all of the core spaces are filled with grout or loose fill material, such as perlite, vermiculite, sand or expanded clay, shale, slag, or slate, the fire resistance of the wall or slab shall be the same as that of a solid wall or slab of the same type of concrete.

2.2.3 *Flanged panels*—For flanged walls, and floor and roof panels where the flanges taper, the equivalent thickness shall be determined at the location of the lesser distance of two times the minimum thickness or 6 in. from the point of the minimum thickness of the flange (Fig. 2.1).

2.2.4 *Ribbed or undulating panels*—Determine the equivalent thickness t_e of elements consisting of panels with ribbed or undulating surfaces as follows:

1. Where the center-to-center spacing of ribs or undulations is more than four times the minimum thickness; the equivalent thickness t_e is the minimum thickness of the panel neglecting the ribs or undulations (Fig. 2.1);

2. Where the center-to-center spacing of ribs or undulations is equal to or less than two times the minimum thickness, calculate the equivalent thickness t_e by dividing the net cross-sectional area by the panel width. The maximum

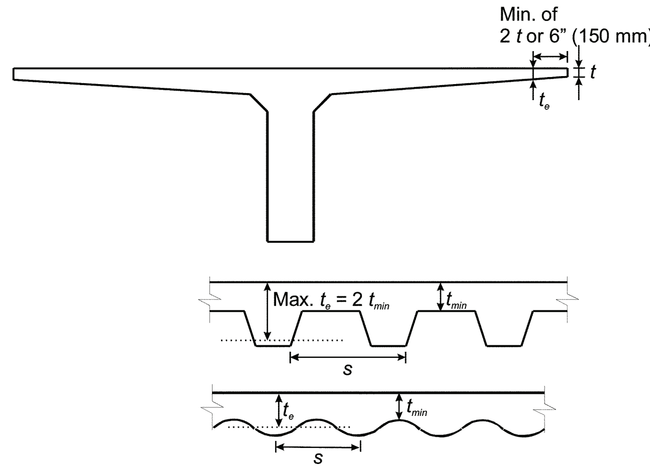


Fig. 2.1—Equivalent thickness of flanged, ribbed, and undulating panels.

thickness used to calculate the net cross-sectional area shall not exceed two times the minimum thickness; and

3. Where the center-to-center spacing of ribs or undulations exceeds two times the minimum thickness but is not more than four times the minimum thickness, calculate the equivalent thickness t_e from the following equation

$$t_e = t_{min} + [(4t_{min}/s) - 1](t_{e2} - t_{min}) \qquad (2\text{-}1)$$

where

s = spacing of ribs or undulations, in.;
t_{min} = minimum thickness, in.; and
t_{e2} = equivalent thickness, in., calculated in accordance with Item 2 of Section 2.2.4.

2.2.5 *Multiple-layer walls, floors, and roofs*—For walls, floors, and roofs consisting of two or more layers of different types of concrete, masonry, or both, determine the fire resistance in accordance with the graphical or numerical solutions in 2.2.5.1, 2.2.5.2, or 2.2.5.3. The fire resistance of insulated concrete floors and roofs shall be determined in accordance with 2.2.6.

2.2.5.1 *Graphical and analytical solutions*—For solid walls, floors, and roofs consisting of two layers of different types of concrete, fire resistance shall be determined through the use of Fig. 2.2 or from Eq. (2-2) or (2-3). Perform separate fire-resistance calculations, assuming each side of the element is the fire-exposed side. The fire resistance shall be the lower of the two resulting calculations, unless otherwise permitted by the building code. For floors and roofs, the bottom surface shall be assumed to be exposed to fire.

2.2.5.2 *Numerical solution*—For floor and roof slabs and walls made of one layer of normalweight concrete and one layer of semi-lightweight or lightweight concrete, where each layer is 1 in. or greater in thickness, the combined fire resistance of the assembly shall be permitted to be determined using the following expressions:

(a) When the fire-exposed layer is of normalweight concrete

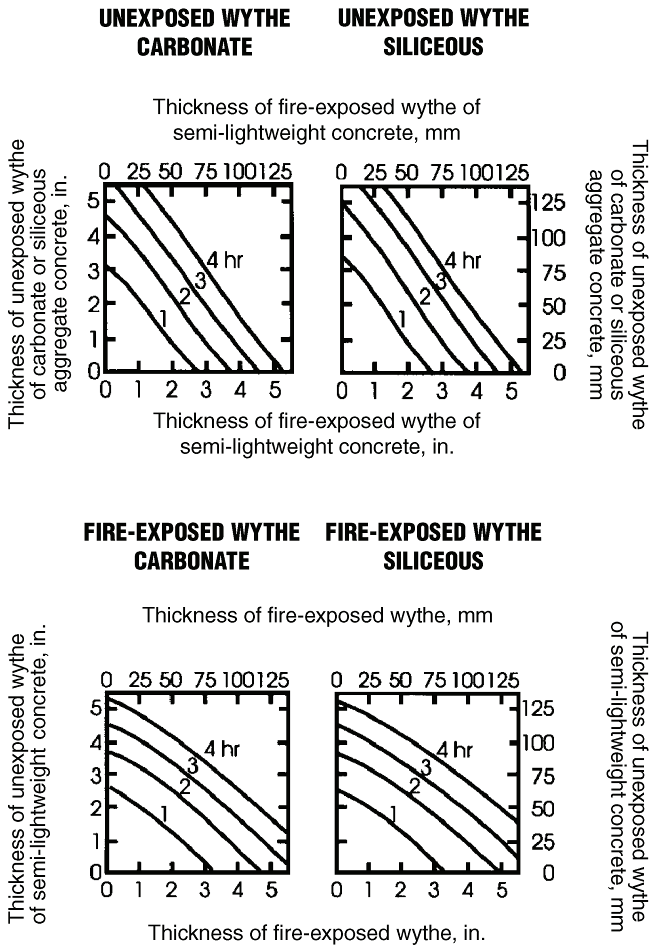


Fig. 2.2—Fire resistance of two-layer concrete walls, floors, and roofs.

$$R = 0.057(2t_{tot}^2 - d_\ell t_{tot} + 6/t_{tot}) \tag{2-2}$$

(b) When the fire-exposed layer is of lightweight or semi-lightweight concrete

$$R = 0.063(t_{tot}^2 + 2d_\ell t_{tot} - d_\ell^2 + 4/t_{tot}) \tag{2-3}$$

where

R = fire resistance, hours;
t_{tot} = total thickness of slab, in.; and
d_ℓ = thickness of fire-exposed layer, in.

2.2.5.3 *Alternative numerical solution*—Determine the fire resistance from Eq. (2-4) for walls, floors, and roofs not meeting the criteria of 2.2.5.1 and consisting of two or more layers of different types of concrete, or consisting of layers of concrete, concrete masonry, clay masonry, or a combination

$$R = (R_1^{0.59} + R_2^{0.59} + ... + R_n^{0.59} + A_1 + A_2 + ... + A_n)^{1.7} \tag{2-4}$$

where

R = fire resistance of assembly, hours;
R_1, R_2, and R_n = fire resistance of individual layers, hours;

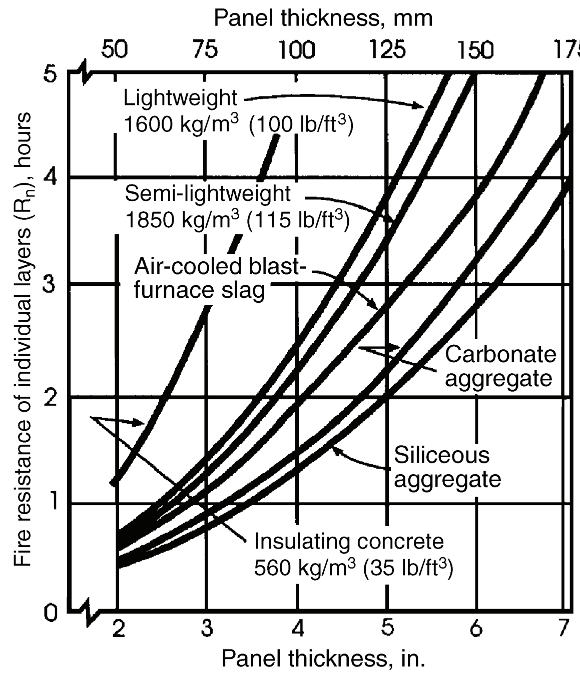


Fig. 2.3—Effect of slab thickness and aggregate type of fire resistance of concrete slabs based on 250 °F (139 °C) rise in temperature of unexposed surface.

A_1, A_2, and A_n = 0.30; the air factor for each continuous air space having a distance of 1/2 to 3-1/2 in. between layers.

Obtain values of R_n for individual layers for use in Eq. (2-4) from Table 2.1 or Fig. 2.3 for concrete materials, from Table 3.1 for concrete masonry, and Table 4.1 for clay masonry. Interpolation between values in the tables shall be permitted. Equation (2-4) does not consider which layer is being exposed to the fire.

2.2.5.4 *Sandwich panels*—Determine the fire resistance of precast concrete wall panels consisting of a layer of foam plastic sandwiched between two layers of concrete by using Eq. (2-4). For foam plastic with a thickness not less than 1 in., use $R_n^{0.59}$ = 0.22 hours in Eq. (2-4). For foam plastic with a total thickness less than 1 in., the fire resistance contribution of the plastic shall be zero. Foam plastic shall be protected on both sides with not less than 1 in. of concrete.

2.2.6 *Insulated floors and roofs*—Use Fig. 2.4(a), (b), and (c) or Fig. 2.5(a) and (b) to determine the fire resistance of floors and roofs consisting of a base slab of concrete with a topping (overlay) of cellular, perlite or vermiculite concrete, or insulation boards and built-up roof. Where a three-ply built-up roof is installed over a lightweight insulating, or semi-lightweight concrete topping, it shall be permitted to add 10 minutes to the fire resistance determined from Fig. 2.4(a), (b), (c) or Fig. 2.6.

2.2.7 *Protection of joints between precast concrete wall panels and slabs*—When joints between precast concrete wall panels are required to be insulated by 2.2.7.1, this shall be done in accordance with 2.2.7.2. Joints between precast concrete slabs shall be in accordance with 2.2.7.3.

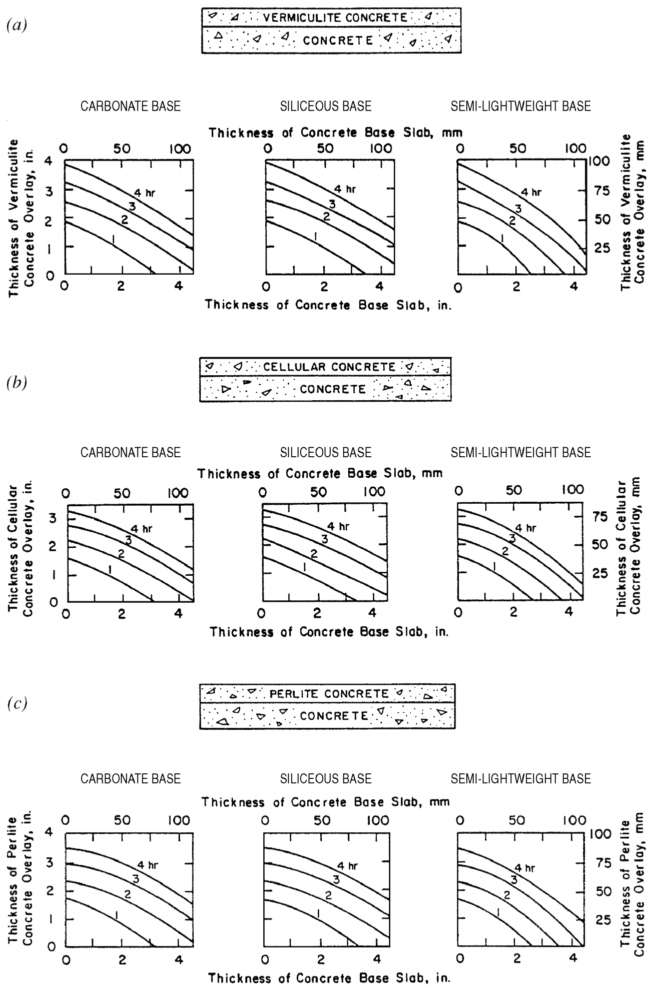


Fig. 2.4—Fire resistance of concrete base slabs with overlays of insulating concrete, 30 lb/ft^3.

2.2.7.1 *Joints in walls required to be insulated*—Where openings are not permitted or where openings are required to be protected, use the provisions of 2.2.7.2 to determine the required thickness of joint insulation. Joints between concrete wall panels that are not insulated as prescribed in 2.2.7.2 shall be considered unprotected openings. Where the percentage of unprotected openings is limited in exterior walls, include uninsulated joints in exterior walls with other unprotected openings. Insulated joints that comply with 2.2.7.2 shall not be considered openings for purposes of determining allowable percentage of openings.

2.2.7.2 *Thickness of ceramic fiber insulation*—The thickness of ceramic fiber blanket insulation required to insulate joints of 3/8 and 1 in. in width between concrete wall panels to maintain fire-resistance ratings of 1 to 4 hours shall be in accordance with Fig. 2.7. For joint widths between 3/8 and 1 in., determine the thickness of insulation by interpolation. Other approved joint treatment systems that maintain the required fire resistance shall be permitted.

2.2.7.3 *Joints between precast slabs*—It shall be permitted to ignore joints between adjacent precast concrete slabs when calculating the equivalent slab thickness, provided that a concrete topping not less than 1 in. thick is used. Where a concrete topping is not used, joints shall be grouted to a depth of at least 1/3 of the slab thickness. In the case of hollow-core slabs, the grout thickness need not exceed the sum of the thicknesses of the top and bottom shells. It shall be permitted to use ceramic fiber blanket insulation in accordance with 2.2.7.2.

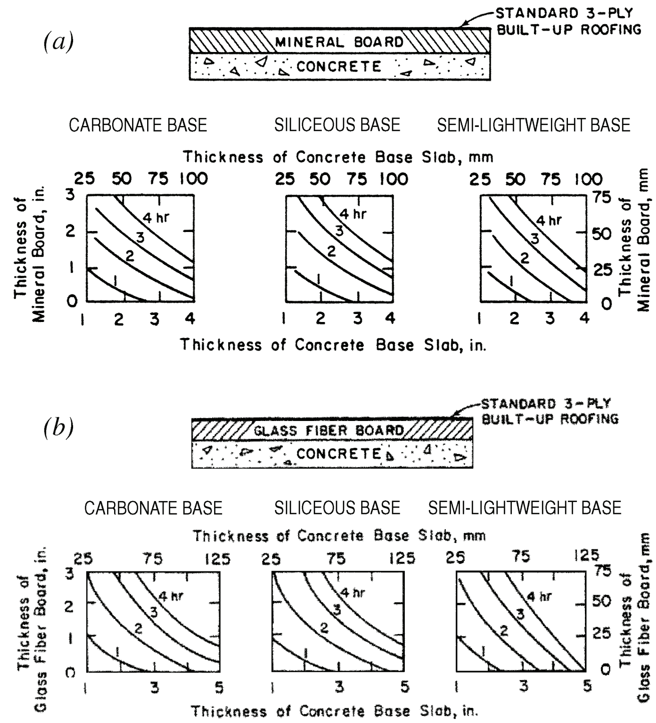


Fig. 2.5—Fire resistance of concrete roofs with board insulation.

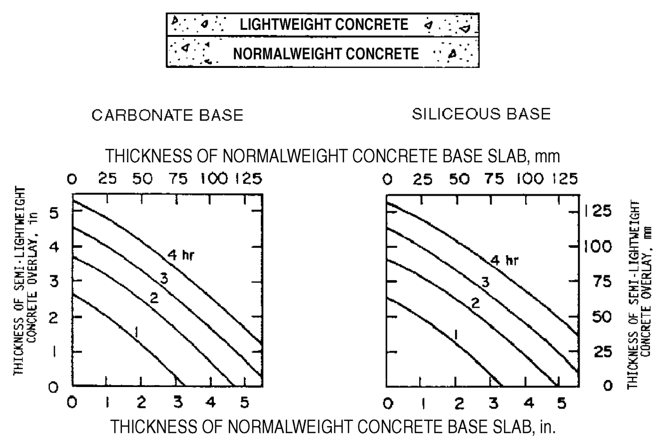


Fig. 2.6—Fire resistance of semi-lightweight concrete overlays on normalweight concrete base slabs.

2.2.8 *Effects of finish materials on fire resistance*—The use of finish materials to increase the fire-resistance rating shall be permitted. The effects of the finish materials, whether on the fire-exposed side or the non-fire-exposed side, shall be evaluated in accordance with the provisions of Chapter 5.

Table 2.2—Construction classification, restrained and unrestrained

Unrestrained	
Wall bearing	Single spans and simply-supported end spans of multiple bays such as concrete or precast units*
Restrained	
Wall bearing	Interior spans of multiple bays: 1. Cast-in-place concrete slab systems 2. Precast concrete where the potential thermal expansion is resisted by adjacent construction†
Concrete framing	1. Beams fastened securely to the framing numbers 2. Cast-in-place floor or roof systems (such as beam/slab systems, flat slabs, pan joists, and waffle slabs) where the floor or roof system is cast with the framing members 3. Interior and exterior spans of precast systems with cast-in-place joints resulting in restraint equivalent to that of Condition 1, concrete framing 4. Prefabricated floor or roof systems where the structural members are secured to such systems and the potential thermal expansion of the floor or roof systems is resisted by the framing system of the adjoining floor or roof construction†

*It shall be permitted to consider floor and roof systems restrained when they are tied into walls with or without tie beams, provided the walls are designed and detailed to resist thermal thrust from the floor or roof system.

†For example, resistance to potential thermal expansion is considered to be achieved when:
1. Continuous concrete structural topping is used;
2. The space between the ends of precast units or between the ends of units and the vertical face of supports is filled with concrete or mortar; or
3. The space between the ends of the precast units and the vertical face of supports, or between the ends of solid or hollow-core slab units, does not exceed 0.25% of the length for normalweight concrete members or 0.1% of the length for structural lightweight concrete members.

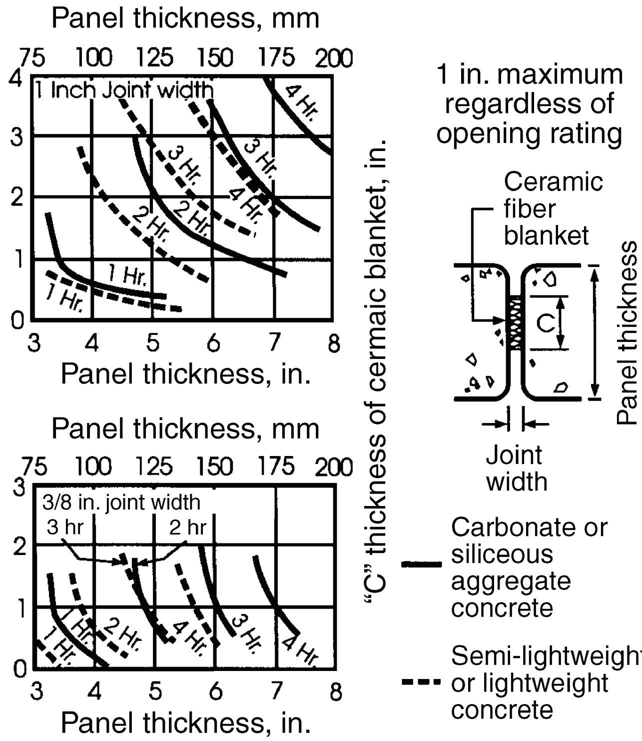


Fig. 2.7—Ceramic fiber joint production.

Table 2.3—Minimum cover in concrete floors and roof slabs

Aggregate type	Cover*† for corresponding fire resistance, in.					
	Restrained	Unrestrained				
	4 or less	1 hour	1-1/2 hours	2 hours	3 hours	4 hours
Nonprestressed						
Siliceous	3/4	3/4	3/4	1	1-1/4	1-5/8
Carbonate	3/4	3/4	3/4	3/4	1-14	1-1/4
Semi-lightweight	3/4	3/4	3/4	3/4	1-1/4	1-1/4
Lightweight	3/4	3/4	3/4	3/4	1-1/4	1-1/4
Prestressed						
Siliceous	3/4	1-1/8	1-1/2	1-3/4	2-3/8	2-3/4
Carbonate	3/4	1	1-3/8	1-5/8	2-1/8	2-1/4
Semi-lightweight	3/4	1	1-3/8	1-1/2	2	2-1/4
Lightweight	3/4	1	1-3/8	1-1/2	2	2-1/4

*Shall also meet minimum cover requirements of 2.3.1.

†Measured from concrete surface to surface of longitudinal reinforcement.

2.3—Concrete cover protection of steel reinforcement

Cover protection determinations in this section are based on the structural end-point. Assemblies required to perform as fire barriers shall additionally meet the heat transmission end-point and comply with the provisions in 2.2.

2.3.1 *General*—Determine minimum concrete cover over bottom longitudinal steel reinforcement (positive moment reinforcement in simple spans) for floor and roof slabs and beams using methods described in 2.3.1.1 through 2.3.1.3. Concrete cover shall not be less than required by ACI 318. For purposes of determining minimum concrete cover, classify slabs and beams as restrained or unrestrained in accordance with Table 2.2.

2.3.1.1 *Cover for reinforcement in slab*—The minimum thickness of concrete cover to positive moment reinforcement (bottom steel) for different types of concrete floor and roof slabs required to provide fire resistance of 1 to 4 hours shall conform to values given in Table 2.3. Table 2.3 is applicable to one-way or two-way cast-in-place beam/slab systems or precast solid or hollow-core slabs with flat undersurfaces.

2.3.1.2 *Cover for nonprestressed flexural reinforcement in beams*—The minimum thickness of concrete cover to nonprestressed bottom longitudinal steel reinforcement for restrained and unrestrained beams of different widths required to provide fire resistance of 1 to 4 hours shall conform to values given in Table 2.4. Values in Table 2.4 for restrained beams apply to beams spaced more than 4 ft apart on center. For restrained beams and joists spaced 4 ft or less on center, 3/4 in. cover shall be permitted to meet fire-resistance requirements of 4 hours or less. Determine cover for intermediate beam widths by linear interpolation.

The concrete cover for an individual bar is the minimum thickness of concrete between the surface of the bar and the fire-exposed surface of the beam. For beams in which several bars are used, the cover, for the purposes of Table 2.4, is the average of the minimum cover of the individual bars. For corner bars (that is, bars equidistant from the bottom and side), the minimum cover used in the calculation shall be 1/2 the actual value. The actual cover for any individual bar shall be not less than 1/2 the value shown in Table 2.4 or 3/4 in., whichever is greater.

2.3.1.3 *Cover for prestressed flexural reinforcement*—For restrained and unrestrained beams and stemmed units

Table 2.4—Minimum cover in nonprestressed beams

Restraint	Beam width, in.	Cover for corresponding fire-resistance rating, in.				
		1 hour	1-1/2 hours	2 hours	3 hours	4 hours
Restrained	5	3/4	3/4	3/4	1	1-1/4
	7	3/4	3/4	3/4	3/4	3/4
	≥10	3/4	3/4	3/4	3/4	3/4
Unrestrained	5	3/4	1	1-1/4	NP*	NP
	7	3/4	3/4	3/4	1-3/4	3
	≥10	3/4	3/4	3/4	1	1-3/4

*Not permitted.

(Table 2.2), the minimum thickness of concrete cover over bottom longitudinal steel reinforcement required to provide fire-resistance of 1 to 4 hours shall conform to values given in Tables 2.5 and 2.6. Values in Table 2.5 apply to members with carbonate, siliceous, or semi-lightweight aggregate and widths not less than 8 in. Values in Table 2.6 apply to prestressed members of all aggregate types and widths that have cross-sectional areas not less than 40 in.^{2}. In case of conflict between the values, it shall be permitted to use the smaller of the values from Tables 2.5 or 2.6. The cover to be used with Tables 2.5 or 2.6 values shall be a weighted average, computed following the provisions in 2.3.1.2, with "strand" or "tendon" substituted for "bar." The minimum cover for nonprestressed bottom longitudinal steel reinforcement in prestressed beams shall be determined in accordance with 2.3.1.2.

2.4—Analytical methods for calculating structural fire resistance and cover protection of concrete flexural members

Instead of using methods described in 2.3, the calculation methods in this section shall be permitted for determining fire resistance and the adequacy of cover protection in concrete flexural members based on the ASTM E 119 time-temperature fire exposure. The provisions in 2.4 do not explicitly account for the effects of restraint of thermally induced expansion; however, the use of comprehensive analysis and design procedures that take into account the effects of moment redistribution and the restraint of thermally induced member expansion shall be permitted. In no case shall cover protection be less than that required by ACI 318.

2.4.1 *Simply supported and unrestrained one-way slabs and beams*—On the basis of structural end-point behavior, the fire resistance of a simply supported, unrestrained, flexural member shall be determined by

$$M_n \geq M_{n\theta} \geq M$$

Assume that the unfactored full service load moment M is constant for the entire fire-resistance period.

The redistribution of moments or the inclusion of thermal restraint effects shall not be permitted in determining the fire resistance of members classified as both simply supported and unrestrained.

2.4.1.1 *Calculation procedure for slabs*—Use Fig. 2.8 to determine the structural fire resistance or amount of concrete cover u to center of the steel reinforcement of concrete slabs.

Table 2.5—Minimum cover in prestressed concrete beams 8 in. or greater in width

Restraint	Aggregate type	Beam width, in.	Cover thickness for corresponding fire-resistance rating, in.				
			1 hour	1-1/2 hours	2 hours	3 hours	4 hours
Restrained*	Carbonate or siliceous	8	1-1/2	1-1/2	1-1/2	1-3/4	2-1/2
		≥12	1-1/2	1-1/2	1-1/2	1-1/2	1-7/8
	Semi-lightweight	8	1-1/2	1-1/2	1-1/2	1-1/2	2
		≥12	1-1/2	1-1/2	1-1/2	1-1/2	1-5/8
Unrestrained	Carbonate or siliceous	8	1-1/2	1-3/4	2-1/2	5†	NP‡
		≥12	1-1/2	1-1/2	1-7/8	2-1/2	3
	Semi-lightweight	8	1-1/2	1-1/2	2	3-1/4	NP
		≥12	1-1/2	1-1/2	1-5/8	2	2-1/2

*Tabulated values for restrained beams apply to beams spaced at more than 4 ft on centers.
†Not practical for 8 in.-wide beams, but shown for purposes of interpolation.
‡Not permitted.

Table 2.6—Minimum cover in prestressed concrete beams of all widths

Restraint	Aggregate type	Area,* in.^{2}	Cover thickness for corresponding fire-resistance rating, in.				
			1 hour	1-1/2 hours	2 hours	3 hours	4 hours
Restrained	All	$40 \leq A \leq 150$	1-1/2	1-1/2	2	2-1/2	NP†
	Carbonate or siliceous	$150 \leq A \leq 300$	1-1/2	1-1/2	1-1/2	1-3/4	2-1/2
		$300 < A$	1-1/2	1-1/2	1-1/2	1-1/2	2
	Lightweight or semi-lightweight	$150 < A$	1-1/2	1-1/2	1-1/2	1-1/2	2
Unrestrained	All	$40 \leq A \leq 150$	2	2-1/2	NP	NP	NP
	Carbonate or siliceous	$150 \leq A \leq 300$	1-1/2	1-3/4	2-1/2	NP	NP
		$300 < A$	1-1/2	1-1/2	2	3‡	3‡
	Lightweight or semi-lightweight	$150 < A$	1-1/2	1-1/2	2	3‡	4‡

*In computing the cross-sectional area for stems, the area of the flange shall be added to the area of the stem, and the total width of the flange, as used, shall not exceed three times the average width of the stem.
†Not permitted.
‡Adequate provisions against spalling shall be provided by U-shaped or hooded stirrups spaced not to exceed the depth of the member, and having a cover of 1 in.

2.4.1.2 *Calculation procedure for simply supported beams*—The same procedures that apply to slabs in 2.4.1.1 shall apply to beams with the following difference: when determining an average value of u for beams with corner bars or corner tendons, an "effective u," u_{ef}, shall be used in its place. Values of u for the corner bars or tendons used in the computation of u_{ef} shall be equal to 1/2 of their actual u value. Figure 2.8 shall be used in conjunction with the computed u_{ef}.

2.4.2 *Continuous beams and slabs*—For purposes of the method within this section, continuous members are defined as flexural members that extend over one or more supports or are built integrally with one or more supports such that moment redistribution can occur during the fire-resistance period.

On the basis of structural end-point behavior, the fire resistance of continuous flexural members shall be determined by

$$M_{n\theta}^{+} = M_{x1}$$

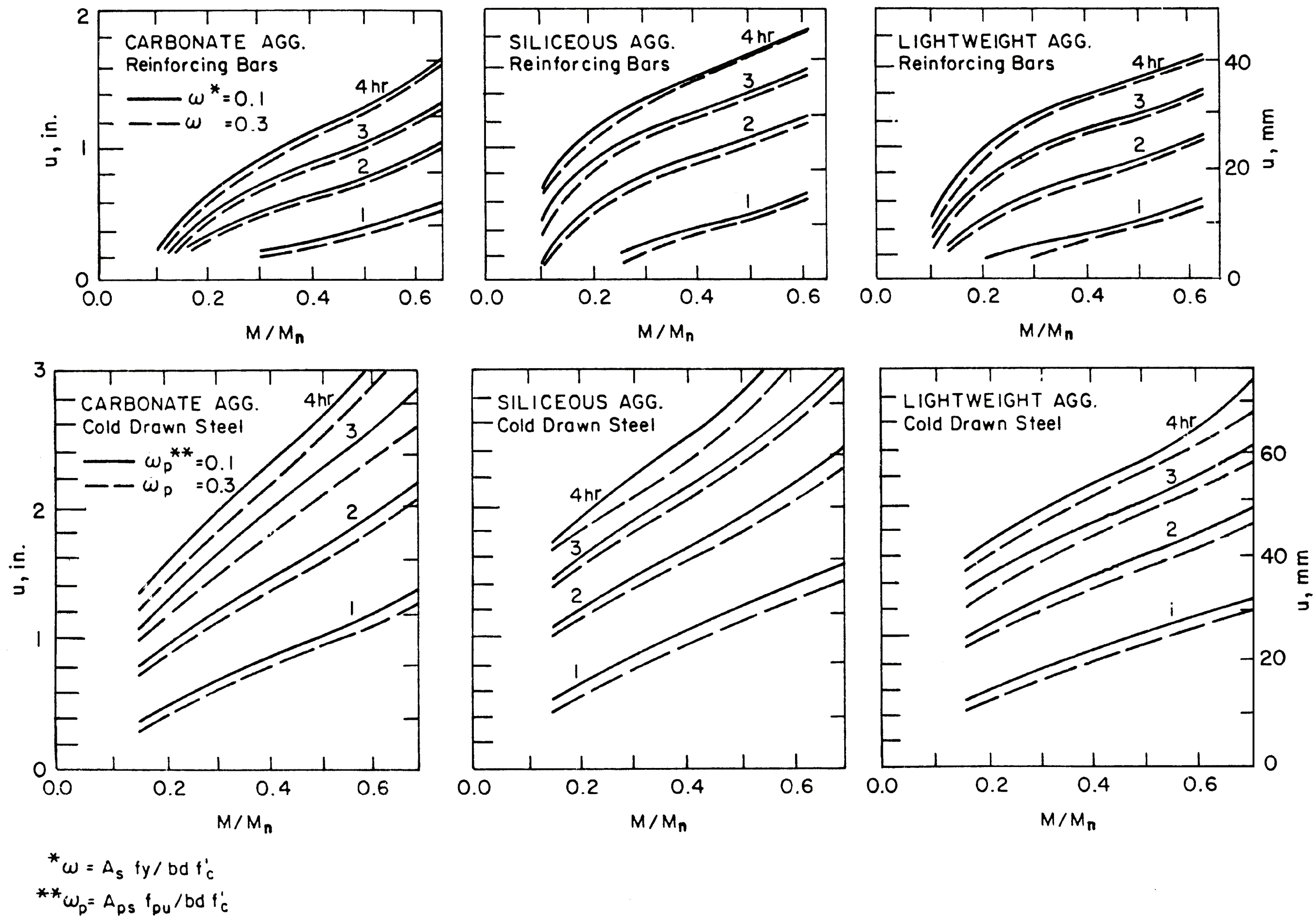


Fig. 2.8—Fire resistance of concrete slabs as influenced by aggregate type, reinforcing steel type, moment intensity, and u, *as defined in 1.4.*

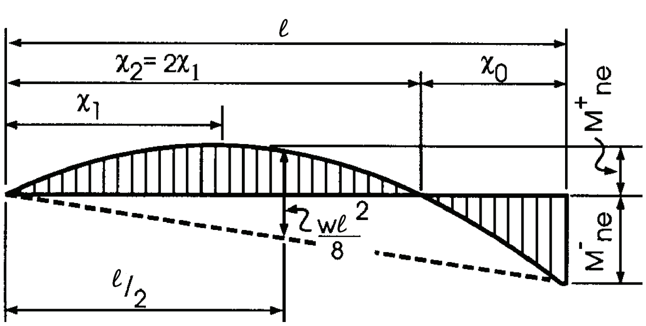


Fig. 2.9(a)—Redistributed applied moment diagram at failure condition for a uniformly loaded flexural member continuous over one support.

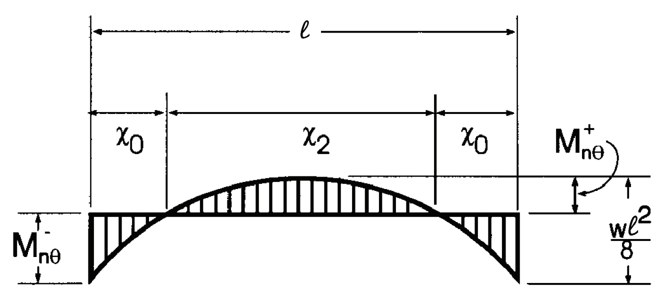


Fig. 2.9(b)—Redistributed applied moment diagram at failure condition for a symmetrical uniformly loaded flexural member continuous at both supports.

that is, when $M^+_{n\theta}$ is reduced to M_{x1}, the maximum value of the redistributed positive moment at distance x_1. For slabs and beams that are continuous over one support, this distance is measured from the outer support. For continuity over two supports, the distance x_1 is measured from either support (Fig. 2.9(a) and (b)).

$M^+_{n\theta}$ shall be computed as required in 2.4.2.2(a). The required and available values of $M_{n\theta}$ shall be determined as required in 2.4.2.2(b) and (d).

2.4.2.1 *Reinforcement detailing*—Design the member so that flexural tension governs the design. Negative moment reinforcement shall be long enough to accommodate the complete redistributed moment and change in the location of inflection points. The required lengths of the negative moment reinforcement shall be determined assuming that the span being considered is subjected to its minimum probable load, and that the adjacent span(s) are loaded to their full unfactored service loads. Reinforcement detailing shall satisfy the provisions in Section 7.13 and Chapter 12 of ACI 318, and the requirement of 2.4.2.1(b) of this standard.

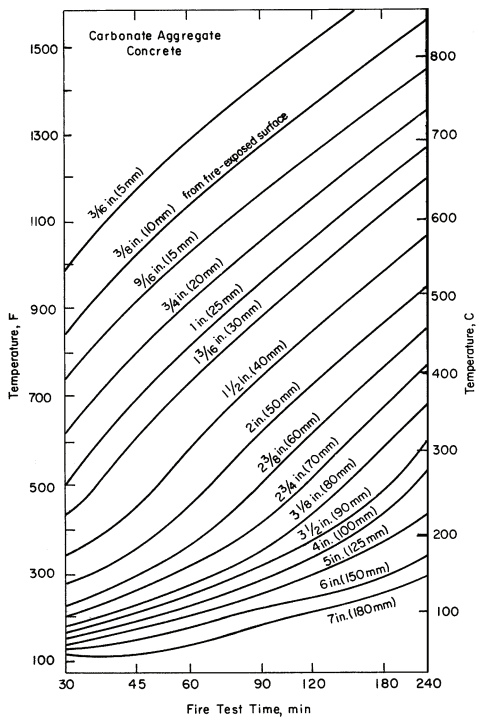


Fig. 2.10(a)—Temperatures within slabs during ASTM E 119 fire tests—carbonate aggregate concrete.

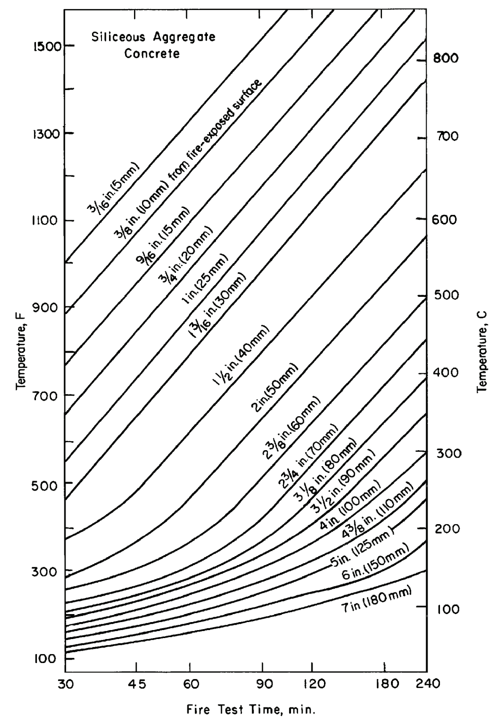


Fig. 2.10(b)—Temperatures within slabs during ASTM E 119 fire tests—siliceous aggregate concrete.

2.4.2.1(a) To avoid compressive failure in the negative moment region, the negative moment tension reinforcement index ω_θ shall not exceed 0.30. In the calculation of ω_θ, concrete hotter than 1400 °F shall be neglected. In this case, a reduced d_{ef} shall be used in place of d, where $\omega_\theta = \rho f_{y\theta}/f'_{c\theta} = A_s f_{y\theta}/bd_{ef}f'_{c\theta}$ for nonprestressed reinforcement; and $\omega_{\rho\theta} = A_{ps}f_{ps\theta}/bd_{ef}f'_{c\theta}$ for prestressed reinforcement.

2.4.2.1(b) When the analysis in 2.4.2.1 indicates that negative moments extend for the full length of the span, not less than 20% of the negative moment reinforcement in the span shall be extended throughout the span to accommodate the negative moment redistribution and change of location of the inflection points.

2.4.2.2 *Calculation procedure for continuous slabs*—Procedures in 2.4.2.2(a) shall be used to determine structural fire resistance and cover protection based on continuity over one support. For continuity over two supports, the procedures in 2.4.2.2(c) shall be used.

2.4.2.2(a) *Determination of structural fire resistance or amount of steel reinforcement for continuity over one support*—Obtain concrete and steel temperatures in the region of maximum positive moment from Fig. 2.10(a) through (c) based on the type of aggregate in concrete, the required fire rating, and an assumed fire test exposure to the ASTM E 119 standard fire condition.

Compute the positive moment capacities as $M^+_{n\theta} = A_s f_{y\theta}(d - a_\theta/2)$ for nonprestressed reinforcement, and $M^+_{n\theta} = A_{ps}f_{ps\theta}(d - a_\theta/2)$ for prestressed reinforcement, where:

$f_{y\theta}$, $f_{ps\theta}$ = the reduced reinforcement strengths at elevated temperatures, determined from Fig. 2.11;

a_θ = $A_s f_{y\theta}/0.85 f'_{c\theta}\, b$ for reinforcing bars;

a_θ = $A_{ps}f_{ps\theta}/0.85 f'_{c\theta}\, b$ for prestressing steel;

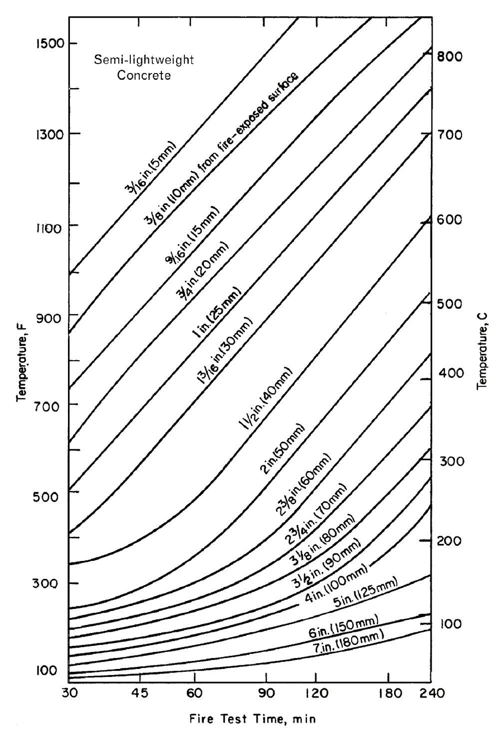


Fig. 2.10(c)—Temperatures within slabs during ASTM E 119 fire tests—semi-lightweight aggregate concrete.

$f'_{c\theta}$ = the reduced compressive strength of the concrete in the zone of flexural compression based on the elevated temperature and concrete aggregate type, determined from Fig. 2.12; and

d = distance from the centroid of the tension reinforcement to the extreme compressive fiber.

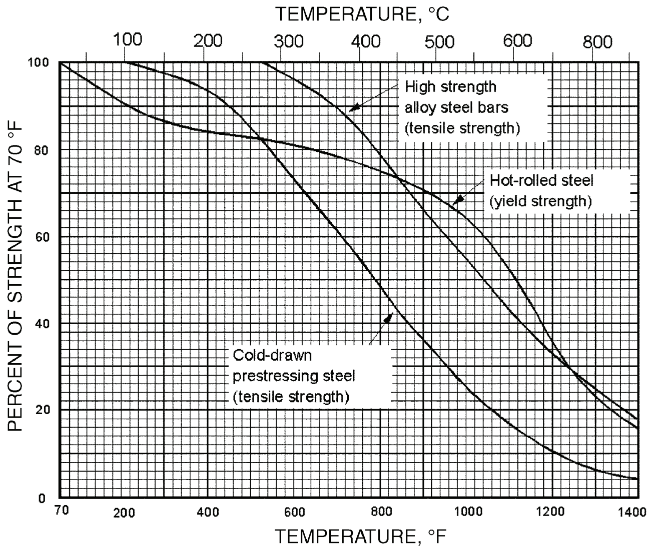


Fig. 2.11—Strength of flexural reinforcement steel bar and strand at high temperatures.

Alternatively, it is also permitted to use Fig. 2.8 to determine the available moment capacity $M^+_{n\theta}$ as a fraction of M^+_n.

2.4.2.2(b) *Design of negative moment reinforcement*—Determine the required negative moment reinforcement and location of an inflection point to calculate its development length by the following procedures:

Calculate $\omega_\theta \leq 0.30$ as in 2.4.2.1(a), and increase compression steel or otherwise alter the section, if necessary.

For a uniformly distributed load w (Fig. 2.9(a))

$$M_{x1} = (wlx_1)/2 - (wx_1^2)/2 - (M^-_{n\theta}\ x_1)/l = M^+_{n\theta}$$

$$M^-_{n\theta} = (wl^2)/2 - wl^2(2M^+_{n\theta}\ /wl^2)^{1/2}$$

$$x_1 = l/2 - M^-_{n\theta}\ /wl$$

$$x_0 = 2M^-_{n\theta}\ /wl$$

where x_0 equals the distance from the inflection point after moment redistribution to the location of the first interior support. The distance x_0 reaches a maximum when the minimum anticipated uniform service load w is applied.

The available negative moment capacity shall be computed as

$$M^-_{n\theta} = A_s f_{y\theta}(d_{ef} - a_\theta/2)$$

where d_{ef} is as defined in 2.4.2.1(a).

2.4.2.2(c) *Determination of structural fire resistance or amount of steel reinforcement for continuity over two supports*—The same procedures shall be used in determining structural fire resistance and cover protection requirements for positive steel reinforcement as in 2.4.2.2(a) for slabs continuous over one support.

2.4.2.2(d) *Design of negative moment reinforcement*—Determine the required negative moment reinforcement and

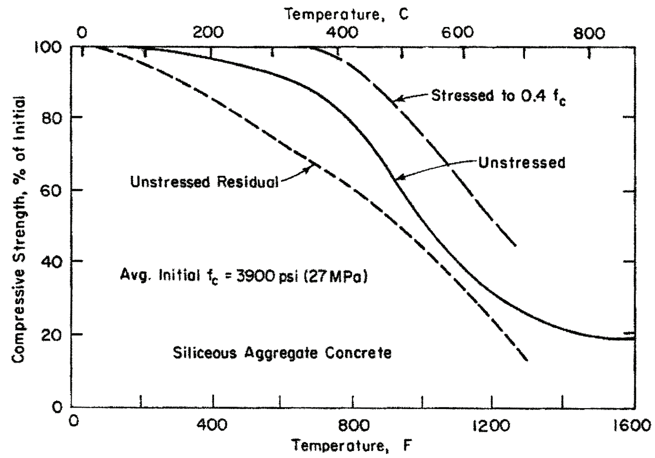


Fig. 2.12(a)—Compressive strength of siliceous aggregate concrete at high temperatures and after cooling.

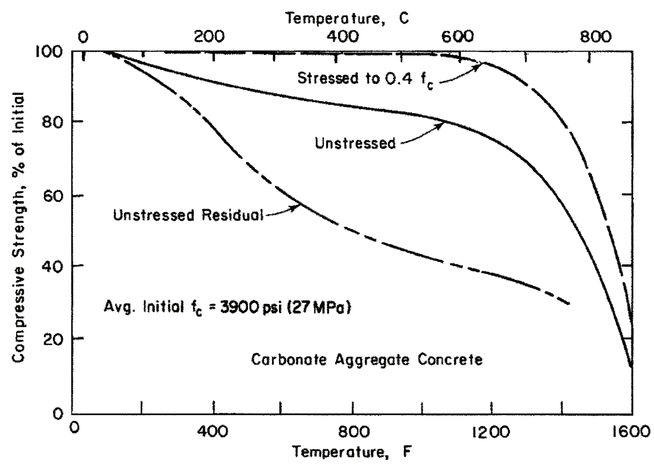


Fig. 2.12(b)—Compressive strength of carbonate aggregate concrete at high temperatures and after cooling.

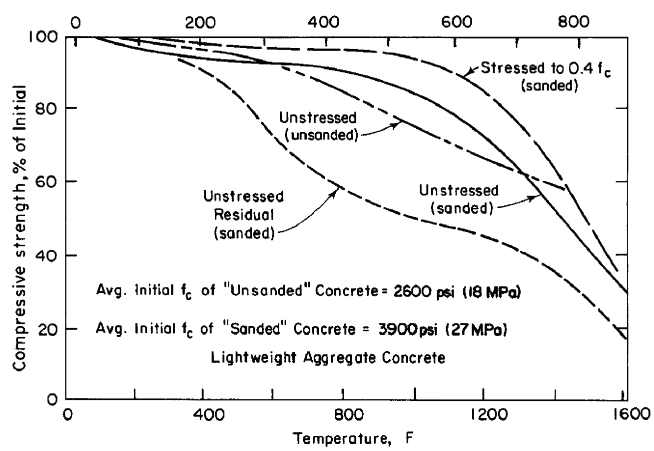


Fig. 2.12(c)—Compressive strength of semi-lightweight concrete at high temperatures and after cooling.

location of inflection points to calculate its development length by the following procedures:

Calculate $\omega_\theta \leq 0.30$ as in 2.4.2.1(a), and increase compression steel or otherwise alter the section if necessary.

Table 2.7—Minimum concrete column size

Aggregate type	Minimum column dimension for fire-resistance rating, in.				
	1 hour	1-1/2 hours	2 hours	3 hours	4 hours
Carbonate	8	9	10	11	12
Siliceous	8	9	10	12	14
Semi-lightweight	8	8-1/2	9	10-1/2	12

Table 2.8—Minimum concrete column size with fire exposure conditions on two parallel sides

Aggregate type	Minimum column dimension for fire-resistance rating, in.*				
	1 hour	1-1/2 hours	2 hours	3 hours	4 hours
Carbonate	8	8	8	8	10
Siliceous	8	8	8	8	10
Semi-lightweight	8	8	8	8	10

*Minimum dimensions are acceptable for rectangular columns with a fire exposure condition on three or four sides, provided that one set of the two parallel sides of the column is at least 36 in. long.

For a uniformly distributed load w

$$M_{x1} = (wx_2^2)/8 = M^+_{n\theta}$$

$$x_2 = (8M^+_{n\theta}/w)^{1/2}$$

where

x_2 = distance between inflection points of the span in question;

$M^-_{n\theta}$ = $(wl^2)/8 - M^+_{n\theta}$;

x_0 = $(l - x_2)/2$.

The distance x_0 reaches a maximum when the minimum anticipated uniform service load w is applied.

2.4.2.3 *Calculation procedure for continuous beams*—The calculation procedure shall be the same as in 2.4.2.2(a) for continuous slabs over one support or in 2.4.2.2(c) for continuous slabs over two supports with the following differences.

Figure 2.13(a) through (m) shall be used for determining concrete and steel temperatures as described in 2.4.2.2(a).

For purposes of calculating an average u value, an "effective u" shall be used by considering the distance of corner bars or tendons to outer beam surfaces as 1/2 of the actual distance.

2.5—Reinforced concrete columns

2.5.1 *Columns having design compressive strength f'_c of 12,000 psi or less*—The least dimension of reinforced concrete columns of different types of concrete having a specified compressive strength equal to or less than 12,000 psi for fire-resistance rating of 1 to 4 hours shall conform to values given in Tables 2.7 and 2.8.

2.5.2 *Columns having design compressive strength f'_c greater than 12,000 psi*

2.5.2.1 The least dimension of reinforced concrete columns of different types of concrete having a specified compressive strength greater than 12,000 psi for a fire-resistance rating of 1 to 4 hours shall be 24 in.

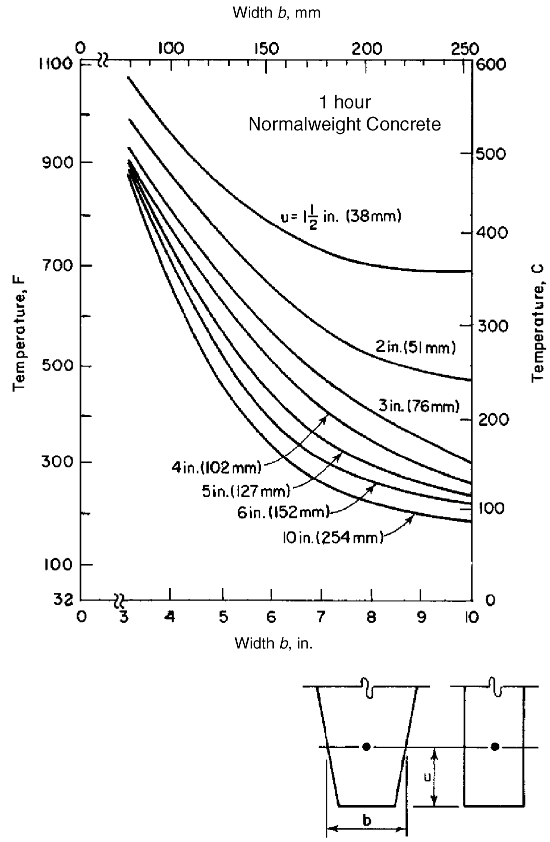


Fig. 2.13(a)—Temperatures in normalweight concrete rectangular and tapered units at 1 hour of fire exposure.

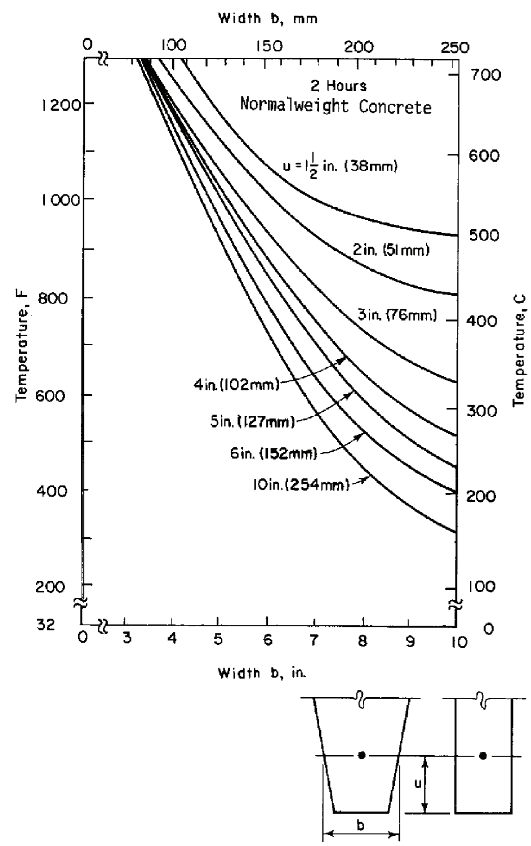


Fig. 2.13(b)—Temperatures in normalweight concrete rectangular and tapered units at 2 hours of fire exposure.

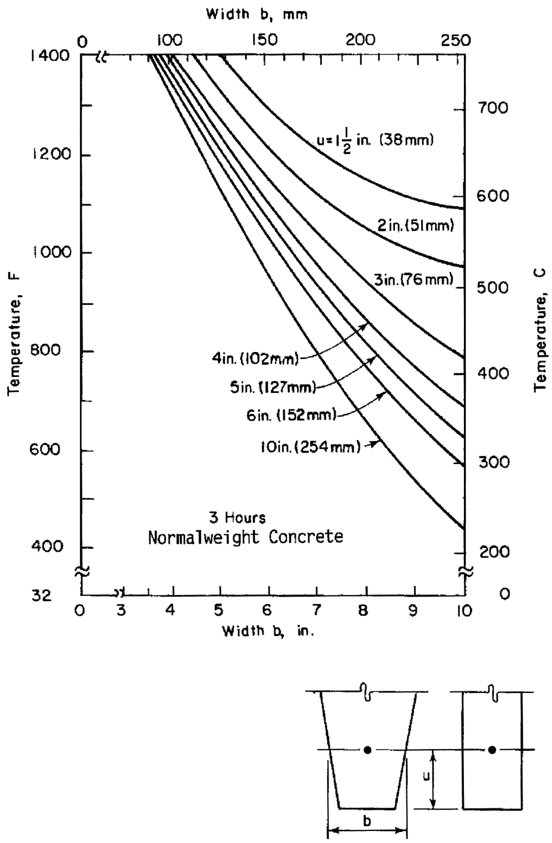


Fig. 2.13(c)—Temperatures in normalweight concrete rectangular and tapered units at 3 hours of fire exposure.

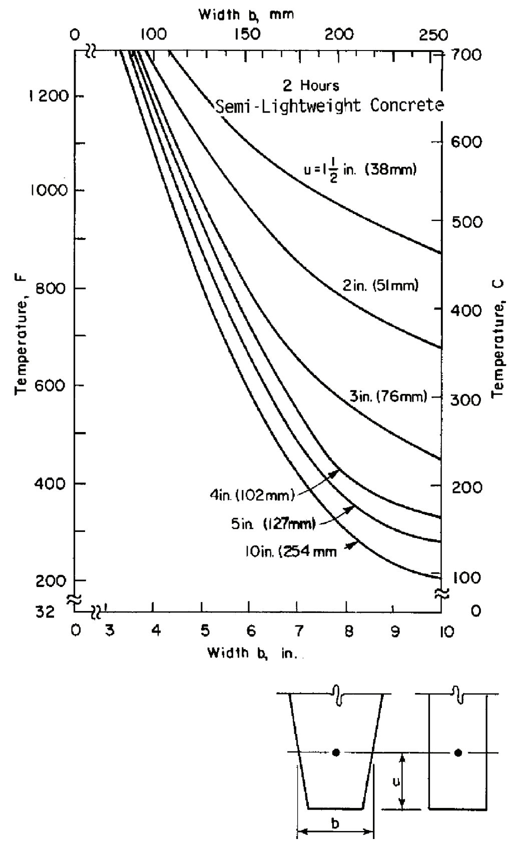


Fig. 2.13(e)—Temperatures in semi-lightweight concrete rectangular and tapered units at 2 hours of fire exposure.

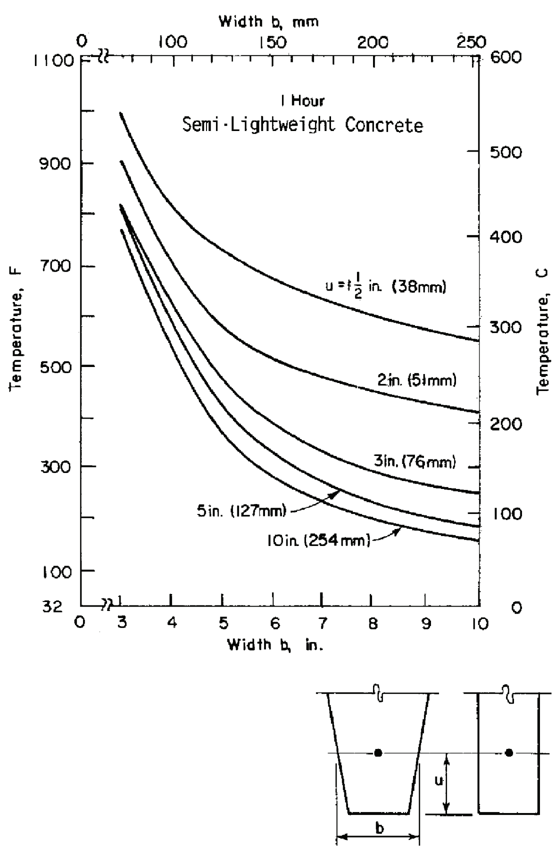


Fig. 2.13(d)—Temperatures in semi-lightweight concrete rectangular and tapered units at 1 hour of fire exposure.

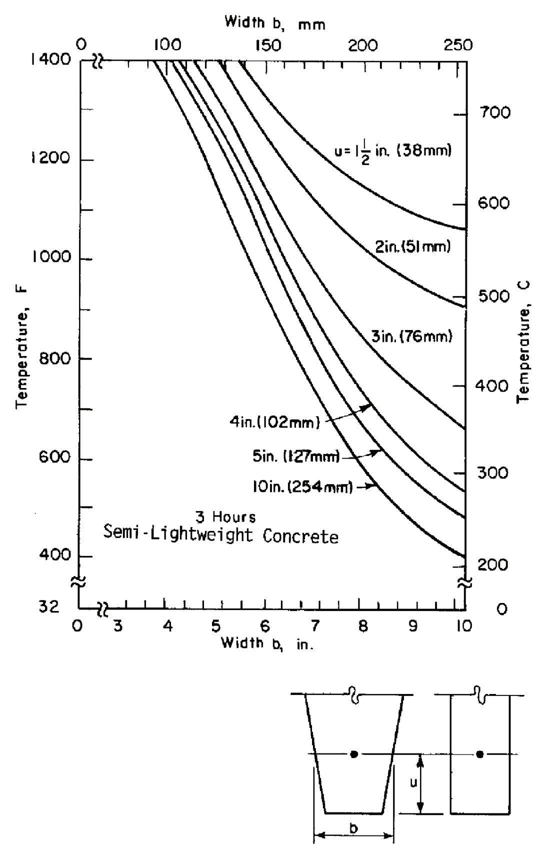


Fig. 2.13(f)—Temperatures in semi-lightweight concrete rectangular and tapered units at 3 hours of fire exposure.

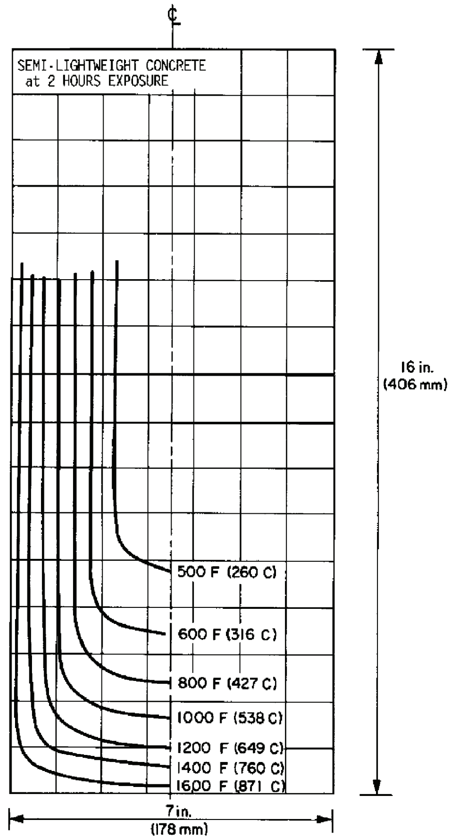


Fig. 2.13(g)—Measured temperature distribution at 2-hour fire exposure for semi-lightweight concrete rectangular unit.

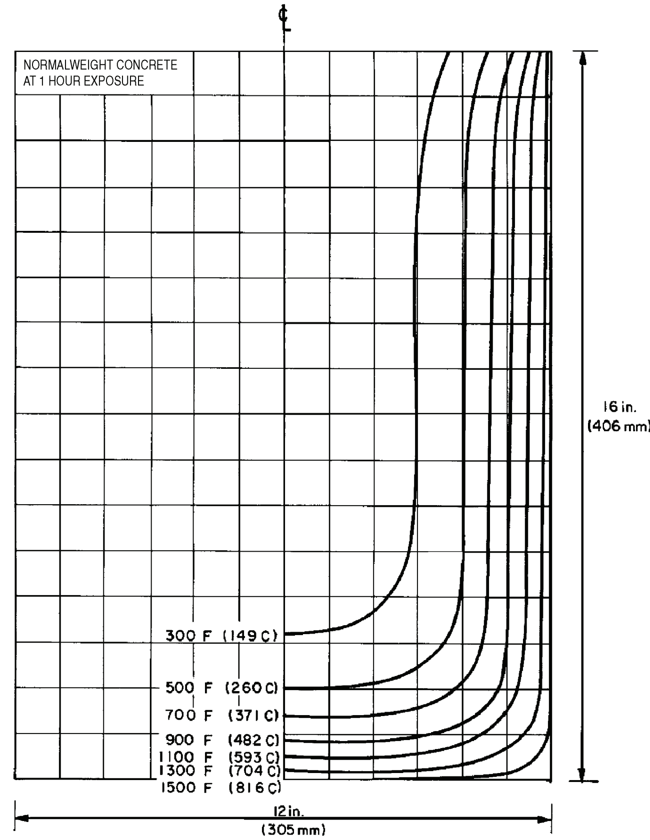


Fig. 2.13(i)—Temperature distribution in a normalweight concrete rectangular unit at 1 hour of fire exposure.

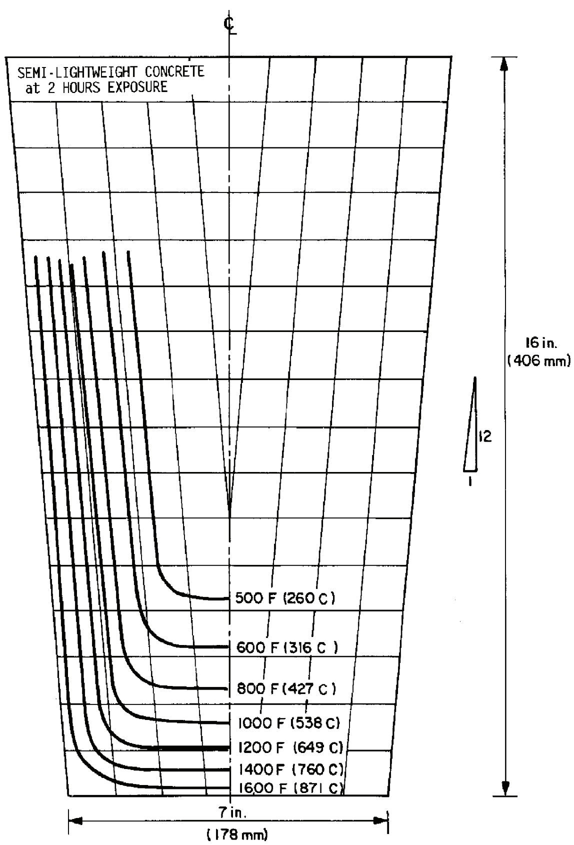


Fig. 2.13(h)—Measured temperature distribution at 2-hour fire exposure for semi-lightweight concrete tapered unit.

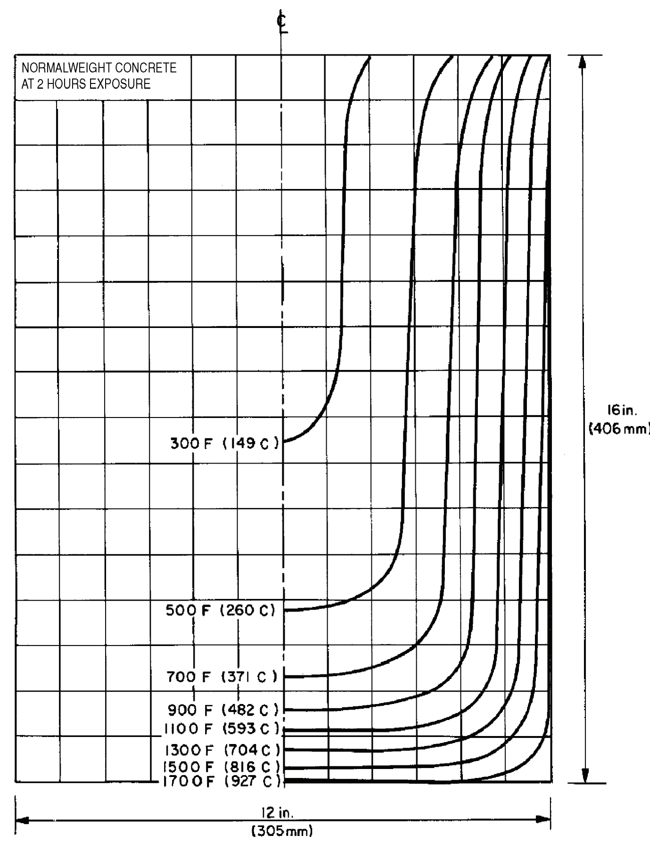


Fig. 2.13(j)—Temperature distribution in a normalweight concrete rectangular unit at 2 hours of fire exposure.

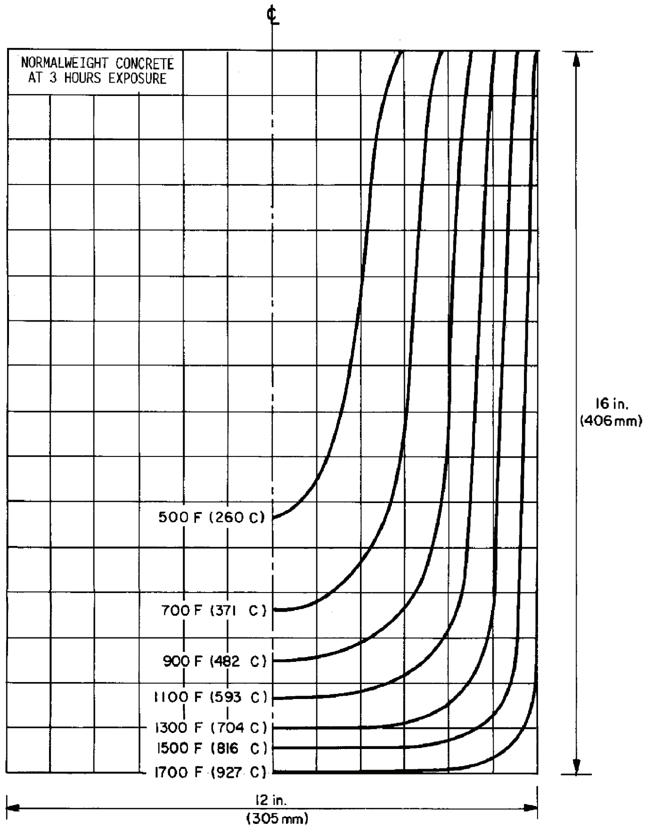


Fig. 2.13(k)—Temperature distribution in a normalweight concrete rectangular unit at 3 hours of fire exposure.

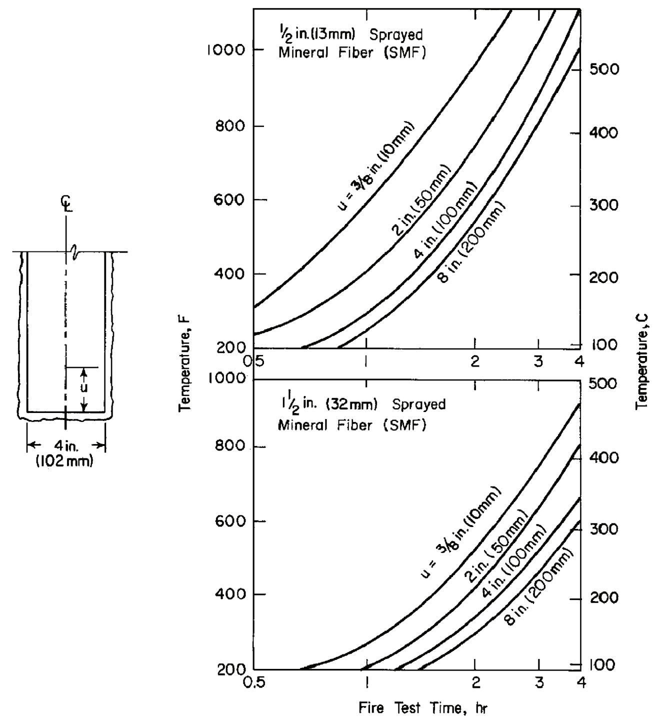


Fig. 2.13(l)—Temperatures along vertical centerlines at various fire exposures for 4 in. (102 mm) wide rectangular units coated with SMF.

2.5.2.2 Ties shall be formed with hooks having a six-diameter extension that engages the longitudinal reinforcement and projects into the interior of the hoop. Hooks for rectangular hoops shall be formed with minimum 135-degree bends. Hooks for circular hoops shall be formed with minimum 90-degree bends.

2.5.3 *Minimum cover for reinforcement*—The minimum thickness of concrete cover to main longitudinal reinforcement in columns, regardless of type of aggregate used in the concrete and specified compressive strength of the concrete, shall not be less than 1 in. times the number of hours of required fire resistance, or 2 in., whichever is less.

2.6—Structural steel columns protected by concrete

The fire resistance of structural steel columns protected by concrete, as illustrated in Fig. 2.14, shall be determined using Eq. (2-5) and (2-6) or Tables A.1 to A.4 if an appropriate combination of column size and concrete type and thickness exists. Equations (2-5) and (2-6) apply to all three cases shown in Fig. 2.14, but the case in Fig. 2.14(c) also requires the application of Eq. (2-7)

$$R = R_o(1 + 0.03m) \qquad (2\text{-}5)$$

where

$$R_o = 10(W/p_s)^{0.7} + 17(h^{1.6}/k_c^{0.2})[1 + 26(H_s/w_c c_c h(L + h))^{0.8}] \qquad (2\text{-}6)$$

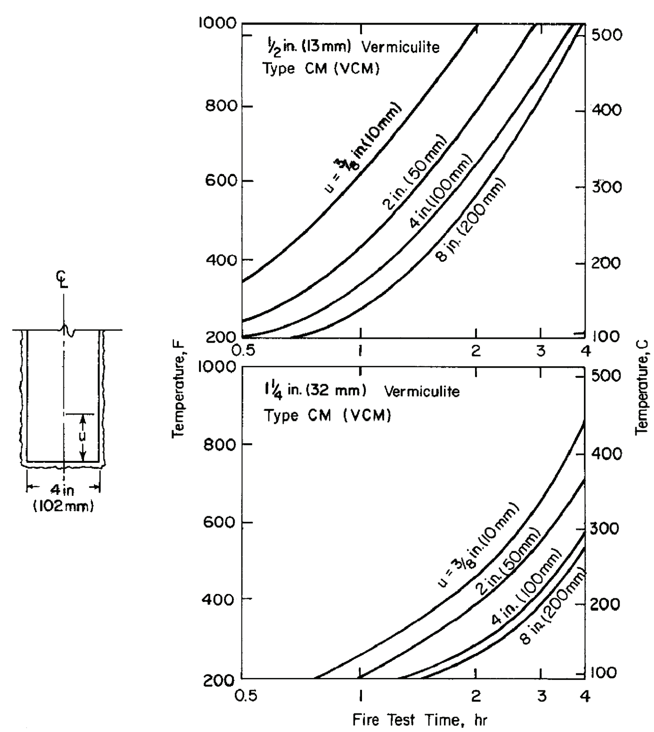
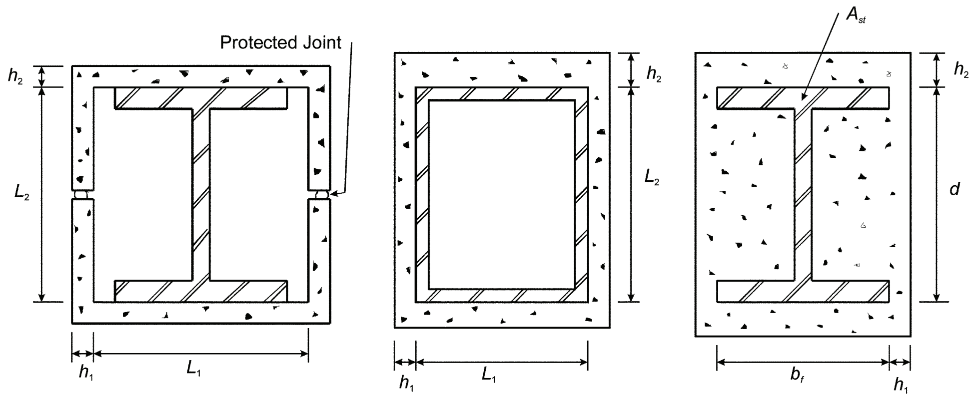


Fig. 2.13(m)—Temperatures along vertical centerlines at various fire exposures for 4 in. (102 mm) wide rectangular units coated with VCM.

As used in these expressions:

R = fire resistance at equilibrium moisture conditions (minutes);

R_o = fire resistance at zero moisture content (minutes);



(a) *(b)* *(c)*

Fig. 2.14—Concrete-protected structural steel columns: (a) precast concrete column cover; (b) concrete-encased structural tube; and (c) concrete-encased wide flange shape.

m = equilibrium moisture content of the concrete by volume (%);
W = average weight of the steel column, lb/ft;
p_s = heated perimeter of steel column, in.;
h = average thickness of concrete cover (Fig. 2.14) = $(h_1 + h_2)/2$, in.;
k_c = ambient temperature thermal conductivity of the concrete, Btu/(h/ft/°F);
H_s = ambient temperature thermal capacity of the steel column = $0.11W$, Btu/(ft/°F);
w_c = concrete density, lb/ft^3;
c_c = ambient temperature specific heat of concrete, Btu/(lb/°F);
L = average interior dimension of rectangular concrete box protection = $(L_1 + L_2)/2$ for precast concrete column covers (Fig. 2.14(a)) or concrete-encased structural tube (Fig. 2.14(b)); or = $(d + b_f)/2$ for concrete-encased wide flange shape (Fig. 2.14(c)), in.

For wide flange steel columns completely encased in concrete with all reentrant spaces filled (Fig 2.14(c)), add the thermal capacity of the concrete within the reentrant spaces to the thermal capacity of the steel column, as follows

$$H_s = 0.11W + (w_c c_c/144)(b_f d - A_{st}) \tag{2-7}$$

where
b_f = flange width of the steel column, in.;
d = depth of the steel column, in.; and
A_{st} = cross-sectional area of the steel column, in.^{2}

When specific data on the properties of concrete are not available, use the values given in Table 2.9.

For structural steel columns encased in concrete with all reentrant spaces filled (Fig 2.14(c)), use Tables A.1 and A.2 (Appendix A) to determine the thickness of concrete cover required for various fire-resistance ratings for typical wide flange sections. The thicknesses of concrete given in these tables also apply to structural steel columns larger than those listed.

For structural steel columns protected with precast concrete column covers, as shown in Fig 2.14(a), use Table A.3 for normalweight concrete, and use Table A.4 for structural lightweight concrete to determine the thickness of the column covers required for various fire-resistance ratings for typical wide flange shapes. The thicknesses of concrete given in these tables also apply to structural steel columns larger than those listed.

Notes:

1. When the inside perimeter of the concrete protection is not square, L shall be taken as the average of L_1 and L_2. When the thickness of concrete cover is not constant, h shall be taken as the average of h_1 and h_2

2. Joints shall be protected with a minimum 1 in. thickness of ceramic fiber blanket, but in no case less than 1/2 the thickness of the column cover (Fig. 2.14(a)).

Table 2.9—Thermal properties of concrete

Density D_c, lb/ft^3	Thermal conductivity k_c, Btu/(h/ft/°F)	Specific heat c_c, Btu/(lb/°F)
50	0.113	0.21
60	0.138	0.21
70	0.169	0.21
80	0.206	0.21
90	0.252	0.21
100	0.308	0.21
110	0.376	0.21
120	0.459	0.21
130	0.563	0.22
140	0.685	0.22
150	0.836	0.22

CHAPTER 3—CONCRETE MASONRY

3.1—General

The fire resistance of concrete masonry assemblies shall be determined in accordance with the provisions of this chapter. The minimum equivalent thicknesses of concrete masonry assemblies required to provide fire resistance of 1 to 4 hours shall conform to values given in Tables 3.1, 3.2, or 3.3, as is appropriate to the assembly being considered. Except where the provisions of this chapter are more stringent, the design, construction, and material requirements of

Table 3.1—Fire-resistance rating of concrete masonry assemblies

Aggregate type	Minimum equivalent thickness T_{ea} for fire-resistance rating, in.*†						
	1/2 hour	3/4 hour	1 hour	1-1/2 hours	2 hours	3 hours	4 hours
Calcareous or siliceous gravel (other than limestone)	2.0	2.4	2.8	3.6	4.2	5.3	6.2
Limestone, cinders, or air-cooled slag	1.9	2.3	2.7	3.4	4.0	5.0	5.9
Expanded clay, expanded shale, or expanded slate	1.8	2.2	2.6	3.3	3.6	4.4	5.1
Expanded slag or pumice	1.5	1.9	2.1	2.7	3.2	4.0	4.7

*Fire-resistance ratings between the hourly fire-resistance rating periods listed shall be determined by linear interpolation based on the equivalent thickness value of the concrete masonry assembly.

†Minimum required equivalent thickness corresponding to the fire-resistance rating for units made with a combination of aggregates shall be determined by linear interpolation based on the percent by dry-rodded volume of each aggregate used in manufacturing the units.

Table 3.2—Reinforced masonry structures

Fire resistance, hours	1	2	3	4
Minimum nominal column dimensions, in.	8	10	12	14

Table 3.3—Reinforced masonry lintels

Nominal lintel width, in.	Minimum longitudinal reinforcement cover for fire-resistance rating, in.			
	1 hour	2 hours	3 hours	4 hours
6	1-1/2	2	NP*	NP*
8	1-1/2	1-1/2	1-3/4	3
10 or more	1-1/2	1-1/2	1-1/2	1-3/4

*Not permitted without a more detailed analysis.

concrete masonry including units, mortar, grout, control joint materials, and reinforcement shall comply with ACI 530/ASCE 5/TMS 402 and ACI 530.1/ASCE 6/TMS 602. Concrete masonry units shall comply with ASTM C 55, C 73, C 90, C 129, or C 744.

3.2—Equivalent thickness

The equivalent thickness of concrete masonry construction shall be determined in accordance with the provisions of this section.

The equivalent thickness of concrete masonry assemblies T_{ea} shall be computed as the sum of the equivalent thickness of the concrete masonry unit T_e as determined by 3.2.1, 3.2.2, or 3.2.3 plus the equivalent thickness of finishes T_{ef} determined in accordance with Chapter 5

$$T_{ea} = T_e + T_{ef} \tag{3-1}$$

$$T_e = V_n/LH \tag{3-2}$$

where

T_e = equivalent thickness of concrete masonry unit determined in accordance with ASTM C 140, in.;

V_n = net volume of masonry unit determined in accordance with ASTM C 140, in.^{3};

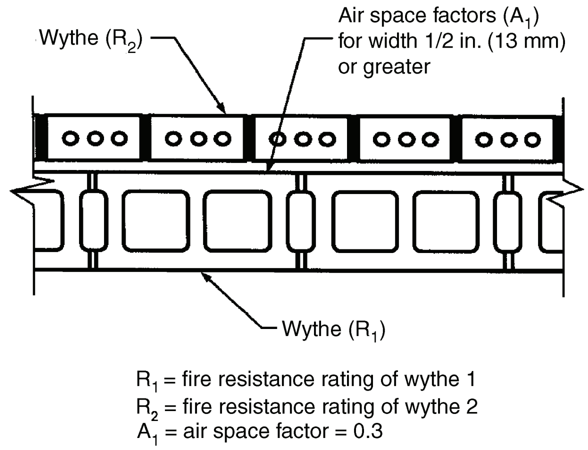


Fig. 3.1—Multi-wythe walls.

L = length of masonry unit determined in accordance with ASTM C 140, in.; and

H = height of masonry unit determined in accordance with ASTM C 140, in.

3.2.1 *Ungrouted or partially grouted construction*—The equivalent thickness T_e of an ungrouted or partially grouted concrete masonry assemblage shall be taken equal to the value determined by Eq. (3-1).

3.2.2 *Solid grouted construction*—The equivalent thickness T_e of solid grouted concrete masonry units shall be taken equal to the thickness of the unit determined in accordance with ASTM C 140.

3.2.3 *Air spaces and cells filled with loose fill material*—The equivalent thickness T_e of hollow concrete masonry units completely filled is the thickness of the unit determined in accordance with ASTM C 140 when loose fill materials are: sand, pea gravel, crushed stone, or slag that meet ASTM C 33 requirements; pumice, scoria, expanded shale, expanded clay, expanded slate, expanded slag, expanded fly ash, or cinders that comply with ASTM C 331; perlite meeting the requirements of ASTM C 549; or vermiculite meeting the requirements of ASTM C 516.

3.3—Concrete masonry wall assemblies

The minimum equivalent thickness of various types of plain or reinforced concrete masonry bearing or nonbearing walls required to provide fire-resistance ratings of 1 to 4 hours shall conform to Table 3.1.

3.3.1 *Single-wythe wall assemblies*—The fire-resistance rating of single-wythe concrete masonry walls shall be determined in accordance with Table 3.1.

3.3.2 *Multi-wythe wall assemblies*—The fire resistance of multi-wythe walls (Fig. 3.1) shall be calculated using the fire resistance of each wythe and any air space between each wythe in accordance with Eq. (2-4).

3.3.3 *Expansion or contraction joints*—Expansion or contraction joints in fire-rated masonry wall assemblies in which openings are not permitted, or in wall assemblies where openings are required to be protected, shall comply with Fig. 3.2.

3.4—Reinforced concrete masonry columns

The fire resistance of reinforced concrete masonry columns shall be determined using the least plan dimension of the column in accordance with the requirements of Table 3.2. The minimum cover for longitudinal reinforcement shall be 2 in.

3.5—Concrete masonry lintels

The fire resistance of concrete masonry lintels shall be established based on the nominal width of the lintel and the minimum cover of longitudinal reinforcement in accordance with Table 3.3.

3.6—Structural steel columns protected by concrete masonry

The fire resistance of structural steel columns protected by concrete masonry shall be determined using the following equation

$$R = 0.401(A_{st}/p_s)^{0.7} + [0.285(T_{ea}{}^{1.6}/k_{cm}{}^{0.2})] \qquad (3\text{-}3)$$

$$[1.0 + 42.7\{(A_{st}/w_{cm}T_{ea})/(0.25p + T_{ea})\}^{0.8}]$$

where

R = fire resistance of the column assembly, hours;
A_{st} = cross-sectional area of the structural steel column, in.^{2};
w_{cm} = density of the concrete masonry protection, lb/ft^3;
p = inner perimeter of concrete masonry protection (Fig. 3.3(a)), in.;
p_s = heated perimeter of steel column (Eq. (3-4), (3-5), and (3-6)), in.;
T_{ea} = equivalent thickness of concrete masonry protection assembly, in.; and
k_{cm} = thermal conductivity of concrete masonry ((Eq. (3-7)), Btu/(h/ft/°F)

$$p_s = 2(b_f + d_{st}) + 2(b_f - t_w) \text{ [W-section]} \qquad (3\text{-}4)$$

$$p_s = \pi d_{st} \text{ [pipe section]} \qquad (3\text{-}5)$$

$$p_s = 4d_{st} \text{ [square structural tube section]} \qquad (3\text{-}6)$$

where

b_f = width of flange, in.;
d_{st} = column dimension (Fig. 3.3), in.;
p_s = heated perimeter of steel column (Eq. (3-4), (3-5), and (3-6)), in.; and
t_w = thickness of web (Fig. 3.3, w-shape), in.

It shall be permitted to calculate the thermal conductivity of concrete masonry for use in Eq. (3-3) as

$$k_{cm} = 0.0417e^{0.02}, \text{ Btu/(h/ft/°F)} \qquad (3\text{-}7)$$

The minimum required equivalent thickness of concrete masonry units for specified fire-resistance ratings of several commonly used column shapes and sizes is shown in Appendix B.

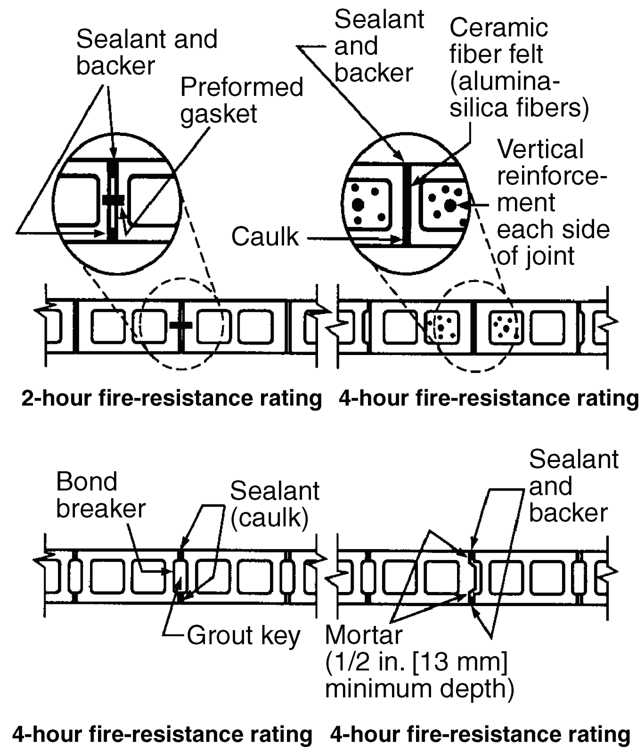


Fig. 3.2—Expansion or construction joints in masonry walls with 1/2 in. (13 mm) maximum width having 2- or 4-hour fire resistance.

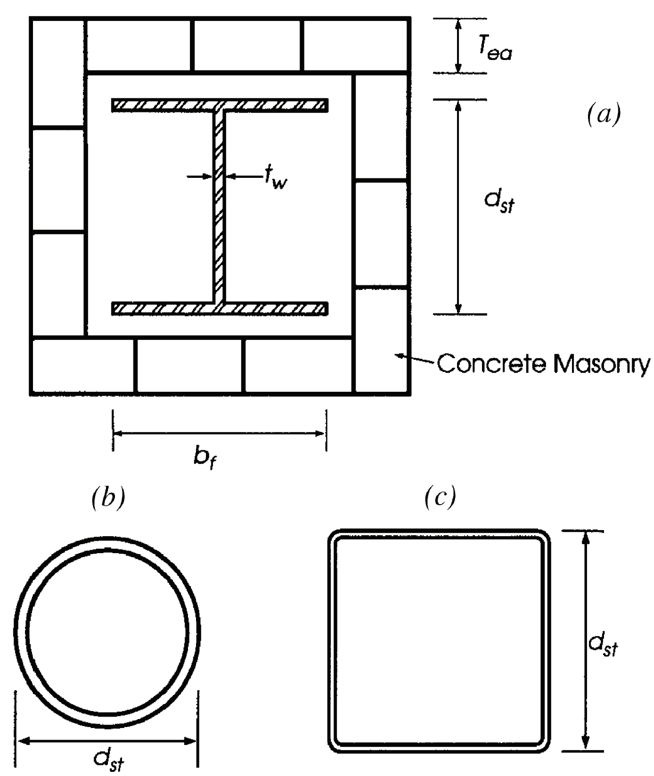


Fig. 3.3—Structural steel shapes protected by concrete masonry.

CHAPTER 4—CLAY BRICK AND TILE MASONRY

4.1—General

The calculated fire resistance of clay masonry assemblies shall be determined based on the provisions of this chapter. Except where the provisions of this chapter are more stringent, the design, construction, and material requirements of clay masonry including units, mortar, grout, control joint materials, and reinforcement shall comply with ACI 530/ASCE 5/TMS 402 and ACI 530.1/ASCE 6/TMS 602. Clay masonry units shall comply with ASTM C 34, C 56, C 62, C 73, C 126, C 212, C 216, or C 652.

4.2—Equivalent thickness

The equivalent thickness of clay masonry assemblies shall be determined in accordance with the provisions of this section.

The equivalent thickness of hollow clay masonry construction shall be based on the equivalent thickness of the clay masonry unit as determined by 4.2.1, 4.2.2, 4.2.3, and Eq. (4-1).

$$T_e = V_n/LH \tag{4-1}$$

where

T_e = equivalent thickness of the clay masonry unit, in.;

V_n = net volume of the masonry unit, in.^{3};

L = specified length of the masonry unit, in.; and

H = specified height of the masonry unit, in.

4.2.1 *Ungrouted or partially grouted construction*—The equivalent thickness T_e of an ungrouted or partially grouted clay masonry unit shall be taken equal to the value determined by Eq. (4-1).

4.2.2 *Solid grouted construction*—The equivalent thickness of solidly grouted clay masonry units shall be taken as the actual thickness of the unit.

4.2.3 *Air spaces and cells filled with loose fill material*—The equivalent thickness of hollow clay masonry units completely filled shall be taken as the actual thickness of the unit when loose fill materials are: sand, pea gravel, crushed stone, or slag that meet ASTM C 33 requirements; pumice, scoria, expanded shale, expanded clay, expanded slate, expanded slag, expanded fly ash, or cinders in compliance with ASTM C 331; perlite meeting the requirements of ASTM C 549; or vermiculite meeting the requirements of ASTM C 516.

4.3—Clay brick and tile masonry wall assemblies

The fire resistance of clay brick and tile masonry wall assemblies shall be determined in accordance with the provisions of this section.

4.3.1 *Filled and unfilled clay brick and tile masonry*—The fire resistance of clay brick and tile walls shall be determined from Table 4.1, using the equivalent thickness calculation procedure prescribed in 4.2.

4.3.2 *Single-wythe walls*—The fire resistance of clay brick and tile masonry walls shall be determined from Table 4.1.

4.3.3 *Multi-wythe walls*—The fire resistance of multi-wythe walls shall be determined in accordance with the provisions of this section and Table 4.1.

Table 4.1—Fire resistance of clay masonry walls

Material type	Minimum equivalent thickness for fire resistance, in.[*†‡]			
	1 hour	2 hours	3 hours	4 hours
Solid brick of clay or shale[§]	2.7	3.8	4.9	6.0
Hollow brick or tile of clay or shale, unfilled	2.3	3.4	4.3	5.0
Hollow brick or tile of clay or shale, grouted or filled with materials specified in 4.2.3	3.0	4.4	5.5	6.6

[*]Equivalent thickness as determined from 4.2.

[†]Calculated fire resistance between the hourly increments listed shall be determined by linear interpolation.

[‡]Where combustible members are framed into the wall, 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, shall not be less than 93% of the thickness shown.

[§]Units in which the net cross-sectional area of cored or frogged brick in any plane parallel to the surface containing the cores or frog is at least 75% of the gross cross-sectional area measured in the same plane.

4.3.3.1 *Multi-wythe clay masonry walls with dimensionally dissimilar wythes*—The fire resistance of multi-wythe clay masonry walls consisting of two or more dimensionally dissimilar wythes shall be based on the fire resistance of each wythe. Equation (2-4) shall be used to determine fire resistance of the wall assembly.

4.3.3.2 *Multi-wythe walls with dissimilar materials*—For multi-wythe walls consisting of two or more wythes of dissimilar materials (concrete or concrete masonry units), the fire resistance of the dissimilar wythes R_n shall be determined in accordance with 2.2; Fig. 2.2 for concrete; and 3.3 and Table 3.1 for concrete masonry units. Equation (2-4) shall be used to determine fire resistance of the wall assembly.

4.3.3.3 *Continuous air spaces*—The fire resistance of multi-wythe clay brick and tile masonry walls separated by continuous air spaces between each wythe shall be determined using Eq. (2-4).

4.4—Reinforced clay masonry columns

The fire resistance of reinforced clay masonry columns shall be based on the least plan dimension of the column in accordance with the requirements of Table 3.2. The minimum cover for longitudinal reinforcement shall be 2 in.

4.5—Reinforced clay masonry lintels

The fire resistance of clay masonry lintels shall be determined based on the nominal width of the lintel and the minimum cover for the longitudinal reinforcement in accordance with Table 3.3.

4.6—Expansion or contraction joints

Expansion or contraction joints in fire-rated clay masonry wall assemblies shall be in accordance with 3.3.3.

4.7—Structural steel columns protected by clay masonry

4.7.1 *Calculation of fire resistance*—It shall be permitted to calculate fire resistance of a structural steel column protected with clay masonry, or to determine the thickness of clay masonry necessary for meeting a fire-resistance requirement, following the methods of 3.6. For this calculation, the thermal conductivity of the clay masonry shall be taken as follows:

Density = 120 lb/ft^3 k_{cm} = 1.25 Btu/(h/ft/°F)

Density = 130 lb/ft^3 k_{cm} = 2.25 Btu/(h/ft/°F)

The minimum required equivalent thicknesses of clay masonry for specified fire resistance of several commonly used column shapes and sizes are shown in Appendix C.

CHAPTER 5—EFFECTS OF FINISH MATERIALS ON FIRE RESISTANCE

5.1—General

Determine the contribution of additional fire resistance provided by finish materials installed on concrete or masonry assemblies in accordance with the provisions of this chapter. The increase in fire resistance of the assembly shall be based strictly on the influence of the finish material's ability to extend the heat transmission end-point in an ASTM E 119 test fire.

5.2—Calculation procedure

The fire-resistance rating of walls or slabs of cast-in-place or precast concrete, or walls of concrete or clay masonry with finishes of gypsum wallboard or plaster applied to one or both sides of the wall or slab shall be determined in accordance with this section.

5.2.1 *Assume each side of wall or slab is the fire-exposed side*—For a wall or slab having no finish on one side or having different types, thicknesses, or both, of finish on each side, perform the calculation procedures in 5.2.2 and 5.2.3, assuming that each side of the wall or slab is the fire-exposed side. The resulting fire resistance of the wall or slab, including finishes, shall not exceed the smaller of the two values calculated, except in the case of the building code requiring that walls or slabs only be rated for fire exposure from one side of the wall or slab.

5.2.2 *Calculation for non-fire-exposed side*—Where the finish is applied to the non-fire-exposed side of the slab or wall, determine the fire resistance of the entire assembly as follows: adjust the thickness of the finish by multiplying the actual thickness of the finish by the applicable factor from Table 5.1 based on the type of aggregate in the concrete or concrete masonry units, or the type of clay masonry. Add the adjusted finish thickness to the actual thickness or equivalent thickness of the wall or slab, then determine the fire resistance of the concrete or masonry, including the effect of finish, from Table 2.1, Fig. 2.1, or Fig. 2.2 for concrete; from Table 3.1 for concrete masonry; or from Table 4.1 for clay masonry.

5.2.3 *Calculation for fire-exposed side*—Where the finish is applied to the fire-exposed side of the slab or wall, determine the fire resistance of the entire assembly as follows: add the time assigned to the finish in Table 5.2 to the fire resistance determined from Table 2.1, Fig. 2.1, or Fig. 2.2 for the concrete alone; from Table 3.1 for concrete masonry; from Table 4.1 for clay masonry; or to the fire resistance as determined in accordance with 5.2.2 for the concrete or masonry and finish on the non-fire-exposed side.

5.2.4 *Minimum fire resistance provided by concrete or masonry*—Where the finish applied to a concrete slab or a concrete or masonry wall contributes to the fire resistance, the concrete or masonry alone shall provide not less than 1/2 of the total required fire resistance. In addition, the contribution to fire resistance of the finish on the non-fire-exposed side of the wall shall not exceed 1/2 the contribution of the concrete or masonry alone.

Table 5.1—Multiplying factor for finishes on non-fire-exposed side of concrete slabs and concrete and masonry walls

Type of material used in slab or wall	Type of finish applied to slab or wall: Portland cement-sand plaster* or terrazzo	Gypsum-sand plaster	Gypsum-vermiculite or perlite plaster	Gypsum washboard
Concrete slab or wall				
Concrete—siliceous, carbonate, air-cooled blast-furnace slag	1.00	1.25	1.75	3.00
Concrete—semi-lightweight	0.75	1.00	1.50	2.25
Concrete—lightweight, insulating concrete	0.75	1.00	1.25	2.25
Concrete masonry wall				
Concrete masonry—siliceous, calcareous, limestone, cinders, air-cooled blast-furnace slag	1.00	1.25	1.75	3.00
Concrete masonry—made with 80% or more by volume of expanded shale, slate or clay, expanded slag, or pumice	0.75	1.00	1.25	2.25
Clay masonry wall				
Clay masonry—solid brick of clay or shale	1.00	1.25	1.75	3.00
Clay masonry—hollow brick or tile of clay or shale	0.75	1.00	1.50	2.25

*For portland cement-sand plaster 5/8 in. or less in thickness and applied directly to concrete or masonry on the non-fire-exposed side of the wall, multiplying factor shall be 1.0.

5.3—Installation of finishes

Finishes on concrete slabs and concrete and masonry walls that are assumed to contribute to the total fire resistance shall comply with the installation requirements of 5.3.1, 5.3.2, and other applicable provisions of the building code. Plaster and terrazzo shall be applied directly to the slab or wall. Gypsum wallboard shall be permitted to be attached to wood or steel furring members or attached directly to walls by adhesives.

5.3.1 *Gypsum wallboard*—Gypsum wallboard and gypsum lath shall be attached to concrete slabs and concrete and masonry walls in accordance with the requirements of this section or as otherwise permitted by the building code.

5.3.1.1 *Furring*—Attach gypsum wallboard and gypsum lath to wood or steel furring members spaced not more than 24 in. on center. Gypsum wallboard and gypsum lath shall be attached in accordance with one of the methods in 5.3.1.1(a) or (b).

5.3.1.1(a)—Self-tapping drywall screws shall be spaced at a maximum of 12 in. on center and shall penetrate

Table 5.2—Time assigned to finish materials on fire-exposed side of concrete and masonry walls

Finish description	Time, min.
Gypsum wallboard	
3/8 in.	10
1/2 in.	15
5/8 in.	20
Two layers of 3/8 in.	25
One layer of 3/8 in. and one layer of 1/2 in.	35
Two layers of 1/2 in.	40
Type "X" gypsum wallboard	
1/2 in.	25
5/8 in.	40
Direct-applied portland cement-sand plaster	*
Portland cement-sand plaster on metal lath	
3/4 in.	20
7/8 in.	25
1 in.	30
Gypsum-sand plaster on 3/8 in. gypsum lath	
1/2 in.	35
5/8 in.	40
3/4 in.	50
Gypsum-sand plaster on metal lath	
3/4 in.	50
7/8 in.	60
1 in.	80

*For purposes of determining the contribution of portland cement-sand plaster to the equivalent thickness of concrete or masonry for use in Tables 2.1, 3.1, or 4.1, it shall be permitted to use the actual thickness of the plaster or 5/8 in., whichever is smaller.

3/8 in. into resilient steel furring channels running horizontally and spaced at a maximum of 24 in. on center.

5.3.1.1(b)—Lath nails shall be spaced at a maximum of 12 in. on center and shall penetrate 3/4 in. into nominal 1 x 2 in. wood furring strips that are secured to the masonry by 2 in. concrete nails, and spaced at a maximum of 16 in. on center.

5.3.1.2 *Adhesive attachment to concrete and clay masonry*—Place a 3/8 in. bead of panel adhesive around the perimeter of the wallboard and across the diagonals. After the wall board is laminated to the masonry surface, secure it with one masonry nail for each 2 ft^2 of panel.

5.3.1.3 *Gypsum wallboard orientation*—Install gypsum wallboard with the long dimension parallel to furring members and with all horizontal and vertical joints supported and finished.

Exception: 5/8 in. thick Type "X" gypsum wallboard is permitted to be installed horizontally on walls with the horizontal joints unsupported.

5.3.2 *Plaster and stucco*—Plaster and stucco attached to a concrete or masonry surface for the purpose of increasing fire resistance shall be applied in accordance with provisions of the building code.

CHAPTER 6—REFERENCES

6.1—Referenced standards

The standards listed below were the latest editions at the time this document was prepared. Because these documents are revised frequently, the reader is advised to contact the proper sponsoring group if it is desired to refer to the latest version.

American Concrete Institute

117-90 Standard Specification for Tolerances for Concrete and Construction and Materials

318-05 Building Code Requirements for Structural Concrete

530-05 Building Code Requirements for Masonry Structures (document is also identified as ASCE 5-05/TMS 402-05)

530.1-05 Specification for Masonry Structures

ASTM International

A 722/A 722M-06 Standard Specification for Uncoated High-Strength Steel Bars for Prestressing Concrete

C 33-03 Standard Specification for Concrete Aggregates

C 34-03 Standard Specification for Structural Clay Load-Bearing Wall Tile

C 36/C 36M-03 Standard Specification for Gypsum Wallboard

C 55-03 Standard Specification for Concrete Building Brick

C 56-05 Standard Specification for Structural Clay Non-Load-Bearing Tile

C 62-05 Standard Specification for Building Brick (Solid Masonry Units Made from Clay or Shale)

C 73-05 Standard Specification for Calcium Silicate Brick (Sand-Lime Brick)

C 90-06b Standard Specification for Load-Bearing Concrete Masonry Units

C 126-99(2005) Standard Specification for Ceramic Glazed Structural Clay Facing Tile, Facing Brick, and Solid Masonry Units

C 129-06 Standard Specification for Nonload-bearing Concrete Masonry Units

C 140-06 Standard Test Methods for Sampling and Testing Concrete Masonry Units and Related Units

C 212-00(2006) Standard Specification for Structural Clay Facing Tile

C 216-06 Standard Specification for Facing Brick (Solid Masonry Units Made from Clay or Shale)

C 330-05 Standard Specification for Lightweight Aggregates for Structural Concrete

C 331-05 Standard Specification for Lightweight Aggregates for Concrete Masonry Units

C 332-99 Standard Specification for Lightweight Aggregates for Insulating Concrete

C 516-02 Standard Specification for Vermiculite Loose Fill Thermal Insulation

C 549-06 Standard Specification for Perlite Loose Fill Insulation

C 567-05a Standard Test Method for Determining Density of Structural Lightweight Concrete

C 612-04 Standard Specification for Mineral Fiber Block and Board Thermal Insulation

C 652-05a Standard Specification for Hollow Brick (Hollow Masonry Units Made from Clay or Shale)

C 726-05 Standard Specification for Mineral Fiber Roof Insulation Board

C 744-05 Standard Specification for Prefaced Concrete and Calcium Silicate Masonry Units

C 796-04 Standard Test Method for Foaming Agents for Use in Producing Cellular Concrete Using Preformed Foam

C 1088-06 Standard Specification for Thin Veneer Brick Units Made from Clay or Shale

E 119-05a Standard Test Methods for Fire Tests of Building Construction and Materials

IEEE/
ASTM SI 10-02 American National Standard for Use of the International System of Units (SI): The Modern Metric System

American Society of Civil Engineers

5-05 Building Code Requirements for Masonry Structures (see also ACI 530-05/TMS 402-05)

6-05 Specification for Masonry Structures (see also ACI 530.1-05/TMS 602-05)

The Masonry Society

402-05 Building Code Requirements for Masonry Structures (see also ACI 530-05/ASCE 5-05)

602-05 Specification for Masonry Structures (see also ACI 530.1-05/ASCE 6-05)

The above documents can be purchased from the following organizations:

American Concrete Institute
P.O. Box 9094
Farmington Hills, MI 48333-9094

American Society of Civil Engineers
1801 Alexander Bell Dr.
Reston, VA 20191-4400

ASTM International
100 Barr Harbor Drive
West Conshohocken, PA 19428-2959

The Masonry Society
3970 Broadway, Unit 201 D
Boulder, CO 80304

APPENDIX A—MINIMUM COVER FOR STEEL COLUMNS ENCASED IN CONCRETE

Table A.1—Minimum cover (in.) for steel columns encased in normalweight concrete* (Fig. 2.14(c))

<table>
<tr><th rowspan="2">Structural shape</th><th colspan="5">Fire resistance rating, h</th></tr>
<tr><th>1</th><th>1-1/2</th><th>2</th><th>3</th><th>4</th></tr>
<tr><td></td><td rowspan="8">1</td><td rowspan="7">1</td><td rowspan="4">1</td><td rowspan="3">1-1/2</td><td>2</td></tr>
<tr><td>W14 x 233</td><td rowspan="4">2-1/2</td></tr>
<tr><td>W14 x 176</td></tr>
<tr><td>W14 x 132</td><td rowspan="4">2</td></tr>
<tr><td>W14 x 90</td><td rowspan="4">1-1/2</td></tr>
<tr><td>W14 x 61</td><td rowspan="3">3</td></tr>
<tr><td>W14 x 48</td></tr>
<tr><td>W14 x 43</td><td>1-1/2</td><td>2-1/2</td></tr>
<tr><td>W12 x 152</td><td rowspan="5">1</td><td rowspan="3">1</td><td>1</td><td rowspan="3">2</td><td rowspan="2">2-1/2</td></tr>
<tr><td>W12 x 96</td><td rowspan="4">1-1/2</td></tr>
<tr><td>W12 x 65</td><td rowspan="3">3</td></tr>
<tr><td>W12 x 50</td><td rowspan="2">1-1/2</td><td rowspan="2">2-1/2</td></tr>
<tr><td>W12 x 40</td></tr>
<tr><td>W10 x 88</td><td rowspan="5">1</td><td rowspan="5">1-1/2</td><td rowspan="4">1-1/2</td><td>2</td><td rowspan="3">3</td></tr>
<tr><td>W10 x 49</td><td rowspan="4">2-1/2</td></tr>
<tr><td>W10 x 45</td></tr>
<tr><td>W10 x 39</td><td rowspan="2">3-1/2</td></tr>
<tr><td>W10 x 33</td><td>2</td></tr>
<tr><td>W8 x 67</td><td rowspan="6">1</td><td>1</td><td rowspan="2">1-1/2</td><td rowspan="3">2-1/2</td><td>3</td></tr>
<tr><td>W8 x 58</td><td rowspan="5">1-1/2</td><td rowspan="4">3-1/2</td></tr>
<tr><td>W8 x 48</td><td rowspan="4">2</td></tr>
<tr><td>W8 x 31</td><td rowspan="3">3</td></tr>
<tr><td>W8 x 21</td></tr>
<tr><td>W8 x 18</td><td>4</td></tr>
<tr><td></td><td rowspan="4">1</td><td rowspan="2">1-1/2</td><td rowspan="2">2</td><td rowspan="5">3</td><td>3-1/2</td></tr>
<tr><td>W6 x 25</td><td rowspan="5"></td></tr>
<tr><td>W6 x 20</td><td rowspan="4">2</td><td rowspan="4">2-1/2</td></tr>
<tr><td>W 6x 16</td></tr>
<tr><td>W6 x 15</td><td rowspan="2">1-1/2</td></tr>
<tr><td>W6 x 9</td><td>3-1/2</td></tr>
</table>

*Tabulated thicknesses are based on the assumed D_c = 145 lb/ft^3, k_c = 0.95 Btu/(h/ft/°F), and c_c = 0.22 Btu/(lb/°F).

Table A.2—Minimum cover (in.) for steel columns encased in structural lightweight concrete* (Fig. 2.14(c))

<table>
<tr><th rowspan="2">Structural shape</th><th colspan="5">Fire resistance rating, h</th></tr>
<tr><th>1</th><th>1-1/2</th><th>2</th><th>3</th><th>4</th></tr>
<tr><td></td><td rowspan="6">1</td><td rowspan="6">1</td><td rowspan="5">1</td><td rowspan="2">1</td><td rowspan="3">1-1/2</td></tr>
<tr><td>W14 x 233</td></tr>
<tr><td>W14 x 193</td><td rowspan="3">1-1/2</td></tr>
<tr><td>W14 x 74</td><td>2</td></tr>
<tr><td>W14 x 61</td><td rowspan="2">2-1/2</td></tr>
<tr><td>W14 x 43</td><td>1-1/2</td><td>2</td></tr>
<tr><td>W12 x 65</td><td rowspan="3">1</td><td rowspan="3">1</td><td rowspan="2">1</td><td>1-1/2</td><td>2</td></tr>
<tr><td>W12 x 53</td><td rowspan="2">2</td><td rowspan="2">2-1/2</td></tr>
<tr><td>W12 x 40</td><td>1-1/2</td></tr>
<tr><td>W10 x 112</td><td rowspan="4">1</td><td rowspan="4">1</td><td rowspan="3">1</td><td rowspan="2">1-1/2</td><td rowspan="2">2</td></tr>
<tr><td>W10 x 88</td></tr>
<tr><td>W10 x 60</td><td rowspan="2">2</td><td rowspan="2">2-1/2</td></tr>
<tr><td>W10 x 33</td><td>1-1/2</td></tr>
<tr><td>W8 x 35</td><td rowspan="4">1</td><td rowspan="3">1</td><td rowspan="4">1-1/2</td><td rowspan="3">2</td><td>2-1/2</td></tr>
<tr><td>W8 x 28</td><td rowspan="3">3</td></tr>
<tr><td>W8 x 24</td></tr>
<tr><td>W8 x 18</td><td>1-1/2</td><td>2-1/2</td></tr>
</table>

*Tabulated thicknesses are based on the assumed D_c = 110 lb/ft^3, k_c = 0.35 Btu/(h/ft/°F), and c_c = 0.21 Btu/(lb/°F).

Table A.3—Minimum cover (in.) for steel columns encased in normalweight precast covers* (Fig. 2.14(a))

<table>
<tr><th rowspan="2">Structural shape</th><th colspan="5">Fire resistance rating, h</th></tr>
<tr><th>1</th><th>1-1/2</th><th>2</th><th>3</th><th>4</th></tr>
<tr><td>W14 x 233</td><td rowspan="8">1-1/2</td><td rowspan="4">1-1/2</td><td rowspan="2">1-1/2</td><td rowspan="3">2-1/2</td><td rowspan="6">3-1/2</td></tr>
<tr><td>W14 x 211</td></tr>
<tr><td>W14 x 176</td><td rowspan="2">2</td></tr>
<tr><td>W14 x 145</td><td rowspan="3">3</td></tr>
<tr><td>W14 x 109</td><td rowspan="4">2</td><td rowspan="4">2-1/2</td></tr>
<tr><td>W14 x 99</td></tr>
<tr><td>W14 x 61</td><td rowspan="2">3-1/2</td><td>4</td></tr>
<tr><td>W14 x 43</td><td>4-1/2</td></tr>
<tr><td>W12 x 190</td><td rowspan="7">1-1/2</td><td rowspan="4">1-1/2</td><td>1-1/2</td><td rowspan="2">2-1/2</td><td rowspan="2">3-1/2</td></tr>
<tr><td>W12 x 152</td><td rowspan="3">2</td></tr>
<tr><td>W12 x 120</td><td rowspan="3">3</td><td rowspan="4">4</td></tr>
<tr><td>W12 x 96</td></tr>
<tr><td>W12 x 87</td><td rowspan="3">2</td><td rowspan="3">2-1/2</td></tr>
<tr><td>W12 x 58</td><td rowspan="2">3-1/2</td></tr>
<tr><td>W12 x 40</td><td>4-1/2</td></tr>
<tr><td>W10 x 112</td><td rowspan="5">1-1/2</td><td rowspan="2">1-1/2</td><td rowspan="2">2</td><td rowspan="3">3</td><td>3-1/2</td></tr>
<tr><td>W10 x 88</td><td rowspan="3">4</td></tr>
<tr><td>W10 x 77</td><td rowspan="3">2</td><td rowspan="3">2-1/2</td></tr>
<tr><td>W10 x 54</td><td rowspan="2">3-1/2</td></tr>
<tr><td>W10 x 33</td><td>4-1/2</td></tr>
<tr><td>W8 x 67</td><td rowspan="6">1-1/2</td><td>1-1/2</td><td>2</td><td>3</td><td rowspan="3">4</td></tr>
<tr><td>W8 x 58</td><td rowspan="3">2</td><td rowspan="3">2-1/2</td><td rowspan="4">3-1/2</td></tr>
<tr><td>W8 x 48</td></tr>
<tr><td>W8 x 28</td><td rowspan="3">4-1/2</td></tr>
<tr><td>W8 x 21</td><td rowspan="2">2-1/2</td><td rowspan="2">3</td></tr>
<tr><td>W8 x 18</td><td>4</td></tr>
<tr><td>W6 x 25</td><td rowspan="3">1-1/2</td><td>2</td><td>2-1/2</td><td rowspan="2">3-1/2</td><td rowspan="4">4-1/2</td></tr>
<tr><td>W6 x 20</td><td rowspan="4">2-1/2</td><td rowspan="4">3</td></tr>
<tr><td>W6 x 16</td><td rowspan="3">4</td></tr>
<tr><td>W6 x 12</td><td rowspan="2">2</td></tr>
<tr><td>W6 x 9</td><td>5</td></tr>
</table>

*Tabulated thicknesses are based on the assumed D_c = 145 lb/ft^3, k_c = 0.95 Btu/(h/ft/°F), and c_c = 0.22 Btu/(lb/°F).

Table A.4—Minimum cover (in.) for steel columns encased in structural lightweight precast covers* (Fig. 2.14(a))

<table>
<tr><th rowspan="2">Structural shape</th><th colspan="5">Fire resistance rating, h</th></tr>
<tr><th>1</th><th>1-1/2</th><th>2</th><th>3</th><th>4</th></tr>
<tr><td>W14 x 233</td><td rowspan="8">1-1/2</td><td rowspan="8">1-1/2</td><td rowspan="5">1-1/2</td><td rowspan="3">2</td><td rowspan="2">2-1/2</td></tr>
<tr><td>W14 x 176</td></tr>
<tr><td>W14 x 145</td><td rowspan="4">3</td></tr>
<tr><td>W14 x 132</td><td rowspan="4">2-1/2</td></tr>
<tr><td>W14 x 109</td></tr>
<tr><td>W14 x 99</td><td rowspan="3">2</td></tr>
<tr><td>W14 x 68</td><td rowspan="2">3-1/2</td></tr>
<tr><td>W14 x 43</td><td>3</td></tr>
<tr><td>W12 x 190</td><td rowspan="8">1-1/2</td><td rowspan="8">1-1/2</td><td rowspan="5">1-1/2</td><td rowspan="3">2</td><td rowspan="2">2-1/2</td></tr>
<tr><td>W12 x 152</td></tr>
<tr><td>W12 x 136</td><td rowspan="2">3</td></tr>
<tr><td>W12 x106</td><td rowspan="4">2-1/2</td></tr>
<tr><td>W12 x 96</td><td rowspan="4">3-1/2</td></tr>
<tr><td>W12 x 87</td><td rowspan="3">2</td></tr>
<tr><td>W1 2x 65</td></tr>
<tr><td>W12 x 40</td><td>3</td></tr>
<tr><td>W10 x 112</td><td rowspan="7">1-1/2</td><td rowspan="6">1-1/2</td><td rowspan="3">1-1/2</td><td>2</td><td rowspan="4">3</td></tr>
<tr><td>W10 x 100</td><td rowspan="4">2-1/2</td></tr>
<tr><td>W10 x 88</td></tr>
<tr><td>W10 x 77</td><td rowspan="4">2</td></tr>
<tr><td>W10 x 60</td><td rowspan="3">3-1/2</td></tr>
<tr><td>W10 x 39</td><td rowspan="2">3</td></tr>
<tr><td>W10 x 33</td><td>2</td></tr>
<tr><td>W8 x 67</td><td rowspan="5">1-1/2</td><td rowspan="3">1-1/2</td><td>1-1/2</td><td rowspan="2">2-1/2</td><td rowspan="2">3</td></tr>
<tr><td>W8 x 48</td><td rowspan="3">2</td></tr>
<tr><td>W8 x 35</td><td rowspan="3">3</td><td rowspan="2">3-1/2</td></tr>
<tr><td>W8 x 28</td><td rowspan="2">2</td></tr>
<tr><td>W8 x 18</td><td>2-1/2</td><td>4</td></tr>
<tr><td>W6 x 25</td><td rowspan="3">1-1/2</td><td rowspan="3">2</td><td>2</td><td rowspan="2">3</td><td>3-1/2</td></tr>
<tr><td>W6 x 15</td><td rowspan="2">2-1/2</td><td rowspan="2">4</td></tr>
<tr><td>W6 x 9</td><td>3-1/2</td></tr>
</table>

*Tabulated thicknesses are based on the assumed D_c = 110 lb/ft^3, k_c = 0.35 Btu/(h/ft/°F), and c_c = 0.21 Btu/(lb/°F).

APPENDIX B—FIRE RESISTANCE OF CONCRETE-MASONRY-PROTECTED STEEL COLUMNS

Table B.1—Fire resistance of concrete-masonry-protected steel columns

W shapes

Column size	Concrete masonry density, lb/ft^3	Minimum equivalent thickness for fire-resistance rating of concrete masonry protection assembly T_e, in.				Column size	Concrete masonry density, lb/ft^3	Minimum equivalent thickness for fire-resistance rating of concrete masonry protection assembly T_e, in.			
		1 hour	2 hours	3 hours	4 hours			1 hour	2 hours	3 hours	4 hours
W14 x 82	80	0.73	1.59	2.31	2.98	W10 x 68	80	0.72	1.58	2.33	3.01
	100	0.89	1.82	2.63	3.35		100	0.87	1.83	2.65	3.38
	110	0.96	1.94	2.78	3.53		110	0.94	1.95	2.79	3.55
	120	1.03	2.06	2.93	3.70		120	1.01	2.06	2.94	3.72
W14 x 68	80	0.83	1.69	2.45	3.13	W10 x 54	80	0.88	1.76	2.53	3.21
	100	0.98	1.94	2.76	3.49		100	1.04	2.01	2.83	3.57
	110	1.06	2.06	2.91	3.66		110	1.11	2.12	2.98	3.73
	120	1.13	2.17	3.05	3.82		120	1.19	2.24	3.12	3.90
W14 x 53	80	0.91	1.81	2.58	3.27	W10 x 45	80	0.92	1.83	2.60	3.30
	100	1.07	2.05	2.88	3.62		100	1.08	2.07	2.90	3.64
	110	1.15	2.17	3.02	3.78		110	1.16	2.18	3.04	3.80
	120	1.22	2.28	3.16	3.94		120	1.23	2.29	2.18	3.96
W14 x 43	80	1.01	1.93	2.71	3.41	W10 x 33	80	1.06	2.00	2.79	3.49
	100	1.17	2.17	3.00	3.74		100	1.22	2.23	3.07	3.81
	110	1.25	2.28	3.14	3.90		110	1.30	2.34	3.20	3.96
	120	1.32	2.38	3.16	3.94		120	1.37	2.44	3.33	4.12
W12 x 72	80	0.81	1.66	3.27	4.05	W8 x 40	80	0.94	1.85	2.63	3.33
	100	0.91	1.88	2.70	3.43		100	1.10	2.10	2.93	3.67
	110	0.99	1.99	2.84	3.60		110	1.18	2.21	3.07	3.83
	120	1.06	2.10	2.98	3.76		120	1.25	2.32	3.20	3.99
W12 x 58	80	0.88	1.76	2.52	3.21	W8 x 31	80	1.06	2.00	2.78	3.49
	100	1.04	2.01	2.83	3.56		100	1.22	2.23	3.07	3.81
	110	1.11	2.12	2.97	3.73		110	1.29	2.33	3.20	3.97
	120	1.19	2.23	3.11	3.89		120	1.36	2.44	3.33	4.12
W12 x 50	80	0.91	1.81	2.58	3.27	W8 x 24	80	1.14	2.09	2.89	3.59
	100	1.07	2.05	2.88	3.62		100	1.29	2.31	3.16	3.90
	110	1.15	2.17	3.02	3.78		110	1.36	2.42	3.28	4.05
	120	1.22	2.28	3.16	3.94		120	1.43	2.52	3.41	4.20
W12 x40	80	1.01	1.94	2.72	3.41	W8 x 18	80	1.22	2.20	3.01	3.72
	100	1.17	2.17	3.01	3.75		100	1.36	2.40	3.25	4.01
	110	1.25	2.28	3.14	3.90		110	1.42	2.50	3.37	4.14
	120	1.32	2.39	3.27	4.06		120	1.48	2.59	3.49	4.28

Note: Tabulated values assume 1 in. air gap between masonry and steel section.

Table B.1(cont.)—Fire resistance of concrete-masonry-protected steel columns

Square structural tubing						Steel pipe					
Nominal tube size, in.	Concrete masonry density, lb/ft^3	Minimum equivalent thickness for fire-resistance rating of concrete masonry protection assembly T_e, in.				Column size	Concrete masonry density, lb/ft^3	Minimum equivalent thickness for fire-resistance rating of concrete masonry protection assembly T_e, in.			
		1 hour	2 hours	3 hours	4 hours			1 hour	2 hours	3 hours	4 hours
4 x 4 1/2 wall thickness	80	0.93	1.90	2.71	3.43	4 double extra-strong 0.674 wall thickness	80	0.80	1.75	2.56	3.28
	100	1.08	2.13	2.99	3.76		100	0.95	1.99	2.85	3.62
	110	1.16	2.24	3.13	3.91		110	1.02	2.10	2.99	3.78
	120	1.22	2.34	3.26	4.06		120	1.09	2.20	3.12	3.93
4 x 4 3/8 wall thickness	80	1.05	2.03	2.84	3.57	4 extra strong 0.337 wall thickness	80	1.12	2.11	2.93	3.65
	100	1.20	2.25	3.11	3.88		100	1.26	2.32	3.19	3.95
	110	1.27	2.35	3.24	4.02		110	1.33	2.42	3.31	4.09
	120	1.34	2.45	3.37	4.17		120	1.40	2.52	3.43	4.23
4 x 4 1/4 wall thickness	80	1.21	2.20	3.01	3.73	4 standard 0.237 wall thickness	80	1.26	2.25	3.07	3.79
	100	1.35	2.40	3.26	4.02		100	1.40	2.45	3.31	4.07
	110	1.41	2.50	3.38	4.16		110	1.46	2.55	3.43	4.21
	120	1.48	2.59	3.50	4.30		120	1.53	2.64	3.54	4.34
6 x 6 1/2 wall thickness	80	0.82	1.75	2.54	3.25	5 double extra-strong 0.750 wall thickness	80	0.70	1.61	2.40	3.12
	100	0.98	1.99	2.84	3.59		100	1.85	1.86	2.71	3.47
	110	1.05	2.10	2.98	3.75		110	0.91	1.97	2.85	3.63
	120	1.12	2.21	3.11	3.91		120	0.98	2.02	2.99	3.79
6 x 6 3/8 wall thickness	80	0.96	1.91	2.71	3.42	5 extra-strong 0.375 wall thickness	80	1.04	2.01	2.83	3.54
	100	1.12	2.14	3.00	3.75		100	1.19	2.23	3.09	3.85
	110	1.19	2.25	3.13	3.90		110	1.26	2.34	3.22	4.00
	120	1.26	2.35	3.26	4.05		120	1.32	2.44	3.34	4.14
6 x 6 1/4 wall thickness	80	1.14	2.11	2.92	3.63	5 standard 0.258 wall thickness	80	1.20	2.19	3.00	3.72
	100	1.29	2.32	3.18	3.93		100	1.34	2.39	3.25	4.00
	110	1.36	2.43	3.30	4.08		110	1.41	2.49	3.37	4.14
	120	1.42	2.52	3.43	4.22		120	1.47	2.58	3.49	4.28
8 x 8 1/2 wall thickness	80	0.77	1.66	2.44	3.13	6 double extra-strong 0.864 wall thickness	80	0.59	1.46	2.23	2.92
	100	0.92	1.61	2.75	3.49		100	0.73	1.71	2.54	3.29
	110	1.00	2.02	2.89	3.66		110	0.80	1.82	2.69	3.47
	120	1.07	2.14	3.03	3.82		120	0.86	1.93	2.83	3.63
8 x 8 3/8 wall thickness	80	0.91	1.84	2.63	3.33	6 extra-strong 0.432 wall thickness	80	0.94	1.90	2.70	3.42
	100	1.07	2.08	2.92	3.67		100	1.10	2.13	2.98	3.74
	110	1.14	2.19	3.06	3.83		110	1.17	2.23	3.11	3.89
	120	1.21	2.29	3.13	3.87		120	1.24	2.34	3.24	4.04
8 x 8 1/4 wall thickness	80	1.10	2.06	2.86	3.57	6 standard 0.280 wall thickness	80	1.14	2.12	2.93	3.64
	100	1.25	2.28	3.19	3.98		100	1.29	2.33	3.19	3.94
	110	1.32	2.38	3.25	4.02		110	1.36	2.43	3.31	4.08
	120	1.39	2.48	3.38	4.17		120	1.42	2.53	3.43	4.22

Note: Tabulated values assume 1 in. air gap between masonry and steel section.

APPENDIX C—FIRE RESISTANCE OF CLAY-MASONRY-PROTECTED STEEL COLUMNS

Table C.1—Fire resistance of clay-masonry-protected steel columns

W shapes

Column size	Clay masonry density, lb/ft^3	Minimum equivalent thickness for fire-resistance rating of clay masonry protection assembly T_e, in.				Column size	Clay masonry density, lb/ft^3	Minimum equivalent thickness for fire-resistance rating of clay masonry protection assembly T_e, in.			
		1 hour	2 hours	3 hours	4 hours			1 hour	2 hours	3 hours	4 hours
W14 x 82	120	1.23	2.42	3.41	4.29	W10 x 68	120	1.27	2.46	3.46	4.35
	130	1.40	2.70	3.78	4.74		130	1.44	2.75	3.83	4.80
W14 x 68	120	1.34	2.54	3.54	4.43	W10 x 54	120	1.40	2.61	3.62	4.51
	130	1.51	2.82	3.91	4.87		130	1.58	2.89	3.98	4.95
W14 x 53	120	1.43	2.65	3.65	4.54	W10 x 45	120	1.44	2.66	3.67	4.57
	130	1.61	2.93	4.02	4.98		130	1.62	2.95	4.04	5.01
W14 x 43	120	1.54	2.76	3.77	4.66	W10 x 33	120	1.59	2.82	3.84	4.73
	130	1.72	3.04	4.13	5.09		130	1.77	3.10	4.20	5.13
W12 x 72	120	1.32	2.52	3.51	4.40	W8 x 40	120	1.47	2.70	3.71	4.61
	130	1.50	2.80	3.88	4.84		130	1.65	2.98	4.08	5.04
W12 x 58	120	1.40	2.61	3.61	4.50	W8 x31	120	1.59	2.82	3.84	4.73
	130	1.57	2.89	3.98	4.94		130	1.77	3.10	4.20	5.17
W12 x 50	120	1.43	2.65	3.66	4.55	W8 x 24	120	1.66	2.90	3.92	4.82
	130	1.61	2.93	4.02	4.99		130	1.84	3.18	4.82	5.25
W12 x 40	120	1.54	2.77	3.78	4.67	W8 x 18	120	1.75	3.00	4.01	4.91
	130	1.72	3.05	4.14	5.10		130	1.93	3.27	4.37	5.34

Square structural tubing						Steel pipe					
Nominal tube size, in.	Concrete masonry density, lb/ft^3	Minimum equivalent thickness for fire-resistance rating of clay masonry protection assembly T_e, in.				Column size	Concrete masonry density, lb/ft^3	Minimum equivalent thickness for fire-resistance rating of clay masonry protection assembly T_e, in.			
		1 hour	2 hours	3 hours	4 hours			1 hour	2 hours	3 hours	4 hours
4 x 4 1/2 wall thickness	120	1.44	2.72	3.76	4.68	4 double extra-strong 0.674 wall thickness	120	1.26	2.55	3.60	4.52
	130	1.62	3.00	4.12	5.11		130	1.42	2.82	3.96	4.95
4 x 4 3/8 wall thickness	120	1.56	2.84	3.88	4.78	4 extra-strong 0.337 wall thickness	120	1.60	2.89	3.92	4.83
	130	1.74	3.12	4.23	5.21		130	1.77	3.16	4.28	5.25
4 x 4 1/4 wall thickness	120	1.72	2.99	4.02	4.92	4 standard 0.237 wall thickness	120	1.74	3.02	4.05	4.95
	130	1.89	3.26	4.37	5.34		130	1.92	3.29	4.40	5.37
6 x 6 1/2 wall thickness	120	1.33	2.58	3.62	4.52	5 double extra-strong 0.750 wall thickness	120	1.17	2.44	3.48	4.40
	130	1.50	2.86	3.98	4.96		130	1.33	2.72	3.84	4.83
6 x 6 3/8 wall thickness	120	1.48	2.74	3.76	4.67	5 extra-strong 0.375 wall thickness	120	1.55	2.82	3.85	4.76
	130	1.65	3.01	4.13	5.10		130	1.72	3.09	4.21	5.18
6 x 6 1/4 wall thickness	120	1.66	2.91	3.94	4.84	5 standard 0.258 wall thickness	120	1.71	2.97	4.00	4.90
	130	1.83	3.19	4.30	5.27		130	1.88	3.24	4.35	5.32
8 x 8 1/2 wall thickness	120	1.27	2.50	3.52	4.42	6 double extra-strong 0.864 wall thickness	120	1.04	2.28	3.32	4.23
	130	1.44	2.78	3.89	4.86		130	1.19	2.60	3.68	4.67
8 x 8 3/8 wall thickness	120	1.43	2.67	3.69	4.59	6 extra-strong 0.432 wall thickness	120	1.45	2.71	3.75	4.67
	130	1.60	2.95	4.05	5.02		130	1.62	2.99	4.10	5.08
8 x 8 1/4 wall thickness	120	1.62	2.87	3.89	4.78	6 standard 0.280 wall thickness	120	1.65	2.91	3.94	4.84
	130	1.79	3.14	4.24	5.21		130	1.82	3.19	4.30	5.27

Note: Tabulated values assume 1 in. air gap between masonry and steel section.

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