Standard Method for Determining Fire Resistance of Concrete and Masonry Construction Assemblies

Reported by ACI/TMS Committee 216

James P. Hurst
Chairman

Gene C. Abbate	Thomas F. Herrell	Mark A. Nunn
Stanley G. Barton	Mark Hogan	John Perry
Ronald G. Burg	Thomas H. Holm	Walter Prebis
Donald O. Dusenberry	Joel R. Irving	John P. Ries
William L. Gamble*	Phillip J. Iverson	Thomas J. Rowe
Richard G. Gewain	T. T. Lie	Jeffery F. Speck
Michael P. Gillen	Tung D. Lin	F. R. Vollert
Tibor Z. Harmathy	Howard R. May	

*Immediate past chairman

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. The standard portion of this document contains such 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 above referenced 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 ratings; fire endurance; fire resistance; fire tests; masonry walls; modulus of elasticity; prestressed concrete; prestressing steels; reinforced concrete; reinforcing steel; structural design; temperature distribution; thermal properties; walls.

CONTENTS

ACI 216.1-97 became effective September 1, 1997.

CHAPTER 1—GENERAL

1.1—Scope

This standard describes acceptable methods for determining the fire resistance of concrete and masonry 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 analytical purposes and shall be based upon 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.

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 upon the fire exposure and applicable end-point criteria specified in ASTM E 119.

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.

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 to axial loads and flexure, but primarily to flexure.

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

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

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

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—Nonstructural insulating concrete made by mixing a preformed foam with portland cement slurry. The dry unit weight is determined in accordance with ASTM C 796. Dry unit weights range from 25 to 110 lb/ft^3, depending on the application requirements. Dry unit weights greater than 75 lb/ft^3 require the addition of sand.

Concrete, lightweight aggregate—Concrete made with lightweight aggregates (expanded clay, shale, slag, or slate or sintered fly ash) having a 28-day air-dry unit weight of 85 to 105 lb/ft^3.

Concrete, normalweight—Concrete having a unit weight of approximately 150 lb/ft^3 made with normalweight aggregates.

Concrete, perlite—Nonstructural lightweight insulating concrete having a dry unit weight of approximately 30 lb/ft^3 made by mixing perlite concrete aggregate complying with ASTM C 332 with portland cement slurry. Note: Perlite concrete can be applied by spraying or other means.

Concrete, plain—Structural concrete with less reinforcement than required for reinforced concrete.

Concrete, reinforced—Concrete containing adequate reinforcement (prestressed or non-prestressed) and designed on the assumption that the two materials act together in resisting forces.

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 a 28-day air-dry unit weight of 105 to 120 lb/ft^3.

Concrete, siliceous aggregate—Concrete made with normalweight coarse aggregates having constituents composed mainly of silica and 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.

Critical temperature—Temperature of the steel in unrestrained flexural members during fire exposure at which the nominal flexural strength of the members is reduced to the moment due to service loads.

End-point criteria—Conditions of acceptance for an ASTM E 119 fire test.

Fire endurance—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.

Fire resistance—The characteristic 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 fire or 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.

Glass fiberboard—Fibrous glass insulation board complying with ASTM C 612.

Gypsum wallboard type “X”—Mill-fabricated product 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, meeting ASTM C 36, Type X.

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

High strength alloy steel bars—Bars used for post-tensioning conforming to the requirements of ASTM A 722.

Hot-rolled steel—Steel used for reinforcing bars or structural steel members.

Intumescent mastic—Spray-applied coating that reacts to heat at about 300 deg F by foaming to a multicellular structure having 10 to 15 times its initial thickness.

Integrity end point—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.

Joist—A comparatively narrow beam, used in closely-spaced arrangements to support floor or roof slabs, as defined in ACI 116R.

Masonry, plain—Masonry without reinforcement or masonry reinforced only for either shrinkage or thermal change.

Masonry, reinforced—Unit masonry in which reinforcement is embedded in such a manner that the two materials act together in resisting forces.

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 C1088.

Masonry unit, concrete—Hollow or solid unit 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 or C 129.

Mineral board—Mineral fiber insulation board complying with ASTM C 726.

Sprayed mineral fiber—A blend of refined mineral fibers and inorganic binders. Water is added during the spraying operation, and the untamped unit weight is about 13 lb/ft^3.

Standard fire exposure—The time-temperature relationship defined by ASTM E 119.

Standard fire test—The test prescribed by ASTM E 119.

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

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

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

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

Vermiculite cementitious material—A cementitious mill-mixed material to which water is added to form a mixture suitable for spraying. The mixture has a wet unit weight of about 55 to 60 lb/ft^3.

1.4—Notation

a = depth of equivalent rectangular concrete compressive stress block at nominal flexural strength
A_1, A_2 and A_n = air factor for each continuous air space having a distance of $^1/_2$ in. to $3^1/_2$ in. between wythes
A_{ps} = cross-sectional area of prestressing strands or tendons
a_θ = depth of equivalent concrete rectangular stress block at elevated temperature
A_{st} = cross-sectional area of the steel column (Section 3.6)
A_s = cross-sectional area of non-prestressed reinforcement (Section 2.4.2)
b = width of concrete slab or beam
b_f = width of flange (Chapter 3)
D = density of masonry protection
d_{st} = column dimension, (see Fig. 3.3)
d_ℓ = thickness of fire-exposed concrete layer (Section 2.2.5.2)
d = effective depth, distance from centroid of the tension reinforcement to extreme compressive fiber (Section 2.4.2)
d_{ef} = distance from the centroid of tension reinforcement to the extreme concrete compressive fiber where the temperature does not exceed 1400 deg F (Section 2.4.2)
F = degrees Fahrenheit
f_c = measured compressive strength of concrete test cylinders at ambient temperature
f'_c = specified compressive strength of concrete
$f'_{c\theta}$ = reduced compressive strength of concrete at elevated temperature
f_{ps} = stress in prestressing steel at nominal strength
$f_{ps\theta}$ = reduced strength of prestressing steel at elevated temperature
f_{pu} = specified tensile strength of prestressing tendons
f_y = specified yield strength of non-prestressed reinforcing steel
$f_{y\theta}$ = reduced strength of non-prestressed reinforcing steel at elevated temperature
H = specified height of masonry unit
k = thermal conductivity at room temperature
L = specified length of masonry unit
ℓ = span length
M = moment due to full service load on the member
$M^+_{n\theta}$ = nominal positive moment flexural strength at section at elevated temperature
$M^-_{n\theta}$ = nominal negative moment flexural strength at section at elevated temperature
M_n = nominal flexural strength of member
$M_{n\theta}$ = nominal flexural strength at section at elevated temperature
M_{x1} = maximum value of the redistributed positive moment at some distance x_1
p = inner perimeter of concrete masonry protection
ps = heated perimeter of steel column
R = Fire resistance of assembly
R_1, R_2,...R_n = fire resistance of layer 1, 2,...n, respectively
s = spacing of ribs or undulations
t = time in minutes
t_{min} = minimum thickness, in. (Section 2.2.4)
t_{tot} = total slab thickness (Section 2.2.5.2)
T_E = equivalent thickness of clay masonry unit
T_e = equivalent thickness of concrete masonry unit
t_e = equivalent thickness of a ribbed or undulating concrete section
T_{ea} = equivalent thickness of concrete masonry assembly
T_{ef} = equivalent thickness of finishes
t_w = thickness of web, (see Fig. 3.3)
u = average thickness of concrete between the center of main reinforcing steel and fire-exposed surface
u_{ef} = an adjusted value of u to accommodate beam geometry where fire exposure to concrete surfaces is from three sides (Chapter 2)
V_n = net volume of masonry unit
w = applied load (unfactored dead + live)
x_0 = distance from the inflection point after moment redistribution to the location of the first interior support (Chapter 2)
x_1 = distance at which the maximum value of the redistributed positive moment occurs measured from: (a) the outer support for continuity over one support; and (b) either support where conti-

nuity extends over two supports (Chapter 2)

x_2 = the distance between inflection points for a continuous span (Chapter 2)

ρ_g = ratio of total reinforcement area to cross sectional area of column

θ = subscript denoting changes of parameter due to elevated temperature

ρ = reinforcement ratio

ω_p = reinforcement index for concrete beam reinforced with prestressing steel

ω_θ = reinforcement index for concrete beam at elevated temperature

ω_r = reinforcement index for concrete beam reinforced with non prestressed steel

1.5—Fire resistance determinations

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—Alternative Methods.

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

In some cases distinctions are made between normal weight concretes 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 hr 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 walls or of walls or slabs, or of 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.

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

Aggregate type	Minimum equivalent thickness for fire resistance rating, in.				
	1 hr	$1^1/_2$ hr	2 hr	3 hr	4 hr
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

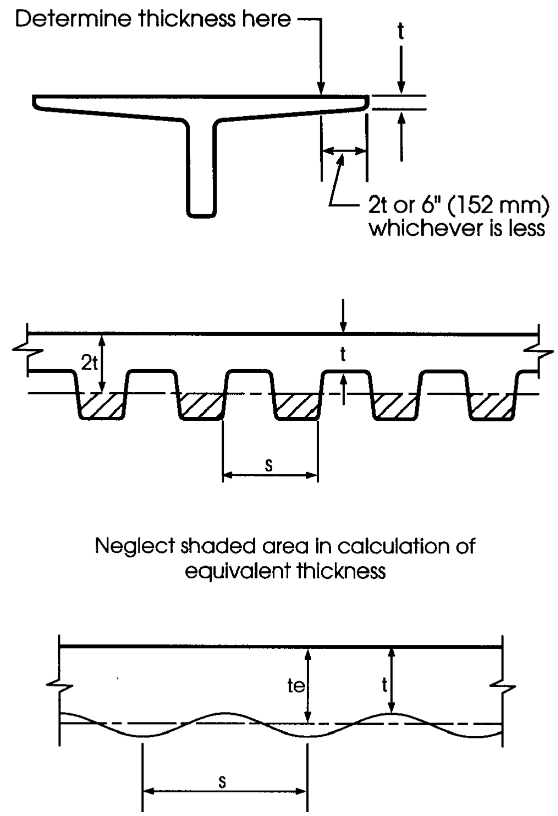

Fig. 2.0—Equivalent thickness of flanged, ribbed, and undulating panels

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 (see Fig. 2.0).

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

A. Where the center-to-center spacing of ribs or undulations is not less than four times the minimum thickness, the equivalent thickness is the minimum thickness of the panel.

B. 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 by dividing the net cross-sectional area by the panel width. The maximum thickness used to calculate the net cross-sectional area shall not exceed two times the minimum thickness.

C. Where the center-to-center spacing of ribs or undulations exceeds two times the minimum thickness but is less than four times the minimum thickness, calculate the equivalent thickness from the following equation:

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

where:

s = spacing of ribs or undulations, in.
t_{min} = minimum thickness, in.
t_e = equivalent thickness, in., calculated in accordance with Item B in 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. 2.1 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. Exception: In the cases of 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,

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

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

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

where

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

2.2.5.3 *Alternative numerical solution*—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 of lay-

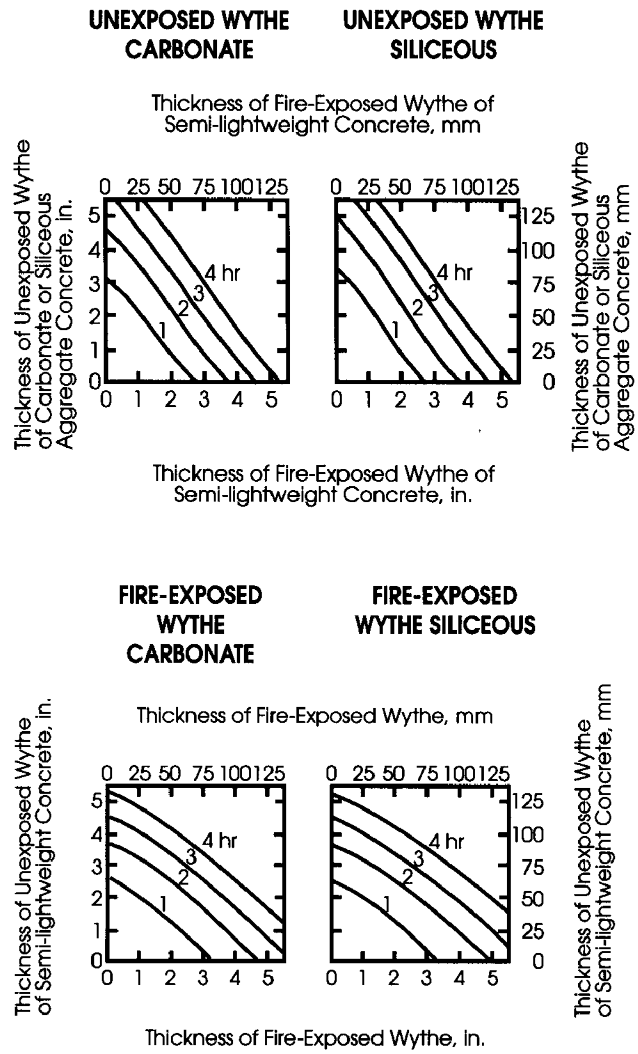

Fig 2.1—Fire resistance of two-layer concrete walls, floors and roofs

ers of concrete, concrete masonry and/or clay masonry, determine the fire resistance from Eq. (2-4):

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

where

R = fire resistance of assembly, hr
R_1, R_2 and R_n = fire resistance of individual layers, hr
A_1, A_2 and A_n = 0.30; the air factor for each continuous air space having a distance of $^1/_2$ in. 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. 2.2 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. Note: Eq. (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 hr in Eq. (2-4). For foam plastic with a total thickness less than 1 in., the fire resistance contribution

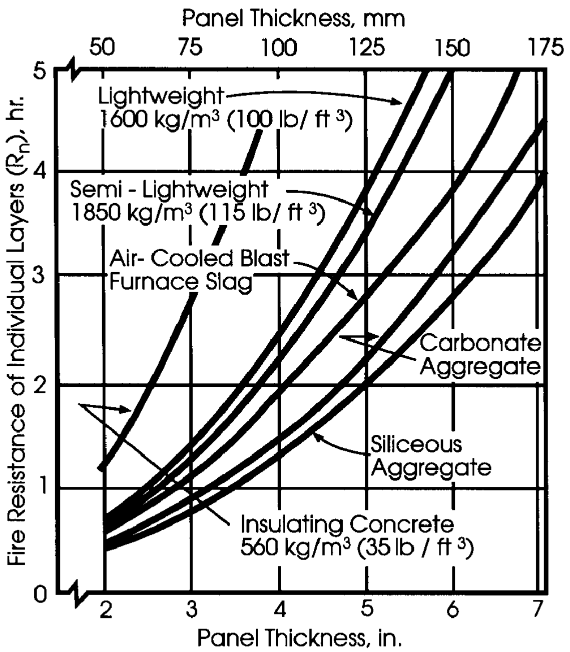

Fig. 2.2—Effect of slab thickness and aggregate type on fire resistance of concrete slabs based on 250 deg F (139 deg C) rise in temperature of unexposed surface

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. 2.3 (a), (b) and (c) or Fig. 2.3.1 (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 3-ply built-up roof is installed over a lightweight insulating, or semi-lightweight concrete topping, it shall be permitted to add 10 min to the fire resistance determined from Fig. 2.3 (a), (b), (c) or 2.4.

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.

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 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 hr to 4 hr shall be in accordance with Fig. 2.5. 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 grouted to a depth of at least one-third the slab thickness at the joint, but not less than side), the minimum cover used in the calculation shall be one-half the actual value. The actual cover for any individual bar shall be not less than one-half the value shown in Table 2.4 or $^3/_4$ in., whichever is greater.

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.

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 positive moment reinforcement 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 slab reinforcement*—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 hr 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 under-surfaces.

2.3.1.2 *Cover for non-prestressed flexural reinforcement in beams*—The minimum thickness of concrete cover to non-prestressed positive moment reinforcement (bottom steel) for restrained and unrestrained beams of different widths required to provide fire resistance of 1 to 4 hr 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 hr 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 one-half the actual value. The actual cover for any individual bar shall be not less than one-half the value shown in Table 2.4 or $^3/_4$ in., whichever is greater.

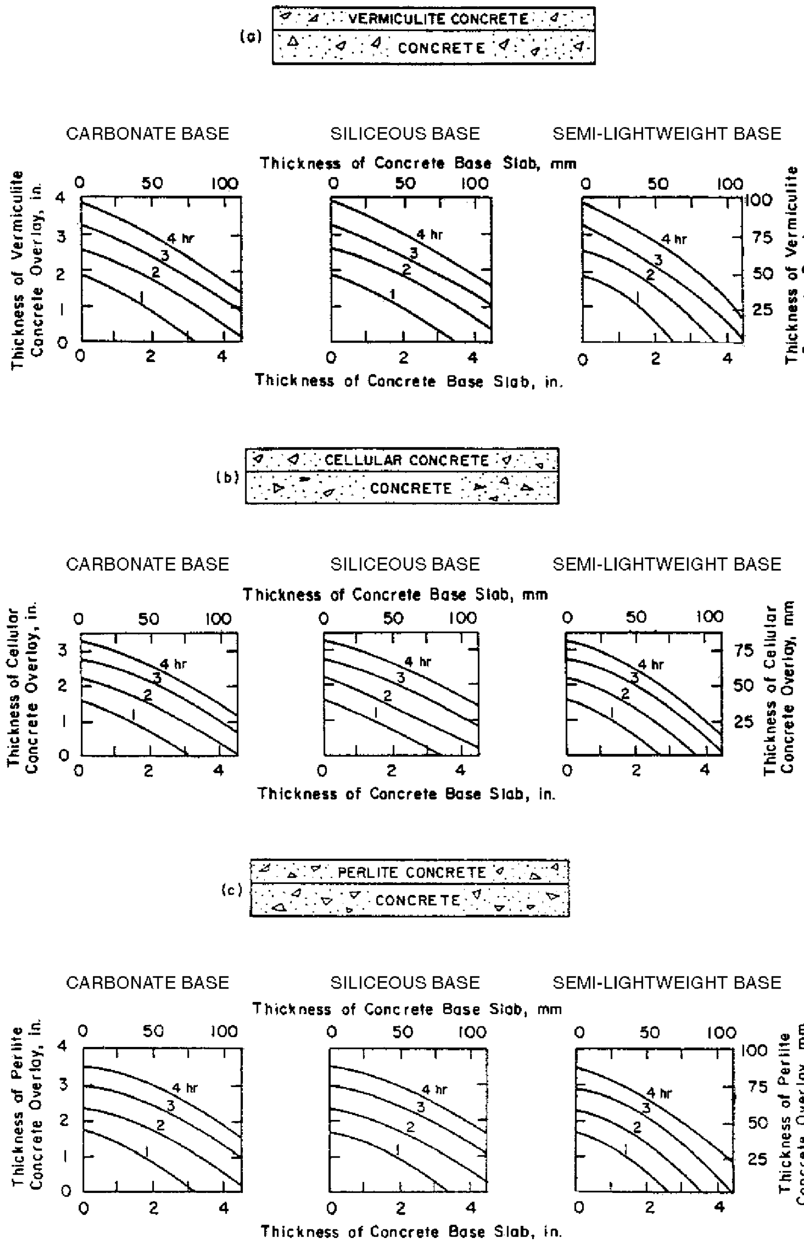

Fig. 2.3 (a), (b), and (c)—Fire resistance of concrete base slabs with overlays of insulating concrete, 30 lb/ft^3

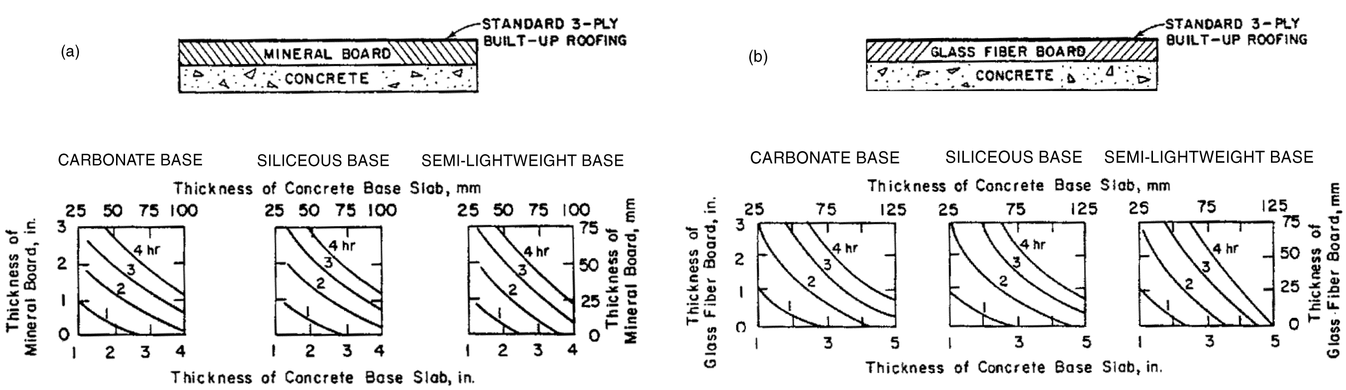

Fig. 2.3.1(a) and (b)—Fire resistance of concrete roofs with board insulation

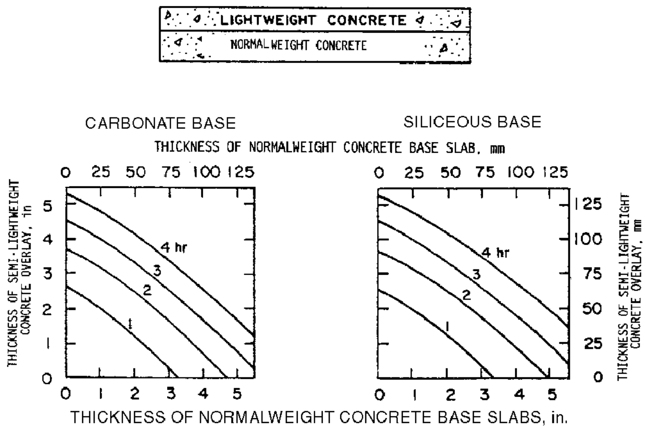

Fig. 2.4—Fire resistance of semi-lightweight concrete overlays on normalweight concrete base slabs

2.3.1.3 *Cover for prestressed flexural reinforcement*—The minimum thickness of concrete cover to positive moment reinforcement (bottom steel) for restrained and unrestrained beams and stemmed units of different widths and of different types of concrete required to provide fire resistance of 1 to 4 hr shall conform to values given in Tables 2.5 and 2.6. Values in Table 2.5 apply to members with widths not less than 8 in. Values in Table 2.6 apply to prestressed members of all 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 Table 2.5 or Table 2.6. The cover to be used with Table 2.5 or Table 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 non-prestressed positive moment reinforcement in prestressed beams shall determined be in accordance with 2.3.1.2.

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

In lieu 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 less than that required by ACI 318 be permitted.

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:

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

where:

$M_{n\theta}$ = nominal flexural strength at elevated temperatures, and

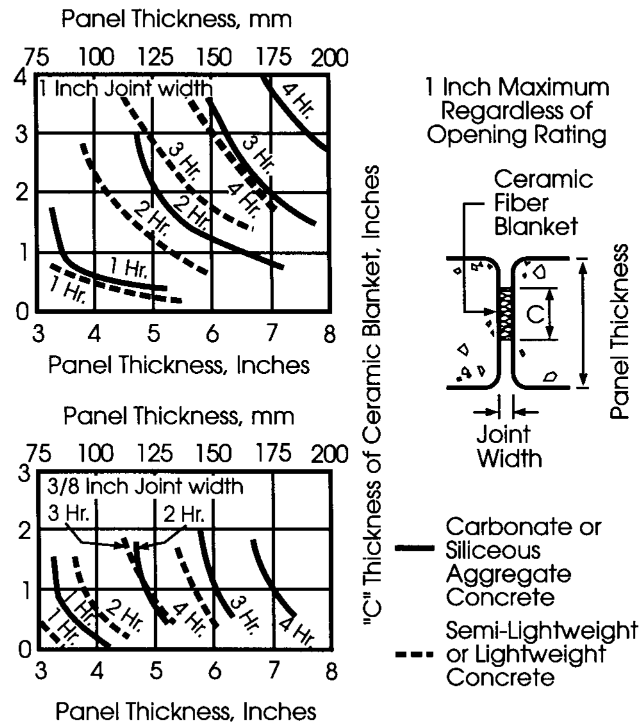

Fig 2.5—Ceramic fiber joint protection

M = unfactored full service load moment on the member, that is $(w\ell^2)/8$ for a uniformly loaded beam or slab, and,

M_n = nominal flexural strength of the member at room temperature calculated as provided for in ACI 318.

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. 2.6 to determine the structural fire resistance or amount of concrete cover, u, to center of the steel reinforcement of concrete slabs.

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. Fig.2.6 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 elements 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:

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

Table 2.2—Construction classification, restrained and construction and unrestrained

Unrestrained	
Wall bearing	Single spans and simply-supported end spans of multiple bays such as concrete slabs or precast units[A]
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[B]
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 or the adjoining floor or roof construction[B]

A. 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.

B. 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 precast units and the vertical face of supports, or between the ends of solid or hollow-core slab units, does not exceed 0.25 percent of the length for normal weight concrete members or 0.1 percent of the length for structural lightweight concrete members.

Table 2.3—Minimum cover for concrete floor and roof slabs

Aggregate type	Cover[A,B] for corresponding fire resistance, in.					
	Restrained	Unrestrained				
	4 or less	1 hr	$1^1/_2$ hr	2 hr	3 hr	4 hr
Nonprestressed						
Siliceous	$^3/_4$	$^3/_4$	$^3/_4$	1	$1^1/_4$	$1^5/_8$
Carbonate	$^3/_4$	$^3/_4$	$^3/_4$	$^3/_4$	$1^1/_4$	$1^1/_4$
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	$2^1/_4$

A. Shall also meet minimum cover requirements of 2.3.1

B. Measured from concrete surface to surface of longitudinal reinforcement

Table 2.4—Minimum cover for nonprestressed

Restraint	Beam width, in.	Cover for corresponding fore resistance, in.				
		1 hr	$1^1/_2$ hr	2 hr	3 hr	4 hr
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[A]	NP
	7	$^3/_4$	$^3/_4$	$^3/_4$	$1^3/_4$	3
	≥10	$^3/_4$	$^3/_4$	$^3/_4$	1	$1^3/_4$

A. Not permitted.

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

Restraint	Aggregate type	Beam width, in.	Cover thickness for corresponding fire resistance rating, in.				
			1 hr	$1^1/_2$ hr	2 hr	3 hr	4 hr
Restrained[A]	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[B]	NP[C]
		≥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	$2^1/_2$

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

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

Restraint	Aggregate type	Area,[A] in.^{2}	Cover thickness for corresponding fire resistance, in.				
			1 hr	$1^1/_2$ hr	2 hr	3 hr	4 hr
Restrained	All	40 ≤ A ≤ 150	$1^1/_2$	$1^1/_2$	2	$2^1/_2$	NP[C]
	Carbonate or siliceous	150 < A ≤ 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 ≤ A ≤ 150	2	$2^1/_2$	NP	NP	NP
	Carbonate or siliceous	150 < A ≤ 300	$1^1/_2$	$1^3/_4$	$2^1/_2$	NP	NP
		300 < A	$1^1/_2$	$1^1/_2$	2	3[B]	4[B]
	Lightweight or semi-lightweight	150 < A	$1^1/_2$	$1^1/_2$	2	3[B]	4[B]

A. 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.
B. Adequate provisions against spalling shall be provided by U-shaped or hooped stirrups spaced not to exceed the depth of the member, and having a cover of 1 in.
C. Not permitted.

that is, when $M^+_{n\theta}$ is reduced to M_{x1}, the maximum value of the redistributed positive moment at some 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 [See Fig. 2.7 (a) and Fig. 2.7 (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 2.4.2.2 (d).

2.4.2.1 *Reinforcement detailing*—Design the member to ensure 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.

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 deg F shall be neglected. In this case, a reduced d_{ef} shall be used in place of d, where d_{ef} equals the distance from the centroid of the tension steel reinforcement to the extreme compressive fiber where the temperature does not exceed 1400 deg F.

Where:

$\omega_\theta = \rho f_{y\theta}/f'_{c\theta} = A_s f_{y\theta}/bd_{ef}f'_{c\theta}$ for non-prestressed 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 percent of the negative moment reinforcement in the span shall be extended throughout the span to accommodate

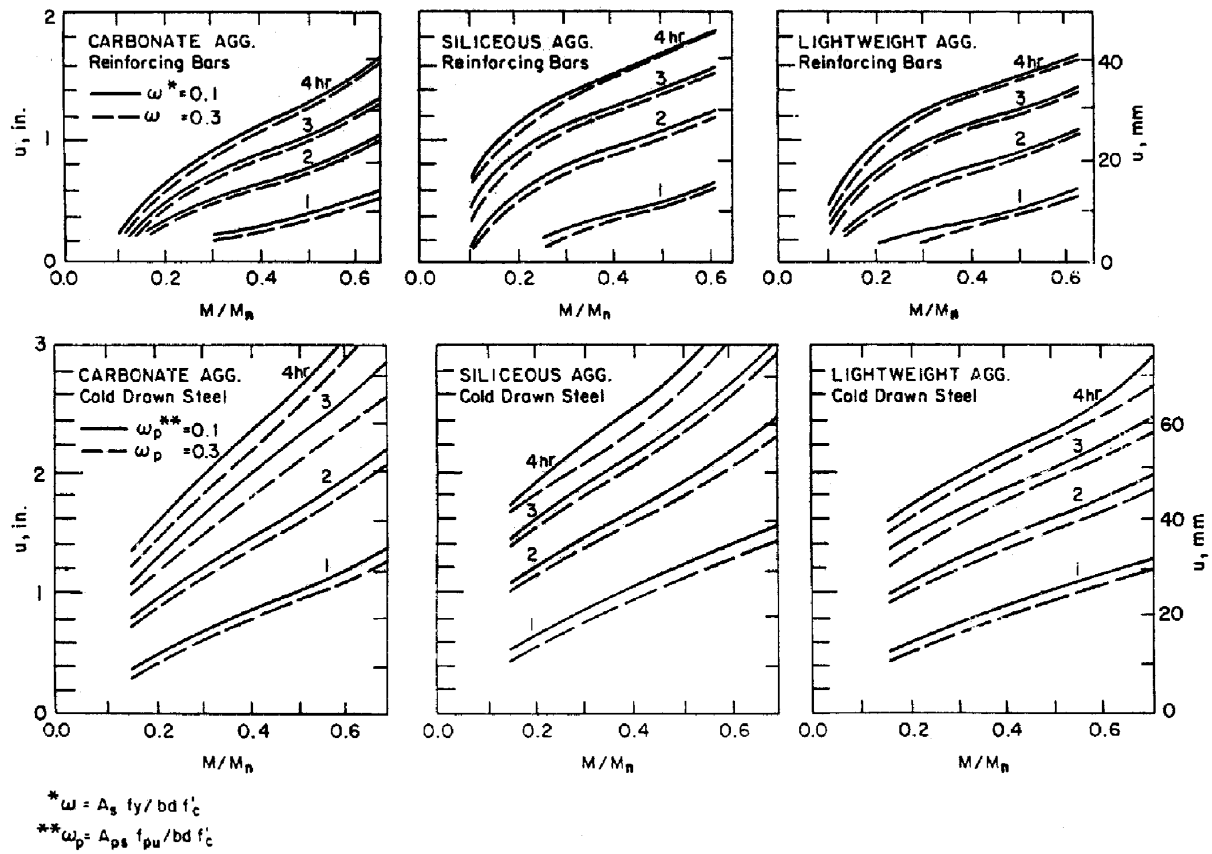

Fig. 2.6—Fire resistance of concrete slabs as influenced by aggregate type, reinforcing steel type, moment intensity, and u, *as defined in* ***1.4***

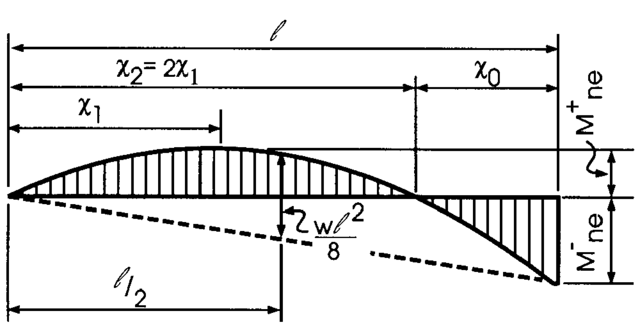

Fig. 2.7 (a)—Redistributed applied moment diagram at failure condition for a uniformly loaded flexural member continuous over one support

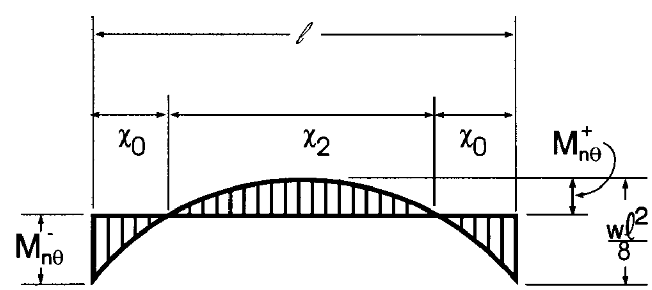

Fig. 2.7 (b)—Redistributed applied moment diagram at failure condition for a symmetrical uniformly loaded flexural member continuous at both supports

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. 2.8 (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 non-prestressed 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. 2.9.

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

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

$f'_{c\theta}$ = 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. 2.10.

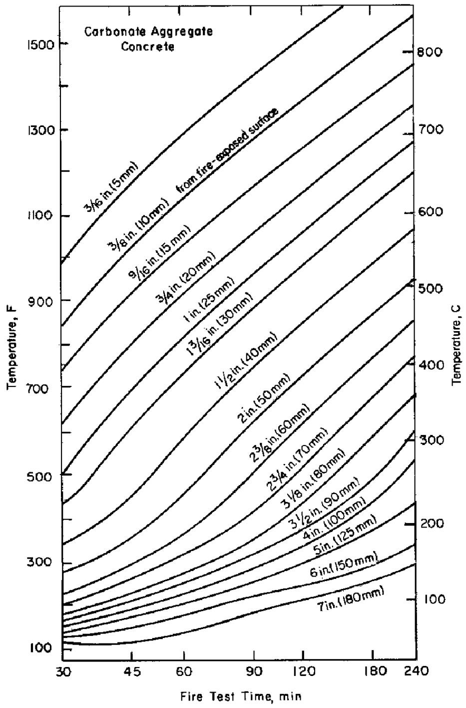

Fig. 2.8 (a)—Temperatures within slabs during ASTM E 119 fire tests—carbonate aggregate concrete

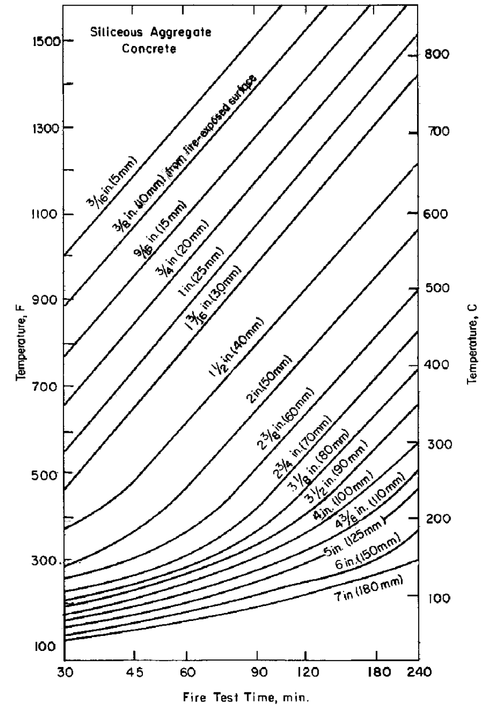

Fig. 2.8 (b)—Temperatures within slabs during ASTM E 119 fire tests—siliceous aggregate concrete

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

The reinforcement ratio, ρ, the reinforcement index, ω, for nonprestressed reinforcement, and the reinforcing index, ω_p, for prestressed reinforcement shall not exceed values permitted by ACI 318,

where

$\rho = A_s/bd$,
$\omega = \rho f_y/f'_c$ for nonprestressed reinforcement, and
$\omega_p = A_{ps}f_{ps}/bdf'_c$ for prestressed reinforcement.

Alternatively, it is also permitted to use Fig. 2.6 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 $\omega_\theta \le 0.30$ as in 2.4.2.1 (a) and increase compression steel or otherwise alter the section, if necessary.

For a uniformly distributed load, w, [See Fig. 2.7 (a)]

$$M_{x1} = (w\ell x_1)/2 - (wx_1^2)/2 - (M^-_{n\theta}x_1)/\ell = M^+_{n\theta}$$
$$M^-_{n\theta} = (w\ell^2)/2 \pm w\ell^2\,(2M^+_{n\theta}/w\ell^2)^{1/2}$$
$$x_1 = \ell/2 - M^-_{n\theta}/w\ell$$
$$x_0 = 2M^-_{n\theta}/w\ell$$

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:

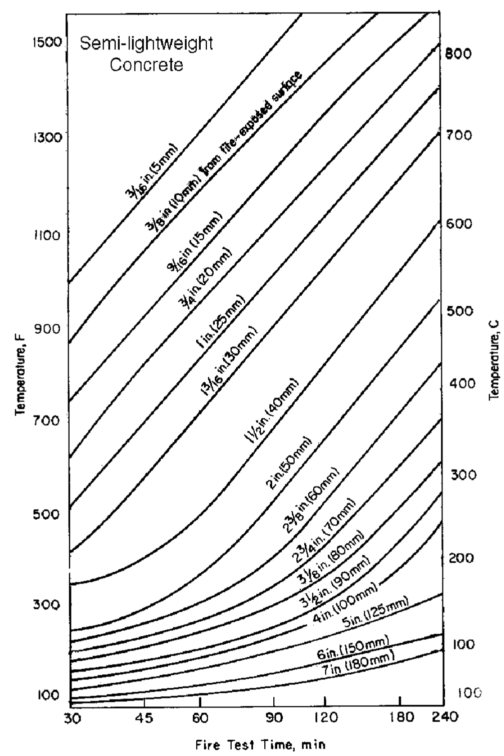

Fig. 2.8 (c)—Temperatures within slabs during ASTM E 119 fire tests—semi-lightweight concrete

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

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

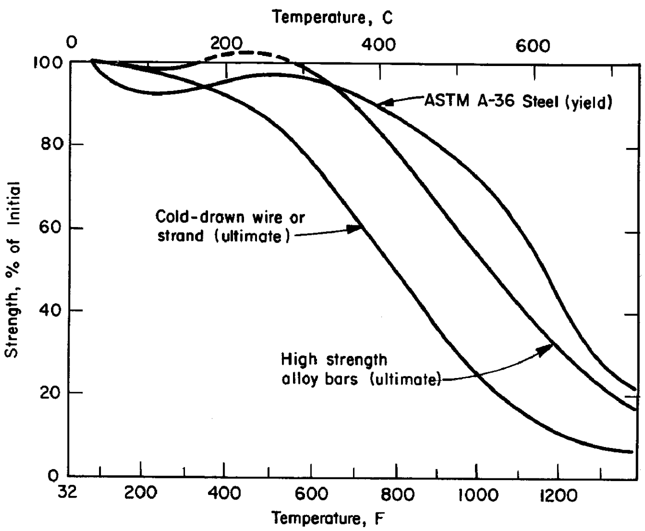

Fig. 2.9—Strength of flexural reinforcement steel bar and strand at high temperatures

positive steel reinforcement as in 2.4.2.2 (a) for continuous slabs over one support.

2.4.2.2 (d) *Design of negative moment reinforcement*—Determine the required negative moment reinforcement and location of inflection points to calculate its development length by the following procedures.

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

For a uniformly distributed load, w,

$$M_{x1} = (wx_2^{\,2})/8 = M^+_{n\theta} \text{ and,}$$
$$x_2 = (8M^+_{n\theta}/w)^{1/2}$$

Where:

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

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

$x_0 = \ell - x_2$

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.

Fig. 2.11 (a) through 2.11 (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

The least dimension of reinforced concrete columns of different types of concrete for fire resistance of 1 to 4 hr shall conform to values given in Tables 2.7 and 2.8.

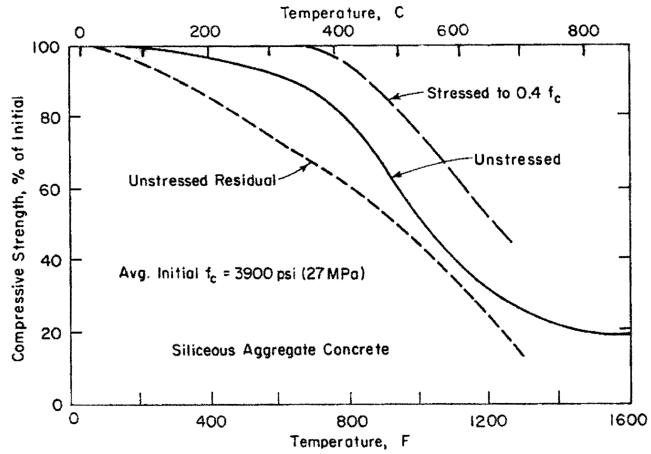

Fig. 2.10 (a)—Compressive strength of siliceous aggregate concrete at high temperatures and after cooling

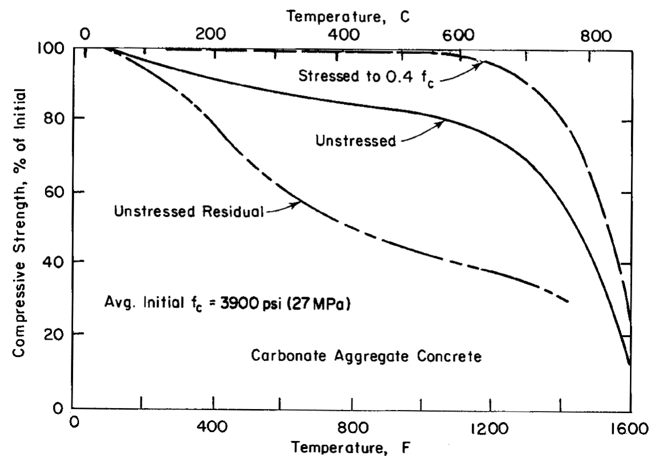

Fig. 2.10 (b)—Compressive strength of carbonate aggregate concrete at high temperatures and after cooling

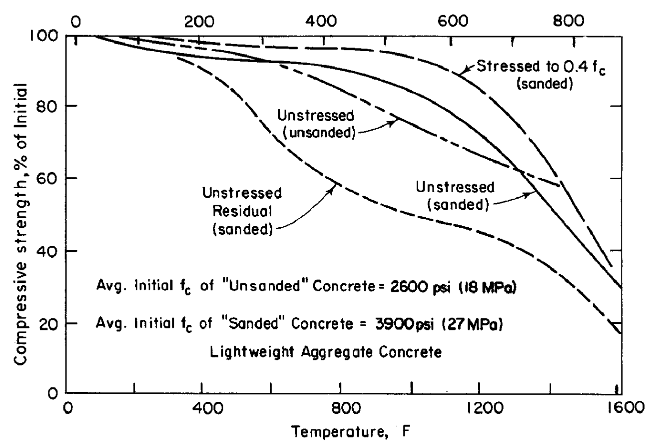

Fig. 2.10 (c)—Compressive strength of semi-lightweight concrete at high temperatures and after cooling

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

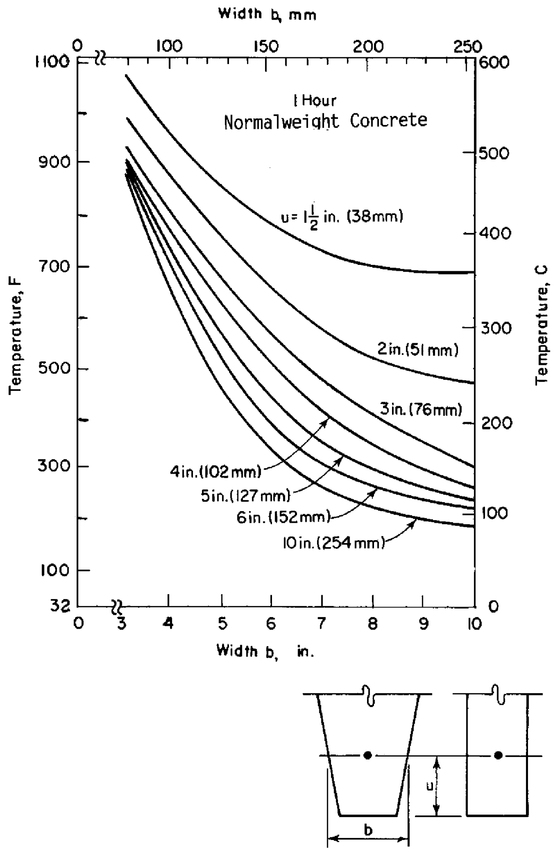

Fig. 2.11 (a)—Temperatures in normalweight concrete rectangular and tapered units at 1 hour of fire exposure

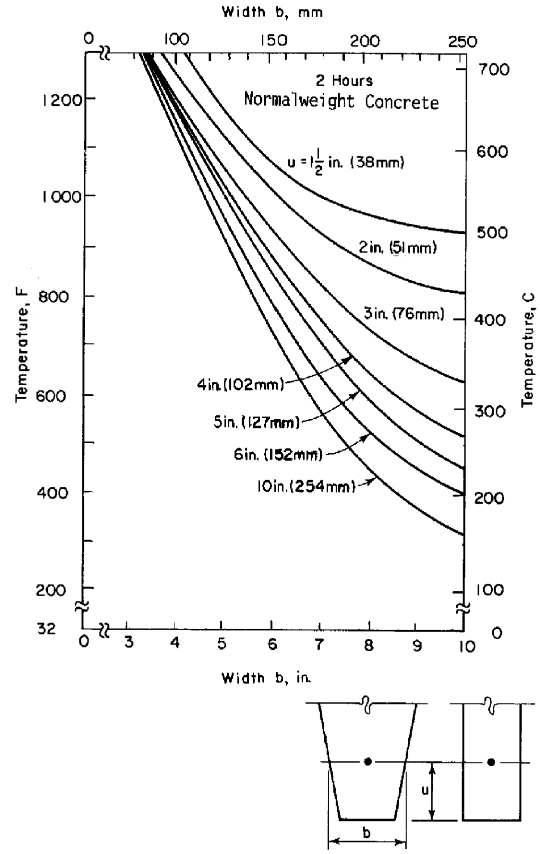

Fig 2.11 (b)—Temperatures in normalweight concrete rectangular and tapered units at 2 hours of fire exposure

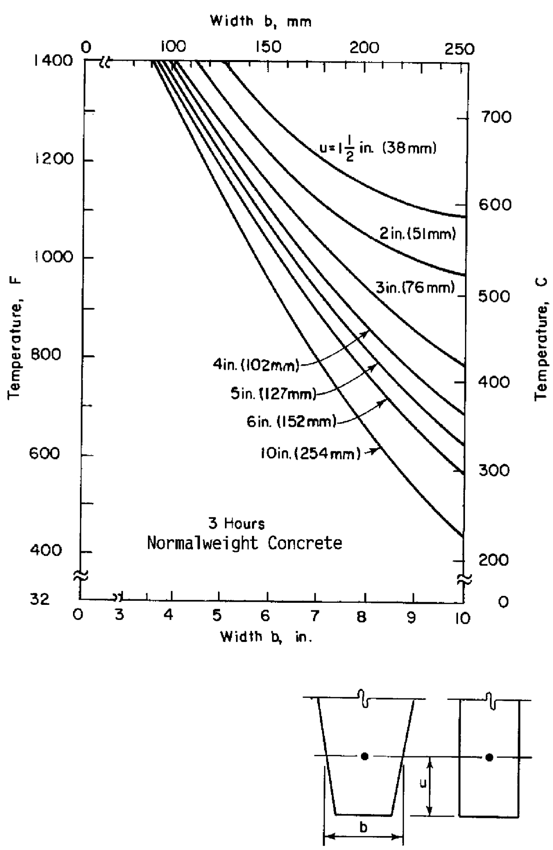

Fig. 2.11 (c)—Temperatures in normalweight concrete rectangular and tapered units at 3 hours of fire exposure

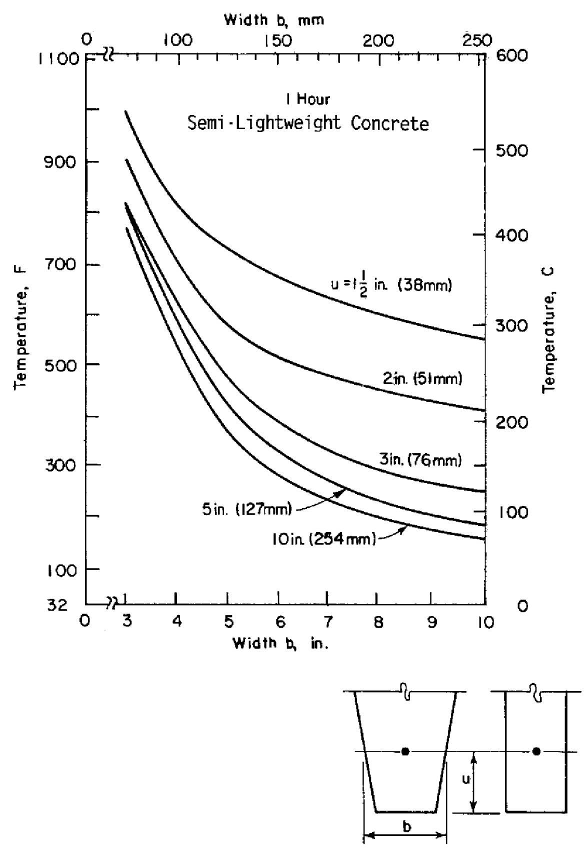

Fig. 2.11 (d)—Temperatures in semi-lightweight concrete rectangular and tapered units at 1 hour of fire exposure

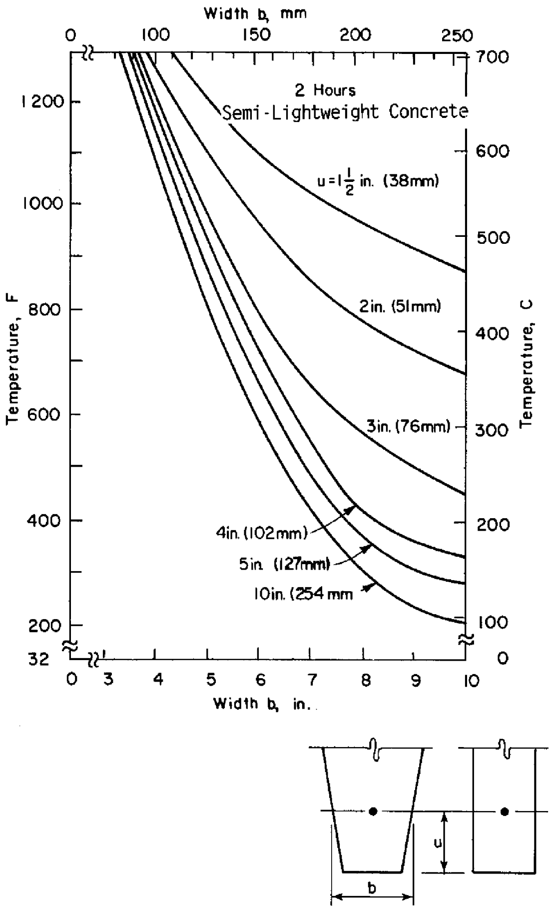

Fig. 2.11 (e)—Temperatures in semi-lightweight concrete rectangular and tapered units at 2 hours of fire exposure

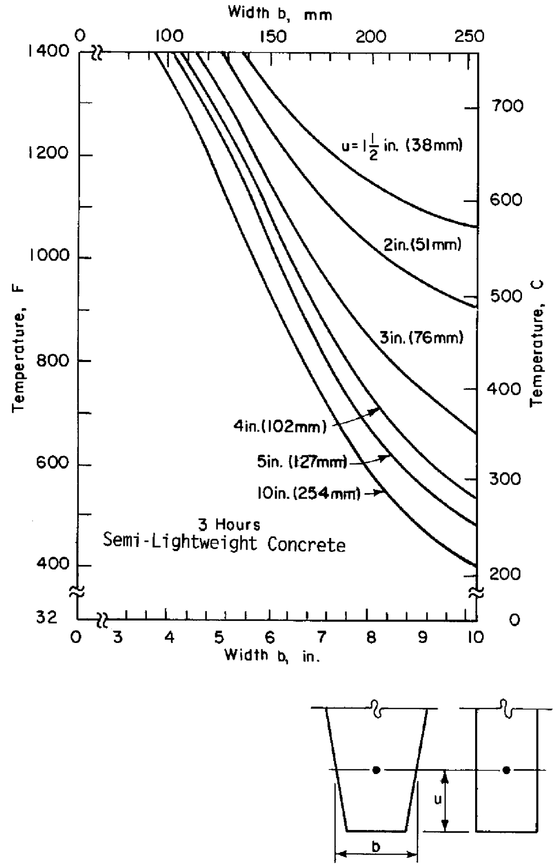

Fig. 2.11 (f)—Temperatures in semi-lightweight concrete rectangular and tapered units at 3 hours of fire exposure

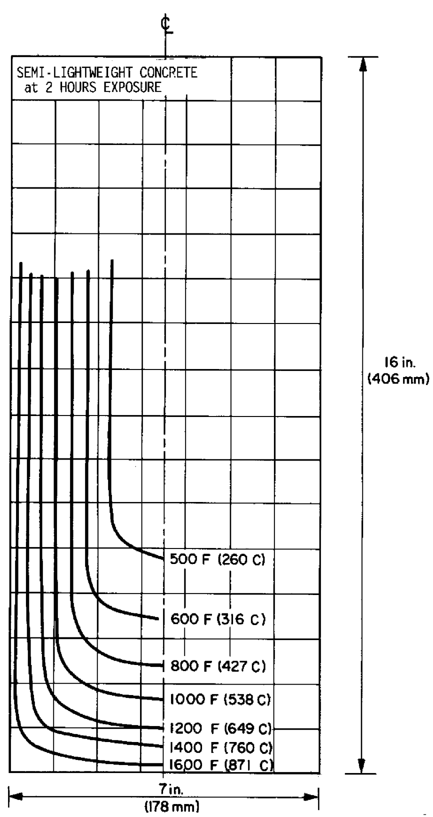

Fig. 2.11 (g)—Measured temperature distribution at 2 hour fire exposure for semi-lightweight concrete rectangular unit

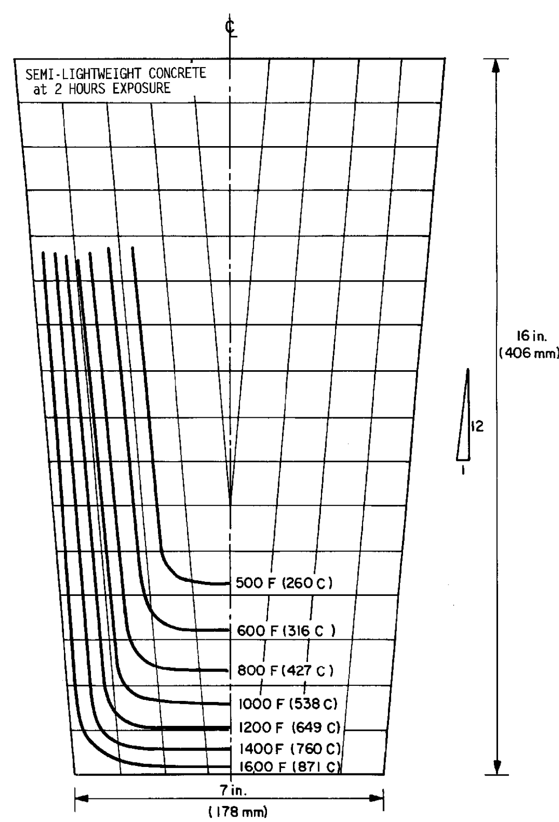

Fig. 2.11 (h)—Measured temperature distribution at 2 hour fire exposure for semi-lightweight concrete tapered unit

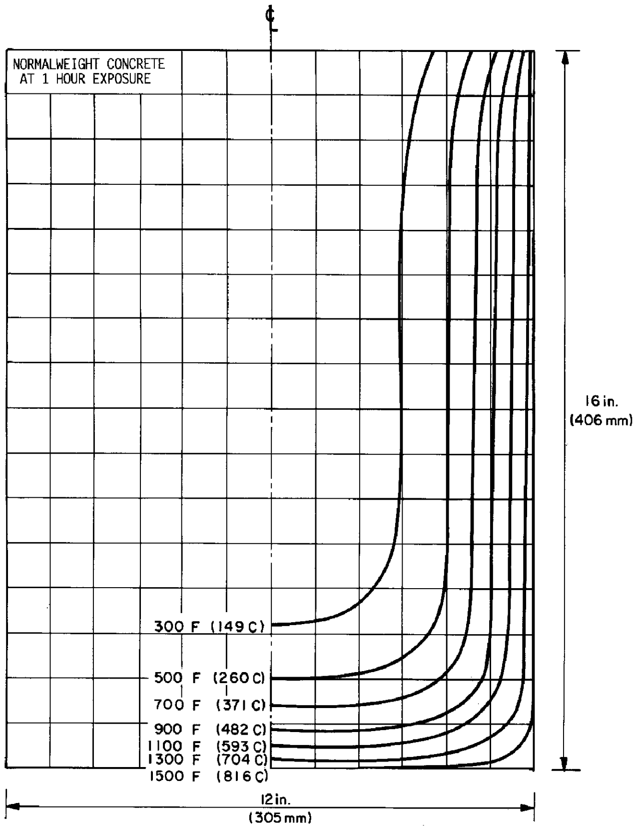

Fig. 2.11 (i)—Temperature distribution in a normalweight concrete rectangular unit at 1 hour of fire exposure

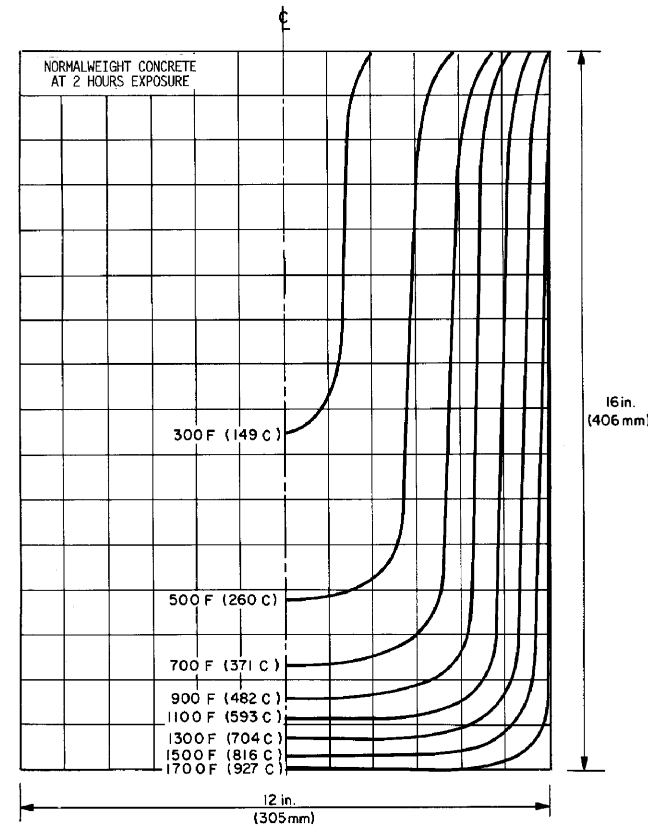

Fig. 2.11 (j)—Temperature distribution in a normalweight concrete rectangular unit at 2 hours of fire exposure

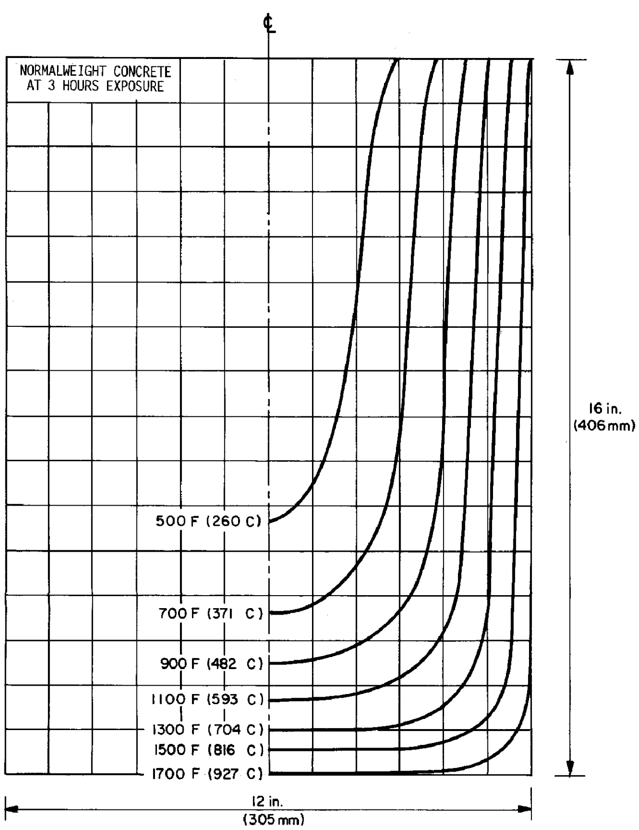

Fig. 2.11 (k)—Temperature distribution in a normalweight concrete unit at 3 hours of fire exposure

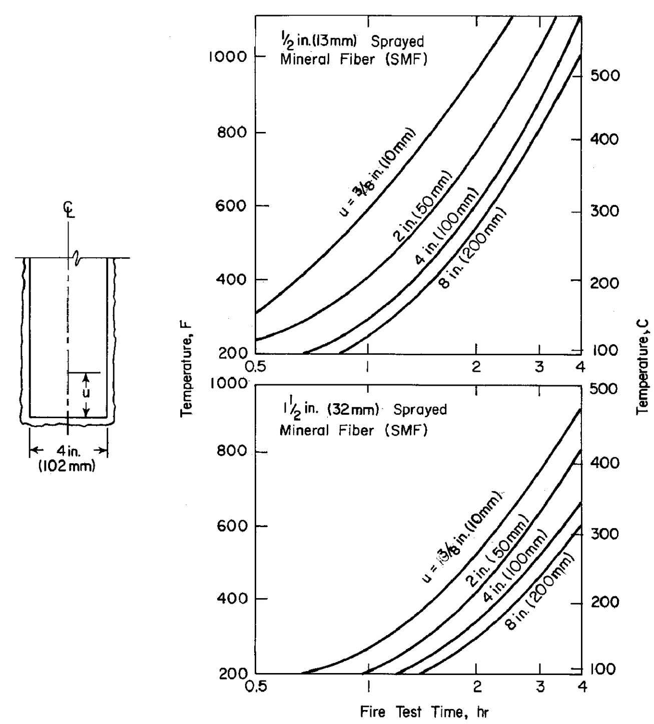

Fig. 2.11 (l)—Temperatures along vertical centerlines at various fire exposures for 4.0 in. (102 mm) wide rectangular units coated with SMF

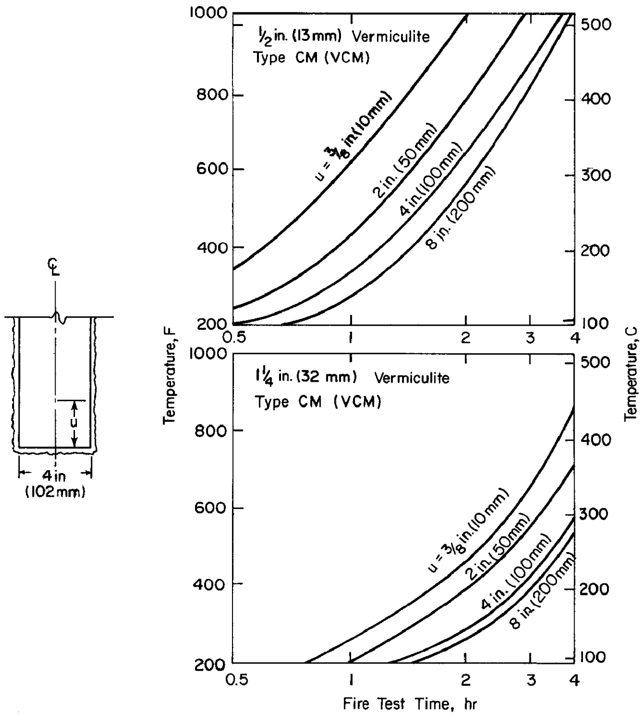

Fig. 2.11 (m)—Temperatures along vertical centerlines at various fire exposures for 4.0 in. (102 mm) wide rectangular units coated with VCM

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

3.2—Equivalent thickness

The equivalent thickness of concrete masonry construction shall be determined in accordanovisions 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:

$$T_{ea} = T_e + T_{ef} \quad (3\text{-}1)$$

$T_e = V_n/LH$ = equivalent thickness of concrete masonry unit, in. (3-2)

where

V_n = net volume of masonry unit, in.^{3}
L = specified length of masonry unit, in.

Table 2.7—Minimum concrete column size

Aggregate type	Minimum column dimension for fire resistance, in.				
	1 hr	$1^1/_2$ hr	2 hr	3 hr	4 hr
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, in.[A]				
	1 hr	$1^1/_2$ hr	2 hr	3 hr	4 hr
Carbonate	8	8	8	8	10
Siliceous	8	8	8	8	10
Semi-lightweight	8	8	8	8	10

A. Minimum dimensions are acceptable for rectangular columns with a fire exposure condition on 3 or 4 sides provided that one set of the two parallel sides of the column is at least 36 in. long.

H = specified height of masonry unit, in.

3.2.1 *Ungrouted or partially grouted construction*—T_e shall be the value obtained for the concrete masonry unit determined in accordance with ASTM C 140.

3.2.2 *Solid grouted construction*—The equivalent thickness, T_e, of solid grouted concrete masonry units is the actual thickness of the unit.

3.2.3 *Air spaces and cells filled with loose fill material*—The equivalent thickness of completely filled hollow concrete masonry is 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 that comply with ASTM C 331; or perlite or vermiculite meeting the requirements of ASTM C 549 and C 516, respectively.

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 hr 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 in accordance with Table 3.1.

3.3.2 *Multi-wythe wall assemblies*—Base the fire resistance of multi-wythe walls (Fig. 3.1) on the fire resistance of each wythe and the 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 where openings are required to be protected shall be in accordance with Fig. 3.2.

3.4—Reinforced concrete masonry columns

Base the fire resistance of reinforced concrete masonry columns 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.

Table 3.1—Fire resistance rating of concrete masonry assemblies

Aggregate type	Minimum required equivalent thickness for fire resistance rating, in.[A,B]				
	1 hr	$1^1/_2$ hr	2 hr	3 hr	4 hr
Calcareous or siliceous gravel (other than limestone)	2.8	3.6	4.2	5.3	6.2
Limestone, cinders, or air-cooled slag	2.7	3.4	4.0	5.0	5.9
Expanded clay, expanded shale or expanded slate	2.6	3.3	3.6	4.4	5.1
Expanded slag or pumice	2.1	2.7	3.2	4.0	4.7

A. 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.

B. 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 volume of each aggregate used in the manufacture.

Table 3.2—Reinforced masonry columns

Fire resistance, hr	1	2	3	4
Minimum column dimension, in.	8	10	12	14

Table 3.3—Reinforced masonry lintels

Nominal lintel width, in.	Minimum longitudinal reinforcement cover for fire resistance, in.			
	1 hr	2 hr	3 hr	4 hr
6	$1^1/_2$	2	NP[A]	NP
8	$1^1/_2$	$1^1/_2$	$1^3/_4$	3
10 or more	$1^1/_2$	$1^1/_2$	$1^1/_2$	$1^3/_4$

A. Not permitted.

3.5—Concrete masonry lintels

The fire resistance of concrete masonry lintels shall be established based upon 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

Determine the fire resistance of structural steel columns protected by concrete masonry by using the following equation:

$$R = 0.401(A_{st}p_s)^{0.7} + [0.285(T_{ea}{}^{1.6}/k^{0.2})] \quad (3\text{-}3)$$
$$[1.0 + 42.7\{A_{st}/DT_{ea})/(0.25p + T_{ea})\}^{0.8}]$$

where

R = Fire resistance of the column assembly, hr

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

D = Density of the concrete masonry protection, lb/ft^3

p = Inner perimeter of concrete masonry protection, in. (see Fig. 3.3a)

ps = Heated perimeter of steel column, in. [Eq. (3-4), (3-5), and (3-6)]

T_{ea} = Equivalent thickness of concrete masonry protection assembly, in.

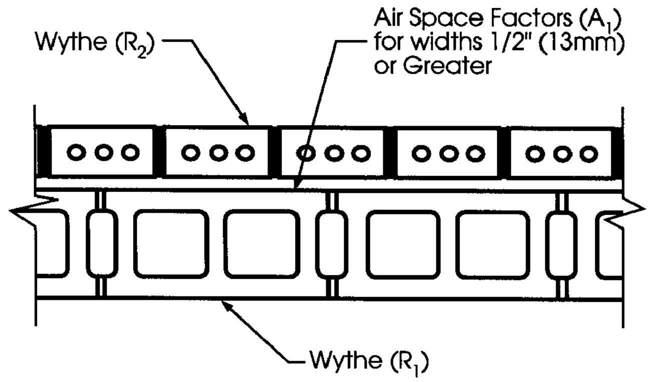

Fig. 3.1—Multi-wythe walls

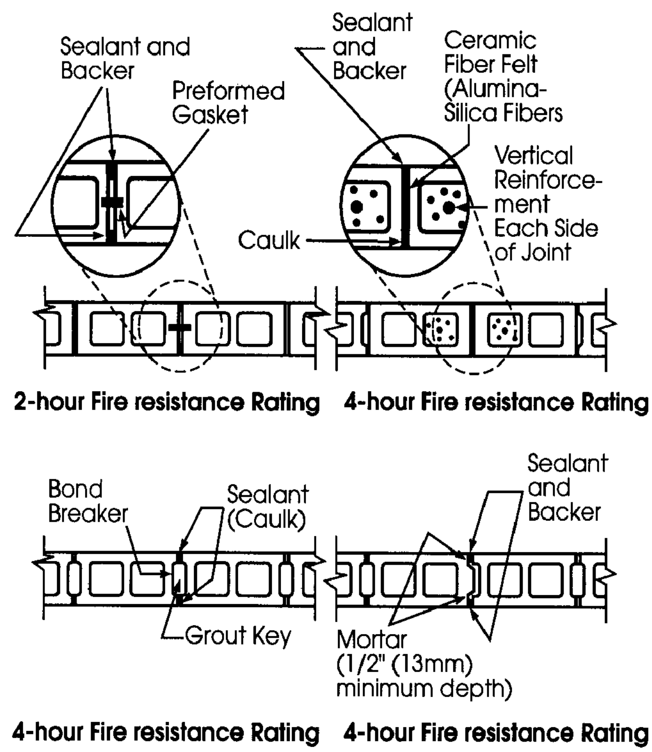

Fig. 3.2—Expansion or contraction joints in masonry walls with 1/2 in. (13 mm) maximum width having 2- or 4-hour fire resistance

k = Thermal conductivity of concrete masonry, BTU/hr ft deg F [(See Eq. (3-7)]

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

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

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

where

b_f = Width of flange, in.

d_{st} = Column dimension, in. (see Fig. 3.3)

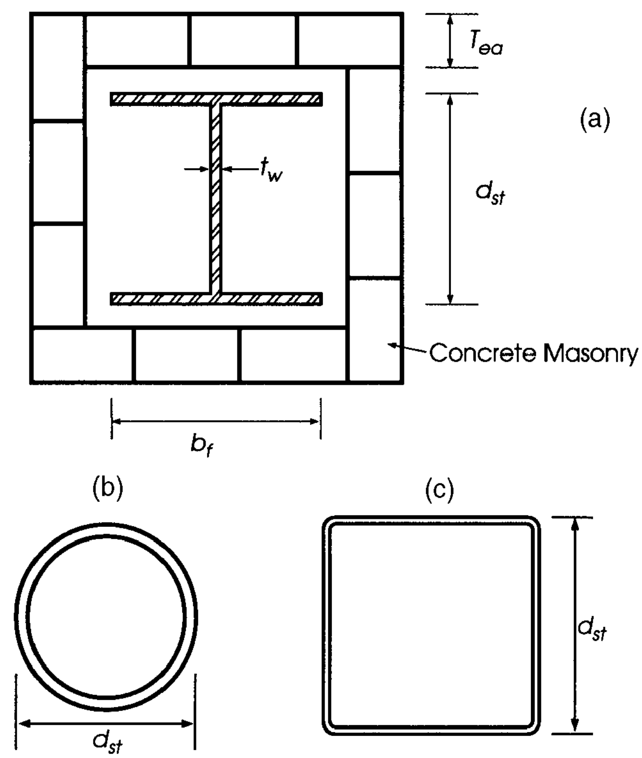

Fig. 3.3—Structural steel shapes protected by concrete masonry

t_w = Thickness of web, in. (see Fig. 3.3, W-Shape)

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

$$k = 0.0417e^{0.02D}, \text{ BTU/hr ft deg F} \qquad (3\text{-}7)$$

where

D = Density of concrete masonry, lb/ft^3

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 A.

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. Clay masonry units shall comply with ASTM C 34, C56, C 62, C 73, C 126, C212, C 216, or C 652.

4.2—Equivalent thickness

Determine the equivalent thickness of clay masonry assemblies in accordance with the provisions of this section.

Base the equivalent thickness of hollow clay masonry construction 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).

$$T_E = V_n/LH \qquad (4\text{-}1)$$

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.
H = specified height of the masonry unit, in.

4.2.1 *Ungrouted or partially grouted construction*—T_E shall be the value obtained for the hollow clay masonry unit as determined in accordance with ASTM C 67.

4.2.2 *Solid grouted construction*—Take the equivalent thickness of solidly grouted clay masonry units as the actual thickness of the unit.

4.2.3 *Air spaces and cells filled with loose fill material*—The equivalent thickness of completely filled hollow clay masonry units is 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; or perlite or vermiculite meeting the requirements of ASTM C 549 and C 516, respectively.

4.3—Clay brick and tile masonry wall assemblies

Determine fire resistance of clay brick and tile masonry wall assemblies in accordance with the provisions of this section.

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

4.3.2 *Single-wythe walls*—Determine fire resistance of clay brick and tile masonry walls from Table 4.1.

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

4.3.3.1 *Multi-wythe clay masonry walls with dimensionally dissimilar wythes*—Determine fire resistance of multi-wythe clay masonry walls consisting of two or more dimensionally dissimilar wythes based on the fire resistance of each wythe. Use Eq. (2-4) 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), determine fire resistance of the dissimilar wythes, R_n, in accordance with 2.2, Fig. 2.2 for concrete; 3.3, Table 3.1 for concrete masonry units. Use Eq. (2-4) to determine fire resistance of the wall assembly.

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

4.4—Reinforced clay masonry columns

Base fire resistance of reinforced clay masonry columns 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.

Table 4.1—Fire resistance of clay masonry walls

Material type	Minimum required equivalent thickness for fire resistance, in.[A,B,C]			
	1 hr	2 hr	3 hr	4 hr
Solid brick of clay or shale[D]	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

A. Equivalent thickness as determined from section 4.2.
B. Calculated fire resistance between the hourly increments listed shall be determined by linear interpolation.
C. 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 percent of the thickness shown.
D. For units in which the net cross-sectional area of cored brick in any plane parallel to the surface containing the cores shall be at least 75 percent of the gross cross-sectional area measured in the same plane.

4.5—Reinforced clay masonry lintels

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 = 1.25 BTU/hr ft deg F

Density = 130 lb/ft^3 k = 2.25 BTU/hr ft deg 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 B.

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

5.2.2 *Calculation for non-fire-exposed side*—Where the finish of gypsum wallboard, plaster, or terrazzo 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 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 of gypsum wallboard or plaster 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, of 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 one-half 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 one-half the contribution of the concrete or masonry alone.

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 and 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

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

Type of finish applied to slab or wall	Type of material used in slab or wall		
	Siliceous or carbonate aggregate concrete or concrete masonry unit; solid clay brick masonry	Semi-lightweight concrete; hollow clay brick; clay tile	Lightweight concrete; concrete masonry units of expanded shale, expanded clay, expanded slag, or pumice less than 20 percent sand
Portland cement-sand plaster[A] or terrazzo	1.00	0.75	0.75
Gypsum-sand plaster	1.25	1.00	1.00
Gypsum-vermiculite or perlite plaster	1.75	1.50	1.25
Gypsum wallboard	3.00	2.25	2.25

A. 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.

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 5.3.1.1 (b).

5.3.1.1 (a) Self-tapping drywall screws shall be spaced at a maximum of 12 in. on center and shall penetrate $^3/_8$ 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 wood furring strips which 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 Apply plaster and stucco finishes for purposes of increasing fire resistance to the surface of concrete or masonry in accordance with the provisions of the building code.

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	A
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

A. 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.

CHAPTER 6—REFERENCES

The documents of the various standards producing organizations referred to in this document are listed below with their serial designation.

American Concrete Institute

ACI 318-95 Building Code Requirements for Structural Concrete

ACI 530-95 Building Code Requirements for Masonry Structures (document also available as ASCE 5-95/TMS 402-95)

American Society for Testing and Materials

ASTM A 722-90 Specification for Uncoated High-Strength Steel Bar for Prestressing Concrete

ASTM C 33-93 Specification for Concrete Aggregates

ASTM C 34-93 Specification for Structural Clay Load-Bearing Wall Tile

ASTM C 36-95b Specification for Gypsum Wallboard

ASTM C 55-95a Specification for Concrete Building Brick

ASTM C 56-93 Specification for Structural Clay Non-Load-Bearing Tile

ASTM C 62-95a Specification for Building Brick (Solid Masonry Units Made from Clay or Shale)

ASTM C 67-94 Methods of Sampling and Testing Brick and Structural Clay Tile

ASTM C 73-96 Specification for Calcium Silicate Face Brick (Sand-Lime Brick)

ASTM C 90-96 Specification for Load-Bearing Concrete Masonry Units

ASTM C 126-95 Specification for Ceramic Glazed

	Structural Clay Facing Tile, Facing Brick, and Solid Masonry Units
ASTM C 129-96	Specification for Non-Load-Bearing Concrete Masonry Units
ASTM C 140-96	Methods of Sampling and Testing Concrete Masonry Units
ASTM C 212-93	Specification for Structural Clay Facing Tile
ASTM C 216-95a	Specification for Facing Brick (Solid Masonry Units Made from Clay or Shale
ASTM C 330-89	Specification for Lightweight Aggregates for Structural Concrete
ASTM C 331-94	Specification for Lightweight Aggreates for Concrete Masonry Units
ASTM C 332-87(91)	Specification for Lightweight Aggregates for Insulating Concrete
ASTM C 516-80(90)	Specification for Vermiculite Loose Fill Thermal Insulation
ASTM C 549-81(95)	Specification for Perlite Loose Fill Insulation
ASTM C 612-93	Specification for Mineral Fiber Block and Board Thermal Insulation
ASTM C 652-95a	Specification for Hollow Brick (Hollow Masonry Units Made from Clay or Shale)
ASTM C 726-88	Specification for Mineral Fiber Roof Insulation Board
ASTM C 796-87a(93)	Method for Testing Foaming Agents for Use in Producing Cellular Concrete Using Preformed Foam
ASTM C 1088-94	Specification for Thin Veneer Brick Units Made from Clay or Shale
ASTM E 119-95a	Methods for Fire Tests of Building Construction and Materials
ASTM E 176-95	Standard Terminology of Fire Standards

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

American Society for Testing and Materials
100 Barr Harbor Drive
West Conshohocken, PA 19428-2959

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

APPENDIX A

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

W shapes											
Column size	Concrete masonry density, lb/ft^3	Minimum required equivalent thickness for fire resistance rating of concrete masonry protection assembly $T_{e, in.}$				Column size	Concrete masonry density, lb/ft^3	Minimum required equivalent thickness for fire resistance rating of concrete masonry protection assembly $T_{e, in.}$			
		1 hr	2 hr	3 hr	4 hr			1 hr	2 hr	3 hr	4 hr
W14x82	80	0.74	1.61	2.36	3.04	W10x68	80	0.72	1.58	2.33	3.01
	100	0.89	1.85	2.67	3.40		100	0.87	1.83	2.65	3.38
	110	0.96	1.97	2.81	3.57		110	0.94	1.95	2.79	3.55
	120	1.03	2.08	2.95	3.73		120	1.01	2.06	2.94	3.72
W14x68	80	0.83	1.70	2.45	3.13	W10x54	80	0.88	1.76	2.53	3.21
	100	0.99	1.95	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	1.14	2.18	3.05	3.82		120	1.19	2.24	3.12	3.90
W14x53	80	0.91	1.81	2.58	3.27	W10x45	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	3.18	3.96
W14x43	80	1.01	1.93	2.71	3.41	W10x33	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	3.27	4.05		120	1.37	2.44	3.33	4.12
W12x72	80	0.81	1.66	2.41	3.09	W8x40	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
W12x58	80	0.88	1.76	2.52	3.21	W8x31	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
W12x50	80	0.91	1.81	2.58	3.27	W8x24	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
W12x40	80	1.01	1.94	2.72	3.41	W8x18	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 A.1—continued

Square structural tubing						Steel pipe					
Nominal tube size, in.	Concrete masonry density, lb/ft^3	Minimum required equivalent thickness for fire resistance rating of concrete masonry protection assembly $T_{e, in.}$				Nominal tube size, in.	Concrete masonry density, lb/ft^3	Minimum required equivalent thickness for fire resistance rating of concrete masonry protection assembly $T_{e, in.}$			
		1 hr	2 hr	3 hr	4 hr			1 hr	2 hr	3 hr	4 hr
4x4 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
4x4 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
4x4 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
6x6 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	0.85	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
6x6 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
6x6 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
8x8 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	1.91	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
8x8 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	3.19	3.98		120	1.24	2.34	3.24	4.04
8x8 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	3.13	3.87		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 B

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

W shapes											
Column size	Clay masonry density, lb/ft^3	Minimum required equivalent thickness for fire resistance rating of concrete masonry protection assembly $T_{e, in.}$				Column size	Clay masonry density, lb/ft^3	Minimum required equivalent thickness for fire resistance rating of concrete masonry protection assembly $T_{e, in.}$			
		1 hr	2 hr	3 hr	4 hr			1 hr	2 hr	3 hr	4 hr
W14x82	120	1.23	2.42	3.41	4.29	W10x68	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
W14x68	120	1.34	2.54	3.54	4.43	W10x54	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
W14x53	120	1.43	2.65	3.65	4.54	W10x45	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
W14x43	120	1.54	2.76	3.77	4.66	W10x33	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
W12x72	120	1.32	2.52	3.51	4.40	W8x40	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
W12x58	120	1.40	2.61	3.61	4.50	W8x31	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
W12x50	120	1.43	2.65	3.66	4.55	W8x24	120	1.66	2.90	3.92	4.82
	130	1.61	2.93	4.02	4.99		130	1.84	3.18	4.28	5.25
W12x40	120	1.54	2.77	3.78	4.67	W8x18	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.	Clay masonry density, lb/ft^3	Minimum required equivalent thickness for fire resistance rating of concrete masonry protection assembly $T_{e, in.}$				Nominal pipe size, in.	Clay masonry density, lb/ft^3	Minimum required equivalent thickness for fire resistance rating of concrete masonry protection assembly $T_{e, in.}$			
		1 hr	2 hr	3 hr	4 hr			1 hr	2 hr	3 hr	4 hr
4x4 $^1/_2$ 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
4x4 $^3/_8$ 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
4x4 $^1/_4$ 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
6x6 $^1/_2$ 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
6x6 $^3/_8$ 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
6x6 $^1/_4$ 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
8x8 $^1/_2$ 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
8x8 $^3/_8$ 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	4.65
	130	1.60	2.95	4.05	5.02		130	1.62	2.99	4.10	5.08
8x8 $^1/_4$ 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

APPENDIX C

CONVERSION FACTORS—INCH-POUNDS TO SI (METRIC)[A]

To convert from	to	Multiply by
Length		
inch	millimeter (mm)	25.4E[B]
foot	meter (m)	0.3048E
yard	meter (m)	0.9144E
mile (statute)	kilometer (km)	1.609
Area		
square inch	square millimeter (mm^2)	645.1
square foot	square meter (m^2)	0.0929
square yard	square meter (m^2)	0.8361
Volume (capacity)		
ounce	milliliters (mL)	29.57
gallon	cubic meter (m^3)[C]	0.003785
cubic inch	cubic millimeter (mm^3)	16390
cubic foot	cubic meter (m^3)	0.02832
cubic yard	cubic meter (m^3)	0.7646
Force		
kilogram-force	newton (N)	9.807
kip-force	kilo newton (kN)	4.448
pound-force	newton (N)	4.448
Pressure or stress (force per area)		
kilogram-force/square meter	pascal (Pa)	9.807
kip-force/square inch (ksi)	megapascal (MPa)	6.895
newton/square meter (N/m^2)	pascal (Pa)	1.000E
pound-force/square foot	pascal (Pa)	47.88
pound-force/square inch (psi)	kilopascal (kPa)	6.895
Bending moment or torque		
inch-pound-force	newton-meter (N^2m)	0.1130
foot-pound-force	newton-meter (N^2m)	1.356
meter-kilogram-force	newton-meter (N^2m)	9.807
Mass		
ounce-mass (avoirdupois)	gram (g)	28.34
pound-mass (avoirdupois)	kilogram (kg)	0.4536
ton (metric)	megagram (Mg)	1.000E
ton (short, 2000 lbm)	kilogram (kg)	907.2
Mass per volume		
pound-mass/cubic foot	kilogram/cubic meter (kg/m^3)	16.02
pound-mass/cubic yard	kilogram/cubic meter (kg/m^3)	0.5933
pound-mass/gallon	kilogram/cubic meter (kg/m^3)	119.8
Temperature[D]		
degrees Fahrenheit (F)	degrees Celsius (C)	$t_C = (t_F - 32)/1.8$
degrees Celsius (C)	degrees Fahrenheit (F)	$t_F = 1.8t_C + 32$

A. This selected list gives practical conversion factors of units found in concrete technology. The reference sources for information on SI units and more exact conversion factors are ASTM E 380 and E 621. Symbols of metric units are given in parentheses.
B. "E" indicates that the figure given is exact.
C. One liter (cubic decimeter) equals 0.001 m^3 or 1000 cm^3.
D. These equations convert one temperature reading to another and include the necessary scale corrections. To convert the difference in temperature from Fahrenheit degrees to Celsius degrees, divide by 1.8 only, i.e., a change from 70 to 88 deg F represents a change of 18 deg F, or 18/1.8 = 10 deg C.