

An ACI/TMS Standard

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

Reported by ACI/TMS Committee 216



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American Concrete Institute
38800 Country Club Drive
Farmington Hills, MI 48331
Phone: +1.248.848.3700
Fax: +1.248.848.3701

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An ACI and TMS Standard

Reported by ACI Committee 216 joint with TMS

Venkatesh Kumar R. Kodur, Chair

Charles B. Clark Jr.
Donald O. Dusenberry
William L. Gamble
Dennis W. Graber
Thomas F. Herrell
Robert Iding
Joel R. Irvine

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T. D. Lin
Richard J. McGrath
John D. Perry
Stephen Pessiki
Long T. Phan
Walter J. Prebis

John P. Ries
Thomas J. Rowe
Jay G. Sanjayan
Jeffrey F. Speck
Stephen S. Szoke

Consulting Members
Max Kalafat
Wasseem Khan
Steven K. Rowe
Phillip J. Samblanet

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 TMS 402/ACI 530/ASCE 5, 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 ACI 318 and TMS 402/ACI 530/ASCE 5, as in the case of cover protection of steel reinforcement, the more stringent of the requirements shall apply.

Keywords: beams; columns; 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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PREFACE

This standard provides requirements for determining fire resistance of concrete and masonry elements and assemblies. Calculation procedures for determining fire resistance are provided for concrete walls, floors, roofs, and columns and masonry walls, lintels, and columns. Procedures are also included for determining requirements for concrete cover, protection of structural steel columns using concrete or masonry, and for hollow structural steel columns filled with concrete. Procedures for determining the contribution of additional fire resistance provided by finish materials on concrete or masonry assemblies are also included.

CHAPTER 1—GENERAL**1.1—Scope**

This standard describes acceptable methods for determining the fire resistance of concrete 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 E119**. This standard does not apply to composite metal deck floor or roof assemblies.

The primary intended use of this standard 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**. Masonry construction shall comply with **TMS 402/ACI 530.1/ASCE 6**.

The provisions of this standard establish fire resistance based on calculations. 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.

1.2—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 E119**. Computer models, when used, shall be validated and supported by published literature to substantiate their accuracy. Alternative methods include:

Qualification by testing—Materials and assemblies of materials of construction tested in accordance with the requirements set forth in **ASTM E119** shall be classified for fire resistance in accordance with the results and conditions of such tests.

Approval through past performance—The application of fire resistance ratings to elements and assemblies that have been applied in the past and have been proven through performance shall be permitted.

Other 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—NOTATION AND DEFINITIONS**2.1—Notation**

- $A_1, A_2, \text{ and } A_n$ = air factor for each continuous air space having a distance of 1/2 to 3-1/2 in. between wythes
- A_{ps} = cross-sectional area of prestressing tendons, in.²
- A_s = cross-sectional area of nonprestressed 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_0 = 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 = compressive force due to unfactored dead load and live load, kip
- c_c = ambient temperature specific heat of concrete, Btu/(lb-°F)
- d = effective depth, distance from centroid of tension reinforcement to extreme compressive fiber or depth of steel column, in.
- D = for hollow structural steel columns, outside diameter for circular columns, in.; outside dimension for square columns, in.; and least outside dimension for rectangular columns, in.
- D_c = oven-dried density of concrete, lb/ft³

d_{ef} = distance from centroid of tension reinforcement to most extreme concrete compressive fiber at which point temperature does not exceed 1400°F, in.	t_{min} = minimum thickness, in.
d_l = thickness of fire-exposed concrete layer, in.	t_{tot} = total slab thickness, in.
d_{st} = column width, in.	t_w = thickness of web, in.
f_c = measured compressive strength of concrete test cylinders at ambient temperature, psi	T = specified thickness of concrete masonry and clay masonry unit, in.
f'_c = specified compressive strength of concrete, psi	T_e = equivalent thickness of concrete, concrete masonry and clay masonry unit, in.
$f_{c\theta}$ = reduced compressive strength of concrete at elevated temperature, psi	T_{ea} = equivalent thickness of concrete masonry assembly, in.
f_{ps} = stress in prestressing steel at nominal flexural strength, psi	T_{ef} = equivalent thickness of finishes, in.
$f_{ps\theta}$ = reduced stress of prestressing steel at elevated temperature, psi	u = average thickness of concrete between the center of main reinforcing steel and fire-exposed surface, in.
f_{pu} = specified tensile strength of prestressing tendons, psi	u_{ef} = an adjusted value of u to accommodate beam geometry where fire exposure to concrete surfaces is from three sides, in.
f_y = specified yield strength of nonprestressed reinforcing steel, psi	V_n = net volume of masonry unit, in. ³
$f_{y\theta}$ = reduced yield strength of nonprestressed reinforcing steel at elevated temperature, psi	W = average weight of the steel column, lb/ft
H = specified height of masonry unit, in.	w = sum of unfactored dead and live service loads, lb/ft
H_s = ambient temperature thermal capacity of steel column, Btu/(ft-°F)	w_c = density of concrete, lb/ft ³
h = average thickness of concrete cover, in.	w_{cm} = density of masonry protection, lb/ft ³
KL = column effective length, ft	x_0 = distance from inflection point to location of first interior support, measured after moment redistribution has occurred, ft
k_c = thermal conductivity of concrete at room temperature, Btu/(h-ft-°F)	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, ft
k_{cm} = thermal conductivity of concrete masonry at room temperature, Btu/(h-ft-°F)	x_2 = in continuous span, distance between adjacent inflection points, ft
L = specified length of masonry unit or interior dimension of rectangular concrete box protection for steel column, in.	θ = subscript denoting changes of parameter due to elevated temperature
ℓ = clear span between supports, ft	ρ = reinforcement ratio (A_s/bd)
M = moment due to full service load on member, lb-ft	ρ_g = ratio of total reinforcement area to cross-sectional area of column
M_n = nominal moment capacity at section, lb-ft	ω_p = reinforcement index for concrete beam reinforced with prestressing steel
$M_{n\theta}$ = nominal moment capacity of section at elevated temperature, lb-ft	$\omega_{p\theta}$ = reinforcement index for concrete beam reinforced with prestressing steel at elevated temperature
$M_{n\theta}^+$ = nominal positive moment capacity of section at elevated temperature, lb-ft	ω_r = reinforcement index for concrete beam reinforced with nonprestressed steel
$M_{n\theta}^-$ = nominal negative moment capacity of section at elevated temperature, lb-ft	ω_θ = reinforcement index for concrete beam at elevated temperature
M_{x1} = maximum value of redistributed positive moment at some distance x_1 , lb-ft	ψ = modification factor reflecting type of column infill
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_m = fire resistance of assembly, minutes	
R_0 = fire resistance at zero moisture content, minutes	
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 = time, minutes	
t_e = equivalent thickness of a ribbed or undulating concrete section, in.	
t_{e2} = equivalent thickness t_e calculated by dividing the net cross-sectional area by the panel width	

2.2—Definitions

The following terms are defined for general use in this code.

bar, high-strength alloy steel—reinforcement conforming to the requirements of [ASTM A722](#).

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

beam—a structural member subjected to axial load and flexure but primarily to flexure.

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

building official—(1) the official charged with administration and enforcement of the applicable building code; (2) the duly authorized representative of the official.

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

ceramic fiber blanket—mineral wool insulating material made of alumina-silica fibers and having a density of 4 to 8 lb/ft³.

cellular concrete—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 used).

cementitious materials—pozzolans and hydraulic cements.

clay masonry unit—solid or hollow unit (brick or tile) composed of clay, shale, or similar naturally occurring earthen substance shaped into prismatic units and subjected to heat treatment at elevated temperature (firing), meeting requirements of [ASTM C34](#), [C56](#), [C62](#), [C126](#), [C212](#), [C216](#), [C652](#), or [C1088](#).

cold-drawn wire reinforcement—steel wire made from rods that have been hot rolled from billets and cold-drawn through a die.

concrete masonry unit—either a hollow or solid unit (block) composed of portland-cement concrete; often referred to by indicating the type of mineral aggregate incorporated (for example, lightweight or sand-gravel block), meeting the requirements of [ASTM C55](#), [C73](#), [C90](#), [C129](#), [C744](#), or [C1634](#).

continuous slab or beam—a slab or beam that extends as a unit over three or more supports in a given direction.

critical temperature—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.

end-point criteria—conditions of acceptance for an [ASTM E119](#) 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 E119](#).

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—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.

glass fiberboard—fibrous glass insulation board complying with [ASTM C612](#).

gypsum type X wallboard—mill-fabricated product, complying with [ASTM C1396](#), 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.

heat transmission end-point—An acceptance criterion of [ASTM E119](#) 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.

hollow brick or tile of clay or shale—clay or shale masonry units in which the net cross-sectional area in any plane parallel to the surface, containing the cores, cells, or frogs, is less than 75 percent of its gross cross-sectional area measured in the same plane.

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

integrity end-point—an acceptance criterion of [ASTM E119](#) 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.

intumescent mastic—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.

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.

lightweight-aggregate concrete—concrete made with aggregates conforming to [ASTM C330](#) or [C331](#).

mineral board—board made of mineral fiber insulation complying with [ASTM C726](#).

normalweight concrete—concrete containing only aggregate that conforms to [ASTM C33](#).

perlite concrete—nonstructural lightweight insulating concrete having a density of approximately 30 lb/ft³, made by mixing perlite aggregate complying with [ASTM C332](#) with portland cement slurry.

plain concrete—structural concrete with no reinforcement or less reinforcement than the minimum amount specified in [ACI 318](#) for reinforced concrete.

reinforced concrete—structural concrete reinforced with no less than the minimum amount of prestressing steel or nonprestressed reinforcement as specified in [ACI 318](#).

reinforced masonry—masonry in which reinforcement is used to resist tensile forces.

semi-lightweight concrete—concrete made with a combination of lightweight aggregates (expanded clay, shale, slag, slate, or sintered fly ash) and normalweight aggregates, having an equilibrium density of 105 to 120 lb/ft³ in accordance with [ASTM C567](#).

siliceous-aggregate concrete—concrete made with normal-density aggregates having constituents composed mainly of silica or silicates (such as quartz or granite).

solid brick of clay or shale—clay or shale units in which the net cross-sectional area in any plane parallel to the surface, containing the cores or frogs, is at least 75 percent of the gross cross-sectional area measured in the same plane.

sprayed mineral fiber—a blend of refined mineral fibers and inorganic binders to which water is added during the spraying operation.

standard fire exposure—the time-temperature relationship defined by [ASTM E119](#).

standard fire test—the test prescribed by ASTM E119.

steel temperature end-point—an acceptance criterion of ASTM E119 defining the limiting steel temperatures for unrestrained assembly classifications.

strand—an assembly of wires twisted about a center wire or core.

structural concrete—plain or reinforced concrete in a member that is part of a structural system required to transfer gravity, lateral loads, or both, along a load path to the ground.

structural end-point—the acceptance criterion of ASTM E119 that states that the specimen shall sustain with applied load without collapse.

tendon—an assembly consisting of a tensioned element (such as a wire, bar, rod, strand, or a bundle of these elements) used to impart compressive stress in concrete, along with any associated components used to enclose and anchor the tensioned element.

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

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

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

CHAPTER 3—REFERENCED STANDARDS

American Concrete Institute

ACI 117-10—Specification for Tolerances for Concrete Construction and Materials and Commentary

ACI 318-11—Building Code Requirements for Structural Concrete and Commentary

American Institute of Steel Construction

ANSI/AISC 360-10—Specification for Structural Steel Buildings

ASTM International

A722/A722M-12—Standard Specification for Uncoated High-Strength Steel Bars for Prestressing Concrete

ASTM C33/C33M-13—Standard Specification for Concrete Aggregates

ASTM C34-13—Standard Specification for Structural Clay Load-Bearing Wall Tile

ASTM C55-14—Standard Specification for Concrete Building Brick

ASTM C56-13—Standard Specification for Structural Clay Nonloadbearing Tile

ASTM C62-13a—Standard Specification for Building Brick (Solid Masonry Units Made from Clay or Shale)

ASTM C73-10—Standard Specification for Calcium Silicate Brick (Sand-Lime Brick)

ASTM C90-14—Standard Specification for Load-Bearing Concrete Masonry Units

ASTM C126-14—Standard Specification for Ceramic Glazed Structural Clay Facing Tile, Facing Brick, and Solid Masonry Units

ASTM C129-14—Standard Specification for Nonload-bearing Concrete Masonry Units

ASTM C140/C140M-14a—Standard Test Methods for Sampling and Testing Concrete Masonry Units and Related Units

ASTM C212-14—Standard Specification for Structural Clay Facing Tile

ASTM C216-14—Standard Specification for Facing Brick (Solid Masonry Units Made from Clay or Shale)

ASTM C330/C330M-14—Standard Specification for Lightweight Aggregates for Structural Concrete

ASTM C331/C331M-14—Standard Specification for Lightweight Aggregates for Concrete Masonry Units

ASTM C332-09—Standard Specification for Lightweight Aggregates for Insulating Concrete

ASTM C516-08(2013)^{e1}—Standard Specification for Vermiculite Loose Fill Thermal Insulation

ASTM C549-06 (2012)—Standard Specification for Perlite Loose Fill Insulation

ASTM C567/C567M-14—Standard Test Method for Determining Density of Structural Lightweight Concrete

ASTM C612-14—Standard Specification for Mineral Fiber Block and Board Thermal Insulation

ASTM C652-14—Standard Specification for Hollow Brick (Hollow Masonry Units Made from Clay or Shale)

ASTM C726-12—Standard Specification for Mineral Wool Roof Insulation Board

ASTM C744-14—Standard Specification for Prefaced Concrete and Calcium Silicate Masonry Units

ASTM C1088-14—Standard Specification for Thin Veneer Brick Units Made from Clay or Shale

ASTM C1396/C1396M-14—Standard Specification for Gypsum Board

ASTM C1405-14—Standard Specification for Glazed Brick (Single Fired, Brick Units)

ASTM C1634-11—Standard Specification for Concrete Building Brick

ASTM E119-12a—Standard Test Methods for Fire Tests of Building Construction and Materials

The Masonry Society

TMS 402-13/ACI 530-13/ASCE 5-13—Building Code Requirements for Masonry Structures

TMS 602-13/ACI 530.1-13/ASCE 6-13—Specification for Masonry Structures

CHAPTER 4—CONCRETE

4.1—General

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

Table 4.2—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

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 fire resistance.

In some cases, distinctions are made between normal-weight 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.

4.2—Concrete walls, floors, and roofs

Concrete bearing or nonbearing walls, floor slabs, and roof slabs required to provide fire-resistance ratings of 1 to 4 hours shall comply with the minimum equivalent thickness values in Table 4.2. For solid walls and slabs with flat surfaces, the equivalent thickness shall be determined in accordance with 4.2.1. 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 4.2.2 through 4.2.4. Minimum cover protection of steel reinforcement shall be determined in accordance with 4.3.

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

4.2.2 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, the equivalent thickness shall be calculated 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.

4.2.3 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. 4.2.3).

4.2.4 Ribbed or undulating panels—the equivalent thickness t_e of elements consisting of panels with ribbed or undulating surfaces shall be calculated as follows:

4.2.4.1 Where the center-to-center spacing of ribs or undulations, s , is more than four times the minimum thickness, the equivalent thickness t_e shall be the minimum thickness of the panel neglecting the ribs or undulations (Fig. 4.2.3).

4.2.4.2. Where the center-to-center spacing of ribs or undulations is equal to or less than two times the minimum

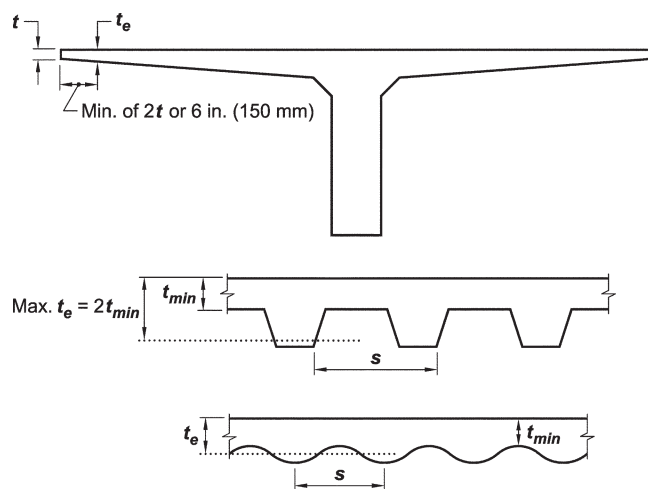


Fig. 4.2.3—Equivalent thickness of flanged, ribbed, and undulating panels.

thickness, the equivalent thickness t_e shall be calculated 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.

4.2.4.3. 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, the equivalent thickness t_e shall be calculated by the following equation

$$t_e = t_{min} + [(4t_{min}/s) - 1](t_{e2} - t_{min}) \quad (4.2.4.3)$$

where t_e is the equivalent thickness of a ribbed or undulating concrete section, in.; t_{min} is the minimum thickness, in.; s is the center-to-center spacing of items such as ribs or undulations, in.; and t_{e2} is calculated in accordance with 4.2.4.2.

4.2.5 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, the fire resistance shall be determined in accordance with the graphical or numerical solutions in 4.2.5.1, 4.2.5.2, or 4.2.5.3. The fire resistance of insulated concrete floors and roofs shall be determined in accordance with 4.2.6.

4.2.5.1 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. 4.2.5.1 or from Eq. (4.2.5.2a) or (4.2.5.2b). Separate fire-resistance calculations, assuming each side of the element is the fire-exposed side, shall be performed. 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.

4.2.5.2 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 fire resistance of the assembly shall be permitted to be determined using one of the following expressions (when both sides are fire exposed, the lower calculated fire resistance governs):

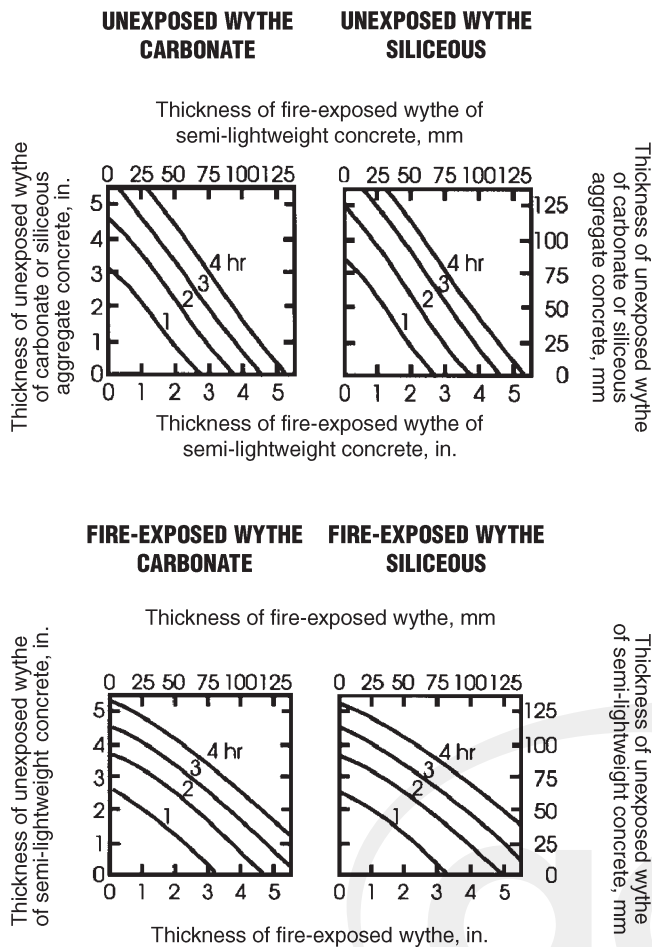


Fig. 4.2.5.1—Fire resistance of two-layer concrete walls, floors, and roofs.

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

$$R = 0.057(2t_{tot}^2 - d_l t_{tot} + 6/t_{tot}) \quad (4.2.5.2a)$$

where R is the fire resistance of assembly, hours; t_{tot} is the total slab thickness, in.; and d_l is the thickness of fire-exposed concrete layer, in.

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

$$R = 0.063(t_{tot}^2 + 2d_l t_{tot} - d_l^2 + 4/t_{tot}) \quad (4.2.5.2b)$$

4.2.5.3 Alternative numerical solution—The fire resistance for walls, floors, and roofs not meeting the criteria of 4.2.5.1 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, shall be determined by Eq. (4.2.5.3).

$$R = (R_1^{0.59} + R_2^{0.59} + \dots + R_n^{0.59} + A_1 + A_2 + \dots + A_n)^{1.7} \quad (4.2.5.3)$$

where R_1 , R_2 , and R_n are fire resistance of layers 1, 2, ..., n , respectively, hours; and $A_1 = A_2 = A_n = 0.30$, the air factor for

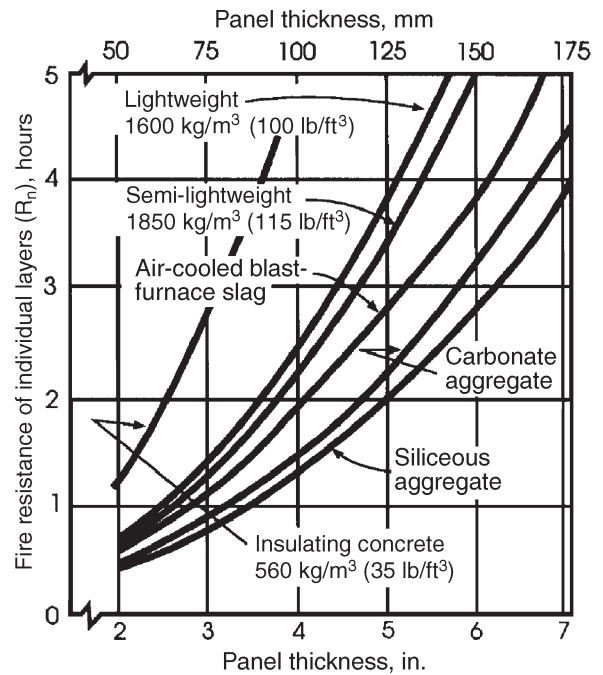


Fig. 4.2.5.3—Effect of slab thickness and aggregate type of fire resistance of concrete slabs based on 250°F rise in temperature of unexposed surface.

each continuous air space having a distance of 1/2 to 3-1/2 in. between wythes.

Obtain values of R_n for individual layers for use in Eq. (4.2.5.3) from Table 4.2 or Fig. 4.2.5.3 for concrete materials, from Table 5.1a for concrete masonry, and Table 6.3.1 for clay masonry. Interpolation between values in the tables shall be permitted. Equation (4.2.5.3) does not consider which layer is being exposed to the fire.

4.2.5.4 Sandwich panels—The fire resistance of precast concrete wall panels consisting of a layer of foam plastic sandwiched between two layers of concrete shall be determined by using Eq. (4.2.5.3). For foam plastic with a thickness not less than 1 in., use $R_n^{0.59} = 0.22$ hours in Eq. (4.2.5.3). 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.

4.2.6 Insulated floors and roofs—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, shall be determined using Fig. 4.2.6a or Fig. 4.2.6b. 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. 4.2.6a or Fig. 4.2.6c.

4.2.7 Protection of joints between precast concrete wall panels and slabs—When joints between precast concrete wall panels are required to be insulated by 4.2.7.1, this shall be done in accordance with 4.2.7.2. Joints between precast concrete slabs shall be protected in accordance with 4.2.7.3.

4.2.7.1 Joints in walls required to be insulated—Where openings are not permitted, where openings are required

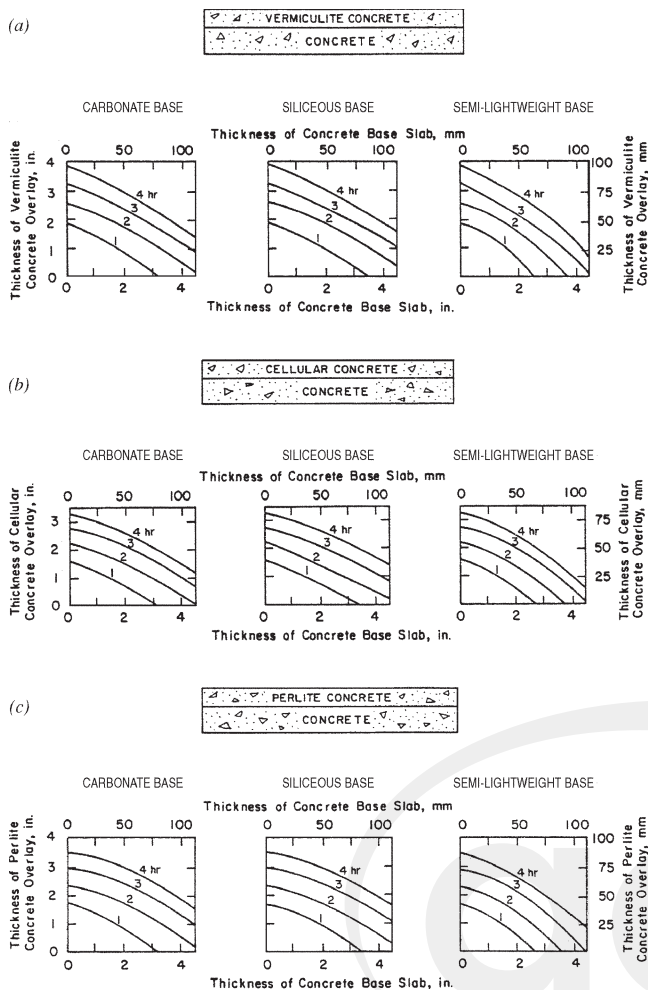


Fig. 4.2.6a—Fire resistance of concrete base slabs with overlays of insulating concrete, 30 lb/ft³.

to be protected, the provisions of 4.2.7.2 shall be used to determine the required thickness of joint insulation. Joints between concrete wall panels that are not insulated as prescribed in 4.2.7.2 shall be considered unprotected openings. Where the percentage of unprotected openings is limited in exterior walls, uninsulated joints in exterior walls with other unprotected openings shall be included. Insulated joints that comply with 4.2.7.2 shall not be considered openings for purposes of determining allowable percentage of openings.

4.2.7.2 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. 4.2.7.2. For joint widths between 3/8 and 1 in., determine the thickness of insulation by interpolation. When approved by the building official, other joint treatment systems that maintain the required fire resistance shall be permitted.

4.2.7.3 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

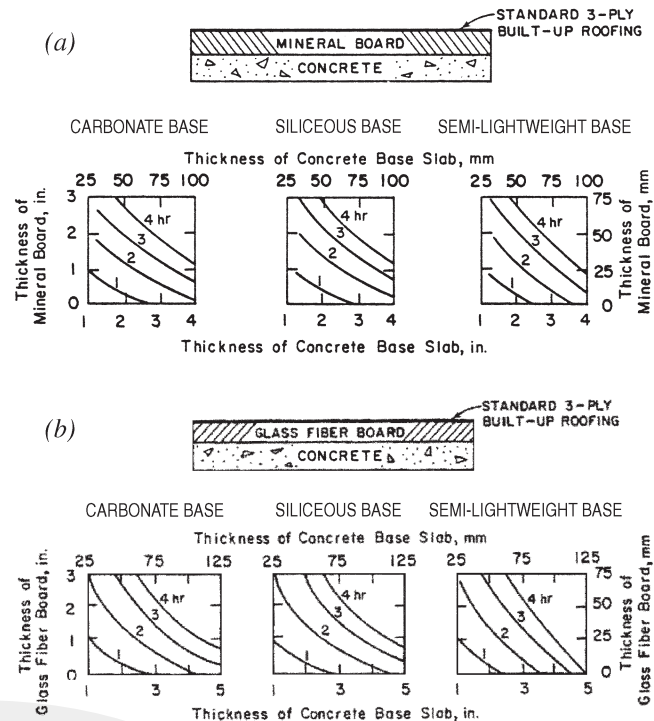


Fig. 4.2.6b—Fire resistance of concrete roofs with board insulation.

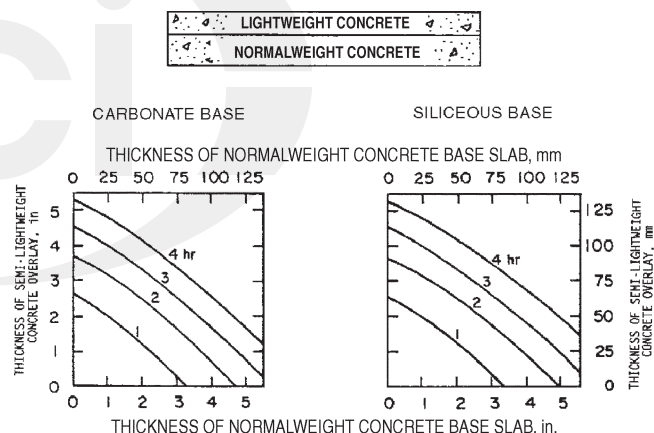


Fig. 4.2.6c—Fire resistance of semi-lightweight concrete overlays on normalweight concrete base slabs.

depth of at least one-third 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 4.2.7.2.

4.2.8 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 7.

4.3—Concrete cover protection of steel reinforcement

Cover protection determinations in this section shall be based on the structural end-point assemblies required to