PCI MNL 124-18

Specification for Fire Resistance of Precast/Prestressed Concrete

A PCI Standard

FOREWORD

The Precast/Prestressed Concrete Institute first promulgated a manual for the design for fire resistance of precast prestressed concrete in 1977. A second edition was prepared in 1989 and a third edition in 2011. Recommended design procedures in these three editions were based on fire test data and reports for precast prestressed concrete dating back to the 1960’s. Little has changed in fundamental design for fire resistance. While fire resistance is discussed in other publications as “calculated” fire resistance, these provisions have generally been prescriptive. That is, tables of information are used to select concrete mass or protection for steel. Since the first edition of the PCI manual, rational design, which is truly a fire resistance calculation procedure, has been illustrated. Though not a standard, the first edition of the International Building Code in 2000 referenced the procedures in the PCI fire design manual as being acceptable for prestressed slabs not covered elsewhere.

With 2014 designation of PCI as an ANSI Accredited Standards Developer by the American National Standards Institute, the material for fire resistance of precast and prestressed concrete was deemed important enough to the precast industry that the newest edition of the provisions would be developed in a consensus standard form. Thus, the design procedures would be referenced in the 2021 International Building Code as a standard developed through a ANSI consensus process.

PREFACE

This standard was developed following the protocols required by the PCI Group Operations Manual. The provisions were first generated and balloted in the PCI Fire Committee. A review and comment by the PCI Technical Activities Council (TAC) followed and resulted in substantive changes to the document. These changes were balloted by the PCI Fire Committee and finally accepted by the PCI TAC. The document was then submitted to the PCI Standards Committee where additional review and balloting took place. The membership of that committee is balanced according to the rules of ANSI accreditation. In addition, a public review period was provided and public comments were resolved through the PCI Standards Committee. The entire process is a consensus process involving PCI members, non-members of PCI and the general public.
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CHAPTER 1—GENERAL

1.1—Scope. This document specifies requirements for the design of precast and precast, prestressed concrete elements to resist fire and provide fire protection. For the purposes of this standard, “precast concrete element” shall mean a plant-cast concrete member reinforced with any combination of nonprestressed deformed reinforcement or prestressed strand. This standard provides acceptable methods to determine the fire resistance of precast concrete structural elements, including walls, floor and roof slabs, beams, and columns, and the fire protection for structural steel columns with precast concrete covers. The fire exposure and applicable end-point criteria of ASTM E119 shall be used in the application of these methods for design. Except where the requirements of this standard are more stringent, elements shall conform to the requirements of ACI 318.

1.2—Definitions. The following definitions shall apply for the purposes of this standard:

- **approved**—approved by the building official responsible for enforcing the legally adopted building code of which this standard is a part, or approved by some other authority having jurisdiction.
- **bar, high-strength alloy steel**—steel bars conforming to the requirements of ASTM A722/A722M.
- **beam**—a structural member with a primary load demand in flexure or shear.
- **blanket, ceramic fiber**—mineral wool insulating material made of alumina-silica fibers and having a density of 4 to 8 lb/ft³ (64 to 128 kg/m³).
- **board, mineral**—a rigid, felted thermal insulation board complying with ASTM C726.
- **building code**—a legal document that establishes the minimum requirements necessary for building design and construction to provide for public health and safety.
- **concrete, carbonate aggregate**—concrete made with coarse aggregate consisting mainly of calcium or magnesium carbonate or a combination of calcium and magnesium carbonate (for example, limestone or dolomite).
- **concrete, lightweight-aggregate**—concrete made with aggregates conforming to ASTM C330/C330M.
- **concrete, normalweight**—concrete made with aggregates conforming to ASTM C33/C33M.
- **concrete, perlite**—nonstructural lightweight insulating concrete made by mixing perlite aggregate complying with ASTM C332 with portland cement slurry, having a density of approximately 30 lb/ft³ (481 kg/m³).
- **concrete, sand-lightweight**—concrete made with lightweight coarse aggregate conforming to ASTM C330/C330M and normal weight fine aggregate conforming to ASTM C33/C33M.
- **concrete, siliceous aggregate**—normal weight concrete having aggregates composed mainly of silica or silicate compounds other than calcium or magnesium carbonate (for example granite).
- **concrete, vermiculite**—nonstructural lightweight insulating concrete in which the aggregate consists of exfoliated vermiculite, having a density of approximately 30 lb/ft³ (481 kg/m³).
- **end-point criteria**—conditions of acceptance for an ASTM E119 fire test.
- **end-point, heat transmission**—An acceptance criterion of ASTM E119 limiting the temperature rise of the unexposed surface to an average of 250°F (121°C) for all measuring points or a maximum of 325°F (163°C) at any one point.
- **end-point, integrity**—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. This term also applies to the hose-stream test of a fire-exposed wall.
- **end-point, steel temperature**—an acceptance criterion of ASTM E119 defining the limiting steel temperatures for unrestrained assembly classifications.
- **end-point, structural**—ASTM E119 criteria that specify the conditions of acceptance for structural performance of a tested assembly.
- **endurance, fire**—a measure of the elapsed time during which a material or assembly continues to exhibit fire resistance. Elapsed time as applied to elements of buildings shall be measured in accordance with ASTM E119.
- **fiberboard, glass**—fibrous glass insulation board complying with ASTM C612.
- **fiber, sprayed mineral [SMF]**—a blend of refined mineral fibers and inorganic binders.
- **fire resistance**—the property of a material or assembly to withstand fire or provide protection from it. It is characterized by the ability to confine a fire and/or continue to perform a given structural function when exposed to fire.
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.

insulation, mineral wool—resilient, noncombustible spun mineral fiber with a minimum density of 10 lb/ft³ (160 kg/m³).

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.

mastic, intumescent—spray-applied coating that reacts to heat at approximately 300°F (149°C) by foaming to a multicellular structure having 10 to 15 times its initial thickness.

material, vermiculite cementitious [VCM]—cementitious material containing mill-mixed vermiculite to which water is added to form a mixture suitable for spraying, with an approximate wet unit weight between 55 and 60 lb/ft³ (881 to 961 kg/m³).

reinforcement, cold-drawn wire—steel wire made from rods that have been rolled from billets, cold-drawn through a die; for concrete reinforcement of a diameter not less than 0.08 in. (2 mm) nor greater than 0.625 in. (15.9 mm).

standard fire exposure—the time-temperature relationship defined by ASTM E119.

standard fire test—the test prescribed by ASTM E119.

steel, cold-drawn—uncoated steel used in prestressing wire or strand but not including high-strength alloy steel bars used for post-tensioning tendons.

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

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

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

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

wallboard, gypsum type “X”—mill-fabricated product complying with ASTM C1396/C1396M Type X, made of a gypsum core containing special minerals and encased in a smooth, finished paper on the face side and liner paper on the back.

1.3—Notation. The following notation shall be used in the application of the design methods specified herein:

\[ A = \text{cross-sectional area, in.}^2 \text{ (mm}^2 \text{)} \]
\[ A_{ps} = \text{cross-sectional area of prestressing tendons, in.}^2 \text{ (mm}^2 \text{)} \]
\[ A_t = \text{cross-sectional area of nonprestressed longitudinal tension reinforcement, in.}^2 \text{ (mm}^2 \text{)} \]
\[ a = \text{depth of equivalent rectangular concrete compressive stress block at nominal flexural strength, in. (mm)} \]
\[ a_{\theta} = \text{depth of equivalent concrete rectangular stress block at elevated temperature, in. (mm)} \]
\[ b = \text{width of compression zone (flexure), in. (mm)} \]
\[ b = \text{width of beam or joist at centroid of reinforcement (temperature from fire exposure), in. (mm)} \]
\[ d = \text{distance from centroid of longitudinal tension reinforcement to extreme compressive fiber, in. (mm)} \]
\[ E = \text{modulus of elasticity of concrete, psi or ksi (MPa)} \]
\[ f_c = \text{measured compressive strength of concrete, psi or ksi (MPa)} \]
\[ f_{c}^* = \text{specified compressive strength of concrete, psi or ksi (MPa)} \]
\[ f_{c,\theta} = \text{reduced compressive strength of concrete at elevated temperature, psi or ksi (MPa)} \]
\[ f_{ps} = \text{stress in prestressing steel at nominal flexural strength, psi or ksi (MPa)} \]
\[ f_{ps,\theta} = \text{stress in prestressing steel at elevated temperature, psi or ksi (MPa)} \]
\[ f_{pu} = \text{specified ultimate tensile strength of prestressing steel, psi or ksi (MPa)} \]
\[ f_{pu,\theta} = \text{ultimate tensile strength of prestressing steel at elevated temperature, psi or ksi (MPa)} \]
\[ f_y = \text{yield strength of nonprestressed reinforcing steel, psi or ksi (MPa)} \]
\[ h = \text{average thickness of concrete cover, in. (mm)} \]
\[ \theta = \text{clear span between supports, ft (mm)} \]
\[ M = \text{applied moment due to full service load on member, lb-ft (kN-m)} \]
\[ M_n = \text{nominal flexural strength at section, lb-ft (kN-m)} \]
\[ M_{n,0} = \text{nominal flexural strength at section at elevated temperature, lb-ft (kN-m)} \]
\[ R = \text{fire resistance, minutes} \]
\[ R_i = \text{fire resistance of individual components, minutes} \]
\[ s = \text{spacing of ribs, in. (mm)} \]
\[ t = \text{thickness, in. (mm)} \]
\[ t_e = \text{equivalent thickness, in. (mm)} \]
\[ T_e = \text{equivalent thickness calculated in 3.2.2.3(2)(b), in. (mm)} \]
\[ u = \text{average thickness of concrete between the center of main reinforcing steel and fire-exposed surface, in. (mm)} \]
\[ \bar{u} = \text{effective } u, \text{ the average thickness of concrete between the centroid of the multiple strands and the nearest fire-exposed surface, in. (mm)} \]
\[ u_s = \text{distance from side of beam or joist to a point within the member, in. (mm)} \]
\[ w = \text{uniformly distributed load on a flexural member} \]
\[ X_0 = \text{distance from inflection point to location of first interior support, measured after moment redistribution has occurred, in. (mm)} \]
\[ X_1 = \text{distance along length of a flexural member from a support to a point of maximum moment, in. (mm)} \]
\[ X_2 = \text{distance along length of flexural member between points of zero moment, in. (mm)} \]
\[ \theta = \text{subscript denoting changes of parameter due to elevated temperature} \]
\[ \phi = \text{strength reduction factor as specified in ACI 318} \]
\[ \omega_p = \text{reinforcement index for concrete beam reinforced with prestressing steel, taken as } A_{psf}/bdf'c \]
\[ \omega_n = \text{reinforcement index for concrete beam reinforced with nonprestressed steel, taken as } A_{fsy}/bdf'c \]

1.4—Referenced standards.

American Concrete Institute
- 117-10 Standard Specification for Tolerances for Concrete Construction and Materials and Commentary
- 216.1-14 Code Requirements for Determining Fire Resistance of Concrete and Masonry Construction Assemblies
- 318-14 Building Code Requirements for Structural Concrete and Commentary

ASTM International
- A722/A722M-15 Standard Specification for Uncoated High-Strength Steel Bars for Prestressed Concrete
- C33/C33M-16e1 Standard Specification for Concrete Aggregates
- C330/C330M-14 Standard Specification for Lightweight Aggregates for Structural Concrete
- C331/C331M-14 Standard Specification for Lightweight Aggregates for Concrete Masonry Units
- C332-09 Standard Specification for Lightweight Aggregates for Insulating Concrete
- C516-08(2013)e1 Standard Specification for Vermiculite Loose Fill Thermal Insulation
- C567/C567M-14 Standard Test Method for Determining Density of Structural Lightweight Concrete
- C612-14 Standard Specification for Mineral Fiber Block and Board Thermal Insulation
- C726-17 Standard Specification for Mineral Wool Roof Insulation Board
- C796/C796M-12 Standard Test Method for Foaming Agents for Use in Producing Cellular Concrete Using Preformed Foam
- C1396/C1396M-14a Standard Specification for Gypsum Board

International Code Council
- IBC-18 International Building Code
2.1—General. The provisions in this section shall be used to perform the calculations necessary to determine the fire resistance of precast concrete.

2.1.1 Alternate documentation. Where approved, other technical substantiation to establish the material criteria needed for performance of the fire resistance calculations specified herein shall be permitted.

2.2—Steel properties. If uncoated hot-rolled and cold-drawn steel or high-strength alloy steel bars are used for the structural design of the precast concrete elements, the residual strength of the steel at elevated temperatures from fire exposure shall be determined using Fig. 2.2(a).

Figure 2.2(a)
Strength-temperature relationships of steel.

Note: °F = (°C × 1.8) + 32; 1 ksi = 6.895 MPa.

2.2.1 Steel temperatures. The temperature of the reinforcement at the required fire resistance shall be determined based on the temperature of the concrete at the centroid of the reinforcement in accordance with the following.
a) Figures 2.2(b), 2.2(c), or 2.2(d) for solid and hollow core slabs.

b) Figures 2.2(e), 2.2(f), 2.2(g), 2.2(h), 2.2(i), and 2.2(j) for beams and stemmed members with widths between 3 and 10 in. (76 and 254 mm).

c) For beams and slabs not conforming to (a) or (b), isotherm diagrams shall be determined based on test data.

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**Figure 2.2(b)**

Steel temperature based on carbonate concrete cover.

Note: °F = (°C × 1.8) + 32; 1 in. = 25.4 mm.
Figure 2.2(c)
Steel temperature based on siliceous concrete cover.
Note: °F = (°C × 1.8) + 32; 1 in. = 25.4 mm.
Figure 2.2(d)
Steel temperature based on sand-lightweight concrete cover.

Note: °F = (°C × 1.8) + 32; 1 in. = 25.4 mm.
Figures 2.2(e)
Steel temperature based on beams and stem size at ½ hr exposure.
Note: °F = (°C × 1.8) + 32; 1 in. = 25.4 mm.

Figures 2.2(f)
Steel temperature based on beams and stem size at 1 hr exposure.
Note: °F = (°C × 1.8) + 32; 1 in. = 25.4 mm.
Figures 2.2(g)
Steel temperature based on beams and stem size at 1 ½ hr exposure.
Note: °F = (°C × 1.8) + 32; 1 in. = 25.4 mm.

Figures 2.2(h)
Steel temperature based on beams and stem size at 2 hr exposure.
Note: °F = (°C × 1.8) + 32; 1 in. = 25.4 mm.
Figures 2.2(i)
Steel temperature based on beams and stem size at 3 hr exposure.
Note: °F = (°C × 1.8) + 32; 1 in. = 25.4 mm.

Figures 2.2(j)
Steel temperature based on beams and stem size at 4 hr exposure.
Note: °F = (°C × 1.8) + 32; 1 in. = 25.4 mm.
2.3—Concrete properties. If sand-lightweight, carbonate or siliceous aggregate concrete are used for the structural design of the precast concrete elements, the residual compressive strength of the concrete at elevated temperatures from fire exposure shall be determined using Fig. 2.2(k).

![Figure 2.2(k)
Strength-temperature relations of concrete.](image)

Note: °F = (°C × 1.8) + 32; 1 psi = 6.895 kPa.

2.3.1 Concrete temperatures. The temperature of the concrete, at the required fire resistance, shall be determined in accordance with the following.

a) Figures 2.2(b), 2.2(c), or 2.2(d) for solid and hollow core slabs.

b) Figures 2.2(e), 2.2(f), 2.2(g), 2.2(h), 2.2(i), and 2.2(j) for beams and stemmed members with widths between 3 and 10 in. (76 and 254 mm).

c) For beams and slabs not conforming to (a) or (b), isotherm diagrams shall be determined based on test data.

2.4—Determining restrained/unrestrained conditions. In determining the fire resistance, the precast concrete elements shall be classified as being in a restrained or unrestrained condition, in accordance with 2.4.1. Precast concrete elements that do not comply with 2.4.1 shall be classified as unrestrained.

2.4.1 Restrained conditions. Precast and cast-in-place concrete floor or roof systems are permitted to be considered restrained where the floor or roof elements are secured to the building frame such that the thermal expansion of the floor or roof system is resisted by the frame. The following conditions are permitted to be classified as a restrained condition.
1) Single-span or simply supported end spans of multiple bay structures if the spans are tied into walls with or without tie beams, and the walls are designed and detailed to resist thermal expansion from the span.

2) Interior spans of multiple bay structures where (a), (b), (c), (d), or (e) is satisfied:
   a) A continuous structural concrete slab or topping.
   b) The space between the ends of precast concrete elements is filled with concrete or mortar.
   c) The space between the ends of precast concrete elements and the vertical face of the support is filled with concrete or mortar.
   d) The space between the end of precast concrete elements does not exceed 0.25% of the length for members made with normalweight concrete and 0.10% of the length for members made with structural lightweight-aggregate or sand-lightweight concrete.
   e) The space between the ends of precast concrete solid or hollow-core slab elements and the vertical face of the supports does not exceed 0.25% of the length for members made with normalweight concrete and 0.10% of the length for members made with structural lightweight-aggregate or sand-lightweight concrete.

3) End bays of steel-framed or concrete-framed buildings if precast concrete decks are secured to the framing and the framing or the adjoining floor or roof construction is designed and detailed to resist thermal expansion from the span.

4) Interior and exterior spans of precast concrete systems with cast-in-place concrete joints, pour strips with chord reinforcement or welded chord connections, or topping.

2.5—Methods for determining structural fire resistance of precast concrete elements. The fire resistance of precast concrete elements shall be determined in accordance with 2.5.1 or 2.5.2.

Exception. Fire resistance for precast concrete elements determined in accordance with other approved standards.

2.5.1 Prescriptive fire-resistant design. The fire resistance of precast concrete elements shall be permitted to be determined in accordance with the prescriptive provisions in 3.2 to show compliance with the required fire resistance.

2.5.2 Rational design. The fire resistance of precast concrete elements shall be permitted to be calculated in accordance with the rational provisions in 3.3 to show compliance with the required fire resistance.
CHAPTER 3—PRECAST CONCRETE ELEMENTS

3.1—General. The fire resistance of precast concrete elements shall be determined in accordance with 3.2 or 3.3.

3.2—Prescriptive requirements. The fire resistance for precast concrete columns, walls, beams, and slabs shall be determined in accordance with 3.2.1 through 3.2.4.

3.2.1 Columns. The fire resistance of precast concrete columns shall be determined in accordance with 3.2.1.1 and 3.2.1.2. The fire resistance of steel columns protected by precast concrete covers shall be determined in accordance with 3.2.1.3.

3.2.1.1 Columns dimensions. The minimum dimension on any side for precast concrete columns with a compressive strength less than or equal to 12,000 psi (82.7 MPa) shall be determined from Table 3.2.1 based on the type of concrete used and the required fire resistance. Precast concrete columns with a compressive strength greater than 12,000 psi (82.7 MPa) shall have a minimum dimension of 24 in. (610 mm) on any side for all concrete types and all fire-resistance ratings.

Table 3.2.1 Minimum precast concrete column dimensions

<table>
<thead>
<tr>
<th>Fire resistance, hours</th>
<th>Minimum precast concrete column dimensions, in. (mm)</th>
<th>Siliceous</th>
<th>Carbonate</th>
<th>Sand-lightweight, lightweight</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td></td>
<td>8 (203)</td>
<td>8 (203)</td>
<td>8 (203)</td>
</tr>
<tr>
<td>1½</td>
<td></td>
<td>9 (229)</td>
<td>9 (229)</td>
<td>8½ (216)</td>
</tr>
<tr>
<td>2</td>
<td></td>
<td>10 (254)</td>
<td>10 (254)</td>
<td>9 (229)</td>
</tr>
<tr>
<td>3</td>
<td></td>
<td>12 (305)</td>
<td>11 (279)</td>
<td>10½ (267)</td>
</tr>
<tr>
<td>4†</td>
<td></td>
<td>14 (356)</td>
<td>12 (305)</td>
<td>12 (305)</td>
</tr>
</tbody>
</table>

* Where two parallel sides of a column are at least 36 in. (914 mm) in width, the minimum dimension of the other sides can be reduced to 8 in. (203 mm).
† Where two parallel sides of a column are at least 36 in. (914 mm) in width, the minimum dimension of the other sides can be reduced to 10 in. (254 mm).

3.2.1.2 Column reinforcement cover. The main longitudinal reinforcement in all precast concrete columns shall be provided with a minimum of 1 in. (25 mm) of concrete cover for each hour of fire resistance up to a maximum cover thickness of 2 in. (51 mm). Spiral and tie reinforcement for precast concrete columns with a compressive strength $f'$, greater than 12,000 psi (82.7 MPa) shall also satisfy (a) through (e).

a) Free ends of rectangular ties shall be terminated with a 135-degree standard hook.
b) Free ends of circular ties shall be terminated with a 90-degree standard hook.
c) Free ends of spirals shall be terminated with a 90-degree standard hook. This requirement also applies to free ends of lap splices.
d) Hook extensions shall be six (6) bar diameters and at least 3 in. (76 mm), except for no. 6, no. 7, and no. 8 bars in 90-degree hooks where hook extensions shall be twelve (12) bar diameters.
e) Hook extensions shall be directed into the core of the column.

3.2.1.3 Steel columns protected by precast concrete cover. The fire resistance of steel columns shall be permitted to be provided by precast concrete cover elements that satisfy the requirements of this section.

3.2.1.3.1 Thickness of precast concrete cover. The thickness of the precast concrete cover shall be determined from Fig. 3.2(a) or 3.2(b) based on the required fire resistance for the steel column, size of the steel column, and the concrete type used for the precast concrete cover. Precast concrete covers in accordance with Fig. 3.2(c) shall be permitted.
Figure 3.2(a) and (b)
Fire endurance of steel columns protected by concrete covers.
Note: 1 in. = 25.4 mm.

Figure 3.2(c)
Precast concrete covers.
3.2.1.3.2 Other steel column sizes and shapes. Where the steel column size or shape specified is not shown, the precast concrete cover shall be permitted to determined based on interpolation between curves based on the unit weight per foot of the steel.

3.2.1.3.3 Vertical movement. The precast concrete covers shall be attached to the steel columns with connections that permit vertical movement of the covers due to expansion from fire.

3.2.1.3.4 Joints and gaps in precast concrete covers. The vertical and horizontal joints between precast concrete covers shall be provided with protection in accordance with 4.2.2. Gaps at the top between the precast concrete cover and the steel column shall be filled with mineral fiber or ceramic fiber material to the same depth as required for the vertical or horizontal joints.

3.2.2 Walls. The fire resistance for precast concrete wall assemblies shall be determined in accordance with 3.2.2.1 through 3.2.2.4.

3.2.2.1 Solid precast concrete wall panels. The fire resistance of solid precast concrete wall panels shall be determined in accordance with Table 3.2.2(a) based on the thickness of the concrete and the aggregate used for the concrete mixture. Where the precast concrete wall panel is provided with a layer of 5/8 in. (16 mm) thick Type X gypsum board on the fire-exposed side of the wall, the fire resistance shall be permitted to be determined in accordance with Table 3.2.2(b) based on the thickness of the concrete and the aggregate used for the concrete mixture.

Table 3.2.2(a) Thickness of solid concrete wall panels for fire endurance

<table>
<thead>
<tr>
<th>Aggregate</th>
<th>Thickness in in. (mm) for fire endurance of</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1 hour</td>
</tr>
<tr>
<td>All Lightweight</td>
<td>2.5 (64)</td>
</tr>
<tr>
<td>Sand-lightweight</td>
<td>2.7 (69)</td>
</tr>
<tr>
<td>Carbonate</td>
<td>3.2 (81)</td>
</tr>
<tr>
<td>Siliceous</td>
<td>3.5 (89)</td>
</tr>
</tbody>
</table>

Table 3.2.2(b) Thickness of concrete wall panels faced with 5/8 in. (16 mm) thick type X gypsum wallboard for fire endurance

<table>
<thead>
<tr>
<th>Aggregate</th>
<th>Thickness in in. (mm) for fire endurance of</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>2 hour</td>
</tr>
<tr>
<td>Sand-lightweight</td>
<td>2.5 (64)</td>
</tr>
<tr>
<td>Carbonate</td>
<td>2.8 (71)</td>
</tr>
<tr>
<td>Siliceous</td>
<td>2.9 (74)</td>
</tr>
</tbody>
</table>

3.2.2.2 Multi-course solid precast concrete wall panels. Where precast concrete wall panels are constructed of two courses, the fire resistance of the two-course precast concrete wall panels shall be determined in accordance with Table 3.2.2(c) based on the thickness of the concrete, the aggregate used for the concrete mixture, and the fire-exposed wythe material.
### Table 3.2.2(c) Thickness of inside wythes in in. (mm) for fire endurance for two-course panels

<table>
<thead>
<tr>
<th>Fire Endurance</th>
<th>Inside wythe material (fire exposed side)</th>
<th>Siliceous</th>
<th>Sand-lightweight</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>1 ½ in. (38 mm)</td>
<td>2 in. (51 mm)</td>
</tr>
<tr>
<td>1 hour</td>
<td>Carbonate aggregate concrete</td>
<td>1.9 (48)</td>
<td>1.4 (36)</td>
</tr>
<tr>
<td></td>
<td>Siliceous aggregate concrete</td>
<td>2.0 (51)</td>
<td>1.5 (38)</td>
</tr>
<tr>
<td></td>
<td>Lightweight aggregate concrete</td>
<td>1.5 (38)</td>
<td>1.2 (30)</td>
</tr>
<tr>
<td></td>
<td>Cellular concrete¹</td>
<td>0.7 (18)</td>
<td>0.5 (13)</td>
</tr>
<tr>
<td></td>
<td>Perlite concrete¹</td>
<td>0.8 (20)</td>
<td>0.6 (15)</td>
</tr>
<tr>
<td></td>
<td>Vermiculite concrete¹</td>
<td>0.9 (23)</td>
<td>0.6 (15)</td>
</tr>
<tr>
<td></td>
<td>Sprayed mineral fiber</td>
<td>0.4 (10)</td>
<td>0.3 (8)</td>
</tr>
<tr>
<td></td>
<td>Sprayed vermiculite cementitious</td>
<td>0.4 (10)</td>
<td>0.3 (8)</td>
</tr>
<tr>
<td>2 hour</td>
<td>Carbonate aggregate concrete</td>
<td>3.3 (84)</td>
<td>2.8 (71)</td>
</tr>
<tr>
<td></td>
<td>Siliceous aggregate concrete</td>
<td>3.5 (89)</td>
<td>3.0 (76)</td>
</tr>
<tr>
<td></td>
<td>Lightweight aggregate concrete</td>
<td>2.5 (64)</td>
<td>2.1 (53)</td>
</tr>
<tr>
<td></td>
<td>Cellular concrete¹</td>
<td>1.2 (30)</td>
<td>1.0 (25)</td>
</tr>
<tr>
<td></td>
<td>Perlite concrete¹</td>
<td>1.4 (36)</td>
<td>1.1 (28)</td>
</tr>
<tr>
<td></td>
<td>Vermiculite concrete¹</td>
<td>1.6 (41)</td>
<td>1.3 (33)</td>
</tr>
<tr>
<td></td>
<td>Sprayed mineral fiber</td>
<td>1.1 (28)</td>
<td>0.8 (20)</td>
</tr>
<tr>
<td></td>
<td>Sprayed vermiculite cementitious</td>
<td>1.0 (25)</td>
<td>0.8 (20)</td>
</tr>
<tr>
<td>3 hour</td>
<td>Carbonate aggregate concrete</td>
<td>4.4 (112)</td>
<td>3.9 (99)</td>
</tr>
<tr>
<td></td>
<td>Siliceous aggregate concrete</td>
<td>4.7 (119)</td>
<td>4.2 (107)</td>
</tr>
<tr>
<td></td>
<td>Lightweight aggregate concrete</td>
<td>3.4 (86)</td>
<td>3.1 (79)</td>
</tr>
<tr>
<td></td>
<td>Cellular concrete¹</td>
<td>1.6 (41)</td>
<td>1.3 (33)</td>
</tr>
<tr>
<td></td>
<td>Perlite concrete¹</td>
<td>1.9 (48)</td>
<td>1.6 (41)</td>
</tr>
<tr>
<td></td>
<td>Vermiculite concrete¹</td>
<td>2.2 (56)</td>
<td>1.8 (46)</td>
</tr>
<tr>
<td></td>
<td>Sprayed mineral fiber</td>
<td>NA</td>
<td>1.4 (36)</td>
</tr>
<tr>
<td></td>
<td>Sprayed vermiculite cementitious</td>
<td>1.6 (41)</td>
<td>1.4 (36)</td>
</tr>
<tr>
<td>4 hour</td>
<td>Carbonate aggregate concrete</td>
<td>5.2 (132)</td>
<td>4.8 (122)</td>
</tr>
<tr>
<td></td>
<td>Siliceous aggregate concrete</td>
<td>5.6 (142)</td>
<td>5.1 (130)</td>
</tr>
<tr>
<td></td>
<td>Lightweight aggregate concrete</td>
<td>4.2 (107)</td>
<td>3.8 (97)</td>
</tr>
<tr>
<td></td>
<td>Cellular concrete¹</td>
<td>2.1 (53)</td>
<td>1.9 (48)</td>
</tr>
<tr>
<td></td>
<td>Perlite concrete¹</td>
<td>2.3 (58)</td>
<td>2.0 (51)</td>
</tr>
<tr>
<td></td>
<td>Vermiculite concrete¹</td>
<td>2.7 (69)</td>
<td>2.3 (58)</td>
</tr>
<tr>
<td></td>
<td>Sprayed mineral fiber</td>
<td>NA</td>
<td>NA</td>
</tr>
<tr>
<td></td>
<td>Sprayed vermiculite cementitious</td>
<td>1.8 (46)</td>
<td>1.3 (33)</td>
</tr>
</tbody>
</table>

130 lb/ft³ density (481 kg/m³)

#### 3.2.2.3 Nonuniform precast concrete wall panels

The fire resistance of precast concrete wall panels with nonuniform thickness shall be determined in accordance with Table 3.2.2(a) using an equivalent thickness determined by one of the following methods based on the type of cross section provided.

1. **Hollow-core panels.** For hollow-core concrete wall panels with uniform cross-sectional area of cores along the panel length, the equivalent thickness shall be equal to the net cross-sectional area of the concrete divided by the nominal wall panel width. Where all of the cores of the wall panel are filled with expanded shale, clay or slag, or vermiculite or perlite, the equivalent thickness shall be the nominal wall panel thickness.
2) **Ribbed panels.** For precast concrete wall panels with ribbed cross sections, the equivalent thickness shall be determined by the thinnest portion of the panel thickness $t$ based on Fig. 3.2(d) and (a), (b), or (c):

a) If $t \leq \frac{s}{4}$, the equivalent thickness shall be $t$.

b) If $t \geq \frac{s}{2}$, the equivalent thickness shall be the cross-sectional area divided by the panel width, where area in sections greater than twice the minimum thickness shall be neglected.

c) If $\frac{s}{2} > t > \frac{s}{4}$, the equivalent thickness shall be calculated by Eq. (3.2.2-1).

\[
t_e = t + (4t/s - 1)(T_e - t)
\]

(3.2.2-1)

where

$T_e$ = equivalent thickness calculated in (b)

![Figure 3.2(d)](image)

Cross sections of ribbed wall panels (add “s” in fig (a) above)

3) **Tapered panels.** For precast concrete wall panels with tapered cross sections, the equivalent thickness $t_e$ shall be determined at a distance equal to the lesser of $2t$ or 6 in. (152 mm) from the thinnest portion of the panel thickness based on Fig. 3.2(d).

3.2.2.4 **Insulated panels.** The fire resistance of precast concrete insulated wall panels manufactured with multiple wythes of concrete cast with insulation between the wythes shall be determined in accordance with Table 3.2.2(d) based on the thickness of the individual wythes of concrete, the type of aggregate used, and type and thickness of the insulation. For insulated wall panels not covered by Table 3.2.2(d), the fire resistance shall be determined from Eq. (3.2.2.4-1) using values from Fig. 3.2(e).

\[
R = (R_1^{0.59} + R_2^{0.59} + \ldots + R_n^{0.59})^{1.7}
\]

(3.2.2.4-1)
### Table 3.2.2(d) Fire endurance of precast concrete insulated panels

<table>
<thead>
<tr>
<th>Inside wythe Thickness in in. (mm)</th>
<th>Insulation Thickness in in. (mm)</th>
<th>Outside wythe Thickness in in. (mm)</th>
<th>Fire Endurance Hour:minutes</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 ½ (38) Siliceous aggregate</td>
<td>1 (25) cellular plastic&lt;sup&gt;2&lt;/sup&gt;</td>
<td>1 ½ (38) Siliceous aggregate</td>
<td>1:23</td>
</tr>
<tr>
<td>1 ½ (38) Carbonate aggregate</td>
<td>1 (25) cellular plastic&lt;sup&gt;2&lt;/sup&gt;</td>
<td>1 ½ (38) Carbonate aggregate</td>
<td>1:23</td>
</tr>
<tr>
<td>1 ½ (38) Sand-lightweight</td>
<td>1 (25) cellular plastic&lt;sup&gt;2&lt;/sup&gt;</td>
<td>1 ½ (38) Sand-lightweight</td>
<td>1:45</td>
</tr>
<tr>
<td>2 (51) Siliceous aggregate</td>
<td>1 (25) cellular plastic&lt;sup&gt;2&lt;/sup&gt;</td>
<td>2 (51) Siliceous aggregate</td>
<td>1:50</td>
</tr>
<tr>
<td>2 (51) Carbonate aggregate</td>
<td>1 (25) cellular plastic&lt;sup&gt;2&lt;/sup&gt;</td>
<td>2 (51) Carbonate aggregate</td>
<td>2:00</td>
</tr>
<tr>
<td>2 (51) Sand-lightweight&lt;sup&gt;1&lt;/sup&gt;</td>
<td>1 (25) cellular plastic&lt;sup&gt;2&lt;/sup&gt;</td>
<td>2 (51) Sand-lightweight&lt;sup&gt;1&lt;/sup&gt;</td>
<td>2:32</td>
</tr>
<tr>
<td>3 (76) Siliceous aggregate</td>
<td>1 (25) cellular plastic&lt;sup&gt;2&lt;/sup&gt;</td>
<td>3 (76) Siliceous aggregate</td>
<td>3:07</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Inside wythe Thickness in in. (mm)</th>
<th>Insulation Thickness in in. (mm)</th>
<th>Outside wythe Thickness in in. (mm)</th>
<th>Fire Endurance Hour:minutes</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 ½ (38) Siliceous aggregate</td>
<td>¼ (19) glass fiber board</td>
<td>1 ½ (38) Siliceous aggregate</td>
<td>1:39</td>
</tr>
<tr>
<td>2 (51) Siliceous aggregate</td>
<td>¼ (19) glass fiber board</td>
<td>2 (51) Siliceous aggregate</td>
<td>2:07</td>
</tr>
<tr>
<td>2 (51) Sand-lightweight&lt;sup&gt;1&lt;/sup&gt;</td>
<td>¼ (19) glass fiber board</td>
<td>2 (51) Sand-lightweight&lt;sup&gt;1&lt;/sup&gt;</td>
<td>2:52</td>
</tr>
<tr>
<td>2 (51) Siliceous aggregate</td>
<td>¼ (19) glass fiber board</td>
<td>3 (76) Siliceous aggregate</td>
<td>3:10</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Inside wythe Thickness in in. (mm)</th>
<th>Insulation Thickness in in. (mm)</th>
<th>Outside wythe Thickness in in. (mm)</th>
<th>Fire Endurance Hour:minutes</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 ½ (38) Siliceous aggregate</td>
<td>1 ½ (38) glass fiber board</td>
<td>1 ½ (38) Siliceous aggregate</td>
<td>2:35</td>
</tr>
<tr>
<td>2 (51) Siliceous aggregate</td>
<td>1 ½ (38) glass fiber board</td>
<td>2 (51) Siliceous aggregate</td>
<td>3:08</td>
</tr>
<tr>
<td>2 (51) Sand-lightweight&lt;sup&gt;1&lt;/sup&gt;</td>
<td>1 ½ (38) glass fiber board</td>
<td>2 (51) Sand-lightweight&lt;sup&gt;1&lt;/sup&gt;</td>
<td>4:00</td>
</tr>
</tbody>
</table>

115 lb/ft<sup>3</sup> maximum (1842 kg/m<sup>3</sup>)

Polystyrene or polyurethane

35 lb/ft<sup>3</sup> maximum (561 kg/m<sup>3</sup>)
<table>
<thead>
<tr>
<th>$R$, minutes</th>
<th>$R^{0.59}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>60</td>
<td>11.20</td>
</tr>
<tr>
<td>120</td>
<td>16.85</td>
</tr>
<tr>
<td>180</td>
<td>21.41</td>
</tr>
<tr>
<td>240</td>
<td>25.37</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Material</th>
<th>$R^{0.59}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cellular plastic (1 in. or thicker)</td>
<td>2.57</td>
</tr>
<tr>
<td>¾ in. thick glass fiber board</td>
<td>4.03</td>
</tr>
<tr>
<td>1½ in. thick glass fiber board</td>
<td>8.57</td>
</tr>
<tr>
<td>Continuous air space</td>
<td>3.33</td>
</tr>
<tr>
<td>Two continuous air spaces</td>
<td>6.67</td>
</tr>
</tbody>
</table>

**Figure 3.2(e)**

**Design aid for Eq. 3.2.2.4-1**

Note: 1 in. = 25.4 mm.
3.2.3 Beams. The fire resistance for concrete beams shall be determined in accordance with 3.2.3.1 through 3.2.3.3. Alternatively, the provisions of 2.5.2 shall be permitted.

3.2.3.1 Restrained beam reinforcement cover. The positive moment reinforcement for all prestressed concrete beams that meet the requirements for restrained conditions in 2.4.1 shall be provided with concrete cover in accordance with Table 3.2.3(a) or 3.2.3(b), based on aggregate type and beam width or beam cross-sectional area. Where differences in values between Tables 3.2.3(a) and 3.2.3(b) occur, the smaller value is permitted to be used. The positive moment reinforcement for all reinforced concrete beams that meet the requirements for restrained conditions in 2.4.1 shall be provided with concrete cover in accordance with Table 3.2.3(c), based on beam width.

3.2.3.2 Unrestrained beam reinforcement cover. The positive moment reinforcement for all prestressed concrete beams that do not meet the requirements for restrained conditions in 2.4.1 shall be provided with concrete cover in accordance with Table 3.2.3(d) or 3.2.3(e), based on aggregate type and beam width or beam cross-sectional area. Where differences in values between Tables 3.2.3(d) and 3.2.3(e) occur, the smaller value is permitted to be used. The positive moment reinforcement for all reinforced concrete beams that do not meet the requirements for restrained conditions in 2.4.1 shall be provided with concrete cover in accordance with Table 3.2.3(f), based on beam width.

3.2.3.3 Determining reinforcement cover for concrete beams. The concrete cover for prestressing tendons shall be determined in accordance with 3.2.3.3.1. The concrete cover for nonprestressed reinforcement shall be determined in accordance with 3.2.3.3.2.

3.2.3.3.1 Prestressing tendon cover

a) For an individual tendon, the cover is the distance between the surface of the individual tendon and the nearest fire-exposed surface of the beam.

b) For an ungrouted duct, the cover is the distance between the surface of the duct and the fire-exposed surface of the beam.

c) For beams with two or more tendons, the cover is the average of the minimum distances between the individual tendons and the fire-exposed surface of the beam.

d) The cover for corner tendons with equal spacing to the bottom and side, shall be one half of the actual distance between the surface of the tendon and the fire exposed surface of the beam.

e) For stemmed members with two or more tendons located vertically along the center of the stem, the cover is the average distance from the centroid of the tendons to the bottom of the stem.

f) For any one tendon, the actual cover shall not be less than one half of the smaller values in Tables 3.2.3(a), 3.2.3(b), 3.2.3(d), or 3.2.3(e) but at least 1 in. (25 mm).

3.2.3.3.2 Nonprestressed reinforcement cover

a) For an individual reinforcement bar, the cover is the distance between the surface of the individual bar and the nearest fire-exposed surface of the beam.

b) The cover for corner bars shall be one half of the actual distance between the surface of the bar and the fire exposed surface of the beam.
Table 3.2.3(a) Concrete cover for restrained prestressed beams 8 in. (203 mm) or greater in width

<table>
<thead>
<tr>
<th>Fire resistance, hours</th>
<th>Concrete cover for restrained prestressed beams, in. (mm)</th>
<th>Sand-lightweight, lightweight</th>
</tr>
</thead>
<tbody>
<tr>
<td>Beam width = 8 in. (203 mm)*</td>
<td>Beam width ≥ 12 in. (305 mm)</td>
<td>Beam width = 8 in. (203 mm)*</td>
</tr>
<tr>
<td>1</td>
<td>1½ (38)</td>
<td>1½ (38)</td>
</tr>
<tr>
<td>1½</td>
<td>1½ (38)</td>
<td>1½ (38)</td>
</tr>
<tr>
<td>2</td>
<td>1½ (38)</td>
<td>1½ (38)</td>
</tr>
<tr>
<td>3</td>
<td>1½ (38)</td>
<td>1½ (38)</td>
</tr>
<tr>
<td>4</td>
<td>2½ (64)</td>
<td>1 7/8 (48)</td>
</tr>
</tbody>
</table>

* Direct interpolation for minimum cover is permitted for beam widths between 8 and 12 in. (203 and 305 mm)
† Values are based on beams spaced at more than 4 ft (1219 mm) on center. For beam spacings less than 4 ft (1219 mm) on center, the minimum concrete cover is permitted to be reduced to ¾ in. (19 mm) for 4 hour ratings or less.

Table 3.2.3(b) Concrete cover for restrained prestressed beams of all widths

<table>
<thead>
<tr>
<th>Fire resistance, hours</th>
<th>Concrete cover for restrained prestressed beams, in. (mm)*</th>
<th>All aggregate</th>
</tr>
</thead>
<tbody>
<tr>
<td>150 in.² &lt; A ≤ 300 in.² (96700 mm² &lt; A ≤ 194000 mm²)</td>
<td>300 in.² &lt; A ≤ 194000 mm² &lt; A</td>
<td>150 in.² &lt; A ≤ 194000 mm² &lt; A</td>
</tr>
<tr>
<td>1</td>
<td>1½ (38)</td>
<td>1½ (38)</td>
</tr>
<tr>
<td>1½</td>
<td>1½ (38)</td>
<td>1½ (38)</td>
</tr>
<tr>
<td>2</td>
<td>1½ (38)</td>
<td>1½ (38)</td>
</tr>
<tr>
<td>3</td>
<td>1½ (38)</td>
<td>1½ (38)</td>
</tr>
<tr>
<td>4</td>
<td>2½ (64)</td>
<td>2 (51)</td>
</tr>
</tbody>
</table>

Note: n/a = not applicable.
* Values are based on beams spaced at more than 4 ft (1219 mm) on center. For beam spacings less than 4 ft (1219 mm) on center, the minimum concrete cover is permitted to be reduced to ¾ in. (19 mm) for 4 hour ratings or less.
† A = beam area, in.² (mm²) A portion of the flange is permitted to be included in the cross-sectional area of a stem where the width of the flange included in the area calculation does not exceed three times the average width of the stem.

Table 3.2.3(c) Concrete cover for restrained concrete beams

<table>
<thead>
<tr>
<th>Fire resistance, hours</th>
<th>Concrete cover for restrained concrete beams, in. (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Beam width = 5 in. (127 mm)*</td>
<td>Beam width = 7 in. (178 mm)*</td>
</tr>
<tr>
<td>Beam width ≥ 10 in. (254 mm)*</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>¾ (19)</td>
</tr>
<tr>
<td>1½</td>
<td>¾ (19)</td>
</tr>
<tr>
<td>2</td>
<td>¾ (19)</td>
</tr>
<tr>
<td>3</td>
<td>1½ (25)</td>
</tr>
<tr>
<td>4</td>
<td>1¼ (32)</td>
</tr>
</tbody>
</table>

* Direct interpolation for minimum cover is permitted for beam widths between the values shown.
† Values are based on beams spaced at more than 4 ft (1219 mm) on center. For beam spacings less than 4 ft (1219 mm) on center, the minimum concrete cover is permitted to be reduced to ¾ in. (19 mm) for 4 hour ratings or less.
Table 3.2.3(d) Concrete cover for unrestrained prestressed beams 8 in. (203 mm) or greater in width

<table>
<thead>
<tr>
<th>Fire resistance, hours</th>
<th>Concrete cover for unrestrained prestressed beams, in. (mm)</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Concrete cover for unrestrained prestressed beams, in. (mm)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Siliceous or carbonate</td>
<td>Sand-lightweight, lightweight</td>
</tr>
<tr>
<td>Beam width = 8 in. (203 mm)*</td>
<td>1½ (38)</td>
<td>1½ (38)</td>
</tr>
<tr>
<td>Beam width ≥ 12 in. (305 mm)*</td>
<td>1½ (44)</td>
<td>1½ (38)</td>
</tr>
<tr>
<td>Beam width = 8 in. (203 mm)*</td>
<td>2½ (64)</td>
<td>1 7/8 (48)</td>
</tr>
<tr>
<td>Beam width ≥ 12 in. (305 mm)*</td>
<td>3½ (127)</td>
<td>2½ (64)</td>
</tr>
</tbody>
</table>

Note: n/a = not applicable.
* Direct interpolation for minimum cover is permitted for beams between 8 and 12 in. (203 and 305 mm).
† This value is not possible for 8 in. (203 mm) beam widths but is shown for interpolation purposes.

Table 3.2.3(e) Concrete cover for unrestrained prestressed beams of all widths

<table>
<thead>
<tr>
<th>Fire resistance, hours</th>
<th>Concrete cover for unrestrained prestressed beams, in. (mm)</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Concrete cover for unrestrained prestressed beams, in. (mm)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Siliceous or carbonate</td>
<td>Sand-lightweight</td>
</tr>
<tr>
<td>150 in.*² &lt; A ≤ 300 in.*² (96700 mm² &lt; A ≤ 194000 mm²)</td>
<td>1½ (38)</td>
<td>1½ (38)</td>
</tr>
<tr>
<td>300 in.*² &lt; A ≤ 1500 in.*² (194000 mm² &lt; A ≤ 96700 mm²)</td>
<td>1½ (44)</td>
<td>1½ (38)</td>
</tr>
<tr>
<td>40 in.*² ≤ A ≤ 150 in.*² (25800 mm² ≤ A ≤ 96700 mm²)</td>
<td>2½ (64)</td>
<td>2 (51)</td>
</tr>
<tr>
<td>Beam width = 5 in. (127 mm)*</td>
<td>n/a</td>
<td>3½ (76)</td>
</tr>
</tbody>
</table>

Note: n/a = not applicable.
* A = beam area, in.*² (mm²) A portion of the flange is permitted to be included in the cross-sectional area of a stem where calculation does not exceed three times the average width of the stem.
† U-shaped or hooped stirrups spaced not to exceed the depth of the beam with a minimum cover of 1 in. (25 mm) shall be provided.

Table 3.2.3(f) Concrete cover for unrestrained concrete beams

<table>
<thead>
<tr>
<th>Fire resistance, hours</th>
<th>Concrete cover for unrestrained concrete beams, in. (mm)</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Beam width = 5 in. (127 mm)*</td>
<td>3/4 (19)</td>
<td>3/4 (19)</td>
</tr>
<tr>
<td>Beam width = 7 in. (178 mm)*</td>
<td>1 (25)</td>
<td>3/4 (19)</td>
</tr>
<tr>
<td>Beam width ≥ 10 in. (254 mm)*</td>
<td>1½ (32)</td>
<td>3/4 (19)</td>
</tr>
</tbody>
</table>

Note: n/a = not applicable.
* Direct interpolation for minimum cover is permitted for beam widths between the values shown.

3.2.4 Floor and roof slabs. The fire resistance for precast concrete floor and roof slabs shall be determined in accordance with 3.2.4.1 through 3.2.4.4. Alternatively, the provisions of 2.5.2 shall be permitted.
3.2.4.1 **Solid single-course slabs.** The fire resistance of solid precast concrete slabs shall be determined in accordance with Table 3.2.2(a) based on the thickness of the concrete and the aggregate used for the concrete mixture.

3.2.4.1.1 **Nonuniform thickness slabs.** The equivalent thickness \( t_e \) of nonuniform slabs shall be determined in accordance with 3.2.2.3.

3.2.4.1.2 **Additional component layers.** If the underside of the precast concrete slab is provided with an additional layer of 5/8 in. (16 mm) thick Type X gypsum board on the fire-exposed side of the slab, the fire resistance shall be permitted to be determined in accordance with Fig. 3.2.4(a) based on the thickness of the concrete, the aggregate used for the concrete mixture, and the depth of the air space between the slab and the gypsum board. If vermiculite cementitious material, sprayed mineral fiber, or intumescent mastics are applied to the precast concrete element, the concrete thickness shall be permitted to be increased based on the values in Fig. 3.2.4(b).

---

**Figure 3.2.4(a)**

*Fire endurance of single-course floor slab.*

Note: 1 in. = 25.4 mm.
Figures 3.2.4(b)
Equivalent concrete cover with vermiculite cementitious material, sprayed mineral fiber, or intumescent mastics.
Note: 1 in. = 25.4 mm.

3.2.4.2 Multi-course floor slabs. The fire resistance of precast concrete floor slabs provided with an additional course of lightweight concrete, cellular concrete, perlite concrete, vermiculite concrete, vermiculite cementitious material, sprayed mineral fiber, or intumescent mastics shall be determined in accordance with Fig. 3.2.4(c) through 3.2.4(e) based on the thickness of the concrete, the aggregate used for the concrete mixture and the type and location of the added course.

3.2.4.3 Multi-course roof slabs. The fire resistance of precast concrete roof slabs provided with an additional course of mineral board or glass fiber board shall be determined in accordance with Fig. 3.4.1(f) based on the thickness of the concrete, the aggregate used for the concrete mixture and the type and location of the added course.
Figure 3.2.4(c)
Fire endurance of multi-course floor slab with normalweight and lightweight concrete.

Note: 1 in. = 25.4 mm.
Figure 3.2.4(d)

Fire endurance of multi-course floor slab with normalweight concrete and vermiculite cementitious material, sprayed mineral fiber, or intumescent mastics.

Note: 1 in. = 25.4 mm.
Figure 3.2.4(e)
Fire endurance of multi-course floor slab with normalweight concrete and cellular, vermiculate, or perlite concrete.

Note: 1 in. = 25.4 mm.
Figure 3.2.4(f)
Fire endurance of multi-course roof slab with normalweight concrete and mineral board or glass fiber board.

Note: 1 in. = 25.4 mm.
3.2.4.4 Slab reinforcement cover. The reinforcement for all precast, prestressed or cast-in-place concrete slabs that meet the requirements for restrained conditions in 2.4.1 shall be provided with a minimum of ¼ in. (19 mm) of concrete cover for fire resistance ratings up to four hours. The reinforcement for all precast, prestressed concrete slabs that do not meet the requirements for restrained conditions in 2.4.1 shall be provided with concrete cover in accordance with Table 3.2.4(a). The reinforcement for all nonprestressed slabs that do not meet the requirements for restrained conditions in 2.4.1 shall be provided with concrete cover in accordance with Table 3.2.4(b).

Table 3.2.4(a) Concrete cover for unrestrained prestressed slabs

<table>
<thead>
<tr>
<th>Fire resistance, hours</th>
<th>Concrete cover for unrestrained prestressed slabs, in. (mm)</th>
<th>Siliceous</th>
<th>Carbonate</th>
<th>Sand-lightweight, lightweight</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1 1/8 (29)</td>
<td>1 (25)</td>
<td>1 (25)</td>
<td></td>
</tr>
<tr>
<td>1½</td>
<td>1½ (38)</td>
<td>1 3/8 (35)</td>
<td>1 3/8 (35)</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>1¼ (44)</td>
<td>1 5/8 (41)</td>
<td>1½ (38)</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>2 3/8 (60)</td>
<td>2 1/8 (54)</td>
<td>2 (51)</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>2 3/4 (70)</td>
<td>2 ¼ (57)</td>
<td>2 ¼ (57)</td>
<td></td>
</tr>
</tbody>
</table>

Table 3.2.4(b) Concrete cover for unrestrained nonprestressed slabs

<table>
<thead>
<tr>
<th>Fire resistance, hours</th>
<th>Concrete cover for unrestrained nonprestressed slabs, in. (mm)</th>
<th>Siliceous</th>
<th>Carbonate</th>
<th>Sand-lightweight, lightweight</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>¾ (19)</td>
<td>¼ (19)</td>
<td>¼ (19)</td>
<td></td>
</tr>
<tr>
<td>1½</td>
<td>¾ (19)</td>
<td>¼ (19)</td>
<td>¼ (19)</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>1 (25)</td>
<td>¼ (19)</td>
<td>¼ (19)</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>1¼ (32)</td>
<td>1¼ (32)</td>
<td>1¼ (32)</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>1 5/8 (41)</td>
<td>1¼ (32)</td>
<td>1¼ (32)</td>
<td></td>
</tr>
</tbody>
</table>

3.2.4.4.1 Determining reinforcement cover for slabs. The concrete cover to reinforce shall be determined in accordance with 3.2.3.3

3.3—Rational design for slabs and beams. Precast concrete slabs and beams designed in accordance with 3.3.1 through 3.3.5 shall demonstrate that sectional strength considering concrete and steel material properties at elevated temperatures is greater than or equal to the load effects at the required fire resistance. Except as permitted by the building code, minimum thickness requirements in 3.2.4.1 through 3.2.4.3 for heat transmission shall be satisfied.

3.3.1 Concrete temperature. If the concrete temperature in the compression zone exceeds 900°F (482°C), the reduced concrete compressive strength $f'_{c0}$ shall be used in calculating the value of the depth of the equivalent rectangular stress block $a_w$.

3.3.2 Unrestrained simply supported slabs and beams. For unrestrained simply supported horizontal structural members the applied moment $M$ shall not exceed the nominal flexural strength at elevated temperature $M_{nθ}$ of the member, based on the internal temperature of the concrete and steel for a given fire resistance rating. The nominal flexural strength at elevated temperature $M_{nθ}$ of the member shall be determined in accordance with Eq. (3.3.2-1), (3.3.2-2), and (3.3.2-3).

\[ M_{nθ} = A_{ps} f_{ps} \left( d - \frac{a_θ}{2} \right) \]  \hspace{1cm} (3.3.2-1)

\[ f_{psθ} = f_{psθ} \left( 1 - \frac{0.5 A_{ps} f_{psθ}}{bd_fθ} \right) \]  \hspace{1cm} (3.3.2-2)
3.3.3 Restrained simply supported slabs and beams. For restrained simply supported horizontal structural members the applied moment $M$ shall not exceed the nominal flexural strength $M_{n\theta}$ calculated in accordance with Eq. (3.3.2-1), (3.3.2-2), and (3.3.2-3) with the internal temperature of the concrete and steel determined at one-half the required fire resistance rating of the restrained member, but not less than 1 hour.

3.3.4 Beams and slabs continuous at supports. For horizontal structural members with continuity at supports, the applied moment $M$ shall not exceed the nominal flexural strength at elevated temperature $M_{n\theta}$ of the member, based on the internal temperature of the concrete and steel for a given fire resistance rating.

3.3.4.1 Positive moment capacity. The positive nominal flexural strength at elevated temperature, $M_{n\theta}$, of the member shall be determined in accordance with Eq. (3.3.2-1).

3.3.4.2 Applied positive moment. The applied positive moment $M^+$ shall be the lesser of the simple span moment and the positive nominal moment capacity from Eq. (3.3.4-1).

$$M^+ = \frac{w\ell^2}{8} \leq M_{n\theta}^+$$  \hspace{1cm} (3.3.4-1)

3.3.4.3 Negative moment capacity. The negative nominal flexural strength at elevated temperature $M_{n\theta}$ at supports where slabs and beams are continuous shall be determined in accordance with Eq. (3.3.2-1). The applied negative moment $M^-$ shall not exceed the negative nominal flexural strength at elevated temperature $M_{n\theta}$.

3.3.4.4 Applied negative moment. The applied negative moment at supports where slabs and beams are continuous shall be determined in accordance with (a) through (c).

a) Uniformly loaded member continuous at one support. The applied negative moment at the continuous support shall be determined in accordance with Fig. 3.3(a) and Eq. (3.3.4-2) through (3.3.4-4).

$$M^- = \frac{w\ell^2}{2} \pm w\ell^2 \sqrt{\frac{2M^+}{w\ell^2}}$$  \hspace{1cm} (3.3.4-2)

$$X_1 = \frac{\ell}{2} \frac{M^-}{w\ell}$$  \hspace{1cm} (3.3.4-3)

$$X_\theta = \frac{2M^-}{w\ell}$$  \hspace{1cm} (3.3.4-4)
b) Uniformly loaded member continuous at two supports. The applied negative moment at the continuous support shall be determined in accordance with Fig. 3.3(b) and Eq. (3.3.4-5) through (3.3.4-7).

\[ M^d = \frac{w\ell^2}{8} - M^+ \quad (3.3.4-5) \]

\[ X_2 = \sqrt{\frac{2M^+}{w}} \quad (3.3.4-6) \]

\[ X_0 = \frac{1}{2}(\ell - X_2) \quad (3.3.4-7) \]

Figure 3.3(b)
Moment diagram for uniformly loaded members continuous at both supports.

c) Other cases. For cases not described in (a) and (b), the applied negative moment at the end of a member shall distribute the applied loads based on any reasonable assumptions for member stiffness of the structural elements at the design fire conditions.

3.3.4.5 Negative moment reinforcement. The design shall consider the amount of and the effects of negative reinforcement on moment redistribution to prevent a secondary failure. At least 20% of the maximum negative moment reinforcement shall be extended through the length of the span \( \ell \). In addition, negative moment reinforcement shall extend a development length beyond the inflection point \( X \) calculated using one-half of the required live load.

3.3.5 Moment intensity. Figures 3.3(c), 3.3(d) or 3.3(e) shall be permitted to be used to determine the fire resistance of slabs and beams based on the moment intensity \( M/M_n \) of the design of precast concrete elements.
using carbonate, siliceous, and sand-lightweight concrete, respectively. For precast concrete elements wider than 10 in. (254 mm), the strands shall be spaced uniformly in horizontal rows and the fire resistance shall be based on the effective $u, \bar{u}$. These figures shall not be applied if strands are bundled.

Figures 3.3(c)

Fire endurance of prestressed concrete slabs as affected by moment intensity – carbonate aggregate

Note: 1 in. = 25.4 mm.
Figures 3.3(d)

Fire endurance of prestressed concrete slabs as affected by moment intensity – siliceous aggregate

Note: 1 in. = 25.4 mm.
Figures 3.3(e)

Fire endurance of prestressed concrete slabs as affected by moment intensity – sand-lightweight aggregate

Note: 1 in. = 25.4 mm.
CHAPTER 4—SPECIAL CONSIDERATIONS

4.1—General The fire resistance design of precast concrete shall include consideration of the effect on fire resistance of openings through precast concrete elements and connections between precast concrete elements. Openings shall be protected in accordance with 4.2 and connections shall be protected in accordance with 4.3.

4.2—Protection of openings. Openings through precast concrete elements required to have a fire resistance by poke-thru devices and joints shall be protected to provide the necessary fire resistance of the element. Poke-thru devices shall be protected in accordance with 4.2.1. Joints in precast concrete elements shall comply with 4.2.2.

4.2.1 Poke-thru devices. Poke-thru devices shall be provided with the protection necessary to achieve the required fire resistance in accordance with one of (a) through (e). Approved alternative materials and methods shall be permitted.

a) Sprayed mineral fiber cover for the required thickness in accordance with Fig. 4.2(a)

b) Vermiculite cementitious material cover for the required thickness in accordance with Fig. 4.2(b)

c) Perlite concrete shield for the required thickness in accordance with Fig. 4.2(c)

d) Mineral insulation board shield for the required thickness in accordance with Fig. 4.2(d)

e) Mineral wool insulation shield for the required thickness in accordance with Fig. 4.2(e)

Figure 4.2(a)  
Fittings undercoated with sprayed mineral fiber

Figure 4.2(b)  
Fittings undercoated with vermiculite cementitious material

Note: °F = (°C × 1.8) + 32; 1 in. = 25.4 mm.
4.2.2 Joints in precast concrete elements. Joints in precast concrete wall, floor, or roof assemblies required to have a fire resistance shall be protected in accordance with this section.

Note: °F = (°C × 1.8) + 32; 1 in. = 25.4 mm.
4.2.2.1 Walls. Joints in walls shall comply with (a) or (b).

a) Joints in exterior walls shall be permitted to be included in the allowable area of unprotected openings permitted in exterior walls in accordance with the building code.

b) Joints in fire-resistant exterior and interior walls that require protection shall be constructed in accordance with Fig. 4.2(f), 4.2(g), 4.2(h), or 4.2(i) based on the joint type, joint materials, joint width, wall panel thickness, and required fire endurance.

Figure 4.2(f) Two-stage cavity joint

Figure 4.2(g) Two-stage shiplap joint

Note: 1 in. = 25.4 mm.
Figure 4.2(h)

Sealant and backer rod joints

Note: 1 in. = 25.4 mm.
Figure 4.2(i)

Ceramic blanket protection for joints

Note: 1 in. = 25.4 mm.
4.2.2.2 Slabs. Joints in floor and roof slabs shall comply with one of (a) through (c).

a) Joints in slabs shall be permitted to be unprotected in accordance with the building code.

b) 1 in. (25 mm) minimum thickness of concrete topping over the joint.

c) Grout to a depth of at least 1 in. (25 mm), but not less than one third of the thickness of the slab at the joint.

4.3—Protection of connections. Connections for precast concrete elements shall meet the lesser required fire resistance of the elements being connected. Connections for precast concrete elements required to have a fire resistance shall be protected to provide the necessary fire resistance of the element.

Exception: Verification of connection fire resistance by testing shall be permitted.

4.3.1 Structural steel brackets. Exposed steel brackets that serve as connections for fire-resistant precast concrete elements that will be weakened by fire exposure and affect the stability of the structure shall be protected to the same degree as that required for the lesser fire resistance of the precast concrete element or the supporting member. The exposed steel brackets shall be protected with sprayed mineral fiber, vermiculite cementitious material, or intumescent mastics in accordance with Fig. 4.3(a), or dry-packed concrete or mortar in accordance with Fig. 4.3(b). Approved alternative methods shall be permitted.

<table>
<thead>
<tr>
<th>FIRE ENDURANCE, hr</th>
<th>THICKNESS OF PROTECTION MATERIAL, in.</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.5 (SMF)</td>
</tr>
<tr>
<td>2</td>
<td>1.0 (SMF or VCM)</td>
</tr>
<tr>
<td>3</td>
<td>1.5 (SMF or VCM)</td>
</tr>
<tr>
<td>4</td>
<td>2.0 (SMF or VCM)</td>
</tr>
</tbody>
</table>

Figure 4.3(a) Fire protection for steel brackets

<table>
<thead>
<tr>
<th>CONCRETE OR DRY-PACK MORTAR</th>
</tr>
</thead>
<tbody>
<tr>
<td>FIRE ENDURANCE, hr</td>
</tr>
<tr>
<td>-------------------</td>
</tr>
<tr>
<td>1</td>
</tr>
<tr>
<td>2</td>
</tr>
<tr>
<td>3</td>
</tr>
<tr>
<td>4</td>
</tr>
</tbody>
</table>

Figure 4.3(b) Concrete or mortar protection for steel brackets

Note: 1 in. = 25.4 mm.

4.3.2 Ledges, pockets, and concrete corbels. Ledges, pockets, or concrete corbels integral with a precast concrete element supporting other elements shall not require additional protection if the element providing the support is designed to the required fire resistance.