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# Fire Resistance of Architectural Precast Concrete Envelopes

PCI designer'snotebook

# FIRE RESISTANCE OF ARCHITECTURAL PRECAST CONCRETE ENVELOPES

In the interest of life safety and property protection, building codes require that resistance to fire be considered in the design of buildings. The degree of fire resistance required depends on the type of occupancy, the size of the building, its location (proximity to property lines and within established fire zones), and in some cases, the amount and type of fire detection and extinguishing equipment available in the structure. Precast concrete members are inherently noncombustible and can be designed to meet any degree of fire resistance that may be required by building codes, insurance companies, and other authorities.

Although life safety is of paramount importance, casualty insurance companies and owners are also concerned with the damage that might be inflicted upon the building and its contents during a fire. This means that both fire resistance and containment must be considered. Insurance rates are usually substantially lower for buildings with higher fire-resistance designs incorporating containment features. Building codes commonly assign fire resistance ratings on the basis of results of standard fire tests. However, in recent years, there has been a trend toward calculating the fire endurance of building components, rather than relying entirely on fire tests. Much research work has been conducted on the behavior of materials and building components in fires. This article summarizes the available information on the behavior of architectural precast concrete under fire conditions. The article is based on the PCI "*Design for Fire Resistance of Precast/Prestressed Concrete*" 3rd Edition, (MNL-124-11). MNL-124 is referenced in the International Building Code (IBC). It can also be accepted as an alternate method to what is specified in IBC or UBC Section 703.3 based on ICC-ES Evaluation Report, ESR-1997.

Fire resistance ratings of building components are measured and specified in accordance with ASTM E119. Fire endurance is defined as the period of time elapsed before a prescribed condition of failure or end point is reached during a standard fire test. The major "end points" used to evaluate performance in a fire test include:

1. Structural End Point. Collapse of loadbearing specimens (structural end point).
2. Flame Passage End Point. Formation of holes, cracks, or fissures through which flames or gases hot enough to ignite cotton waste may pass.
3. Heat Transmission End Point. Temperature increase of the unexposed surface of floors, roofs, or walls reaching an average of 250 °F (122 °C) or a maximum of 325 °F (163 °C) at any one point.
4. Hose Stream Test. Collapse of walls and partitions during a hose-stream test or inability to support twice the super-imposed load following the hose stream test.

A fire-resistance rating (sometimes called a fire rating, a fire-resistance classification, or an hourly rating) is a legal term defined in building codes, usually based on fire endurance. Building codes specify required fire-resistance ratings depending on the construction classification, occupancy, and fire separation distance. In IBC

2012, Table 601 defines the required fire-resistance rating based on type of construction and Table 602 defines the required fire-resistance rating based on separation distance. The more restrictive would apply. Performance is defined by the authorities (regulatory and insurance) as the time for which each component would reach its controlling end point if it were subjected to a standard test.

# Fire Endurance of Exterior Walls

The fire endurances of precast concrete walls, as determined by fire tests, are almost universally governed by the ASTM E119 criteria for heat transmission (temperature rise of the unexposed surface) rather than by structural behavior during fire tests. This is probably due to the low level of stresses, even in concrete bearing walls, and the fact that reinforcement generally does not perform a primary structural function. Concrete cover as specified in ACI 318 for durability will be sufficient for fire ratings up to 4-hr.

Most of the information on heat transmission was derived from fire tests of assemblies tested in a horizontal position simulating floors or roofs. The data is slightly conservative for assemblies tested vertically, such as walls. Nevertheless, it is suggested that no correction be made unless more specific data derived from fire tests of walls are used.

For concrete wall panels, the temperature rise of the unexposed surface depends mainly on the thickness and aggregate type in the concrete mixture. Other less important factors include unit weight, moisture condition, air content, and maximum aggregate size. Within the usual ranges, water-cement ratio, strength, and age have insignificant effects.

**Table 1.** Fire Endurances for Single-Mixture Concrete Panel.

| Aggregate | Thickness for fire endurance, in. | | | |
|---|---|---|---|---|
| | 1 hr | 2 hr | 3 hr | 4 hr |
| All lightweight | 2.5 | 3.6 | 4.4 | 5.1 |
| Sand-lightweight | 2.7 | 3.8 | 4.6 | 5.4 |
| Carbonate | 3.2 | 4.6 | 5.7 | 6.6 |
| Siliceous | 3.5 | 5.0 | 6.2 | 7.0 |

From information that has been developed from fire tests, it is possible to accurately estimate the thickness of many types of single-course and multicourse (face and backup mixtures) walls that will provide fire endurances of 1, 2, 3, or 4 hours, based on the temperature rise of the unexposed surface. Based on fire test data, the thicknesses shown in Fig. 1 and Tables 1 and 2 can be expected to provide the fire endurances indicated for single-course and two-course walls. Figure 1 shows the fire endurance (heat transmission) of concrete as influenced by aggregate type and thickness. Interpolation of varying concrete unit weights is acceptable in this figure. Table 1 provides the thickness (in inches) of solid concrete wall panels for various fire endurances, while Table 2 provides the same for two-course panels. Table 3 provides reduced required thickness when $^5/_8$ in. thick Type X gypsum wallboard covers the fire-exposed surface.

As used in this article, concrete aggregates are designated as lightweight, sand-lightweight, carbonate, or siliceous.

**Table 2.** Thickness of Wythes to Provide Various Fire Endurances for Panels with Facing and Backup Materials.

| Fire Endurance, hr | Backup Material<br>Inside Wythe Material (Fire-Exposed Side) | Siliceous Aggregate Concrete, in. (Facing Material) | | | Sand-Lightweight Concrete, in. (Facing Material) | | |
|---|---|---|---|---|---|---|---|
| | | $1^1/_2$ | 2 | 3 | $1^1/_2$ | 2 | 3 |
| 1 | Carbonate aggregate concrete* | 1.9 | 1.4 | 0.45 | 1.7 | 1.0 | 0 |
| 1 | Siliceous aggregate concrete | 2.0 | 1.48 | 0.48 | 1.7 | 1.0 | 0 |
| 1 | Lightweight aggregate concrete | 1.5 | 1.2 | 0.25 | 1.13 | 0.63 | 0 |
| 2 | Carbonate aggregate concrete* | 3.25 | 2.8 | 1.9 | 3.2 | 2.6 | 1.25 |
| 2 | Siliceous aggregate concrete | 3.5 | 3.0 | 2.0 | 3.3 | 2.7 | 1.3 |
| 2 | Lightweight aggregate concrete | 2.5 | 2.1 | 1.4 | 2.26 | 1.76 | 0.76 |
| 3 | Carbonate aggregate concrete* | 4.4 | 3.9 | 3.0 | 4.2 | 3.7 | 2.4 |
| 3 | Siliceous aggregate concrete | 4.65 | 4.15 | 3.15 | 4.4 | 3.8 | 2.5 |
| 3 | Lightweight aggregate concrete | 3.4 | 3.1 | 2.4 | 3.12 | 2.62 | 1.62 |
| 4 | Carbonate aggregate concrete* | 5.15 | 4.8 | 3.85 | 5.2 | 4.7 | 3.5 |
| 4 | Siliceous aggregate concrete | 5.55 | 5.05 | 4.05 | 5.5 | 4.9 | 3.7 |
| 4 | Lightweight aggregate concrete | 4.2 | 3.8 | 3.0 | 3.87 | 3.37 | 2.37 |

*Tabulated values for thickness of inside wythe are conservative for carbonate aggregate concrete.
Note: 1. NA = not applicable; that is, a thicker facing material is needed.
2. To obtain thickness of concrete for a specific fire endurance, read across and then up. For example, a 2 hr fire endurance for a 2 in. siliceous facing and carbonate backup requires 4.8 in. of concrete.

1. Lightweight aggregates include expanded clay, shale, slate, and sintered fly ash. These materials produce concretes having unit weights of about 90 to 105 pcf (1520 to 1680 kg/m$^3$) without sand replacement.
2. Lightweight concretes in which sand is used as part of or all of the fine aggregate, and unit weight of 105 to 120 pcf (1680 to 1920 kg/m$^3$), are designated as sand-lightweight.

**Table 3.** Use of $^5/_8$ in. thick type X gypsum wallboard required to provide fire endurances of 2 hr and 3 hr.

| Aggregate | Thickness of concrete panel, in., for fire endurance of 2 hr and 3 hr | |
|---|---|---|
| | 2 hr | 3 hr |
| Sand-lightweight | 2.5 | 3.6 |
| Carbonate | 2.8 | 4.0 |
| Siliceous | 2.9 | 4.2 |

3. Carbonate aggregates include limestone and dolomite (minerals consisting mainly of calcium and/or magnesium carbonate).
4. Siliceous aggregates include quartzite, granite, basalt, and most rocks other than limestone and dolomite.

Ribbed panel heat transmission is influenced by both the thinnest portion of the panel and by the panel's "equivalent thickness." Here, equivalent thickness is defined as the net cross-sectional area of the panel divided by the width of the cross-section. In calculating the net cross-sectional area of the panel, portions of ribs that project beyond twice the minimum thickness should be neglected (Fig. 2).

The fire endurance (as defined by the heat transmission end point) can be governed by either the thinnest section, the average thickness, or a combination of the two. The following rule-of-thumb expressions describe the conditions under which each set of criteria governs.

Let $t$ = minimum thickness, in.

$t_e$ = equivalent thickness of panel, in.

$s$ = rib spacing, in.

If $t \leq s/4$, fire endurance, $R$, is governed by $t$ and is equal to $R_t$.

If $t \geq s/2$ , fire endurance, $R$, is governed by $t_e$ and is equal to $R_{te}$.

If $s/2 > t > s/4$:

$$R = R_t + (4t/s - 1)(R_{te} - R_t) \quad \text{(Eq. 1)}$$

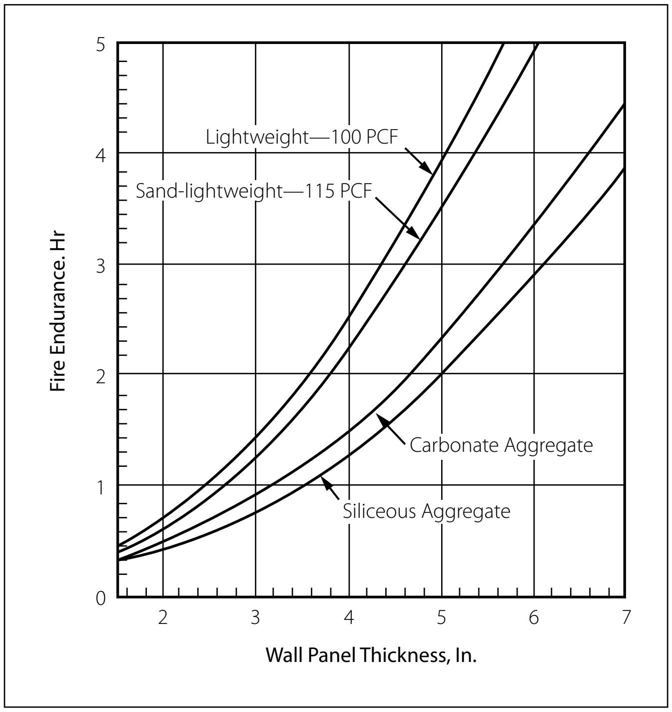



**Figure 1** Fire endurance (heat transmision) as a function of panel thickness.

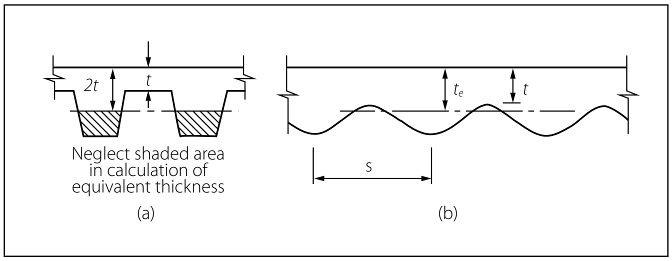



**Figure 2** Cross-section of ribbed wall panels.

where $R$ is the fire endurance of a concrete panel and subscripts $t$ and $t_e$ relate the corresponding $R$ values to a concrete slab of thicknesses $t$ and $t_e$, respectively.

These expressions apply to ribbed and corrugated panels, but they give excessively low results for panels with widely spaced grooves or rustications. Consequently, engineering judgment must be used when applying these expressions.

**Insulated precast concrete panels** have insulating materials between the two wythes of concrete. Exterior walls of buildings of Type I, II, III, or IV construction of any height must comply with IBC Sections 2603.5.1 through 2603.5.7. Insulated precast concrete panels are Type I and II. Exterior walls of cold storage buildings required to be constructed of noncombustible materials, where the building is more than one story in height, must also comply with the provisions of Sections 2603.5.1 through 2603.5.7.

The exterior wall assembly must be tested in accordance with and comply with the acceptance criteria of NFPA 285 with the following exceptions:

1. One-story buildings complying with (2012) IBC Section 2603.4.1.4.
2. The 2015 IBC in Section 2603.5.5 includes the following additional exceptions. Wall assemblies where the foam plastic insulation is covered on each face by a minimum of 1-inch (25 mm) thickness of concrete or masonry and meeting one of the following:
   a. There is no air space between the insulation and the concrete or masonry; or
   b. The insulation has a flame spread index of not more than 25 as determined in accordance with ASTM E 84 or UL 723 and the maximum air space between the insulation and the concrete or masonry is not more than 1-inch (25 mm).

It should be noted that cellular plastics melt and are consumed at about 400 to 600° F (205 to 316° C). Thus, thickness of cellular plastics greater than 1.0 in. (25 mm) or changes in composition probably have only a minor affect on the fire endurance of insulated precast concrete panels. The danger of toxic fumes caused by the burning of cellular plastics is practically eliminated when the plastics are completely encased within the two concrete withes.

It is possible to calculate the thicknesses of various materials in an insulated precast concrete panel required to achieve a given fire rating using Equation 2.

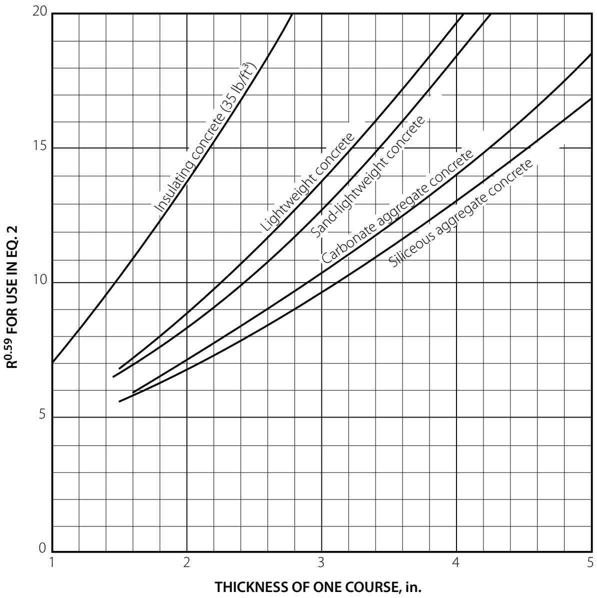
$$R^{0.59} = R_1^{0.59} + R_2^{0.59} \dots R_n^{0.59} \qquad \text{(Eq. 2)}$$

where $R$ = fire endurance of the composite assembly in minutes and $R_1$, $R_2$, and $R_n$ = fire endurance of each of the individual courses in minutes.

A design graph for solving the equation is provided in Fig. 3.

Table 4 lists fire endurances for insulated precast concrete panels with either cellular plastic, glass fiber board used as the insulating material. The values were obtained using Eq. 2.

**Walls** that have windows and are required to be fire resistive have limits imposed on the area of window openings by the building code. Openings in exterior walls must comply with Section 705.8 (2012 IBC). These limits are based on the construction classification, occupancy, fire separation distance, and use of sprinklers. For example, Table 705.8 of the IBC permits no openings in exterior walls when the fire separation distance is less than 3 ft (0.9 m). Where protected openings are allowed 2012 IBC Tables 716.5 and 716.6 provide the rating required for fire doors and windows in the exterior wall. For example, exterior walls with a 1-hour rating require fire doors and window assemblies with a 45-minute rating. For 2- and 3-hour rated exterior walls, door and window openings must have a 90-minute rating.




| R, Minutes | $R^{0.59}$ |
|---|---|
| 60 | 11.20 |
| 120 | 16.85 |
| 180 | 21.41 |
| 240 | 25.37 |
| **Material** | **$R^{0.59}$** |
| Cellular plastic (i in. or thicker) | 2.57 |
| $^3/_4$ in. thick glass fiber board | 4.03 |
| $1^1/_2$ in. thick glass fiber board | 8.57 |
| Continuous air space | 3.33 |
| Two continuous air spaces | 6.67 |

**Figure 3** Design aid for use in solving Eq. 2.

For buildings that are more than three stories in height, openings in exterior walls in adjacent stories are to be separated vertically to protect against fire spread on the exterior of the buildings where the openings are within 5 ft (1.5 m) of each other horizontally and the opening in the lower story is not a protected opening with not less than $^3/_4$ hr. rating. Such openings are to be separated vertically by at least 3 ft (1 m) by spandrel girders, exterior walls, or other similar assemblies that have a fire-resistance rating of at least 1 hour or by flame barriers having a fire-resistance rating of at least 1 hour that extends horizontally at least 30 in. (762 mm) beyond the exterior wall.

Requirements for various occupancies differ somewhat but generally follow the same pattern and certain exceptions often apply. The IBC code relates fire separation distance and maximum area of openings to the area of the exposed building face. Percentages of opening areas are then tabulated in the code for various percentages of area of the exterior wall per story and fire separation distance. The percentage of openings permitted increases as the fire separation distance increases.

Where the allowable area of protected openings is not limited or the allowable area of protected openings is limited and the equivalent area from Eq. 3 satisfies the limit, the heat transmission end point for the exterior wall does not apply. The equivalent opening factor is a function of the temperature on the unexposed surface of the wall and the fire rating of the wall.

Table 4. Fire Endurance of Insulated Precast Concrete Panels.

| Inside Wythe, in. | Insulation, in. | Outside Wythe, in. | Fire Endurance, hr: min |
|---|---|---|---|
| $1^1/_2$ Sil | 1 CP | $1^1/_2$ Sil | 1:23 |
| $1^1/_2$ Carb. | 1 CP | $1^1/_2$ Carb. | 1:23 |
| $1^1/_2$ SLW | 1 CP | $1^1/_2$ SLW | 1:45 |
| 2 Sil | 1 CP | 2 Sil | 1:50 |
| 2 Carb. | 1 CP | 2 Carb | 2:00 |
| 2 SLW | 1 CP | 2 SLW | 2:32 |
| 3 Sil | 1 CP | 3 Sil | 3:07 |
| $1^1/_2$ Sil | $^3/_4$ GFB | $1^1/_2$ Sil | 1:39 |
| 2 Sil | $^3/_4$ GFB | 2 Sil | 2:07 |
| 2 SLW | $^3/_4$ GFB | 2 SLW | 2:52 |
| 2 Sil | $^3/_4$ GFB | 3 SLW | 3:10 |
| $1^1/_2$ Sil | $1^1/_2$ GFB | $1^1/_2$ Sil | 2:35 |
| 2 Sil | $1^1/_2$ GFB | 2 Sil | 3:08 |
| 2 SLW | $1^1/_2$ GFB | 2 SLW | 4:00 |

Note: Carb = carbonate aggregate concrete; Sil = siliceous aggregate concrete; SLW = sand-lightweight concrete (115 pcf maximum); CP = cellular plastic (polystyrene or polyurethane); GFB = glass fiber board.

$$A_c = A + A_t F_{eo} \qquad \text{(Eq. 3)}$$

where

$A_c$ = equivalent area of protected openings.

$A$ = actual area of protected openings

$A_t$ = area of exterior wall surface in the story under consideration exclusive of openings, on which the temperature limitation of the standard fire test is exceeded.

Equation 3 can be rearranged to solve for $F_{eo}$ from which a panel thickness can be determined from Figure 4.

Pockets into the thickness of a panel may be required for many reasons. The concrete thickness outside the pocket must be considered in determining the fire resistance of the wall. One approach is to consider the reduction in wall thickness the same as an opening which would occur with complete through penetration.

If the wall is close to the property line, within 5 ft (1.5 m), then openings may not be allowed. This could require restoring the pocket to its original fire rating by applying a fire-resistive spray, inserting various fire-retardant materials, or during design moving the pocket to the opposite wall or using a corbel or ledge instead of a pocket.

# Detailing Precautions

If precast concrete wall panels could be designed and installed such that no space exists between the wall panel and floor, a fire below the floor could not pass through the joint between the floor and wall. However, all exterior panels are designed such that a space does exist, a space referred to as a "safe-off" area.

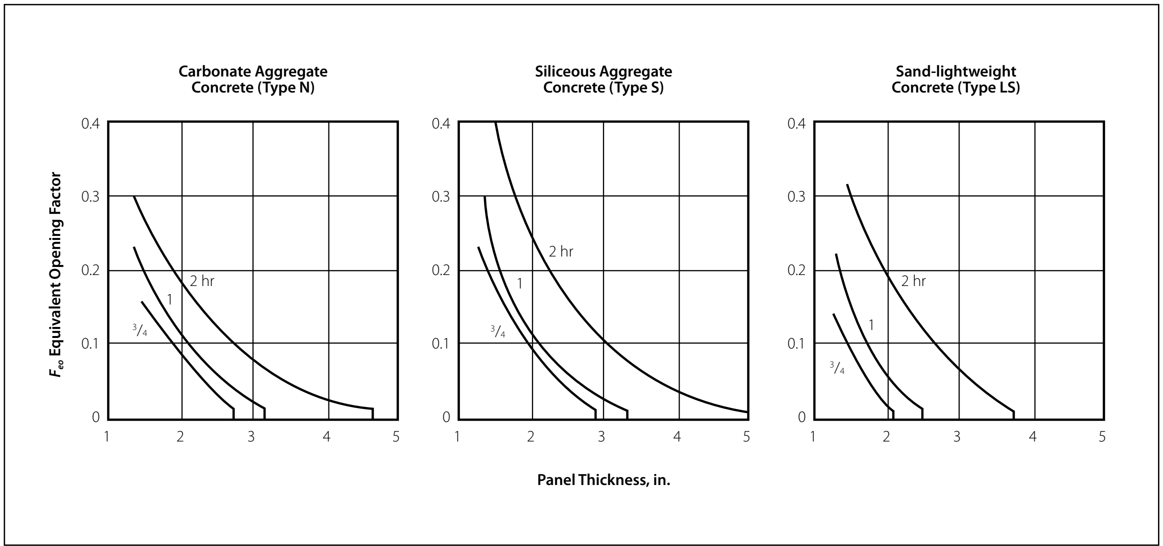



**Figure 4** Equivalent opening factor, $F_{eo}$.

Figure 5 shows a method of fire stopping such safe-off areas. Safing is supported on a steel angle, with or without Z-shaped impaling pins, depending on gauge of steel angle. Safing insulation is available as mineral fiber mats of varying dimensions and densities.

The mineral fiber should be sealed with a sprayed-on firestop caulk. Care must be taken during installation to ensure that the entire safe-off area is sealed. The safing insulation provides an adequate firestop and accommodates differential movement between the wall panel and the floor.

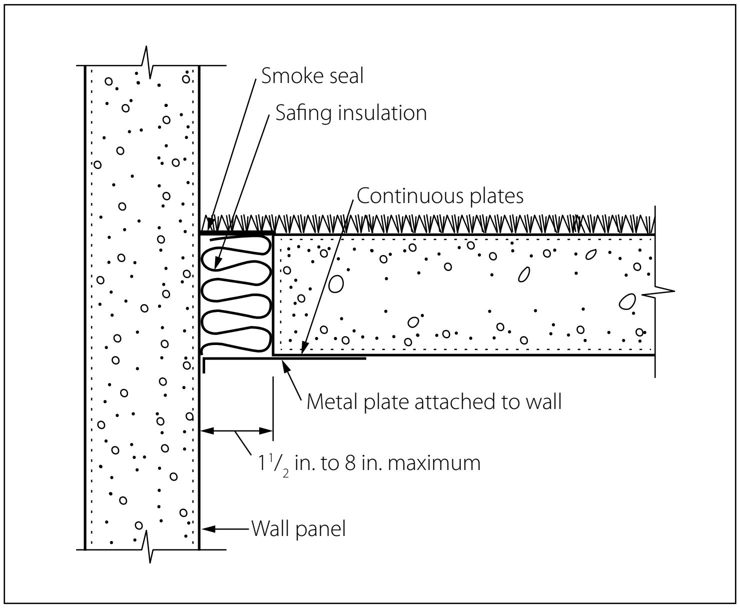



**Figure 5** Methods of installing safing insulation.

# Columns and Column Covers

Reinforced precast concrete columns have for many years served as the standard for fire-resistive construction. Indeed, the performance of concrete columns in actual fires has been excellent.

**Table 5.** Minimum sizes of concrete columns.

| | Minimum column size for fire resistance rating, in. | | | | |
|---|---|---|---|---|---|
| **Aggregate Type** | **1 hr** | **$1^1/_2$ hr** | **2 hr** | **3 hr** | **4 hr** |
| Siliceous | 8 | 9 | 10 | 12 | 14 |
| Carbonate | 8 | 9 | 10 | 11 | 12 |
| Sand-lightweight | 8 | $8^1/_2$ | 9 | $10^1/_2$ | 12 |

The inherent fire resistance of concrete columns results from three factors:

1. Minimum size of a structural column is generally such that the inner core of the column retains much of its strength even after long periods of fire exposure.
2. Concrete cover to the primary reinforcing bars is generally $1^7/_8$ in. or more, thus providing considerable fire protection for the reinforcement.
3. Ties or spirals contain the concrete within the core.

Table 5 shows typical building code requirements for reinforced concrete columns, and the values shown apply to both precast and cast-in-place concrete columns with concrete strength less than or equal to 12,000 psi. In addition, they apply to cast-in-place concrete columns clad with precast concrete column covers, whether the covers serve merely as cladding or as forms for the cast-in-place column.

The IBC Code in Section 722.2.4.2 states that regardless of the type of aggregate used in the concrete and the specified compressive strength, the minimum thickness of concrete cover to the main longitudinal reinforcement shall not be less than 1 in. (25 mm) times the number of hours of required fire resistance, or 2 in. (50 mm), whichever is less.

Precast concrete column covers are often used to clad steel columns for architectural reasons. Such covers also provide fire protection for the columns. Figure 6 shows the relationship between the thickness of a concrete column cover and the fire endurance for various steel column sections. The fire endurances shown are based on an empirical relationship. It was also found that the air space between the steel core and the column cover has only a minor affect on the fire endurance. An air space will probably increase the fire endurance but by an insignificant amount.

Most precast concrete column covers are 3 in. (75 mm) or more in thickness, but some are as thin as $2^1/_2$ in. (63 mm). From Fig. 6, it can be seen that such column covers provide fire endurances of at least 2.5 hours and usually more than 3 hours. For steel column sections other than those shown, including shapes other than wide flange beams, interpolation between the curves on the basis of weight per foot will generally give reasonable results.

For example, the fire endurance afforded by a 3 in. thick (75mm) column cover of normalweight concrete for an 8 x 8 x $^1/_2$ in. (200 x 200 x 13 mm) steel tube column will be about 3 hours 20 minutes (the weight of the section is 47.35 lb/ft [691 N/m]).

Figure 7 displays some of the various shapes of precast concrete column covers, including (a) two L-shaped

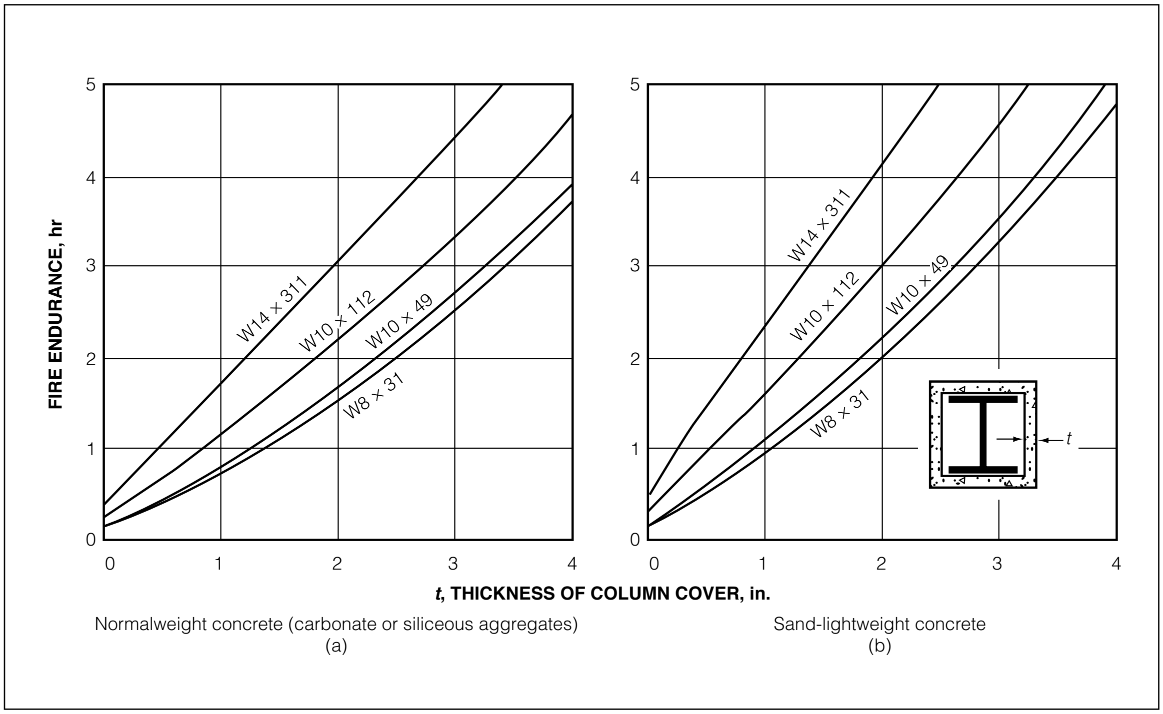



**Figure 6** Fire endurance of steel columns afforded protection by concrete column covers.

units, (b) two mitered units, and (c) two U-shaped units. There are, of course, many other combinations that may be used to accommodate isolated columns, corner columns, and columns in walls.

To be fully effective, the column covers must remain in place without severe distortion. Many types of connections are used to hold the column covers in place. Some connections consist of bolted or welded clip angles attached to the tops and bottoms of the covers. Others consist of steel plates embedded in the covers that are welded to angles, plates, or other shapes which are, in turn, welded or bolted to the steel column. In any case, these connections are used primarily to position the column covers and as such, are not highly stressed. As a result, temperature limits do not need to be applied to the steel in most column cover connections.

If either partially or fully restrained, concrete panels tend to deflect or bow when exposed to fire. For example, for a steel column that is clad with four flat panels attached top and bottom, the column covers will tend to bulge at mid-

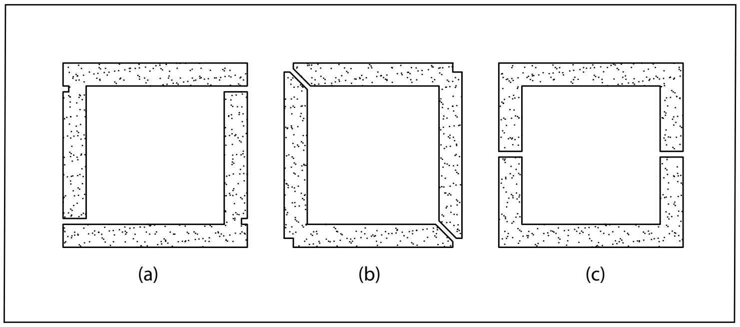



**Figure 7** Types of column covers.



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height, opening gaps along the sides. The gap sizes decrease as the panel thicknesses increase.

With L-, C-, or U-shaped panels, the gap size is further reduced. The gap size can be further minimized by connections installed at mid-height. In some cases, shiplap joints can be used to minimize the effects of joint openings.

Joints should be sealed to prevent the passage of flame to the steel column. A non-combustible material, such as sand-cement mortar, or a ceramic-fiber blanket can be used to seal the joint and then caulking is applied.

Precast concrete column covers should be installed in such a manner that if they are exposed to fire, they will not be restrained vertically. As the covers are heated, they tend to expand, and the connections should accommodate this expansion without subjecting the cover to additional loads. For this reason, the precast concrete column covers should not be restrained vertically.

Fire-resistive compressible materials, such as mineral fiber safing, can be used to seal the tops or bases of the column covers, permitting the column covers to expand without restraint. Similarly, the connections between the covers and columns should be flexible enough to accommodate thermal expansion without inducing much stress into the covers.

# Protection of Reinforcing Steel

For the purpose of establishing fire ratings, the codes currently do not address cover for the reinforcing steel in walls. The codes do require that the serviceability requirements be met by providing adequate cover for protection against weather and other effects. Because of these precautions and the proven performance of concrete walls in real fires, it appears that these requirements furnish the necessary cover demanded for fire ratings. It is recommended that for fire ratings of 1 hour through 4 hours, concrete cover be furnished as specified in ACI 318, Section 7.7.3.

# Protection of Connections

Fireproofing of connections may be necessary, depending on codes and/or insurance requirements. In many cases, fireproofing with concrete cover will also provide corrosion protection. Many types of connections in loadbearing precast concrete construction are not vulnerable to the effects of fire and, consequently, require no special treatment. For example, gravity-type connections such as the bearings between precast concrete floor or roof units and the concrete haunch or corbel do not generally require any special fire protection. If the floor or roof units rest on elastomeric pads or other combustible materials, protection of the pads is not generally required because pad deterioration will not cause collapse. Nevertheless, after a fire, the pads would probably have to be replaced, so protecting the pads might prevent the need for replacement. If the connections are to be fireproofed or concealed, this fact should be indicated in the contract documents.

Connections that can be weakened by fire and thereby jeopardize the structure's stability should be protected to the same degree as that required for the panels. For example, when an exposed steel bracket supports a precast concrete element that is required to have a designated fire rating, the steel bracket must be protected to the same fire rating. Fireproofing of connections is usually accomplished with sprayed cementitious or mineral fiber fireproofing, intumescent mastic compounds, or enclosure with gypsum wallboard.

Many connections simply provide stability and are under little or no stress in service. While fire could substantially reduce the strength of such a connection, no fire protection is necessary. Connections that have steel elements encased in concrete, drypacking, or grout after erection usually need no additional protection.

There is evidence that exposed steel hardware used in connections is less susceptible to fire-related strength reduction than other steel members. This is because the concrete provides a "heat sink," which draws off the heat and reduces the temperature of the steel.

Figure 8(a) shows the thicknesses of various, commonly used, fire-protection materials required for fire endurances up to four hours when applied to connections comprised of structural steel shapes. The values shown are based on a critical steel temperature of 1000° F (538° C) (that is, a stress-strength ratio of about 65%). The values in Fig. 8(b) are applicable to concrete or drypack mortar encasement of structural steel shapes used as brackets.

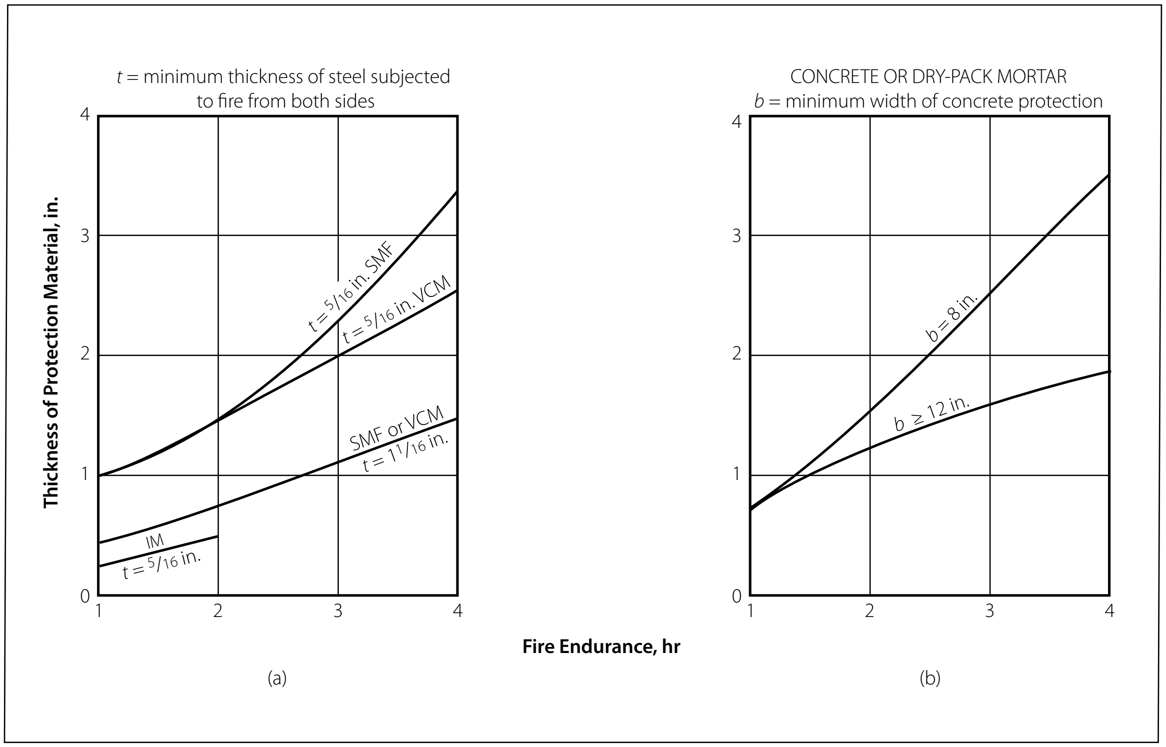


**Figure 8** Thickness of protection materials applied to connections consisting of structural steel shapes. (IM = intumescent mastic, SMF - sprayed mineral fiber, VCM = vermiculite cementitious materials)..

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When a rational analysis or design for fireproofing is not performed and concrete is used to fireproof the connections in the field, a conservative estimate would suggest that such concrete should have a thickness in inches corresponding to the specified hours of fire rating. Unless the nature of the detail itself supports such concrete, it should be reinforced with a light wire fabric.

# Treatment of Joints

Joints between wall panels are similar to openings. Most building codes do not require openings to be protected against fire if the openings constitute only a small percentage of the wall area and if the fire separation distance is greater than some code minimum distance. In such cases, the joints would not require protection. In other cases, openings, including joints, may have to be protected for fire resistance.

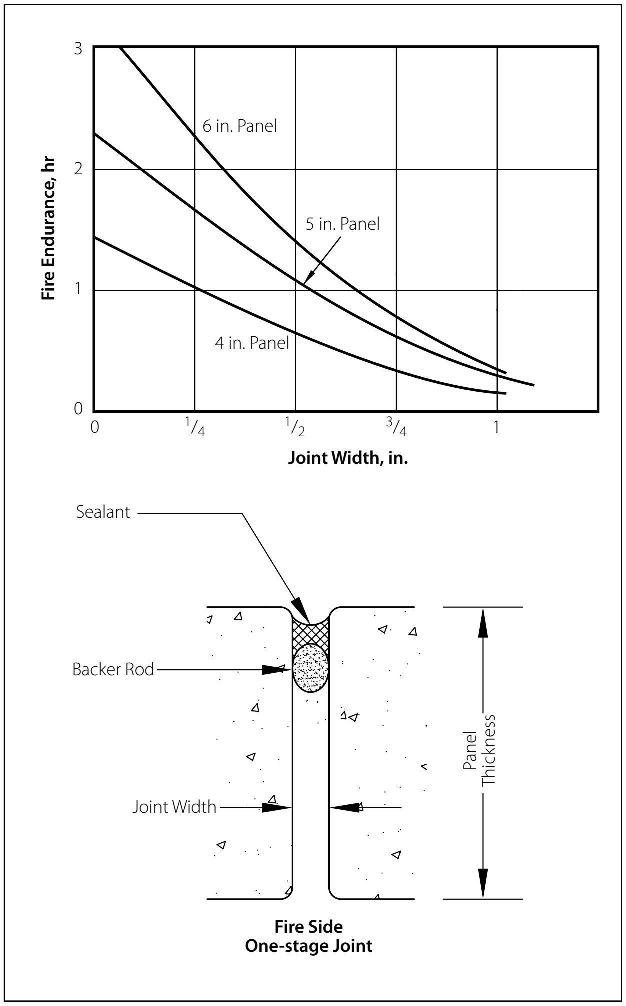



**Figure 9** Fire endurance of one-stage joints..

The IBC addresses joints in exterior walls in various sections of the code.

- In Section 715, joints are specified to have the same fire-resistance rating as the wall. Walls that are permitted to have unprotected openings are noted as an exception to this requirement.
- Table 705.8 is used to determine if unprotected openings are allowed as well as to designate the percentage of unprotected openings allowed.
- Section 722.2.1.3 addresses joints in precast concrete walls. This section requires that unprotected joints be included as openings in the calculation of opening percentages for comparison to the allowed opening percentage of Table 705.8.

Fire tests of wall panel joints have shown that the fire endurance, as determined by a temperature rise of 325° F (163° C) over the unexposed joint, is influenced by joint type, joint treatment (materials), joint width, and panel thickness.

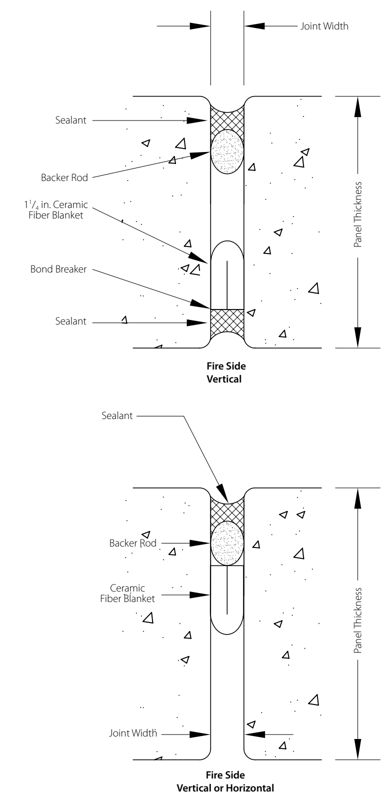
When required for fire rating, joints between wall panels should be detailed to prevent the passage of flames and hot gases. Details should ensure that the transmission of heat through the joints does not exceed the limits specified in

**Table 6.** Protection of joints between wall panels utilizing ceramic fiber felt.

| Panel thickness* (in.) | Thickness of ceramic fiber felt (in.) required for fire resistance ratings and joint widths shown | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Joint width = $^3/_8$ in. | | | | Joint width = 1 in. | | | |
| | 1 hr | 2 hr | 3 hr | 4 hr | 1 hr | 2 hr | 3 hr | 4 hr |
| 4 | $^1/_4$ | N.A. | N.A. | N.A. | $^3/_4$ | N.A. | N.A. | N.A. |
| 5 | 0 | $^3/_4$ | N.A. | N.A. | $^1/_2$ | $2^1/_8$ | N.A. | N.A. |
| 6 | 0 | 0 | $1^1/_8$ | N.A. | $^1/_4$ | $1^1/_4$ | $3^1/_2$ | N.A. |
| 7 | 0 | 0 | 0 | 1 | $1^1/_4$ | $^7/_8$ | 2 | $3^3/_4$ |

N.A. = Not applicable
* Panel equivalent thicknesses are for carbonate concrete. For siliceous aggregate concrete change "4, 5, 6, and 7" to "4.3, 5.3, 6.5, and 7.5". For sand-lightweight concrete change "4, 5, 6, and 7" to "3.3, 4.1, 4.9, and 5.7".
The tabulated values apply to one-stage joints and are conservative for two stage joints. Interpolation may be used for joint widths between $^3/_8$ in. and 1 in.
Note: 1 in. = 25.4 mm.

**Figure 10.** Protection of joints between wall panels utilizing ceramic fiber felt.




ASTM E119 ***Standard Methods of Fire Tests of Building Construction and Materials***. Concrete wall panels expand when heated, so the joints tend to close during fire exposure. By providing the proper thickness of insulating materials within the joint, it is possible to attain fire endurances equal to those of the panels. Flexible, noncombustible materials, such as ceramic fiber blankets, provide thermal, flame, and smoke barriers. These fire resistive blankets and ropes must be installed with a minimum of 10 to 15% compression. When used in conjunction with caulking materials, they can provide the necessary fire protection and weathertightness while permitting normal volume change movements. Joints that do not require movement can be filled with mortar.

Figures 9 shows the fire endurance of one-stage joints in which the joint treatment consisted of sealants and polyethylene backer rods.

Table 6 and Figure 10 are based on results of fire tests of panels with one-stage joints and ceramic fiber felt in the joints. The tabulated values apply to one-stage joints and are conservative for two-stage joints. Fireresisting silicone sealants can provide fire ratings, if required. For high ratings, fire-retardant joint filler materials may also be required.

# About AIA Learning Units

Please visit www.pci.org/elearning to read the complete article, as well as to take the test to qualify for 1.0 HSW Learning Unit.

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If you are new to the Registered Continuing Education Provider system, www.rcep.net will email you a welcome email when PCI uploads your data. That email will contain your account password. Your login name at www.rcep.net will be your email address, so you must include it when submitting your completed quiz.

# Instructions

**Review the learning objectives below.**

**Read** the AIA Learning Units article. Note: The complete article is avaliable at www.pci.org/elearning

**Complete the online test.** You will need to answer at least 80% of the questions correctly to receive the 1.0 HSW Learning Units associated with this educational program.

# Learning Objectives:

1. Discuss behavior of precast concrete under fire conditions.
2. Determine fire endurance of precast concrete walls.
3. Describe fire code requirements for sandwich wall panels and window walls.
4. Explain the necessary fire protection of reinforcing steel and connections as well as treatment of joints.

Questions: contact Education Dept. - Alex Morales, (312) 786-0300 Email amorales@pci.org

# Questions

1. Fire endurance can be determined from fire tests or calculations.

    a. True

    b. False

2. Fire endurance is defined by the following end points.

    a. Structural collapse

    b. Flame passage

    c. Heat transmission

    d. Collapse during hose stream test

    e. All of the above

3. The temperature rise of the unexposed surface is minimally affected by one of the following:

    a. Panel thickness

    b. Water-cement ratio

    c. Aggregate type

    d. Air content

4. Foam plastic insulation has a major affect on the fire endurance of insulated precast concrete panels.

    a. True

    b. False

5. The limits imposed on the area of window openings in fire resistant walls are based on the following:

    a. Occupancy

    b. Construction classification

    c. Fire separation distance

    d. All of the above

6. The percentage of openings permitted decreases as the fire separation distance increases.

   a. True

   b. False

7. Building codes currently do not address concrete cover for reinforcing steel in fire rated walls.

   a. True

   b. False

8. Connections that can be weakened by fire and thereby jeopardize the structure's stability should be protected to the same degree as that required for the panels.

   a. True

   b. False

9. Exposed steel hardware in connections is more susceptible to fire-related strength reduction than other steel members.

   a. True

   b. False

10. Precast concrete wall panels expand when heated, so joints tend to close during fire exposure.

   a. True

   b. False

11. Fire endurance of wall panel joints is influenced by joint type, joint filler materials, joint width and panel thickness.

   a. True

   b. False