

FIRE RESISTANCE

A key goal for the design team and the client is to protect the building from the multiple risks and losses caused by fire. A common misconception is that fire destroys by flames, which can be suppressed by sprinklers. In practice, this oversimplification can leave both property and human life vulnerable during a fire.

Among the goals that must be achieved when designing for fire safety are the following:

- **Contain high heat**, which can melt or ignite materials or kill in one breath.
- **Contain smoke that can blind**, choke, and ruin building components and contents. Smoke is often generated by the sprinkler suppression process, and it is unavoidable.
- **Contain toxic gas**, which is given off when plastics, synthetics, and chemicals burn. They can be deadly at any temperature.
- **Confine the fire event** to its place of origin and prevent it from spreading.
- **Reduce the fuel content** of the building by using non-combustible building materials whenever possible.
- **Avoid the potential for structural collapse** during the fire by protecting all structural framing elements that support the building.
- **Create a passive fire-protection strategy** for the building that will enable it to survive should arson, low water pressure, or a delayed fire-department response occur.
- **Divide the building** into several noncombustible compartments that will help achieve solutions for all the aforementioned hazards. This is the most important aspect of all.
- **Recognize that building codes** provide the minimum protection allowable and may not be enough to achieve the fire protection the building and its occupants will need. Each risk exposure requires a defense.



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Precast concrete provides noncombustible construction that can help contain a fire within minimal boundaries. As a separation wall, precast concrete helps to prevent a fire from spreading throughout a building or jumping between structures. During wildfires, precast concrete walls help provide protection to human life and the occupant's possessions. As an exterior wall, concrete that endures a fire can often be reused when the building is retrofitted.

The fire endurance of concrete can be determined by its thickness and type of aggregate. The American Society for Testing & Materials (ASTM) E119 lists procedures for determining fire endurance of building materials. Another good resource is PCI's *MNL 124-89: Manual on Design for Fire Resistance of Precast, Prestressed Concrete*.

Fire endurance is defined as the period of resistance to a standard fire exposure as defined by ASTM E119 that lapses before an "end point" is reached. Three end points are critical:

- 1. Structural end point.** Loadbearing components must sustain the applied loading for the duration of the required fire endurance. Collapse prior to that is an obvious end point.
- 2. Heat-transmission end point.** When the temperature increase of the unexposed surface of floors, roofs, or walls reaches an average temperature of 250 °F or a maximum of 325 °F at any one point.
- 3. Flame-passage end point.** Holes, cracks, or fissures allowing flames or gases hot enough to ignite cotton waste to pass through must not form.

Structural End Points

Concrete generally fails by heat transmission long before structural failure, whereas other construction materials fail by heat transmission when collapse is imminent.

Heat-Transmission End Points

For single-course precast concrete slabs or wall panels, a two-hour fire endurance means that thermocouples, measuring the passage of heat through the thickness of the wall, are recording an average temperature rise of 250 °F or a maximum temperature reading of 325 °F.

Slabs or wall panels faced with protective materials can provide added endurance. The accompanying table shows the fire endurance of concrete slabs with ⁵/₈-in. gypsum wallboard (Type X) for two cases:

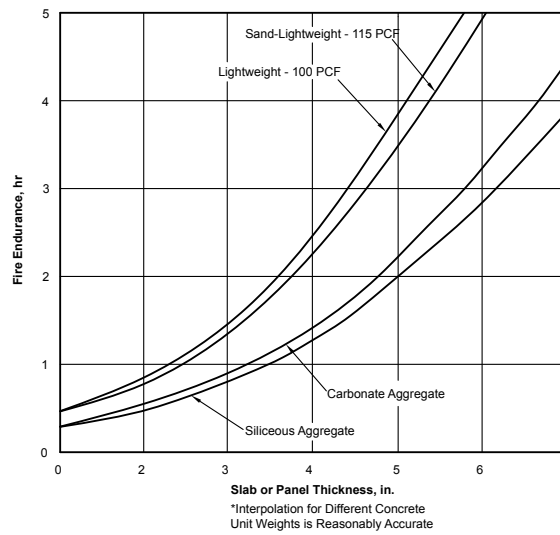
1. A 6-in. air space between the wallboard and slab.
2. No space between the wallboard and slab.

The specified materials and techniques for attaching wallboard should be similar to those used in the test on which the data are based.

| Thickness (in.) of Concrete Panel for Fire Endurance of | With no air space | | With 6 in. air space | |
|---|-------------------|------|----------------------|------|
| | 2 hr | 3 hr | 2 hr | 3 hr |
| Aggregate | | | | |
| Sand-lightweight | 2.5 | 3.6 | 2.0 | 2.5 |
| Carbonate | 2.8 | 4.0 | 2.0 | 2.7 |
| Siliceous | 2.9 | 4.2 | 2.0 | 2.8 |

Thickness of concrete slabs or wall panels faced with 5/8 in. Type X gypsum wallboard to provide fire endurances of 2 and 3 hours.

Heat transmission through a ribbed or corrugated panel is influenced by the thinnest portion of the panel and by the panel's "equivalent thickness." This term 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 ignored.



Fire endurance (heat transmission) of concrete slabs or panels

Multi-course assemblies, such as floors and roofs, often consist of concrete base slabs with overlays or undercoatings of other types of concrete or insulating materials. In addition, roofs generally have built-up roofing. If the fire endurance of the individual courses is known, the fire endurance of the composite assembly can be estimated.

Precast concrete insulated sandwich wall panels must conform to IBC requirements. Those regulations state that where noncombustible construction is specified, combustible elements in walls are limited to thermal and sound insulation having a flame-spread index of 25 or less.

When the insulation is sandwiched between two layers of noncombustible material such as concrete, the maximum flame-spread index allowed is 100, except that it shall not exceed 75 for foam-plastic insulation. When insulation is not installed in this manner, it is required to have a flame spread of not more than 25. Data on flame-spread classifications are available from insulation manufacturers.

Cellular plastics melt and are consumed at about 400 to 600 °F. Thus, additional thickness or changes in composition probably have only a minor effect on the fire endurance of sandwich panels. The danger of toxic fumes caused by burning cellular plastic is practically eliminated when the material is completely encased within concrete sandwich panels. Until more definitive data are provided, PCI recommends that 5 minutes be considered as the value for R for any layer of cellular plastic 1 in. or greater, where R is the fire endurance rating of an assembly.

Flame-Passage End Points

Joints between panels should be detailed so that passage of flame or hot gases is prevented, and transmission of heat does not exceed the limits specified in ASTM E119. Concrete wall panels expand when heated, so the joints tend to close during fire exposure.

Noncombustible materials that are flexible, such as ceramic-fiber blankets, provide thermal, flame, and smoke barriers. When used with caulking, they can provide the necessary weather tightness while permitting normal volume-change movements. Joints that do not move can be filled with mortar.

Where no openings are permitted, the fire endurance required for the wall should be provided at the joints. Joints between adjacent precast floor or roof elements may be ignored in calculating the slab thickness provided that a concrete topping at least 1½ in. thick is used.

Where no concrete topping is used, joints should be grouted to a depth of at least one-third the slab thickness at the joint, or the joints should be made fire-resistive in a manner acceptable to the authority having jurisdiction. No joint treatment is required for parking structures constructed with pretopped double tees.

Codes and Economics

An important aspect of dealing with fire endurance is to understand what the benefits are to the owner of a building in the proper selection of materials incorporated in the structure. These benefits fall into two areas: codes and economics. While code requirements must be met, designers typically have many options in the specification of materials and assemblies that meet these regulations.

Economic benefits associated with increased fire endurance should be considered at the time decisions are made on the structural system. Proper consideration of fire-resistive construction through a life-cycle cost analysis will show the owner the amount of economic benefits that will accrue through the use of different types of construction. These benefits can include lower insurance rates, larger allowable gross area, fewer stairwells and exits, increased value for loan purposes, longer mortgage terms, and better resale value.

Several key areas of code compliance allow owners and designers to provide effective fire protection at an economical cost. The three key areas are:

- 1. Minimum standards.** A fire rating is not the same as fire safety. The IBC includes a variety of compromises. Code trends generally emphasize sprinkler installations by providing trade-offs that encourage their use. These active systems offer valuable protection, but they also include trade-offs such as more liberal fire-separation areas and other changes that decrease required wall and floor performance.
- 2. Building materials.** Wood and steel generally perform poorly in fires. Both must be treated, coated, or covered to meet fire requirements, which increases construction costs. Wood is a natural fuel source and steel begins to fail at 1200 °F. Concrete begins to melt at 2200 °F.
- 3. Sprinklers.** Automatic sprinklers are a desirable, active fire-suppression system and can help control fire spread. But they should not replace passive fire-suppression systems that are designed to inherently protect a building without any mechanical activation required. Relying on active-suppression systems alone can produce an inadequate response during a fire emergency.



A design approach that stresses compartmentalization offers a more fundamental method to protect lives and property. Compartmentalization uses passive, noncombustible floors and walls, such as those made of precast concrete, to construct sections of the building as separate modules that confine fire to a specific area. Once constructed into the building, these passive protectors will protect the building throughout its life.

Noncombustible compartmentalization, combined with an inherently fire-resistant/tolerant structural frame, provide the best combination of economics and protection that owners and users seek. When this passive design combines with other safety measures, including sprinklers and early-warning detection systems, a balanced design approach is achieved.

A variety of precast concrete components can be used in creating a complete passive-design system for a building. Foremost among these are:

- **Hollow-core slabs**, which serve as combined floor/ceiling systems and can also be used as wall panels in either vertical or horizontal configurations.
- **Wall panels**, which offer high fire ratings and work with other components to create a noncombustible envelope. Insulated sandwich wall panels can also be used.
- **Double tees**, which can be used similar to hollow-core planks for roofs, ceilings, floors, or wall panels.
- **Columns and beams**, which create a framework that will resist intense heat and will not add fuel to a fire.

A total-precast concrete system provides an effective design for minimizing fire damage and containing the effects within the smallest space possible for the longest time.

The information above will provide for a structure with acceptable criteria for fire resistance. The designer and owner should also consider the following factors when designing for fire:

- Contain high heat, which can melt or ignite combustible materials.
- Contain smoke that can blind, choke, and ruin building contents. Smoke is often generated by a sprinkler suppression process which may be unavoidable.
- Contain toxic gases that are given off by plastics, synthetics and chemicals when they burn.
- Confine the fire event to its place of origin by using precast concrete components to create compartments.
- Reduce the fuel content of the building by using noncombustible material whenever possible.
- Create several noncombustible compartments in the building
- Understand that the local minimum code requirements may not be adequate to achieve the fire protection that your building and its occupants should have.



A 2005 study sponsored by the Fire Safe Construction Advisory Council compared construction costs among five building systems and found that a compartmentalized construction approach using concrete-based methods costs generally less than 5% of the overall construction cost. The group noted that this amount was less than the contingency budget typically recommended for the owner to carry for unanticipated expenditures during the project.





The project evaluated the impact of building a fire-resistant, multifamily, residential structure using five separate building techniques, to meet requirements of the 2003 IBC. The five systems comprised:

- Conventional wood framing with a wood-floor system using Type 5A or 5B construction;
- Light-gage steel framing with a cast-in-place concrete floor system on a metal form deck;
- Loadbearing concrete masonry construction with a precast concrete plank floor system or a cast-in-place concrete floor system;
- Precast concrete walls with a precast concrete floor system; and
- Insulated concrete form (ICF) walls or interior bearing walls made with concrete masonry units (CMU) with a precast concrete plank floor system or a cast-in-place concrete floor system.

In each case, except the conventional wood-frame system, it was assumed that the partition walls within the building would be constructed using metal studs finished with gypsum board.

The studied building was a four-story structure encompassing 25,000 ft² of space per floor. Two models were created, one with single-bedroom layouts and another with a mix of one- and two-bedroom layouts to address the variety of construction configurations commonly found in the multifamily dwelling marketplace. The team chose three specific locations in which to locate their projects (Framingham, Mass.; Harrisburg, Pa.; and Towson, Md.) to provide diversity in labor and material costs.

The study's consensus was that the costs associated with using a compartmentalized construction method that took advantage of precast concrete's benefits required less than 2% more of the total construction cost.

In addition, although precast concrete's initial in-ground cost was higher, the design did not fully play to the advantages that a total-precast concrete design would offer, as the designers created a layout that could be standardized for use by all material options. Those general parameters would not be necessary if a design intended to use precast concrete from the beginning, and the difference in costs would be lower.

The costing parameters were also unable to take into consideration the schedule advantages that precast concrete's fast erection would provide. Additional advantages, including longer span capability to reduce columns, can provide sufficient cost effectiveness to eliminate the cost differential.

The use of concrete materials can also provide long-term benefits, the report noted. Materials like concrete masonry, precast concrete, and cast-in-place concrete offer advantages beyond their inherent fire performance, such as

resistance to mold growth and damage from vandalism, as well as minimal damage caused by water and fire in the event of a fire. Those attributes can require reduced cleanup costs and quicker reoccupation of the structure (see Reference 9).

