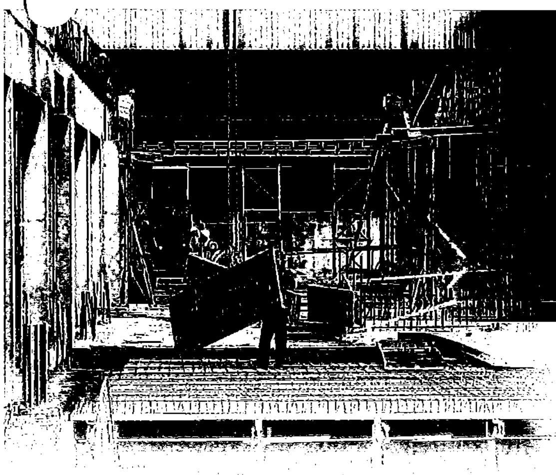


CHAPTER 11

Fire-Resistive Construction

OBJECTIVES

At the conclusion of this chapter, you will be able to:

- Recall the difference between noncombustible and fire-resistive construction.
- Describe different types of concrete structural systems.
- Describe the two types of prestressing.
- Describe the hazards of formwork.
- Describe methods of fireproofing steel and of ensuring a level of fire resistance in concrete.
- Describe how concrete and concrete structural elements react to fire.

Case Study

Figure 11-1 Note the significant sagging of the steel beams in the One Meridian Plaza fire.

Courtesy of USFA/FEMA.

While high-rise fires may be rare compared with other types of fires, they can prove to be the most challenging of all. They can also prove to be deadly, which was unfortunately the case in the nighttime One Meridian Plaza fire in Philadelphia in 1991 (**Figure 11-1**). Fire broke out in a 22nd-floor office under construction, most likely when a pile of oil-soaked rags spontaneously combusted. A delayed initial alarm slowed response to the nighttime fire. Fire fighters encountered a series of problems, most notably the woefully low pressure settings on the standpipe's pressure-reducing hose valves, which was totally inadequate to handle the department's 1¾-inch hose and automatic nozzles. The fire spread quickly upward, through penetrations within the building and through autoexposure on the exterior; it compromised exterior granite panels on a stair enclosure, sending parts of them to the ground. Three fire fighters on the 28th floor became disoriented and ran out of air, succumbing to the effects of smoke inhalation. As the fire consumed the contents of floor after floor, significant concerns were raised about structural collapse. Finally, the fire was stopped by 10 sprinklers on the 30th floor. A subsequent investigation revealed that some floor beams and girders had sagged 3 feet (91 cm) as a result of the heat of the fire.

1. What are the problems with delayed alarms in a fire in a nonsprinklered or partially sprinklered building?
2. Once control has been lost of a high-rise fire, how much concern is there for structural collapse? Which kind of fuel load could initiate a collapse?
3. Do you have unsprinklered high-rises in your district?
4. Which kind of standpipe hose valve is installed? When and how were these valves inspected?

Introduction

From a fire protection perspective, fire-resistive construction is considered to be the best. It is the type of construction most resistant to collapse and does not contribute fuel to a fire. With these attributes, fire-resistive construction is given the largest permissible area and heights, including unlimited area and height. Fire-resistive construction often uses concrete or substantially fire-protected steel (more than noncombustible) as a structural system. We have already covered steel, so we will now analyze concrete in detail.

Concrete

Concrete is a cementitious material produced by a chemical reaction of Portland cement (primarily limestone) and water to which inert materials called aggregates are added. Shortly after it is mixed, concrete sets into a solid mass, but it continues to cure indefinitely Figure 11-2. Construction specifications set a date by which concrete must reach its required compressive strength. For instance, concrete required to reach design strength in 28 days is sometimes referred to as 28-day concrete.

While curing, concrete generates heat of hydration. During its initial curing, concrete must be protected from freezing. Low temperatures retard the curing of concrete, and freezing is harmful to the material. Good concrete results from proper handling of carefully controlled materials. Because there are so many ways to create a poor concrete product, high factors of safety are used in concrete design.

Concrete is weak in tensile strength and has poor shear resistance. Its compressive strength is good, particularly when compared to the cost of steel to resist the same load. Fire service personnel should avoid the common error of using the term *cement*, when *concrete* is the proper term. Cement is a component of concrete.

Figure 11-2 Concrete being poured. For most types of concrete, it will take 28 days to obtain its full strength.

Figure 11-3 The Guggenheim museum in New York, NY.

C crete Structures

Until the post–World War II era, structural concrete was regarded as suitable only for massive, low-rise utilitarian structures in which aesthetics played little part. Fire-resistive high-rise buildings almost universally built of steel frames were often fireproofed with concrete and used cast-in-place concrete floors. Concrete warehouses and factories built before World War II are easily recognizable. Their panel walls, usually of brick or brick and block composite, were built on each floor between the exterior columns.

Precast concrete principally was in the form of cinder blocks. Cinder blocks use cinders as the aggregate to produce a light, relatively inexpensive block. Concrete blocks use other materials for aggregate. Heavier concrete blocks usually have smoother surfaces than cinder blocks.

Underwriters blocks are concrete blocks produced under Underwriters Laboratories, Inc.'s classification. The manufacturer is authorized to issue a certificate giving the type and number of units delivered to a specific job. These blocks are used in assemblies that must meet fire resistance standards.

Today, there is a bewildering variety of mix-and-match building construction elements. Steel-framed buildings now often have cast-in-place concrete floors made with forms that are removable or that can be left in place. The floors may or may not contribute to the stability of the building. Precast concrete and prefabricated metal wall panels are common.

In some cases, an architect may wish to emphasize concrete construction. Instead of considering form marks unattractive, architects have accentuated them in some building designs (Figure 11-3). In other cases, decorative brick veneer is used to conceal the concrete construction.

Over time, substantial brick veneer has been lost from some reinforced concrete buildings. High early strength concrete (special concrete that cures quickly to high strengths) tends to shrink as it matures, but the brick veneer overlying it does not. If proper provision is not made for the contraction, the brick veneer may crack and fall off.

Steel Versus Concrete Framing

Many designers prefer to design in steel, whereas others prefer concrete for framed buildings. Some buildings present a unified exterior appearance, yet have one section concrete framed and another section steel framed. Building owners are sometimes less interested in the material of construction than in speed and cost of construction. When a building is put out for bids, the price often depends on which contractor has readily available personnel and other resources.

Fire Department Problems with Concrete Construction

The problems that fire departments face regarding concrete construction can be divided into three distinct areas:

- Collapse during construction with no fire.
- Fire during construction.
- Fire in completed, occupied buildings.

Types of Concrete Construction

There are two basic types of in-concrete construction:

- *Cast-in-place concrete* includes plain concrete, reinforced concrete, and post-tensioned concrete.
- *Precast concrete* includes plain concrete, reinforced concrete, and pretensioned concrete.

Concrete Definitions

- **Aggregate**: This is material mixed with cement to make concrete. Common aggregates are both fine and coarse. Fine aggregate is usually sand. Coarse aggregate may be one of a great variety of materials, depending upon availability and the characteristics desired in the finished product. Concrete often is described by the name of the aggregate used. Crushed stone, gravel, cinders, breeze (a coke by-product no longer used), expanded slag, shale, slate, clay, vermiculite, and perlite (natural lightweight materials), lightweight stones such as lava and pumice, and fly ash reclaimed from boiler plants have all been used as aggregates.
- **Cast-in-place** concrete: This concrete is molded in the location in which it is expected to remain Figure 11-4.
- **Casting**: This is a process of placing the fluid concrete into molds, generally called forms, in which the concrete is permitted to harden to a certain shape.
- **Chairs**: These are small devices designed to keep the rods up off the surface of the form, so concrete will flow underneath the rods.
- **Composite and combination columns**: These columns use steel and concrete combined into one unit. As in all composite construction, the different elements must react together, and any failure of the bond between them

Figure 11-4 Concrete will be poured into this form, creating a cast-in-place wall.

creates a distressed column. Composite columns were formerly used on the lower floors of a heavy-duty building to avoid surrendering floor space to large-diameter concrete columns made solely of reinforced concrete.

- **Composite construction**: This is a different term than a composite structural element. Reinforced concrete is one of several composite structural elements. The term *composite construction* is often used to describe buildings in which different load-bearing materials are used in different areas, such as exterior columns being made of concrete and interior columns being constructed of steel. Sometimes the top floor of a concrete building is constructed of lightweight steel. This lighter structure may be called a penthouse, meaning any structure above the roof line. The term *penthouse apartment* properly refers only to an apartment built on the roof. Apartments on lower floors that have terraces are properly called terrace apartments.
- **Continuous casting**: This is a process for casting or pouring concrete without interruption from start to finish. This avoids the problem of joining new concrete to concrete already poured. If such a joint is not properly made, cold joints, which are planes of weakness, result.
- **Continuous slipforming**: This entails pouring concrete continuously as forms move upward so that continuous casting may be accomplished.
- **Drop panels**: These are thicker sections of floor near columns to assist in resisting the natural tendency of the floor to shear off at the column Figure 11-5.
- **Flat plate structural system (or continuous beam)**: A cast-in-place floor in which there are no beams supported by columns; the floor plate itself rests directly on the columns.
- **Footings**: Typically thick concrete pads, blocks, or strips of concrete below the surface of the surrounding soil, sometimes heavily reinforced, that transfer the loads of walls, piers, or columns to the ground. Footings attempt to minimize building settlement by spreading the load over the large soil/concrete interface.

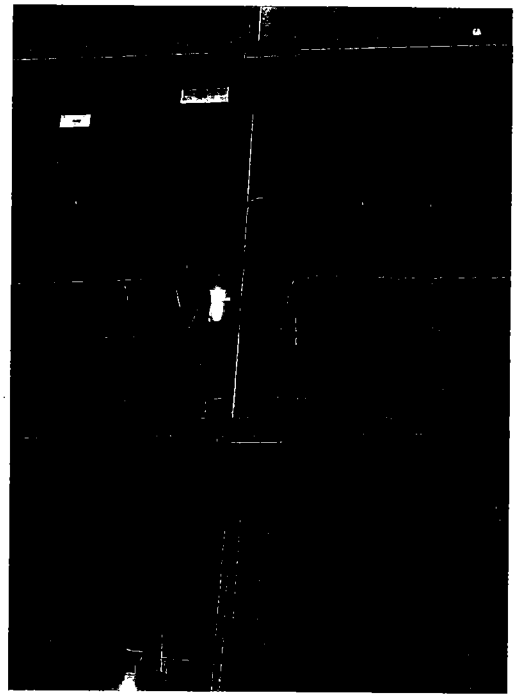


Figure 11-5 Drop panels atop two concrete columns.
Courtesy of Glenn Corbett.

- **Lally columns**: These are steel pipes filled with concrete to increase their load-carrying capacity. In the 1800s, cast-iron Lally columns were usually drilled to provide a vent for the steam generated in the concrete. Today, steel pipe concrete columns are only sometimes drilled. When exposed to heat, they may explode. In one example in a fire in a concrete plant, expanding steam from concrete blew out one end of the Lally columns, creating rockets.
- **Lift slab**: This is a type of construction in which the columns are erected to their full height, then the first-floor slab is cast on the

ground. Each subsequent floor slab and then the roof slab is cast, one directly on top of the other. A bond breaker is used between each slab so there is no adhesion. Starting with the roof, the slabs are successively lifted into position. Steel deck roofs have been assembled on the ground and lifted into position in a similar manner. L'Ambience Plaza, a lift-slab building under construction in Bridgeport, Connecticut, collapsed in 1987 with a loss of 28 lives; a single component in the lifting system failed and caused the collapse Figure 11-6.

- **Monolithic construction**: A method where all the concrete in a building is properly bonded together. The resultant structure can be likened to one piece of stone.
- **Mushroom caps**: These are tapered extensions at the tops of columns that assist in transfer of loads from floor to column. Columns in heavy-duty concrete construction may show both mushroom caps and drop panels.
- **One-way structural system**: This system incorporates floors that have beams running in one direction only Figure 11-7.
- **Plain concrete**: This term refers to concrete that has no reinforcement, except possibly light reinforcement to resist temperature changes. A sidewalk slab and a concrete base for a child's swing set are examples of plain concrete. Some early concrete bridges, such as the Taft Bridge in Washington, D.C., were built of plain concrete. Necessarily, the entire bridge is in compression, as were the early stone arch bridges developed by the Romans.
- **Precast concrete**: This concrete has been cast at a location other than the place where it is to remain. The precasting may be done at a plant miles from the construction site, at the construction site but remote from the ultimate installation location, or immediately adjacent to the point of use. The common cinder block or concrete block is precast plain concrete. Other precast concrete units are reinforced or tensioned.
- **Pretensioning and post-tensioning**: These are processes by which steel **tendons** or rods are placed under tension, drawing the anchors together. The tensioned steel places the concrete in compression.
- **Reinforced concrete**: This is a composite material made of steel and concrete. Steel provides the tensile strength that concrete lacks. Steel may also be used to provide compressive strength. The term *reinforced concrete* is actually a misnomer because it suggests that

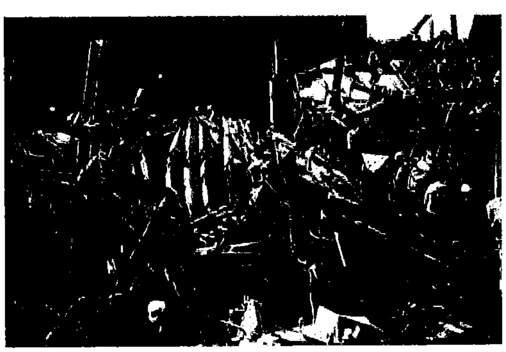


Figure 11-6 The L'Ambience Plaza collapse of 1987.

Courtesy National Institute of Standards and Technology

Figure 11-7 A one-way structural system.

concrete has a certain strength and that steel reinforces that strength. This assumption sometimes leads to a lack of recognition of the hazard of a failure of the bond between the concrete and the steel. Reinforced concrete is a composite, and both elements are equally important. To accomplish the designed function of reinforced concrete, the concrete and steel must remain in contact. Most importantly, exposed steel reinforcement lacks fire resistance, as does any unprotected steel.

- **Reinforcing bars or rods**: These are steel rods or bars that are usually intentionally deformed. A raised pattern in the surface of the steel aids in the transmission of stress from the concrete to the steel. It would be more accurate to call them tension rods. There is also interest in glass fiber reinforcing rods. The effect of fire on fiberglass-reinforced concrete is uncertain.
- **Slipforming**: This is a technique by which forms are moved, usually upward, as the concrete is poured.
- **Spalling**: This term describes the loss of surface material when concrete (or stone) is subjected to heat (Figure 11-8). It is due to the expansion of moisture in the concrete. Some concrete and certain aggregates are more subject to spalling than others. Concrete made with ground-up fire brick is resistant to spalling and is often used at fire testing facilities. Explosive spalling occurs violently, throwing out bits of concrete projectiles. Note the correct pronunciation is *spalling*, not *spallding*.
- **Temperature rods**: These are thin rods installed near the surface of concrete, usually at right angles to the main reinforcing rods to help the concrete resist cracking due to temperature changes. However, failure of the bond between the temperature rods and the concrete does not materially affect the strength of the structure.
- **Two-way structural system**: This system incorporates floors that have beams running in two directions.

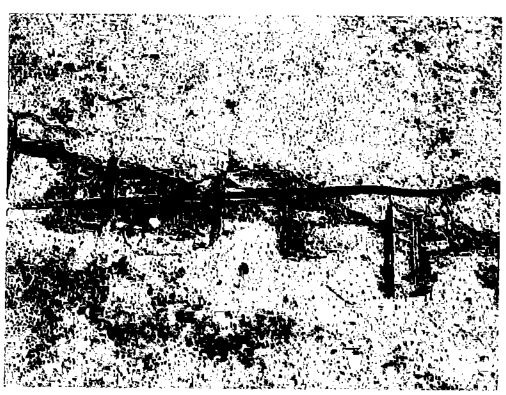


Figure 11-8 Spalling of concrete.

Concrete Structural Elements

Columns

A chief virtue of concrete is its high compressive strength and low cost, which is why concrete is used for columns, even in structures otherwise built of steel, such as highway bridges. A short column with a large cross section in proportion to its length is called a pier. It may be of plain concrete if it is loaded only compressively; otherwise, columns are of reinforced concrete to provide the tensile strength necessary for loads created by eccentric or torsional loading.

The steel reinforcing rods ("rebar") not only provide necessary tensile strength, but also carry some of the compressive load. The compressive strength of steel is many times that of concrete. In early concrete construction, it was the practice to design larger diameter columns successively on lower floors to cope with the increasing loads. At the lowest level, the size of the columns might be so great as to interfere with the use of the building. In some cases, standard steel columns were used within the concrete to take advantage of the far greater compressive strength of steel and reduce the width of the column.

The steel rods are provided with ridges to strengthen the bond between the rod and the concrete Figure 11-9. Over time, however, the steel inevitably begins to corrode within the concrete. Epoxy and stainless steel coatings are applied to minimize this problem. In addition, rods entirely of stainless steel are available. Recently, glass fiber polymer reinforcing rods, with twice the tensile strength of steel, have been put in use to minimize corrosion; they are not capable of being welded, however.

In modern buildings, increasing column sizes is an unsatisfactory solution to the problem of dealing with ever-greater loads because the useable area would vary from floor to floor. This is overcome by increasing the size of the reinforcing steel as the loads increase so the outside dimensions of columns are identical on all floors. In some cases, the columns have so much steel in them that a special additive is mixed into the concrete to permit it to flow into the relatively small spaces between the steel.

Reinforcing rods are long with a relatively thin diameter. Sleeves, reinforced overlaps, or welding is used to connect the ends of rods and transfer the load. The rods in a column are joined by lateral reinforcements called ties or hoops. (In round columns, the ties connecting the outer rods are often formed in a helix. Such reinforcement is wrongly termed *spiral reinforcement.*)

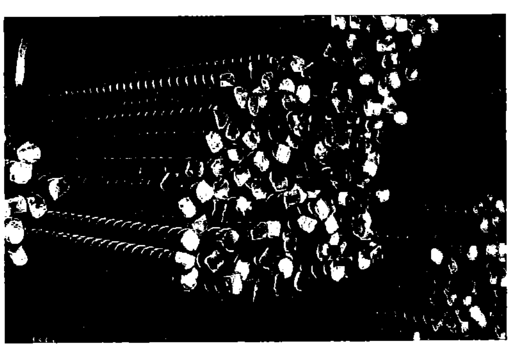


Figure 11-9 Steel reinforcing rods. Note the ridges, which enhance the adhesion of the concrete to the steel rod.

The ties or hoops serve to cut the long slender column into a number of relatively short columns, one on top of the other. Together with the concrete to which they are bonded, the rods form a composite structural element. If the unity of the composite fails, such as by loss of concrete either under normal circumstances or as a result of fire, the steel rods may buckle under the load. Buckling will cause the rods to protrude from the column.

Beams and Girders

Plain concrete is strong in compression but weak in shear, and it does not have any tensile strength. As noted, when a beam is loaded, it deflects. This deflection brings about compression in the top of the beam and tension in the bottom of the beam. Reinforcing bars are placed in the bottom of the concrete beam to provide the necessary tensile strength. Precast beams often have the word *top* cast into the top of the beam to ensure that the beam is installed right side up.

In a cantilever beam, however, the tension is in the top of the beam, and thus the reinforcing (tension) rods are in the top of the beam. The far end of the beam bends downward like a diving board.

In a continuous beam supported at more than two points, there is tension in the top of the beam in the area over the tops of the columns, and tension in the bottom of the beams between columns.

In all cases, reinforcing must be properly designed. Vertical reinforcing bars in concrete beams designed to prevent cracking under shear stresses are called stirrups. Some tensile reinforcing bars may be bent up to accomplish the same purpose.

T-Beams

Concrete below the neutral plane (where there is neither tension nor compression in the beam) serves little purpose. Sufficient concrete is needed to bond with the reinforcing rods for the relatively slight compressive stresses and to protect the steel from fire.

This leads to the characteristic T-beam design in which the neutral plane coincides with the bottom of the wide, thin floor slab Figure 11-10. Double

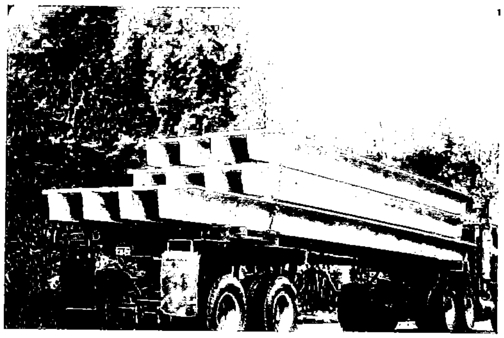


Figure 11-10 Double T-beams being shipped to a construction site.

Courtesy of the estate of Francis L. Brannigan.

T's are floor slab and beam combinations with two beams. Floor beam combinations with four beams are also manufactured.

As in columns, where space requirements are paramount, steel may be substituted for some of the concrete to handle compressive loads. For any unit area, steel has 15 times the compressive strength of concrete. Steel is, however, more costly.

Autoclaved Aerated Concrete Units

Although autoclaved aerated concrete (AAC) has been in existence for nearly 100 years, it has been in use in the United States only since World War II (Figure 11-11). This type of prefabricated concrete uses all of the traditional components of concrete, but adds aluminum powder as well. When the concrete is mixed together, the aluminum powder reacts with the lime in the mix, creating tiny cells in the final concrete product. It is these cells that make the AAC relatively lightweight when compared with traditional concrete (one-fourth the weight by volume). Once the AAC has set, it is placed in a autoclave (kiln) under high-pressure steam where it gains its ultimate strength.

AAC may be formed into panels, blocks, and floor slabs. It can be cut easily, thereby obtaining the desired dimensions. In terms of fire protection, the material has held up well when tested in an American Society for Testing and Materials (ASTM) E-119 furnace, achieving a 4-hour rating with an 8-inch-thick (20.3 cm) block wall.

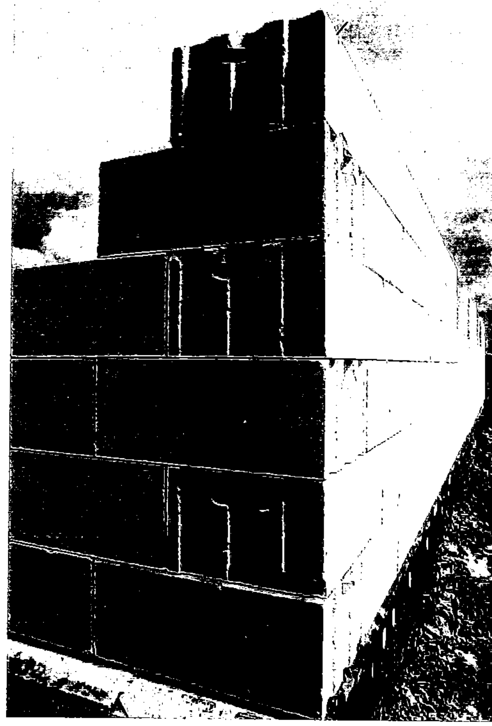


Figure 11-11 Autoclave aerated concrete.

Concrete Floors

Many varieties of concrete floors are used in concrete and/or steel-framed buildings and in ordinary construction. Concrete floors may be cast-in-place or precast.

Concrete was first used for leveling brick and tile arch floors. This led to segmental and flat concrete arches sprung between unprotected wrought iron or steel beams. Other early floors were built of individual beams supporting a floor slab all poured at the same time. The appearance of the underside is reminiscent of wood joists.

Hollow tiles were used in early efforts to lighten concrete floors by eliminating concrete below the neutral plane. The tiles are visible from the ceiling side of the floor. This technique often puzzles modern engineers.

Many concrete floors are designed as continuous beams. The entire floor is one big beam, just as a wooden floor might be made of one huge sheet of thick plywood. In heavy construction, mushroom caps and drop panels are used at columns to cope with high shear stresses.

Concrete floor structural systems may also utilize individual beams. In a one-way structural system, beams run in one direction. Logically, two-way systems have beams running in two directions.

In so-called **waffle concrete**, which comprises a two-way structural system, closely spaced beams are set at right angles to one another, and unnecessary concrete is formed out. The lower side resembles a waffle Figure 11-12.

In lighter construction, the floor may be just a flat plate, with no projections below the floor line. This gives a smooth surface that is easily finished; thus, it is a popular choice for offices and apartment buildings.

When concrete floors are cast onto corrugated steel, the steel is a **left-in-place form**. The steel provides necessary tensile strength. If the bond fails, the floor section may fail. In one parking garage, the steel was eaten away by deicing salt, and a collapse resulted.

When precast T-beam units are used, additional concrete is often cast-in-place on top of the units, which are left rough on top to ensure a bond. The entire unit becomes an integral beam-and-floor element. Precast cored concrete floor units have cylindrical openings cast lengthwise through the units to remove unnecessary weight and to provide channels through which building utility services can be run Figure 11-13. Concrete floors may be simply load bearing or may be an integral part of the structural stability of the building.

Older building codes in some cities required that the street floor of buildings of ordinary construction be of fireproof construction. Consequently, a concrete floor or, more likely, a concrete topping over a wood floor, may be found in a building of ordinary construction. In one case, a concrete topping over wood beams was required by health department regulations for a washable floor in a restaurant. This concealed the destruction of the beams by fire. Four fire fighters died when the floor collapsed without warning.

Figure 11-12 A waffle concrete floor.

Courtesy of Glenn Corbett.

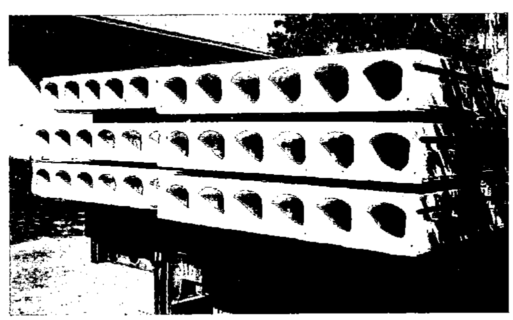


Figure 11-13 This type of floor takes away unnecessary concrete, which decreases the overall weight while allowing openings in which utilities can be run.

Courtesy of the estate of Francis L. Brannigan.

Some 1-hour-rated designs of wood floors include a lightweight concrete topping as much as 1–1.5 inches (25–38 mm) thick. This retards the passage of heat through the floor and delays the temperature rise on the unexposed surface, a condition of the ASTM E-119 fire resistance standard.

Building a cast-in-place concrete floor into ordinary wall-bearing masonry buildings sometimes creates a hazard during construction, and perhaps for the life of the building. As part of the construction, the wall is carried up a story or more beyond the point where the floor is to be located. A slot is left in the wall at the point where the floor is to be cast. The concept is that concrete will fill the slot, thus uniting the floor and wall.

If a windstorm occurs during the time that the slot is open (usually a few unmortared bricks set on end are relied on for temporary support), a collapse may result. A ladder or hose line over the top of the wall may also cause collapse. For all practical purposes, the wall is undercut, as is done in felling a tree.

Unless the concrete is carefully pushed up into the gap when the floor is poured, the wall will always be weak at this point. The finished floor may give no evidence that the continuity of the wall is interrupted by a void that creates a permanent plane of weakness.

Concrete floors in steel buildings may be precast or cast-in-place. They may be only load bearing or they may provide structural stability by being designed to resist lateral loads such as wind. In the latter case, studs are welded to the steel beams and the reinforcing bars are attached to the studs.

Concrete floors in cast-in-place concrete-framed buildings are cast integrally with columns, providing a monolithic rigid-framed building. Precast units may be pinned or can be connected as a monolithic unit. In this case, reinforcing bars are designed to protrude from the finished precast slabs or other units. When the slabs are laid down, a space is left between them. The protruding bars of one slab extend past the ends of the protruding bars of the other slab. They overlap without touching. An 18-inch space, for instance, may be left between slabs with bars that are usually hooked, protruding 12 inches. A form is made, and concrete is poured to level. The sections, thus joined by a wet joint, become monolithic.

Concrete floors in precast pinned concrete buildings may be only load bearing and may not contribute to the building's structural stability. Precast columns are often built with haunches or shelves cast into their sides on which beams are set. Steel plates embedded in the concrete may be welded together. This, of course, is pinned, not monolithic construction. In some cases, the beams are held in place only by gravity.

Prestressed Concrete

Conventional reinforced concrete has been used since the invention of the reinforcing bar in 1885. In recent years, prestressed concrete has been developed. **Prestressing** places engineered stresses in architectural and structural concrete to offset the stresses that occur in the concrete when it is placed under load. The concrete is "preloaded" with stresses to help strengthen it for tensile loads.

Consider a row of books side by side. Used as a beam across two chairs, such a row will fail of its own weight, without any superimposed load. There is no shear resistance between the books. However, drill a hole through the row of books laterally, pass a wire through the books, and tighten the wire against the end books. The row of books would be compressed by tensile stress in the wire and compression in the books. The "beam" could then be placed across two chairs and loaded. The "beam" has been prestressed sufficiently to counteract the stresses placed on it by the load.

Special high-strength, cold-drawn steel **cables**, similar to those used for suspension bridges, or alloy steel bars are commonly used. In building construction they are technically known as tendons, but are called **strands** or cables by those working with them.

High-tensile-strength wire, ordinarily used for prestressing, is more sensitive to high temperatures than structural steel. There is virtually complete loss of prestress at 800°F (427°C)—less than the temperature of a self-cleaning oven. Protection of the tendons from fire is of paramount importance.

There are two methods of prestressing: pretensioning and post-tensioning. The prefixes *pre* and *post* refer to whether the concrete is poured before or after the tension is applied.

Pretensioning is done in a concrete plant in the process of creating some precast concrete building components. High-tensile-strength steel strands are stretched tightly between the ends of a form. Concrete is then poured in the form. As the concrete sets, it bonds to the tensioned steel. When the concrete reaches a specified strength, the tensioned strands are released from the ends of the form. The stretched strands attempt to draw back, thus compressing the concrete. This creates a built-in resistance to loads that produce tensile stresses. The completed units, such as the common T-beams, are shipped to the job site.

Post-tensioning is done on the job site (Figure 11-14). High-tensile-steel strands (tendons, wires), encased in plastic or paper tubing, or wrapped to prevent any adhesion between steel and concrete, are positioned in the forms. The concrete is poured. After the concrete is set and reaches a specified strength, the steel tendons are stretched and anchored at the ends of the unit. Technically, this is called **stressing the tendons**. On the job site, it may be called "jacking the cables." A major advantage of post-tensioning is that floors can be thinner. Thinner floors will allow several more rentable floors in a tall building. Sometimes post-tensioning is performed in increments, as the load of the building increases with additional stories.

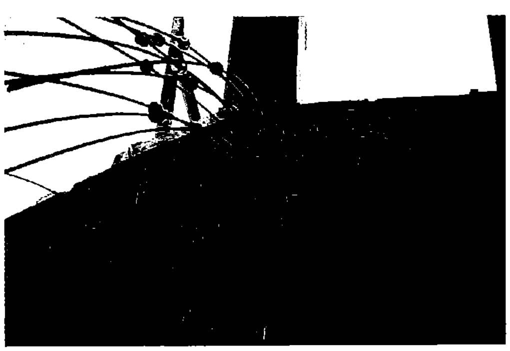


Figure 11-14 This concrete floor is post-tensioned.
Courtesy of the estate of Francis L. Brannigan.

Some bridge girders are tensioned enough to make shipment possible, then post-tensioned after being placed. After tensioning is completed, some designs call for pressure grouting in which a cement paste is forced into the space between the tendon and the concrete to provide a bond. Some tensioned floors consist of small precast units through which tension cables are run, then tensioned.

Reinforced Masonry

There is an economic limit to the height of an ordinary brick bearing wall building. This exists because of the requirement that the walls increase in thickness as the building's height increases. The limit is generally about 6 stories, but there are brick bearing wall buildings as tall as 16 stories. In recent years, it has become possible to build brick bearing wall buildings 20 or more stories in height, with no wall thicker than 12 inches (30.5 cm). Concrete block can be used in a similar fashion.

In one method of construction, two wythes of brick are built. The width of one brick is left between them. Reinforcing rods are placed vertically in the cavity. After the brick masonry sets, concrete is poured into the void. Floors in one such building are of precast tensioned concrete double slabs, but other systems can be used.

Reinforced masonry construction is widely used to resist earthquakes, particularly on the West Coast. Reinforced masonry is unsuitable for multistory buildings in which large clear spans are required, but can be used for buildings where multiple interior walls are acceptable. The interior and exterior walls are equally load bearing. Apartment houses and motels with their characteristic repetitive box construction are well adapted to this method.

In low-rise buildings up to about 70 feet, some recent designs have eliminated reinforced concrete in the wall. High-compressive-strength bricks and special mortar are used along with masonry reinforcement trusses and placed between courses and to tie cross walls to the exterior walls. Together with precast concrete floors integrated into the building by the use of wet joints, these materials can produce a masonry wall bearing building several stories high with no wall thicker than 8 inches.

Similar construction, usually of concrete block, has become popular for some resorts. Some recently built seaside motels consist of individual concrete boxes. When these are serviced by outside open-air stairways and balconies configured in accordance with the Life Safety Code (NFPA [National Fire Protection Association] 101), or the egress-related provisions of the building code in effect, the epitome of life safety in a multiple-unit occupancy is achieved.

Collapse During C istruction

From time to time, concrete structures under :onstruction collapse. The fire department is almost nvariably called to rescue construction workers. The following suggestions are offered as aids in planing a department's role in rescue operations when a uilding collapses and there is no fire. Although the uthority of the incident commander is often clearly pelled out, the authority to act or to direct others at mergencies other than fires is rarely defined. Fire fficers should be well informed on the legal posiion of the fire department, particularly once all vicims have been rescued.

Many building codes assign the power to order he removal of a dangerous structure to the buildng commissioner or similar official, thus making quite clear that the fire department has no right o demolish a structure just because it represents a azard in the view of the senior fire official. Polics, grandstanding, glory grabbing, turf protection, nd potential movie rights have all played a part in isaster operations that are improvised. Every comunity should have clear plans setting forth areas of esponsibilities at emergencies other than fire.

Lawsuits are common today. Often after the dust ett a building collapse, there may be a series of legal actions as the owner, architect, general contractor, subcontractors, and victims attempt to determine financial responsibility. Collapses do not just happen, they are caused—and some of the people at the scene may well know, or at least fear, that the blame may be put on them. They may actively advise or assist the fire department. Be careful. Somebody may be trying to cover up. It may not be your duty to prevent this, but it certainly is not part of your duty to assist. Be wary of such suggestions as "Let's knock down the rest of this before it falls." A study of the surviving portion of a structure may show why the collapse occurred.

An Industry Warning

Some experts have warned of the collapse hazard of concrete structures. They argue that design engineers should use construction loads as governing loads in structures. At times, the loads on buildings under construction exceed the design load and can approach failure load.

Problems of Falsework

Falsework is the temporary structure erected to support concrete work in the course of construction. It is composed of shores, **formwork**, and lateral bracing (Figure 11-15). Formwork is the mold that shapes the concrete. Shores are members that support the

Figure 11-15 These shores and formwork will serve as a temporary structure that will support the load of the concrete during the course of construction.

formwork. Lateral bracing is usually made up of diagonal members that resist lateral loads on the formwork. Formwork can represent 60% of the cost of a concrete structure.

Concrete formwork is designed without the extra strength calculated into a building to compensate for deterioration. It is usually built at the lowest possible cost, out of low-quality material, by people rarely versed in basic engineering and mechanical principles. With formwork, the builder hopes to contain a fluid load that can provide a head pressure of up to 150 pounds per square foot for each foot of height. Large fluid loads are placed at the tops of slender columns, and the loads are then vibrated. The structure must often absorb the impact load of the sudden stopping of motor-powered buggies carrying heavy loads of concrete. It is not surprising that formwork failures occur; what is surprising is that they are relatively rare.

Falsework for walls or columns must have adequate strength to resist the tremendous pressure of the heavy fluid concrete. As concrete sets, the pressure is reduced due to internal friction. If a wall is designed for several successive pours and an overpour occurs, collapse may result. The setting of concrete is temperature dependent; cold weather slows it down. Concrete poured at 50°F (10°C) will develop one-third more pressure than at 70°F (21°C).

Reshoring

Concrete requires time to cure; the length of time depends upon the type of cement used and the temperature during the curing period. After a proportion of the design strength is reached, formwork is removed for use elsewhere. Some shores are set back in place to help carry the load of the still-curing concrete in a process called **reshoring**. The presence of reshoring is an indication that the concrete is not yet up to full strength. It may be unable to handle large superimposed loads, such as debris removed from a collapse, excess numbers of people, or additional apparatus or construction equipment. Avoid adding equipment and construction material to existing loads.

Collapse of Floors

Many collapses involve formwork supporting newly cast floors. Sometimes the collapse is of framework supporting a high bay floor, where two sets of normal floor-high shores are used one on top of the other. Such structures have all the instability characteristics of long, narrow columns. Proper cross-bracing is vital, as is proper footing.

Often, formwork rests on the ground, sometimes on unconsolidated backfill. The planks on which the shores rest are called **mudsills**. If water liquefies the soil and turns it to mud, the bearing may be inadequate. Repeated vibrating of the concrete to provide a dense smooth surface may be the straw that breaks the camel's back, causing a collapse.

A Widely Believed Fallacy

In the first edition of this text, it was stated, "Reinforced concrete which has set hard to the touch usually has developed enough strength to be self-supporting, though it may not be capable of handling superimposed loads." This assertion was based on information from experienced concrete designers, and it is still widely believed.

Unfortunately, this assumption was disproved in the Skyline Towers collapse in Arlington, Virginia, in 1973. In this collapse, shoring was removed from the topmost floor. The floor collapsed, and the collapse was progressive, ending at the ground level **Figure 11-16**.

The removal of the shoring by laborers is no different than its removal by fire; the result would be identical. In short, any concrete formwork failure presents the likelihood for catastrophic collapse, though the potential is even more pronounced in the case of post-tensioned concrete. Few concrete buildings are designed to withstand the collapse of one floor onto another. When this occurs, progressive collapse is almost a certainty.

Hazards of Post-Tensioning

The tendons for post-tensioned concrete are laid out on the formwork before the concrete is poured.

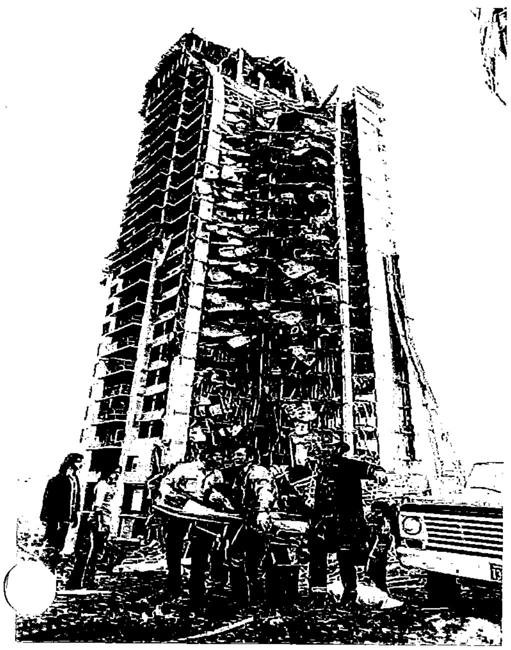


Figure 11-16 The Skyline Towers collapse in Arlington, Virgina.

Courtesy of the Fairfax County Fire and Rescue Department.

When the concrete is being poured, samples are taken in standard sample cylinders and are sent to a testing laboratory for subsequent quality verification and strength testing. When the concrete reaches a designated fraction of its ultimate strength, hydraulic jacks are used to tension the tendons or jack the cables. Until this is accomplished, the entire weight of the concrete is on the formwork. There is no bond between the tendons and the concrete—quite the contrary, the tendon is contained in a sheath to *prevent* bonding. The weight of the concrete is transferred to the columns only when the tensioning is completed, several days after the concrete has been poured.

The 22-story Skyline Towers was made of conventional reinforced concrete. The garage, located behind the Towers, was of post-tensioned construction. When a crane hit the corner of the garage, both floor slabs sheared completely off the columns. Shear resistance of post-tensioned slabs is poor.

Collapse of Reinforced Masonry

Because large numbers of masonry units are used in construction, it is easy for workers to overload a portion of a floor with brick or block. This happened in Pittsburgh, Pennsylvania. The excess load caused the partial collapse of several stories of precast floors.

Collapse of Precast Concrete

Precast concrete buildings under construction are unstable until all connections are completed. Temporary bracing, such as tormentors (adjustable poles set diagonally) or cables, holds units in place. In some cases, wooden temporary shoring is used. The completed structure may be of pinned construction, with bolt-and-nut or welded connections, or it may be made monolithic by the pouring of wet joints to join precast units together. In Montgomery County, Maryland, a three-story parking garage nearing completion totally collapsed at a single connection because an oversized washer was used on a bolt.

Lift-Slab Collapses

In lift-slab construction, the ground floor slab is cast first; later, the other floor slabs and the roof are cast on top of the ground-floor slab. Bond breakers are used between the slabs so they will not adhere to one another. When the slabs reach the designed strength, they are raised up the columns by hydraulic jacks placed on top of the columns. All the jacks are controlled from a central console. As each floor reaches its final position, it is temporarily connected to the columns.

The fatal collapse of the L'Ambience Plaza concrete building under construction in Bridgeport, Connecticut, which resulted in the loss of 28 lives, focused greater attention on this method of construction. This collapse was also due to the failure of a single connection.

Many of the accidents that have occurred while buildings were being constructed using this method have happened while the slabs were being lifted. In some cases, however, failure occurred when no lifting was being done. In San Mateo, California, a roof slab was being lifted 16 feet (4.9 m). The columns were not braced—only bolted to the foundations. As the slab reached the top, the columns were 3 inches (76 mm) out of plumb. As an attempt was made to pull the slab back into place, it collapsed.

Fire Problems of Type I Buildings Under Construction

Concrete buildings under construction can present serious fire problems. Fire in formwork can easily result in major collapse with potential for massive life loss. There is little reserve strength in formwork. There seems to be little understanding by designers, constructors, or even fire officers of the potential catastrophe that could be caused by a fire in formwork. A few knowledgeable people are astonished that fire fighters would place themselves below burning formwork that is supporting the weight of a concrete floor.

Fire Potentials

Numerous fire causes are present at a construction site, including welding, cutting, and plumbers' torches; temporary electrical lines; and arson. Fuels, such as wooden formwork, flammable liquids, and plastics for insulation, are readily available. Glass fiber formwork is also combustible, which is often a surprise to those handling it.

The most dangerous hazard may be from heating. Sometimes workers burn scrap wood in steel barrels or use kerosene heaters to keep warm. By far the most dangerous, and perhaps most common, heating method is the use of liquefied petroleum gas (LPG). To retain heat, the building is sheathed in plastic. Inside the heated area, unsecured gas bottles are present with the nearby open-flame salamanders (heaters) in which the gas is burned. When this is the case, the stage is set for a tremendous disaster. It is important that construction sites using portable heating equipment be inspected by qualified fire inspectors.

Most codes for the use of LPG require storage of the gas away from any open flames, for good reason. In 1963, 74 people died in an LPG explosion at the Indianapolis Coliseum. A gas-fired cooker was being used under the concrete stands. A leaking cylinder exploded when the gas reached the flame of the heater. According to a rescuer, one victim was found in the center of the arena with a huge piece of concrete on him.

In one West Coast city, the practice is to store the gas bottles at ground level and pipe the gas with plastic tubing to the salamanders. When this system is used, an **excess flow valve** should be installed. Such a valve senses a sudden increased flow of gas, as from a broken line, and shuts off the gas, preventing a tragedy. Such installations also must be inspected for fire code compliance.

Hazards of Post-Tensioned Concrete

Post-tensioned, prestressed concrete construction presents catastrophic fire collapse potential. It is vital for a fire department to be aware of any post-tensioned structures being built in its area and recognize the clues that indicate post-tensioning. Possible post-tensioned structures include bridges and parking garages.

Post-tensioned concrete presents a greater catastrophic collapse hazard during a fire than does conventional reinforced concrete. As noted, the entire weight of a post-tensioned concrete floor or beam rests on the falsework until the tensioning transfers the load onto the columns. A falsework fire, therefore, could cause the sudden collapse of an entire concrete floor slab, or the entire structure, onto fire fighters.

After tensioning, the ends of tendons are left hanging and exposed for varying periods of time. In the case of floor slabs, several feet of excess tendon may protrude from the socket until they are cut off and the socket is dry packed. In the case of beams, the anchors may be left exposed for further tensioning or due to normal construction delays. In either case, this represents a serious threat to the stability of the building during a fire. Hanging tendons can act as heat collectors and will fail at about 800°F (427°C).

When a floor is tensioned in increments, the excess tendons are rolled up and attached to a wooden rack. In a fire, the rolled-up tendons would act as a heat collector, transmitting heat to the previously tensioned portion of the tendons. The substantial fuel loads present at construction sites or from exposed buildings may provide the heat to cause tendons to fail. Failure of tendons will cause th('lapse of that part of the structure.

Protection of Tendons

There is one opportunity to control a disaster before it occurs. Insist on protecting tendon anchors immediately after tensioning is completed and on the provision of temporary protection for incrementally tensioned tendons. Instruct all personnel in the hazards of to-be-tensioned concrete.

A Total Collapse

A post-tensioned building under construction in Cleveland, Ohio, suffered a falsework fire. The fire department operated from the adjacent completed section, extinguished the visible fire, and notified the contractor that he had a problem. A second fire occurred. As the fire department was setting up, the entire 18-story building collapsed. No fire fighters were injured because they had been kept out of the collapse zone.

Precast Buildings

When precast concrete units are being erected, te(rary bracing or support is provided until the full space-frame relationships of the building are completed. Columns are usually braced by telescoping tubular steel braces (tormentors), but wood braces are also used. Wooden falsework is often used to support horizontal elements until connections are made. The loss or upset of any such temporary support may precipitate a general collapse. Cold-drawn steel cables (which fail at 800°F [427°C]) often provide diagonal bracing in precast buildings.

Cantilevered Platforms

Cranes are often used to deliver construction materials to buildings under construction. This necessitates a temporary cantilevered platform extending out from the floor. A common method of securing such a platform is to brace it into place by using wooden shores to deliver a compressive load to the floor above. A fire involving such a platform would destroy the shores and drop the platform to the street. Keep all personnel and apparatus clear of the collapse zone.

Tower Cranes

The high tower crane, a common sight in modern construction, seems to climb up the building. As it climbs, it is supported on the building's structural frame. The weight of the crane may be distributed over several floors by falsework. A fire involving this falsework can bring down the crane.

Falsework on an otherwise apparently completed floor should be investigated. It may be supporting a patch over a hole that was left in the building to handle or transport materials or it may be supporting a heavy load such as the crane.

In one example, formwork for concrete placement burned on the 23rd to 25th floors of a high-rise under construction. Flaming debris fell to the street, and the tower crane operator was trapped in his cab above the 28th floor. Fire fighters protected him with a heavy-caliber stream from a nearby roof until an engine company fought its way through the fire to save him.

Fire Problems in Finished Buildings

Fire Resistance

When concrete construction was first developed, it was regarded by some as the answer to all fire protection problems—it was believed to be truly fireproof. After a series of disastrous fires, however, it became evident that concrete, like any other noncombustible material, can be destroyed by fire given sufficient fire load and fire duration.

Concrete is inherently noncombustible. It may have been fabricated to meet a fire resistance standard. Unfortunately, many people, including some who should know better, confuse noncombustibility with fire resistance. Neither is synonymous with fire safety. Concrete construction can be made to deliver different levels of fire resistance. There are a variety of ways of protecting steel, including concrete.

Concrete construction carries no guarantee of life safety. The reinforced concrete Joelma building in Sao Paulo, Brazil, burned in 1974 with a loss of 179 lives. The structure escaped with relatively minor damage. Factors other than the structure itself, such as interior finish and the inability of the occupants to quickly reach a safe nontoxic environment, may be far more important to the safety of the occupants.

Methods of Providing Fire Resistance for Steel, Including Concrete

Fireproofing (Insulating) Steel

Steel is fireproofed by one of several systems. Steel qualifies for a fire resistance rating if the protection system previously passed a standard fire test (ASTM E-119, discussed in other chapters). Although there is no such thing as a truly fireproof building, the term has survived as the designation of the system by which steel is insulated (fireproofing the steel). Steel that has been fireproofed is known as protected steel (which is also the term for weather-protected steel).

Types of Fireproofing

Fireproofing of steel is classified as individual or membrane. Individual fireproofing provides protection for each piece of steel. In one method, steel is encased in a structure, such as concrete, terra-cotta, metal lath and plaster, brick, or gypsum board. This method is called encasement. In another method, fireproofing is directly applied to the steel, usually by spraying. Materials used in this method include an intumescent coating containing noncombustible fibers that swell and char when exposed to flame and cementitious coatings. Asbestos fiber was once used in building construction but is now no longer used.

Membrane fireproofing does not protect individual members. In one method, wire lath and cement plaster are used. In another method, the fireproofing of the floor is accomplished by a rated floor–ceiling assembly. In rating such a fire protection system, Underwriters Laboratories, Inc. tests and lists a floor and ceiling assembly or a roof and ceiling assembly.

In such floor or roof assemblies, the ceiling, hangers, electrical fixtures, bar joists, left-in-place formwork for the concrete floor (usually corrugated steel), air ducts and diffusers, and the concrete floor are tested as a whole unit as it would be built. Therefore, it is incorrect to speak of a fire-rated ceiling because the ceiling is one part of the total assembly.

The assemblies are tested under the ASTM E-119 standard fire test. The original designers of the ASTM E-119 test did not envision an assembly that provides a void trussloft (like a cockloft) in every floor. Fire can and has extended through this void. The designers of the test also did not anticipate the problem of otherwise unprotected columns passing through the trussloft.

Hazards of Floor–Ceiling Assemblies

Buildings with floor–ceiling assemblies, particularly where the columns are unprotected passing through the plenum space above the ceiling, can present a serious menace to the safety of fire fighters who are, generally, unaware of the dangers. The observations and considerations that lead to this opinion are many.

The building trades sometimes disregard detailed instructions, particularly when they do not understand them or they find them inconvenient. A fire inspector found aluminum wire being used to support the ceiling channels. "What's the matter with aluminum?" asked the mechanic.

The value of listing building materials is contingent upon the field assembly being accomplished exactly as performed in the laboratory. It is impossible for inspectors to have the time to follow and examine every item and inch of an assembly.

The ceiling system is at the mercy of all owners, operators, tenants, tradespeople, and mechanics who have reason to remove ceiling tiles. Access to utilities and additional storage space for tall items such as rugs or ladders are only two common reasons to remove tiles. Where the plenum space is part of the air-conditioning supply, employees soon learn that displacement of a tile improves airflow at their location.

The fire codes require that fire-rated assemblies be maintained. Enforcement may be difficult. Replacement acoustical tile, which appears to be identical to the original tile, may be combustible, rated for fire hazard only, rated as part of a fire resistance system but not the system installed in the building in question, or may be the proper tile, which meets the specification of the listing. All electrical fixtures, air-duct openings, and other penetrations of the ceiling must be rated as part of the ceiling system. Proper fire protection and building and fire codes require that fire ratings be maintained. Unfortunately, there are many lapses between code directives and actual practice.

The term *fire rated* is used quite often in the fire protection and building construction fields. By itself it is nonspecific and, therefore, meaningless. With respect to ceiling tiles, it may refer to tiles that have merely met the requirements for flame spread or to tiles that are part of a listed fire resistance system. As has been noted elsewhere, no part of a listed fire resistance system stands by itself.

Owners, managers, and occupants—even of buildings where fire protection equipment is well maintained—are usually totally unaware of the significance of absolute integrity of the ceiling system. A common practice is to remove tiles from the storeroom to replace tiles in public locations. (Who needs a fancy ceiling in the storeroom?) Tiles are also damaged by water leaks. Tiles are removed by tradespeople. Holes are cut through tiles. Displays are hung from the metal grid. Until recently, floor–ceiling systems were not tested with superimposed loads.

The list of ways in which the integrity of a floor–ceiling assembly can be compromised is endless. There are many pictures to prove it. Laboratory fire tests are conducted under a slight negative pressure to remove smoke and fumes. Fires generate positive pressure, and lay-in ceiling tiles may be easily displaced by fire pressures. When a tile is displaced by a worker, it is often dropped back down into place without any restraint to upward motion.

The addition of insulation that is not part of the specifications of the listed ceiling assembly, particularly in a roof and ceiling assembly, can significantly affect the fire performance of the assembly. The insulation will cause heat to be retained in the channels supporting the tiles, causing them to fail earlier than expected. A membrane protection system must be perfect—the failure of even a single tile is the equivalent of a pinhole in a water-filled plastic bag.

It has been noted that, in effect, there is a cockloft between the ceiling and the floor. In one incident, fire starting in one room traveled across a hallway above the ceiling and came down through joints in the tile ceiling of another room to ignite books on a top bookshelf. Only alert fire fighters prevented the full involvement of the floor.

Some code provisions provide for firestopping, particularly along demising walls or tenant boundaries and around columns, but the use of the plenum space for various services makes it probable that the firestopping will only continue to conform to the definition of legal firestopping.

In some buildings, the use of deep long-span trusses to provide clear floor areas creates plenum spaces several feet in height. Wasted space is often intolerable. What is more logical than to provide access to this space and use it for storage? Engineers closely associated with hospital construction call this void interstitial space. Whether the membrane fireproofing is provided by suspended tile or plaster on metal lath is immaterial, the fire load has been placed adjacent to vulnerable unprotected steel, where firefighting will be almost impossible.

Not all floor–ceiling arrangements are intended to be fire resistive. A steel bar-joist floor with concrete topping with flame-spread-rated tiles below may appear to be fire resistive. In fact, it may only be noncombustible construction.

The fact that tiles are obviously missing does not necessarily mean that a fire resistance system has been violated. The building may not be required or intended to be fire resistive; it may be simply of noncombustible construction. In such a case, ceiling tiles are at the option of the owner and need merely to meet flame spread requirements, if any.

The building may be of concrete construction. There are some listed concrete assemblies in which suspended tiles are incorporated, but, in general, the suspended ceiling is installed to provide a hidden void for utilities as well as an acoustical and aesthetic treatment.

Fireproofing and Building Codes

Fireproofing is applied to meet the standards required by the local building code. If, for instance, the code requires 3-hour fire resistance on columns, the designer selects a system that has been approved by the local building department. As a supplement to the building code, the building department will indicate which systems tested at which laboratories are acceptable. After a manufacturer develops a fire resistance system, it is tested at a laboratory to determine whether it meets the standard. Testing laboratories (like Underwriters Laboratories, Inc.) publish lists of tested assemblies, not just for fireproofing applications but for all fire-rated assemblies.

The efficiency of fireproofing depends first on the competence of the subcontractor and the willingness of the builder to demand quality work. It further depends on the building department staff who inspect the original installation, and on the fire department inspectors who determine that fireproofing and fire protection are not compromised. This is particularly important in the case of spray-on fireproofing and membrane floor and ceiling assemblies. There are advantages and disadvantages of each method.

Encasement Method

Terra-cotta tile was an early method used for encasement. The cast-iron columns of the Parker Building in New York City (destroyed by a fire even though it was regarded as the best type of fireproof building) were protected with 3-inch (76 mm) terra-cotta tiles. Electrical conduit was laid against the columns inside the tile. When the heat elongated the conduit, it tore the fireproofing off the column. A major column failed catastrophically. There are buildings still standing that may have this same defective design.

Another error in the encasement was to leave the bottom web of beams unprotected. After a number of failures, this error was corrected by the development of tiles that were shaped to fit around the steel. The tiles (called **skewbacks**) below beams are easily removed to access the beams during alterations, such as to hang equipment from the overhead. As a result, the fireproofing is often seriously defective.

Fireproofing that is easily removed is at the mercy of the person making alterations, who often has no knowledge of why this material is present. In one case, while altering an operating department store for the construction of a subway entrance, a contractor removed the protection from a major column. The sprinklers were shut off in this area. About a hundred cylinders of propane gas were stored adjacent to the column. A fire in the propane could have collapsed the building. Fortunately there was no fire.

At one time, concrete was quite popular as a protective covering for steel, particularly where concrete floors were being used. The wood falsework required for forming concrete provides a high fuel load and has been involved in a number of serious construction fires. Concrete has the advantage of being the most permanent fireproofing because it is so difficult to remove. However, concrete can be knocked off beams and columns by vehicle impacts.

The fireproofing of steel and concrete beams is integral; that means it is accomplished by a specified mix of concrete in a specified thickness. Some concrete, particularly that below the reinforcing rods of a concrete beam, is not necessary for structural strength but is necessary for fireproofing. Because there is no budgetary distinction regarding the material, this may give concrete an economic advantage.

The disadvantage of concrete is its weight. In the effort to reduce the dead weight of a building, and thus its cost, fireproofing is often a tempting target. Encasement systems of gypsum board or wire lath and plaster were developed to save weight. Wire lath covered with cement plaster has been used for fireproofing for many years.

Sprayed-On Fireproofing

The search for lighter fireproofing led to the development of various sprayed-on coatings. Unfortunately, sprayed concrete spalls badly when exposed to fire, so many combinations of asbestos fibers and other materials were developed. Although some of these materials can pass laboratory tests, some serious questions have been raised about their reliability in the field. Ensuring that the material is applied at the specified thickness and density is another problem with sprayed-on coatings. Adhesion of the material to the steel is also of concern; the base steel must be "clean"—free of oils and rust scales.

As a result of the disaster at the World Trade Center in 2001, attention was focused on the reliability of fireproofing. Changes were made to the model building codes to require "stronger" fireproofing (in terms of adhesion to the steel as well as its internal strength to stay together, known as cohesion. Sprayed-on material is often easily knocked off by members of other trades doing their own work (Figure 11-17). Many years ago Frank Brannigan was invited by an insurance executive to the 30th floor of the nearly complete Bank of America Building in San Francisco. The fireproofing had been stripped from all the columns by the plasterers.

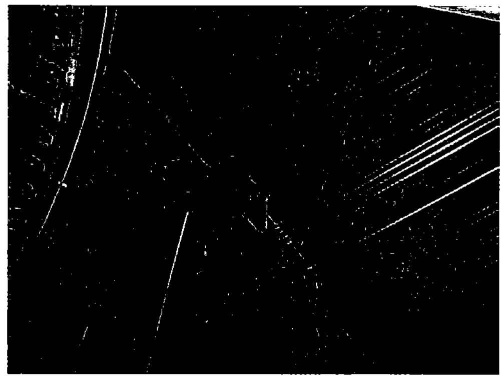


Figure 11-17 It is important for inspectors to conduct routine inspections and to catch problems such as when the fireproofing has been removed from the steel.

Photo courtesy of Blaze-tech Fire Protection

A state office building in California was being sprayed with fireproofing material by a contractor who had no appreciation of the importance of the work. Overspray was swept up from the floor, laid on the lower web of the beams, and covered with a fresh coating. The building was not insured, but an insurance engineer took photos of the work. When a fire occurred in the building, it cost almost as much to repair the damage to the steel as it had to build the building.

On the other hand, the First Interstate Bank Building of Los Angeles, which suffered a multistory fire in 1988, was found to have excellent spray-on cementitious fireproofing. Had the fireproofing been as poorly applied as observed elsewhere, a catastrophic collapse might have occurred.

Asbestos fiber fireproofing is under attack on another front—a serious health hazard arises with its use. It is difficult, if not impossible, to sell a building with asbestos fireproofing. Health regulations have eliminated the use of asbestos fireproofing, and asbestos is being removed from existing buildings.

Published accounts are invariably silent as to what is being done to replace the asbestos.

Signs of Trouble

There are clear signs of possible trouble with concrete elements that can be identified in a prefire plan. Deteriorated concrete, spalling that exposes reinforcing rods, and cracks in concrete that can admit corrosive moisture to the reinforcing rods are indications that the building is in distress.

Many chemical processes give off fumes that can damage or destroy concrete. Chlorine corrosion caused the collapse of a concrete roof of a swimming pool in West Roxbury, Massachusetts. Aluminum also reacts with concrete—aluminum electrical conduit buried in concrete did severe damage to a sports stadium.

Parking garages in areas where salt is used to melt snow and ice are particularly vulnerable to corrosion. The extent of damage is often difficult to determine. In some nonfreezing areas, calcium chloride added to the concrete has caused problems. Preventive measures include sealing the concrete, providing adequate drainage, and flushing surfaces with fresh water in the spring. Rehabilitation of concrete has included removal and replacement, installation of cathodic protection, and using additional steel beams to shorten the span of concrete slabs. Some concrete garages have been demolished when their repair was found to be untenable.

Unprotected Steel

When a concrete structure is in trouble, it is often repaired with steel. In the case of fire-resistive buildings, often no consideration is given to providing equivalent protection for the steel. If steel cables are used, failure will occur below 800°F (427°C).

Fire fighters should be ever watchful about what is being done to buildings. Almost none of what is done to a building after it is completed, except for installation of automatic sprinklers, benefits the fire suppression effort. One fire fighter student saw steel columns being brought into a 3-hour-rated fire-resistive shopping mall. The columns were prepainted to match the wall color in the mall. The roof was failing and the columns were provided to shore it up. The owner did not want the building department to know of the problem.

If steel is initially designed into the structure, the proper degree of fireproofing is specified. If installation of steel is an afterthought, or part of a repair job, it will usually be unprotected. In particular, steel connectors for precast units are often unprotected.

Branniganism

We must go beyond experience to competent risk analysis. We must learn that "fire resistance" is at best just a hope, not a mathematical given, as is often assumed. We must learn that the failure of a single vulnerable connection can precipitate disaster.

Ceiling Finish and Voids

One of the fire protection advantages of concrete construction is that it lacks inherent voids. While voids may be created in the finishing of the building, they are not a necessary part of concrete buildings, although they are useful to the occupants. In one case, a fire in the void between the hanging plaster ceiling and the concrete floor of a former department store proved difficult to find. The fuel for the fire consisted of an 80-year accumulation of dust.

Waffle slab concrete was originally considered ugly and was improved aesthetically by installation of a suspended ceiling. Later architects appreciated the coffered effect and emphasized it. In one mall, imitation plastic waffle concrete is suspended below the structural slab.

Unfortunately, when ceilings were installed, combustible tile with a high fire hazard rating was often used. The combustibility is not intended; it just happens that combustible tile is cheaper than tile with a low fire hazard rating. The interconnected voids above the tile make it possible for the tile to burn on both sides simultaneously.

When suspended ceilings are installed as part of initial construction, it is more likely that they will have satisfactory fire hazard characteristics. But it is necessary for fire officers to be aware of the local code requirements. The tile usually will be only as safe as the law requires.

Combustible tile need not be suspended to create a serious hazard. Tile applied with a flammable adhesive to a noncombustible surface was a key factor in a fatal hospital fire. Installing new ceilings that meet flame spread requirements below old combustible tile ceilings presents a serious hazard. Of particular note is the 1989 fire in the John Sevier Retirement Center in Johnson City, Tennessee, where 16 occupants died in a fire-resistive concrete building. A key factor in this incident was the concealed combustible acoustical tile.

Combustible voids can be created in a variety of ways. In one case, a heavy wooden decorative suspended ceiling was installed in a restaurant of otherwise concrete construction. Sprinklers are below the ceiling. Fire could burn unchecked in the void. The fire resistance of the ceiling hangers, which are attached to anchors (possibly lead), is uncertain. A fire might cause the collapse of the heavy false ceiling. Decorative or functional wall paneling and screens may also create combustible voids.

Although voids are not inherent in concrete construction, they can be useful. In one case, a church was built of concrete without voids. When the church was to be air conditioned, the only solution was to run the ducts on the roof. This created costly maintenance problems. In a modern office building, with its huge communications and other utility requirements, as much as one-third of the height from floor to ceiling may consist of in-ceiling or under-floor voids.

Even when the void is noncombustible, it may still present problems. Combustible thermal or electrical insulation and combustible plastic service piping may be concealed in the ceiling void. Because the fire resistance of a building is achieved by the concrete construction, the hung ceiling, though it may be identical to the ceiling used for membrane fireproofing of steel, is generally not required for the structural integrity of the building. The owner is free in this case to remove or modify the building within code requirements for flame spread. However, there are some rated fire-resistive assemblies that combine precast concrete elements with suspended ceilings. In these cases, the maintenance of the ceiling is necessary for the fire resistance of the floor–ceiling assembly.

The Integrity of Floors

If a building is fire resistive, it is presumed that the floor will act as a barrier to the extension of fire. More and more, however, codes are requiring sprinkler protection in addition to the passive protection provided by compartmentation. Many older buildings were constructed under the less costly but inadequate assumption that compartmentation was all that was required to limit fires. The concept of isolating the fire to a limited area has great appeal, and at first glance appears to have great merit. However, true compartmentation is rarely achieved. Even in a limited area, a high fire load may yield a difficult, costly fire.

Building use often requires that the floor be penetrated for utilities, plumbing, heating, air conditioning, electrical service, and communications wiring. There are proper ways to do this—using listed "through penetration protections systems" (commonly referred to as firestopping) or through the use of fire-rated shafts—so that the integrity of the floor is not compromised. Unfortunately, they are not always used. Further, some of the methods used are open to question.

For whatever reason, enclosures around ducts may be inadequate and have failed in fires. This can permit transmission of fire and/or smoke to other floors. In addition, failure of the enclosure may expose fire fighters to the danger of falling down the shaft.

Poke-throughs are holes provided to draw utility services up to a floor from the void below.

The penetration of the floor for poke-throughs may negate the fire resistance rating of the floor.

In addition, any holes that violate the integrity of concrete floors may provide passage for deadly fire gases. It is not safe to assume that there cannot be an extension of fire from floor to floor in a building because the floors are of concrete. Be aware of the local practices in providing utility services, such as penetrating a floor for cable TV and computer cables. Even if a floor was properly constructed when it was built, it can be compromised by contractors retrofitting utility equipment years after the floor was built.

As penetrations of floors for services increase, the floor may be unable to resist the passage of fire adequately, and the building department may require a suspended ceiling, which, together with the floor, should ideally develop the necessary fire resistance. In this case, the owner is not free to modify the ceiling. Many tested and rated assemblies are floor–ceiling assemblies and, therefore, cannot be modified. Building designers must submit a new design with supporting evidence (e.g., tests, reports) for approval.

Concrete floors require expansion joints. In one case, steel expansion joints transmitted fire from floor to floor in a huge postal building. Aluminum expansion joints dropped molten aluminum into the lower level of McCormick Place in Chicago and extended that 1967 fire. Combustible fiber expansion joints can provide a difficult fire problem.

Concrete shrinks, and this shrinkage may create large cracks. Such cracks may permit the passage of fire from floor to floor, even though the concrete is structurally sound. Shrinkage, distortion, or settlement may put door frames out of alignment, thus preventing the closing of fire barrier doors.

Imitation Materials

Imitation concrete panels are commonly used, particularly on the exterior of buildings. In one product, they are made of two sheets of asbestos board, with a combustible foamed plastic interior. Epoxy glue is painted on the surface, which is then coated with small stones.

The top panels of some buildings are genuine precast concrete. The wall panels are usually imitation concrete. At the base, however, concrete block panel walls are painted with epoxy adhesive and stones are added. The entire building appears to be of identical finish. The fasteners that hold the panels on the building are held in the plastic. If the plastic burns or melts, the panels will drop off the building. Most imitation concrete panels are made of a steel framework with asbestos millboard. Real concrete is applied in a thin coat or stone is epoxyed on.

Energy conservation has brought about the use of exterior insulation finishing systems (EIFS; discussed in other chapters) that give a building the appearance of sand-finished concrete. One type starts with exterior gypsum board screwed to steel studs. Glass fiber insulation is placed between the studs. A foam panel is then glued or mechanically attached to the gypsum board and a woven glass fiber mat is laid over the plastic panels. A layer of adhesive secures the glass fiber. Usually, a coat of organic polymers is added to the finish coat.

Buildings can be finished in this manner when constructed, or EIFS can be added to the building for energy conservation or to change its appearance. A Fort Worth, Texas, courthouse was finished in this manner to make its appearance more consistent with the 19th-century courthouse next door.

Concrete's Behavior in Fire

The concrete in fire-resistive construction serves two purposes—it resists compressive stresses and it protects the tensile strength of steel from fire. The latter function is accomplished in proportion to the thickness of the concrete cover. By sacrificing itself, the concrete provides time to extinguish the fire; however, it may also lose its strength.

Impact loads to damaged concrete, such as from sledges or jackhammers, should be carefully evaluated. All areas where spoiling has reached the reinforcing steel should be shored before any work is done in the area. Concrete floors that are seriously damaged on one side may give no clue to the distress on the other side.

Cutting Tensioned Concrete

Fire tactics sometimes include cutting through a concrete floor to operate distributors on an otherwise inaccessible fire. One department's high-rise unit carries a hole cutter. It is possible to cut a hole in conventional reinforced concrete and, in the process, to cut through reinforcing rods without doing serious structural damage.

This is not the case in tensioned concrete structures. With this approach, the tensile strength is provided by steel cables under tremendous tension, and these cables are not in contact with the concrete. Cutting such a cable would be like cutting any steel cable under tension. The ends might whip about with tremendous energy. The cutting of a cable also might cause a massive structural collapse.

Precast Concrete

A cast-in-place, monolithic concrete building is resistant to collapse. Because this type of building has a rigid frame, the loss of a column does not necessarily cause collapse. The load will be redistributed and other columns, if they are not overloaded, will be sufficiently strong to carry the load.

Precast concrete buildings are another story. The individual columns, floors, girders, and wall panels (load-bearing or non-load-bearing) are usually pinned together by connectors. The fire resistance of the completed structure is dependent upon the protection afforded to the connectors. Connectors are set into the precast element, and mating connectors are provided on the structures to which it is to be attached. Bolts and nuts may be used or the connections may be welded. The recess provided for the joints is then dry packed with a stiff mortar. Often no protective covering is provided for the connectors; it may not even be required.

If an ordinary or noncombustible building is permitted by the code, a builder is free to raise a structure that may appear to be fire resistive, but is not. Typically, in such a case, the connectors are unprotected. This problem should not be overestimated. Connectors must resist wind and other forces, and the fire load usually must be quite severe to cause their failure.

The possible effect of an explosion in a precast, pinned building should be evaluated where such possibilities exist. Such buildings have none of the redundancy that characterizes the rigid-framed monolithic concrete building.

Probably the most spectacular disaster involving precast concrete construction took place in England in 1968 with the Ronan Point collapse (Figure 11-18). A 24-story apartment building was constructed of precast floor and bearing wall panels—literally, a giant concrete house of cards. A gas explosion high up in one corner blew out one wall-bearing panel. This caused the collapse of the floor above, which fell to the floor below. The impact load was too much for the next

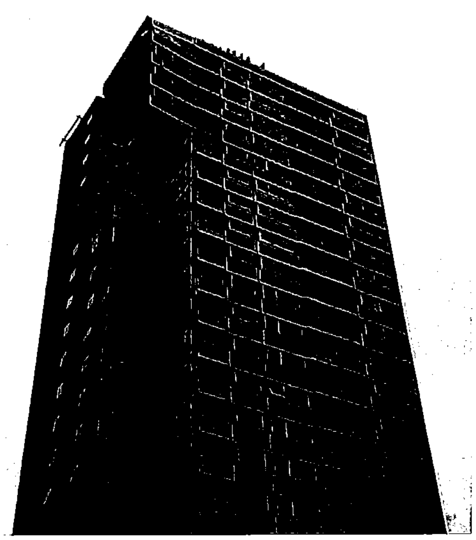


Figure 11-18 The Ronan Point collapse.

lower exterior bearing wall panel and it buckled. Thus, the corner of the building progressively collapsed down to ground level. Five people died in the collapse.

Concrete Trusses

Concrete trusses are not common, though huge concrete trusses are seen in the Tampa, Florida, and Dallas/Fort Worth, Texas, airports and some high-rises Figure 11-19. An American Airlines hanger at Dallas/ Fort Worth has a 1,280 × 280-foot (390 × 85 mm) clear span, with doorways 74 feet (22.5 m) high. Concrete towers 80 feet (24.4 m) high support concrete trusses 76 feet (23.1 m) high. Each pair of concrete trusses supports steel box trusses 20 feet (6.1 m) wide and 280 feet (85.3 m) long.

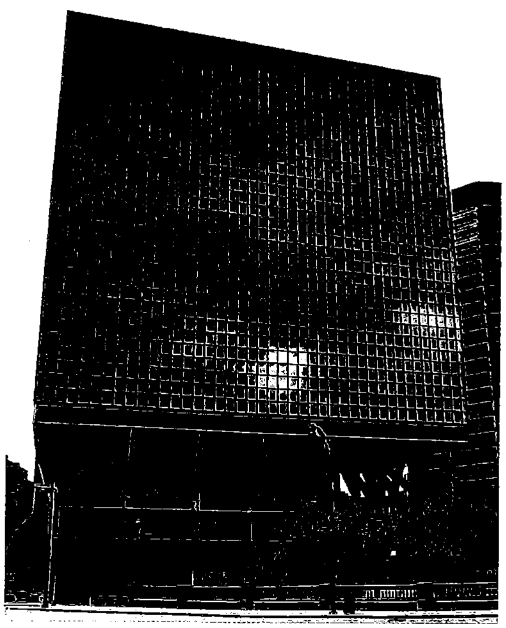


Figure 11-19 Although not constructed with traditional concrete trusses, this unusual high-rise uses laterally braced angled steel columns encased in concrete to support the floors above. The columns are sandwiched between two structural diaphragms, the top diaphragm in compression and the bottom one in tension.

Courtesy of Glenn Corbett.

Fires in Type I Buildings

In 1986, the Los Angeles Central Library suffered the largest loss of any library fire in the United States. An estimated 200,000 books and numerous periodical collections were destroyed, along with the largest collection of patents in the western United States. Built in 1926, the building was of massive concrete construction. Its bearing walls are as much as 3 feet (91 cm) thick, with massive columns and thick roof and floor slabs. The book stacks were on seven tiers of unseparated, unprotected steel loaded to an estimated 93 pounds (42 kg) of fuel per square foot. This would be the equivalent of about 11 hours of fire exposure to the standard fire curve. The fire required a tremendous commitment of apparatus, more than 350 fire fighters, and 7.5 hours to extinguish.

A Christmas tree fire in a 16-story reinforced concrete high-rise apartment building in Dallas, Texas, resulted in $340,000 in damage and the potential for a large loss of life were it not for competent preplanning by the fire department. Utility and vent pipes were punched through the ceilings. The gypsum and steel stud enclosures extended only to the suspended ceiling, not to the underside of the slab. Lighting fixtures and air-conditioning grills pierced the ceilings. Thus, smoke had an unobstructed path from the eighth floor of origin to the floors above.

The Military Records Center near St. Louis, Missouri, was severely damaged in a fire in 1973 Figure 11-20. The building was of concrete construction, six stories in height. The top floor, where the fire occurred, had over 200,000 square feet (18,581 m^2) of undivided floor space. The incredible fire load included over 21 million military personnel files in cardboard boxes on metal shelves. The fire destroyed the top floor, which was subsequently removed from the building. The fire caused the roof to elongate several feet almost all around the perimeter. The elongation caused top floor columns to shear off

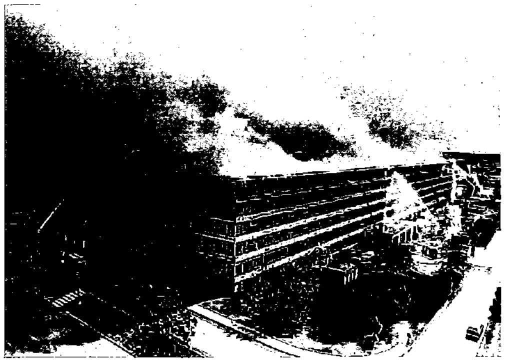


Figure 11-20 The Military Records Center fire.

© Renyold Ferguson/The St. Louis Post-Dispatch.

at either the top or bottom. It should be noted th(1e portion of the roof that collapsed held together for about 22 hours after the start of the fire. The building did all that could be expected of it and more, considering the huge fire load.

Signs of Potential Collapse in Type I Construction

In this chapter, a variety of problems that can result in a disastrous collapse have been identified. In terms of visual indicators of collapse of fire-resistive buildings, it is important to realize that instead of the "recognizable" indicators found in other types of construction like smoke pushing through brick walls (ordinary construction) or noises from cracking wood (wood frame and ordinary construction), an impending collapse it is not always so clear in fire-resistive construction.

While a sagging fireproofing-encased steel beam–supported floor is a clear signal that the floor is in distress, problems with a reinforced concrete column or floor are not so obvious during a fire. It is very difficult to observe that a concrete column or floor has been so severely spalled in a fire that its rebar is exposed. Therefore, instead of relying solely on visual and audible signs (you may still experience some of them in a fire-resistive building), it is equally important to anticipate collapse based upon conditions such as:

- Knowledge of problematic existing building conditions (poor fireproofing, vulnerable connections, etc.).
- Dangerous loads (concentrated, heavy, etc.).
- Cutting tensioned cables.
- Heavy fire conditions over an extended period of time; such fire conditions will ultimately cause any building (or portion of a building) to collapse, regardless of construction type.

Know Your Buildings

For several years, many fire departments complained, "They are building so many buildings so fast here, we can't keep up with them." The 1990 to 1991 recession showed that in many areas of the country there was a glut of buildings of various types, causing a slowdown or even a cessation of construction. Slowdowns present an opportunity to get current on the hazards of specific buildings and to educate fire officers in the hazards of construction before the building boom picks up again.

A fire fighter's nightmare is a fire department charging headlong into a formwork fire in a post-tensioned building under construction, that collapses completely with scores of fire fighter casualties. Fire fighters must learn not to wait for experience. Ben Franklin told us, "Experience keeps a dear school, but fools will learn in no other." In the fire service, the price of experience is blood and grief. The post-tensioned collapse hazard is entirely credible. Make sure your department is not the one to provide the convincing.

TACTICAL CONSIDERATIONS

1. Reinforced concrete is a composite material. Any failure of the bond between the two materials means that the composite has failed and it no longer has the designed intended strength, only dangerous dead weight.
2. Concrete may be hailed as fireproof, but nothing is fireproof. Concrete adds nothing to the fire load. Though concrete is merely noncombustible, fire experience has shown that concrete is subject to serious damage. At a fire, it is impossible for the company officer to know if he is dealing with normal-strength concrete (NSC), or high-strength concrete (HSC). NSC loses about 25% of its compressive strength at about 575°F (302°C) and 75% of its compressive strength at about 11,007°F (6,097°C). (These are temperatures within the concrete, not ambient temperatures.) HSC loses much more strength than NSC in the same temperature ranges. The thing to remember is that concrete spalls (pieces break off from the surface), and when it does, it loses compression strength.
3. Many landscaped recreational fire pits are constructed with curved concrete blocks to form a circle. Additional concrete blocks are stacked forming a three-layered fire pit ring. Moisture expands within the concrete blocks when exposed to sustained heat and begins to lose its surface material. After a season or two of bonfires, if a concrete block is struck with a rock or heavy log, it crumbles apart. The compression strength concrete block is lost after being subjected to the sustained temperatures generated by the bonfire. The concept applies to concrete in structures. At first, they can withstand the radiant heat of the fire, but after the actual concrete is heated to its critical temperatures, it will spall and eventually fail.
4. Remember that when reinforced concrete spalls, it can expose steel tie rods and tendons of prestressed concrete, which can lose total tensile strength at temperatures in excess of 800°F (427°C) (that's cooler than a self-cleaning oven). This can cause a catastrophic collapse in a "good, solid, fire-resistive concrete building" during firefighting operations.
5. From a fire protection standpoint, Type I fire-resistive construction is considered to be the best because it is most resistant to collapse and does not contribute fuel to the fire. Type I construction often uses concrete or substantially fire-protected steel (more than Type II Noncombustible) as a structural system. This gives the incident commander and fire crews the widest safety margin for the time that can be spent on interior fire attacks and support operations. Because it can take so long to establish adequate fire flows in high-rise buildings, interior fire operations have proceeded for nearly 2 hours without the structural compromise.
6. Not every alarm is going to be a fire in an occupied building. We are often called to construction sites for collapse during construction or fires during construction. Rescue operations may be required during the concrete pouring phase of a project. When concrete is being poured, usually there are workers under the structure, bracing and wedging any shores that appear to be distressed. Determine from the supervisor whether all of the workers are accounted for. In one case, the fire department was assured that all the workers were accounted for. While the fire department was preparing to leave the scene, a worker wriggled out from under the plywood.
7. Concrete-on-wood floors require special attention in a fire. The insulating concrete may deceive fire fighters above the fire as to the fire below their feet. The added dead weight may also be a factor in the collapse of the floor–ceiling assembly. This is exactly what happened at the 1995 Mary Pang Fire in Seattle, Washington. Four fire fighters died when the floor collapsed into the burning basement below them. One of the survivors distinctively remembered the lack of heat for the amount of smoke that was on the first floor. Visibility was practically zero, but it wasn't very hot. Then, suddenly, the floor collapsed.

Be advised, these concrete-on-wood floors are typically found in food preparation or food packaging plants. This requirement comes from the health department for sanitary reasons and to prevent entry from rats. This condition is especially dangerous if the fire originates in the basement or the floor below a concrete-on-wood floor.

8. When responding to construction site emergencies, your first contact will usually be with a foreman or supervisor to determine the nature of the emergency. It's critical to the life safety of your fire fighters to understand industry nomenclature inserted into critical fireground information such as, "They haven't jacked the cables yet."
9. It is important to perform a risk–benefit analysis, especially with buildings under construction. Our mission of protecting property doesn't quite extend to construction projects. The property value hasn't been established yet. It is easy to rebuild at that phase of the project. There is no point in risking the lives of fire personnel in a concrete building under construction. All concrete involved in the fire will be torn out and replaced. It is almost impossible to predict the effect of the loss of even a small portion of the falsework in a fire. Fire officers should err on the side of caution. Heavy-caliber streams from safe locations deserve serious tactical consideration. The falsework structure cannot survive the loss of material caused by a fire.
10. When a wall formwork bursts, it usually goes out at the bottom. Workers may be trapped, particularly between formwork and the sides of the excavation. There will probably be no reinforcing steel to interfere with the rescue. Rescue involves uncovering faces, supplying oxygen, digging the victims out, and avoiding further injury. If the patient is able to use his arms, throw a small shovel down to him. It may be possible to lower a roof ladder down to the patient. Crews can then pull the ladder back up to safety with the patient holding on. A ladder may be all he needs to self-extricate and climb out on his own. Bear in mind that the concrete can transmit pressure. Avoid standing on concrete that might transmit the weight of your body to the victim.
11. In a collapse, most of the victims will be on top of the falsework. Use bolt cutters to cut reinforcing rods to manageable lengths. Thicker rods may be required to be cut with a Sawzall, a circular rescue saw, or an oxy-acetylene torch. It would be wise to drill ahead of time in situations where cutting tools are most effective. Rods are tied together in a matting. Further harm may be done by attempting to remove sections that are too large to safely manage.
12. In all buildings under construction, move carefully and deliberately. Floor openings may be inadequately guarded or covered over with a flimsy piece of plywood. Side rails may be nonexistent or of poor quality. Pay special attention to the possibility of elevator shafts. With requirements from the Americans with Disabilities Act (ADA), almost every new construction except for private R3 residences requires an elevator, even for two-story structures. Elevator shafts are serious fall hazards that can kill fire fighters and are present at the start of the project when the foundation is being laid. It is a reasonable risk–benefit conclusion for an incident commander to refuse to place fire fighters on or under new construction structures until all the floor-column connections are permanent. Once workers are accounted for, the remaining life hazard at construction sites are the fire fighters.
13. When a concrete building is finished, there are no clues to help the fire officer determine whether the floors are of conventional reinforced to tensioned construction. If the stranded cables that signal tensioned concrete are found, they must not be cut. The cutting of even a single cable can be disastrous. This is why the boring of holes between concrete floors in high-rise buildings has been abandoned. Besides being time-consuming and labor-intensive work for fire fighters, it's just too risky. Just make it a rule; don't cut cables in concrete Type I fire-resistive construction.
14. The core cutter or concrete blade must never be used to open a hole in a known or suspected post-tensioned floor. Beyond the danger of cutting the cable, tendons are cold-drawn steel and fail at 800°F. Even if the tendon isn't cut, opening a hole over the fire would probably subject one or more tendons to temperatures that would cause failure. In short, all cutting into post-tensioned concrete floors in a fire is unsafe. Abandon all consideration of this tactic. It is too risky; don't do it.
15. In a fire, it is vital that any exposed steel connected to stressed tendons be cooled immediately with hose streams for the duration of the fire, if this can be done from a safe position.
16. Do not fail to examine the ceiling void early on when seeking an unknown source of smoke. Two tools must

be carried by units performing this reconnaissance: a thermal imager (TI) and a 6-foot pike pole. A TI can reduce the time it takes to locate a heat source. Other forcible entry tools like an ax or a Halligan lack the reach to lift up ceiling tiles to check the ceiling space. You need a pike pole. If there is fire overhead, you don't want to be underneath it and you don't want to keep advancing further into the building with fire in the ceiling space. Eventually, the fire will bank down into the hallway behind you and you'll be trapped. This scenario has happened numerous times with tragic results. Don't repeat errors that have already resulted in fatal consequences.

17. Concrete structures represent a massive heat sink compared to other structures. This is beneficial because every British thermal unit (Btu) that heats the concrete is one less that is available to support the fire. However, heat—fed back from the concrete—can seriously affect fire suppression forces. This problem should be recognized and anticipated. Call for additional alarms so you can rotate and rehab crews. It was a serious problem when *The Castle* of the Smithsonian Museum burned in the 1865. Despite the upgraded "fireproof" construction, the fire caused extensive damage to the upper floors of the building and the roof collapsed. The heat-retention characteristics of concrete were also a problem at the 1986 Los Angeles Central Library fire.
18. The Los Angeles Central Library was constructed in 1926 and used the most modern technology available at that time, making it a truly a fire-resistive building. The exterior walls are 16-inch-thick (40.6 m) steel-reinforced concrete. The interior is supported by steel-reinforced concrete columns and cross beams. The roof and floors are 6-inch (15.2 cm) steel-reinforced concrete. The rotunda is 3-foot-thick (91 cm) steel-reinforced concrete. Ventilation was extremely difficult and at times impossible. Visibility was zero. The heavy fire load and the concrete shell made the building act as a heat sink, absorbing a tremendous amount of heat, and allowed interior temperatures to develop in excess of 2,000°F (1,093°C).

    It took 60 companies and 350 fire fighters (45% of the LAFD's [Los Angeles Fire Department's] on-duty strength) 7 hours and 38 minutes to knock down the fire. It was impossible—for hours—to enter the fire area after extinguishment due to the extreme retention of heat. Walls had to be cooled by hose streams for hours after the fire was out and still, full firefighting ensemble and self-contained breathing apparatus (SCBAs) had to be worn to endure the residual heat. There were 50 fire fighter injuries; there were no deaths or critical injuries. Total property loss $22 million: $2 million for the structure, $20 million for the contents. Of the 1.2 million books, only 350,000 received fire or water damage.
19. In any fire-resistive building, the existing fire loads should be compared with the fire resistance rating of the structure. Where high fire loads exist, and where fire suppression efforts will be inadequate, severe structural damage is a distinct possibility. Furthermore, because of their great structural strength, concrete buildings can be heavily loaded with combustibles and, thus, the fire load may be excessive. You'll be forced to implement a defensive strategy.
20. Even if the interior compartmentation were to be perfect, the hazard of exterior extension still exists. Those who saw huge volumes of fire pouring out the windows of the 1988 First Interstate Bank Fire in Los Angeles, California, will have no difficulty understanding the potential of exterior extension in an unsprinklered building. The building is a 62-story steel-frame tower. The exterior perimeter is entirely covered with glass. The fire started on the 12th floor and extended to the 16th. It took 383 LAFD fire fighters, 10,000 feet (3,048 m) of fire hose, one-half million gallons of water, and 3 hours and 39 minutes to knock down the fire.
21. Impact loads to damaged concrete, such as from sledges or jackhammers, should be carefully evaluated. All areas where spoiling has reached the reinforcing steel should be shored before any work is done in those areas. Concrete floors that are seriously damaged on one side may give no clue to the distress on the other side.
22. Protruding rods are a serious sign of possible collapse. A column failure may have catastrophic results. Fortunately, column failures are rare. Any protruding structural members are signs that the building is deteriorating. We are fire fighters, not structural engineers. Recognize what the building is telling you and immediately back out your crews and operate from a safer position.
23. Remember, of all the five construction types, Type I fire-resistive buildings are the most stable to fight a

fire in. They have the best collapse resistance record from the perspective of fire fighter injuries and deaths. There are two basic types of fire-resistive construction: reinforced concrete buildings and structural steel buildings. Both are designed to resist a fire that burns out an entire floor without spreading flames to other floors or collapsing the structure. With limited resources, your best strategy may simply be to protect the exposure floors above the fire and let the fire consume the fuel on the fire floor; in other words, let the fire burn itself out.

24. With serious fires in fire-resistive buildings, the collapse danger lies in the concrete. In reinforced concrete buildings, heated concrete ceilings collapse on fire fighters working underneath. In steel skeleton buildings, heated concrete floors explode upward. Both of these structural failures are caused by spalling.

    Spalling is when small amounts of moisture, normally trapped inside the concrete, expand when ɪated by fire and increase the internal pressure within the concrete. This pressure can cause heavy sections of concrete to crack away from a ceiling and collapse down into the fire or on top of a fire fighter. This type of collapse occurs in a building without a suspended ceiling where the concrete ceiling is directly exposed to flames below.

25. In steel skeleton construction, the underside of each floor is not concrete—it's light-gauge corrugated steel sheets. These steel sheets support several inches of concrete on the floor above. When heat from a fire reaches the underside corrugated steel, it radiates to the concrete above. As the temperature of the concrete increases, so does the internal pressure from the moisture trapped inside the concrete. When spalling occurs, the steel sheets prevent the concrete from collapsing downward. The energy takes the path of least resistance and, therefore, it explodes upwards (an upward collapse). A sudden failure of pressurized concrete erupts and can send chunks of flying concrete 6–12 inches (15-30.5 cm) in the air. If this situation occurs, fire fighters working on the floor above the fire must quickly evacuate to the safety of the stairwell. It means interior crews on the fire floor are not making progress and the fire is getting worse or the fire is being left to burn itself out. Protect the exposure floor above from the safety of the landing. Use the reach of the fire stream to wet down the walls, the floor, and other surfaces.

WRAP-UP

Chapter Summary

- Concrete is a cementitious material produced by a chemical reaction of Portland cement and water to which inert materials called aggregates are added.
- There are two basic types of in-concrete construction: cast-in-place concrete and precast concrete.
- A chief virtue of concrete is its high compressive strength and low cost, which is why concrete is used for columns, even in structures otherwise built of steel such as highway bridges.
- Prestressing places engineered stresses in architectural and structural concrete to offset the stresses that occur in the concrete when it is placed under load.
- Concrete buildings under construction can present serious fire problems. Fire in formwork can easily result in major collapse with potential for massive life loss.
- When concrete construction was first developed, it was regarded by some as the answer to all fire protection problems—it was believed to be truly fireproof.
- After a series of disastrous fires, it became evident that concrete, like any other noncombustible material, can be destroyed by fire given sufficient fire load and fire duration.
- Clear signs of possible trouble can be identified in a prefire plan. Deteriorated concrete, spalling that exposes reinforcing rods, and cracks in concrete that can admit corrosive moisture to the reinforcing rods are indications that a building is in distress.
- One of the fire protection advantages of Type I construction is that it lacks inherent voids.
- The concrete in fire-resistive construction serves two purposes—it resists compressive stresses and protects the tensile strength of steel from fire. The latter function is accomplished in proportion to the thickness of the concrete cover.
- By sacrificing itself, the concrete provides time to extinguish the fire; however, it may also lose its strength.

Key Terms

Aggregates Any of a variety of materials, such as sand and gravel, added to a cement mixture to make concrete.

Cables Special high-strength, cold-drawn steel cables. Also referred to as strands or tendons.

Cast-in-place concrete Includes plain concrete, reinforced concrete, and post-tensioned concrete. This concrete is molded in the location in which it is expected to remain.

Casting A process of placing fluid concrete into molds, generally called forms, in which the concrete is permitted to harden to a certain shape.

Chairs Small devices designed to keep the rods up off the surface of the form so concrete will flow underneath.

Composite and combination columns Columns that use steel and concrete combined into one unit.

Composite construction Buildings in which different load-bearing materials are used in different areas of the building.

Continuous casting Process for casting or pouring concrete without interruption from start to finish.

Continuous slipforming Pouring concrete continuously as forms move upward so that continuous casting may be accomplished.

Drop panel Thicker section of floor on top of columns to assist in resisting the natural tendency of the floor to shear off at the column.

Excess flow valve Valve that senses a sudden increased flow, as from a broken line, and shuts off flammable gas.

Falsework Temporary shoring, formwork, beams, or lateral bracing to support the concrete work in the process of construction.

Flat plate structural system (continuous beam) Cast-in-place floor in which there are no beams supported by columns; the floor plate itself rests directly on the columns.

Footing Typically thick concrete pads, blocks, or strips of concrete below the surface of the surrounding soil, sometimes heavily reinforced, that transfer the loads of walls, piers, or columns to the ground. Footings attempt to minimize building settlement by spreading the load over the large soil/concrete interface.

Formwork Mold that shapes the concrete.

Hollow tile Tile unit composed of vertical hollow cells, utilized in early efforts to lighten concrete floors.

Lally columns Steel pipes filled with concrete to increase their load-carrying capacity.

Left-in-place form Concrete floors that are cast onto corrugated steel.

Lift slab Type of building construction where concrete slabs are cast on the ground and lifted into place.

Monolithic construction Method in which all the concrete in a building is properly bonded together and acts as one.

Mudsills Planks on which formwork shores rest.

Mushroom cap Tapered extension at the tops of columns that assists in the transfer of loads from floor to column.

One-way structural system System that incorporates floors that have beams running in one direction only.

Plain concrete Concrete that has no reinforcement, except possibly light reinforcement to resist temperature changes.

Precast concrete Concrete that has been cast at a location other than the place where it is to remain.

Prestressing Engineered stresses placed in architectural and structural concrete to offset the stresses that occur in the concrete when it is placed under load.

Pretensioning and post-tensioning Processes by which steel tendons or rods are placed under tension, drawing the anchors together. Tensioned steel places the concrete in compression.

Reinforced concrete In concrete masonry structure, steel reinforcement that is embedded in such a manner that the two materials act together in resisting forces.

Reinforcing bars or rods Steel rods or bars used to reinforce concrete.

Reshoring Shores that are put back into concrete to help carry the load of the still-curing concrete.

Skewbacks Tiles shaped to fit around steel.

Slipforming Technique by which forms are moved upward as the concrete is poured.

Spalling Loss of surface material when concrete is subjected to heat.

Strands Special high-strength, cold-drawn steel cables. Also referred to as cables or tendons.

Stressing the tendons After concrete is poured and reaches its specified strength, steel tendons are stretched and anchored at the ends of the unit. Also referred to as "jacking the cables."

Temperature rods Thin rods installed near the surface of concrete, usually at right angles to the main reinforcing rods, to help the concrete resist cracking due to temperature changes.

WRAP-UP

Tendons Special high-strength, cold-drawn steel cables. Also referred to as strands or cables.

Two-way structural system System that incorporates floors that have beams running in two directions.

Underwriters blocks Concrete blocks poured per Underwriters Laboratories, Inc.'s classifications.

Waffle concrete Two-way structural system with closely spaced beams set at tight angles to one another in which unnecessary concrete is formed out; lower side resembles a waffle.

Case Study

You are the lieutenant of a downtown fire company and are on the site of a new Type I high-rise under construction. As you preplan the building, your fire fighters have several questions for you to answer. You consider all the possible answers.

1. By definition, falsework is composed of:

- **A.** Formwork
- **B.** Shores
- **C.** Lateral bracing
- **D.** All of the above

2. The word for loss of surface concrete over time is:

- **A.** Spalding
- **B.** Fissuring
- **C.** Spalling
- **D.** Smalling

3. Which ASTM standard addresses the standard fire resistance rating tests that qualify steel?

- **A.** ASTM E-119
- **B.** NFPA 252
- **C.** NFPA 351
- **D.** ASTM E-84

4. Which type of fireproofing does not protect individual structural members?

- **A.** Asbestos fiber
- **B.** Intumescent coating
- **C.** Cementitious
- **D.** Membrane

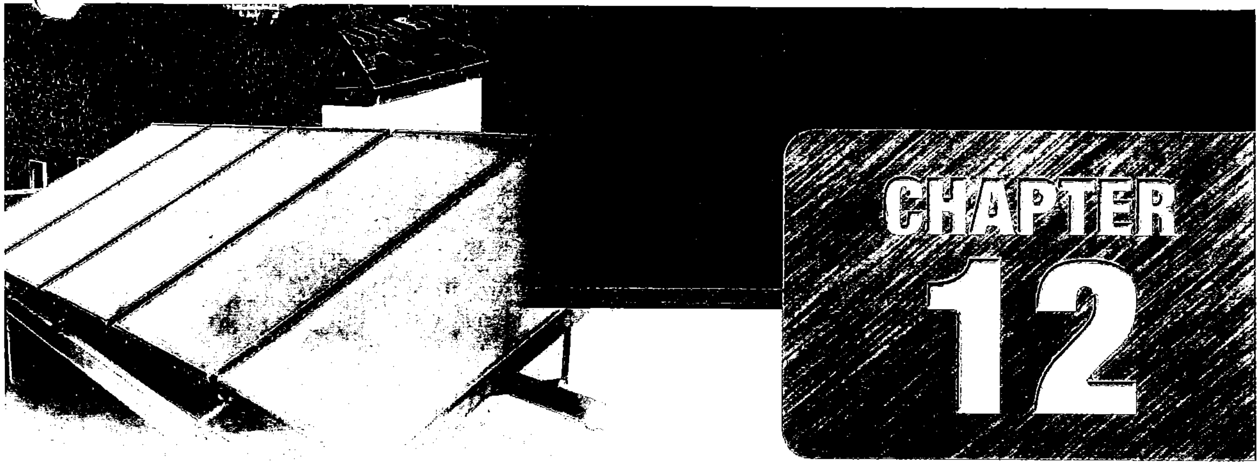
Challenging Questions

1. Identify the ingredients necessary to produce concrete.

2. Detail the differences between flat slab, one-way, and two-way floor systems.

3. List the problems associated with membrane fire protection for steel.

4. Describe the purpose of prestressing concrete and the two methods used to accomplish this goal.



Firefighting Concerns of Green Construction

OBJECTIVES

At the conclusion of this chapter, you will be able to:

- Define green (sustainable) construction.
- Explain the role of green certification rating programs and green construction regulations.
- Identify and describe the four general categories of green construction.
- Identify firefighting hazards associated with each type of green construction material or green building system.

Case Study

Figure 12-1 Note the solar panel array on the roof of the fire building.

Courtesy of Bill Tompkins.

Fire fighters expect the unexpected. Such was the case in 2010 when fire broke out in New York's Chinatown in the rear of a first-floor store in a six-story tenement of ordinary construction. Fire spread vertically rapidly through unprotected voids all the way to the roof. Fire fighters on the roof, however, found something that would not typically be found on a 100-year-old structure—an array of solar panels (**Figure 12-1**). The array extended over a large portion of the roof, covering the building's light shaft and exposing the array's frame to fire, endangering fire fighters working below. With fire spreading throughout the building, a defensive strategy was taken. The seven-alarm fire claimed the life of an elderly resident.

1. What is the impact of green technology in buildings?
2. How would you keep track of green "upgrades" to buildings in your community?

What Is Green Construction?

While the term *green construction* is relatively new, the use of environmentally friendly "technology" has been around for thousands of years. The sod-roofed houses of Ireland, the windmills of Holland, and the old grist mill water wheel are all examples of using nature to generate and conserve energy. It is, however, the more recent concerns over the environmental damages inflicted by fossil fuels that have driven the "green movement" for the last several years.

Green construction is also known as **sustainable construction**, essentially meaning construction that is deemed to be efficient and environmentally friendly in terms of both the materials used and their overall impact. This includes construction materials and methods that save energy or systems that generate energy. From a firefighting perspective, however, *do not assume that all materials used in green construction are "natural."* Numerous synthetic materials—particularly plastic foam insulation—are included in the "green" category because they are used to conserve energy. We have discussed some of these synthetic materials in previous chapters.

The Trend Toward Sustainable Construction

The demand for green construction has led to the creation of several related advocacy groups and certification programs. Most notable is the U.S. Green Building Council, which established a rating program, the Leadership in Energy & Environmental Design (LEED) certification, for actual buildings that meet certain minimum green criteria. The stated objectives of the LEED program are as follows:

- Lower operating costs and increase asset value
- Reduce waste sent to landfills
- Conserve energy and water
- Be healthier and safer for occupants
- Reduce harmful greenhouse gas emissions
- Qualify for tax rebates, zoning allowances, and other incentives in hundreds of cities

Another popular rating system is the Building Research Establishment Environmental Assessment Method (BREEAM), a worldwide program intended to assess the "greenness" of buildings of all types.

As these examples suggest, there are literally dozens of green rating systems, covering all types of buildings and occupancies. For the most part, these rating systems do not deal with fire safety issues. Instead, it is assumed that fire safety is dealt with by local building and fire codes.

This lack of focus on fire safety led to concern within the code enforcement community. In response, the *International Green Construction Code* was issued in 2012 in an attempt to regulate green construction. This code is coordinated with the *International Building Code* and the *International Fire Code*, which were discussed in the chapter that reviews building and fire codes.

It's important to remember that with green construction, the traditional building hazards still exist. In fact, fireground hazards are sometimes *increased* by green construction. For example, a photovoltaic (PV) cell array on the roof of a wood-frame building may delay or eliminate vertical ventilation as a firefighting option. *Do not equate green construction with increased safety.*

For the purposes of studying green construction from a firefighting perspective, we can group these green systems and materials into four general categories: eco-friendly materials, energy conservation, water conservation, and energy generation.

Eco-Friendly Materials

The following "natural" materials are considered green, given their availability, relatively minor impact on the environment, and ability to be recycled:

- *Bamboo*—a quick-growing plant (compared with hardwood trees) that is now used not only to create furniture but also in structural laminated beams, curtain wall panels, and even trusses. In terms of fire resistance, there do not appear to be any American Society for Testing and Materials (ASTM) E-119 type tests conducted of structural bamboo materials. Expect early failure of unprotected bamboo beams and trusses.
- *Adobe*—a composite material made of clay, a fibrous substance (e.g., straw, manure), sand, and earth, baled into bricks.
- *Straw bale*—bales of straw covered with cement plaster or "earth" plaster. While examples of both cement- and earth-coated bales have been tested in accordance with ASTM E-119 (for 2 and 1 hours, respectively), there is little information on the performance of these coatings over time, particularly when abused. A loss of coating will expose the straw, while still densely packed, to a fire.
- **Cob**—a composite material composed of clay, straw, sand, and earth; similar to adobe; typically laid in courses. Plaster is often added to improve its appearance.
- **Biopolymers**—in terms of construction materials, naturally produced "green plastic" made from renewable, living sources (e.g., starches, wood), instead of nonrenewable sources such as oil. Biopolymer plastics are being used to make insulation materials, plastic "building blocks" in which concrete and rebar are placed (similar to traditional insulated concrete forms [ICF] that use petroleum, except in this case, the foam is a natural biopolymer), "lumber," roofing shingles, and even tilt-up walls. Fire experience and fire testing of these materials are lacking, but we should monitor combustibility and flame spread experiences.
- *Ammonia*—an "old" refrigerant in use since the 1870s. When Freons and other "greenhouse gases" were banned in the 1980s, ammonia reemerged as a primary refrigerant replacement for large-scale refrigeration systems Figure 12-2.

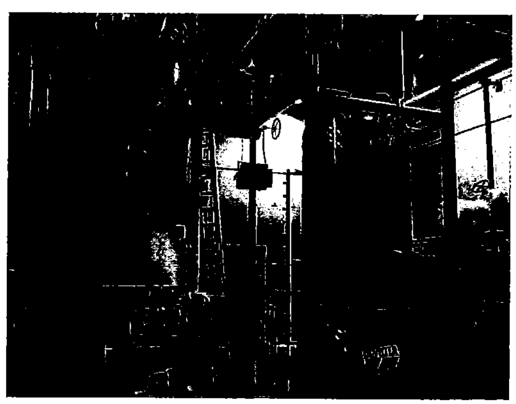


Figure 12-2 A modern ammonia refrigeration system.
Courtesy of John Piho/Piho Engineering.

While considered eco-friendly, such systems pose not only a deadly toxicity hazard, but also an explosion hazard. Ammonia will burn in concentrations as low as 16%.

Energy Conservation

The energy crisis of the 1970s led to the creation of many synthetic—that is, plastic—insulating materials. While these materials have beneficial energy-saving characteristics (making them green), they have been criticized because of their health (smoke toxicity) and recycling problems.

More recently, there has been a move to incorporate vegetation on top of and on the walls of structures to save energy. While such vegetation can help save heating and cooling costs, the materials are still combustible if they dry out due to lack of maintenance (Figure 12-3).

Other energy conservation measures that may be found in green construction include the following:

- *Polystyrene insulation*—a spray-applied foam or rigid plastic insulator. Polystyrene was spray-applied to the surface of older cold storage buildings, while rigid foam panels are used to insulate an enormous number of buildings each year.

Figure 12-3 A green roof structure with vegetation.
Courtesy of Raul A. Angulo.

- *Polyurethane insulation*—a spray-applied foam or rigid plastic insulator. It is very often used in the stud channels of walls.
- *Radiant barriers*—a flexible reflective membrane added to the surfaces of attic spaces to reflect heat, cooling the space and reducing cooling energy costs.
- *Glass*—its use as an insulating material makes it a green material. As discussed earlier in the text, multipane insulated windows also play a role in accelerating fire development, delaying fire-induced breakage in many cases. *Daylighting* advocates for the increased use of glazing to light spaces naturally, reducing energy costs.
- *Green roof*—an insulating roof cover composed of vegetation and materials used to support plant growth. A descendant of the sod roofs used for centuries, this modern version is used to insulate a building's roof. It comprises a complex set of layers below the grasses and shrubs, including soil, filtering fabrics to prevent the soil from being washed away, plastic or metal soil restraints to keep the soil from washing down drains, a drainage layer made of plastic panels or mats to allow water drainage, foam plastic insulating boards, and a waterproofing membrane to keep water out of the building. Collectively, these layers add up to a substantial amount of weight, potentially leading to a collapse. Be wary of installations in existing buildings.

With green roofs, the obvious problem of roof ventilation must be considered when preplanning such structures. In addition, the "mini-wildland fire" is not a far-fetched concept: a recent fire on the roof of a Manhattan high-rise created numerous problems for responding fire fighters, who found it difficult to access the roof under heavy fire conditions. The 2012 edition of the *International Fire Code* now incorporates provisions to limit the size of such gardens, provide nearby standpipe outlets, require more fire-resistant roof surfaces, and require ongoing maintenance of these gardens to avoid the above wildland scenario experienced in New York City.

Green Walls

Walls play a significant role in making buildings green. From a firefighting perspective, these walls can influence fire behavior. It is important to study these green walls (and any other types you may encounter) to anticipate their role in a fire. There is little actual fire experience with them because they are relatively new; therefore, we often need to rely on our intuition to deal with them.

Heavily insulated walls, such as **structural insulated panels (SIP)**, are designed for energy efficiency; SIP are "stud-less" wall assemblies using a core of polyurethane. The more recent use of super insulated panels with higher amounts of polystyrene, polyisocyanurate, and polyurethane plastics add even further to the problem because of their combustibility. **Structural insulated sheathing (SIS)** is installed as an exterior sheathing in wood-frame dwellings, providing st(ural stabilization (similar to plywood and particleboard sheathing over wood studs), insulation, and a barrier to moisture. Its use of polyisocyanurate and polystyrene is an issue of combustibility. While some of these materials may have a low fire spread rating according to ASTM E-84 (discussed earlier in the chapter that reviewed the features of fire protection), they still provide fuel for a fire.

Fires involving sprayed polyurethane foam (SPF) insulation (the foam is applied with a spray gun in the channels between studs and beams) have occurred while the foam was being applied. It is believed that an exothermic chemical reaction occurred after the individual foam chemical components were mixed.

Green concrete includes ICF wall panel systems. Although not combustible, ICF wall panel systems offer the potential of trapping the heat of a fire inside the structure. However, some newer green walls are designed to trap and move heated air up and around a building. The **trombe wall**—essentially a set of glass exterior panels and concrete block wall with a void space in between (used in smaller buildings)—is used to trap sun-heated air and deliver the hot air into the adjacent living pa(through a series of one-way vents. A similar arrangement is known as a double-skin façade, used for ventilation in some modern high-rises. While this void space itself is surrounded by the noncombustible materials, it could provide a vertical path for a fire coming from within the building.

We are all familiar with ivy- and vegetation-covered buildings, often referred to humorously as Chia® buildings because of their similarity to the small clay Chia Pets® knickknacks that sprout grass on their exterior. Today, green advocates have brought the vine-like plants to the interior of the building, using them as a wall covering. Of course, plant vegetation is combustible, particularly when dry. Expect the plants to aid in fire spread.

To complicate this issue even further, some of these living walls are part of a larger biofilter, in which the plants become part of the air-handling system. Air is drawn through a wall of plants attached to a wall growing medium, improving air quality in the building. The plant combustibility problem now becomes even greater; burning plant material can spread fire and smoke through the HVAC system until it is shut down (by a duct smoke detector or manually). Although the filters used in a traditional HVAC system are fire tested, these plant "filters" are not.

Plastic Lumber

Recycled plastic waste have found use in outdoor applications such as decks, boardwalks, furniture, trash cans, and several other products. They exhibit the same combustibility characteristics as the plastics from which they are made. Refer to the chapter on methods and materials of construction, renovation, and demolition for the discussion on thermoplastics and thermosets.

Firefighting Accessibility and Green Construction

Although not a construction issue per se, the use of vegetation for energy conservation has led to the increased use of trees and shrubs to shade buildings from the heat of the sun. In addition, green hardscape soils are used to absorb rainwater runoff. In both of these cases, the accessibility to a burning building may be reduced. Trees can block the use of ladders while large swaths of soil (used to absorb the runoff) can place the building further away from access roadways, increasing hose stretches and putting buildings out of the reach of aerial devices.

Be wary of the use of fire access roadway paving other than asphalt, including concrete pavers. It is best to visit and test these alternative roadway materials somewhere else before accepting them for use. Verify that the weight of your apparatus will be properly supported, all outriggers can be used properly, and that the roadway will not become a muddy mess during a fire when large quantities of firefighting water are used.

The trend toward community walkable streets, in which motorized vehicles are limited or eliminated altogether, will make firefighting more difficult. The only solution is to ensure firefighting access is provided prior to construction. Don't wait until the complex is built.

Water Conservation

Many green buildings use reclamation systems to capture and store rainwater. Of concern from a firefighting perspective are the associated tanks used to store the water. Be wary of the dead load presented by the tank for any structures it may be mounted upon.

Given the water shortages seen in different areas across the United States, a trend toward using nonpotable (nondrinkable) water for firefighting operations is on the rise. From a firefighting perspective, the use of **gray water** for firefighting is becoming more commonplace. Gray water is wastewater from industrial processes, laundries, and other sources. It should not be confused with sewage, which is termed *black water*.

Large industrial plants often use gray water for a variety of purposes, including for supplying private fire hydrants (colored differently than normal hydrants). An aluminum-rolling mill in San Antonio, Texas has such gray water–supplied hydrants. While such water can be considered for firefighting purposes, all apparatus must be thoroughly flushed with potable, fresh water. Gray water is not drinkable; it has not been treated to potable water standards.

The retention of water for conservation can pose additional problems for fire fighters. Tanks may be located on roofs or in buildings, which adds a substantial dead load. Water collection tanks may also be buried under roadways; ensure that fire apparatus access roads do not have water tanks below the driving surface.

Energy Generation

Generating electricity independent of fossil fuels has been a national priority for many years. Making the United States oil independent and protecting the environment are at the heart of this effort. Recent financial incentives, including tax breaks, are making many Americans think about installing their own energy-generating systems, including within existing buildings. A variety of technologies may be used for this purpose.

PV Roof Panels

PV roof panels incorporate individual semiconductor cells that react to energy from the sun and generate direct current (DC) electricity. Each individual PV roof panel—also known as a module—contains many semiconductor cells Figure 12-4. A group of modules is known as an array. The arrays typically face south (sometimes west) to get the maximum exposure to the sun.

PV systems are proliferating across the United States. These systems may be ground mounted or roof mounted. Some systems are actually incorporated into the roof and wall surfaces of a building. There are also freestanding PV structures that are used for covered parking Figure 12-5. Preplanning is critical to locate these systems before an incident occurs.

Obviously, there are a number of potential hazards and firefighting problems associated with these systems. These threats include electric shock, the

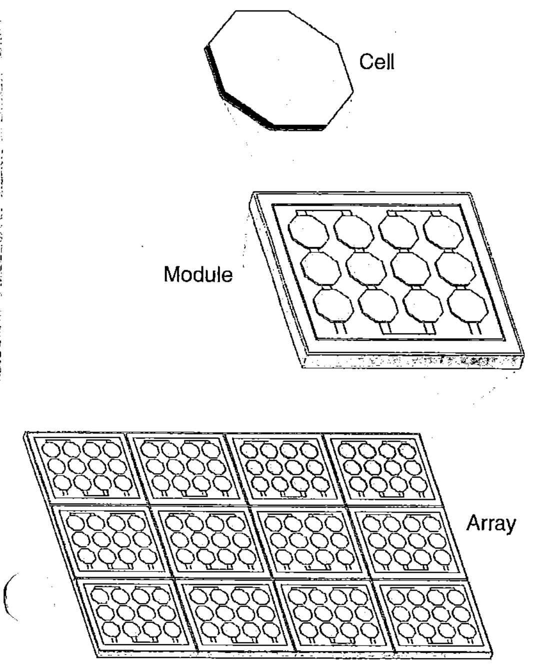


Figure 12-4 The components of a PV roof panel.
Courtesy of Gil Knier/NASA.

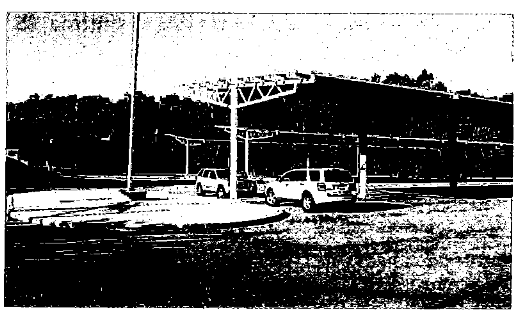


Figure 12-5 A ground-mounted PV array used as a parking space cover at the Bergen County, New Jersey, fire academy.
Courtesy of Glenn Corbett.

dead load of the system on the roof as a fire burns below, the release of a variety of hazardous materials contained in the individual modules, and the batteries used to store the generated electricity.

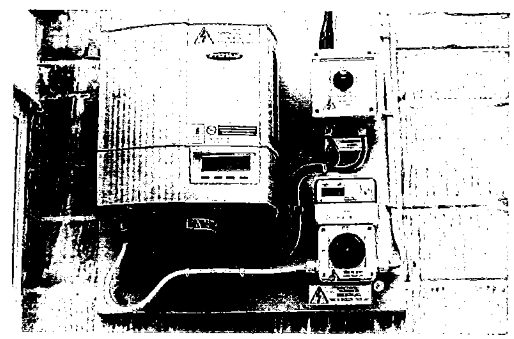


Figure 12-6 A PV inverter.
© Mark Boulton/Alamy Images

When fire fighters determine that a PV system is present in a building on fire, they should take specific precautions to mitigate the hazards associated with this type of energy-generating system. *Do not break or cut through the panels or associated equipment.* The system should be deenergized, including all circuits leading from the PV system, any switches to the building's primary electrical panel, any switchgear on the roof, and, on both sides of the **inverter**, the system device used to convert the DC into the alternating current (AC) used by the building Figure 12-6. Fire fighters should also verify that there are no other electrical supplies (e.g., generators) for the building. Of course, the batteries used to store the electricity will still be energized even if disconnected.

Recent fire incidents have exposed significant problems due to the lack of disconnect switches in these systems. In a 2010 big box retail store fire in Bakersfield, California, fire fighters were unable to deenergize the system due to lack of a specific disconnect switch. A 2012 Trenton, New Jersey, manufacturing plant caught fire when workers installing the system activated it prematurely, sending electricity to the rest of the incomplete system. In 2013, a fire starting at the roof level of a 300,000 square-foot food warehouse in Delanco, N.J.—covered with thousands PV panels and a polyurethane insulated EPDM roof—destroyed the building, in what may be one of the largest PV panel-related fires in U.S. history Figure 12-7.

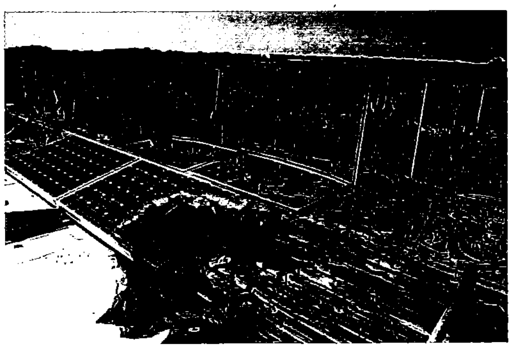


Figure 12-7 This New Jersey food warehouse was totally destroyed in 2013 when a fire apparently began at the roof level near the center of the structure. Thousands of PV panels covered the roof, making it impossible to access the fire. It ignited the rubber roof surface and plastic insulation panels underneath, creating an unstoppable roof fire burning above the sprinkler heads throughout the 300,000 square foot structure. It also started other fires at floor level which destroyed the contents, racks, and steel frame structure.

Courtesy of Glenn Corbett.

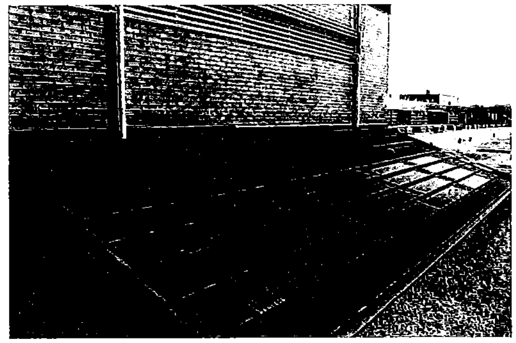


Figure 12-8 A PV roof shingle system.

Courtesy of NIST.

Of particular concern is the conduit (piping) containing the conductors (wiring) coming from the PV panels. During daylight, these conductors will remain energized, creating a significant shock hazard, even if all of the system switches have been disconnected. It's important to locate these conduits and avoid them. They may be labeled, but don't bet on it. A standardized labeling system for all important components of a PV system is only just coming into use across the United States; there are many existing systems without any such labeling.

PV systems are sometimes incorporated into the building itself in the form of either PV shingles (Figure 12-8) or PV wall panel systems, often referred to as **building-integrated photovoltaics (BIPV).** As with roof-mounted arrays, these systems present problems for fire fighters, particularly when attempting to ventilate a building.

The PV shingles can prove to be extremely slippery and will make ventilation difficult or impossible because it is not safe to break the panels or associated equipment. In some cases, the shingles have been added without consideration of the weight they add to the roof. Some new buildings incorporate PV panels into the entire façade of a multistory building. These wall panels will make portions of the face of the building inaccessible for fire fighters. These BIPV systems also share the same problem discussed above in that these systems remain energized while the sun is shining on them.

Flexible laminate solar panels are finding their way on to buildings and other structures, such as boats and tents. These thin panels can simply be unrolled and stuck (self-sticking in many cases) to a flat surface and connected, generating electricity. Many of these panels are small in size; however, when used and installed by individuals with little technical knowledge, these panels can be dangerous to fire fighters. The same rules that apply to PV panels apply here, as well.

Off-grid systems are PV systems that are not connected to a traditional public electrical grid and are often located in rural areas. Although they share the same problems identified above for PV systems, they also pose the additional problem of large-scale battery storage, because they are not connected to the public grid. Because they often have numerous banks of batteries that are interconnected, they pose an electrical shock hazard. The batteries are sometimes

Figure 12-9 A roof-mounted wind turbine system.
Courtesy of Glenn Corbett.

Figure 12-10 An active solar water heating system.
Courtesy of Glenn Corbett.

s' 'd in a separate structure from where the PV p. .ls are located. Often, the rooms in which they are located are not designed for that purpose; significant quantities of hydrogen gas can be generated by the batteries.

Roof-Mounted Wind Turbines

A wind turbine is a device used to capture the kinetic energy of the wind, convert it into mechanical energy so as to drive a generator, and subsequently convert the energy into direct electric current. Small roof-mounted wind turbines have found their way onto the roofs of residential and commercial buildings across the United States Figure 12-9. While these systems present similar hazards to fire fighters to those discussed for PV systems, they have the added danger of the spinning blades of the turbine.

Solar Water Heating Systems

Solar water heating systems use the sun's energy to heat a fluid (typically antifreeze in cold climates and water in warm climates) within a closed loop of tubes, which in turn heats a storage tank of water. Two general types of solar water heating systems are distinguished "active" and "passive."

Active systems use a roof-mounted collector (containing a network of closely spaced tubes; they look similar to a PV panel, but they are not the same) and a pump to move the sun-heated fluid to the water tank Figure 12-10. A heat exchanger then heats the water in the storage tank.

Passive systems heat the water directly through the use of a batch collector, essentially a large well-insulated tank designed to heat the water within. These tanks are often roof mounted, creating substantial dead load and potential for collapse. Consider this risk when the fire is directly underneath the tank.

TACTICAL CONSIDERATIONS

1. Fire departments that perform preplans (transferred to computer files, accessible by a mobile data computer in the fire apparatus) using a notation of "GC electrical roof hazards" can help alert responding companies that there may be an array of PV roof panels that could create an unfamiliar electrical shock hazard. Since most of these panels face south or southwest to capture the maximum exposure to the sun, it is best to ladder the building from the north side of the building to access the roof. Laddering from the opposite side of where the arrays are aimed allows the fire fighters to look underneath the panels to see how they are attached to the roof. It may also reveal the location of disconnect switches.
2. When array PV disconnect switches are encountered, they should be flipped to the "off" position. However, similar to conventional electrical installations, flipping the main circuit breaker on an electrical panel doesn't guarantee the building is deenergized. There may be other panels or subpanels that are still energized. Remember, as long as the sun is shining, the PV panels themselves will be energized. The power utility company has more experience with green energy-generating systems than the fire department does. Dispatchers should contact the power utility crews as soon as the fire department resources are responding. Even after the power company claims the building is deenergized, keep away from power units and electrical wires as much as possible.
3. Many green constructed buildings incorporate living vegetation on the roofs to save on heating, cooling, and insulation costs. Some of these roofs look like manicured lawns, while others look like wild fields. One problem that occurs is when maintenance is neglected or when there hasn't been any precipitation (rain) for months. The shallow root system causes the grass to dry out easily, making ideal conditions for a dry grass fire on the roof. Holidays that are celebrated with fireworks, such as the Fourth of July, are particularly dangerous. A stray bottle rocket can be the source of ignition. Fire brands from a structure fire in close proximity can also land on the dry vegetation and start a fire.
4. Green roofs that use grass and natural vegetation are planted in a layer of soil over a metal roof. There are also other filtering fabrics to keep drains open and to prevent the runoff of the soil. These green systems create additional weight on the roof. They also create impractical, if not impossible, conditions to vertically ventilate the roof using powers saws. The good news is, these green roofs often have skylights or light shafts that can quickly be broken out for vertical ventilation. Break open the skylights or light shafts and get your crew off the roof.
5. Green construction is fairly new to the fire service; at this time, we do not have a lot of experience in dealing with the various roof structures related to energy sources, water conservation, and energy conservation. The roof is the wild card—there is nothing conventional about them. Unless we are very familiar with the green buildings in our district, what we find on the roof may be a surprise. The best way to remain effective and efficient in our firefighting efforts as it relates to the ventilation of green buildings is to rely on horizontal ventilation. There are few, if any, hazards related to breaking out windows. The fastest and safest way to ventilate a green building is to select the exit point for the direction we want to exhaust the smoke, then pressurize the building with PPV fans or an MVU. Unless we need to vertically ventilate a green construction roof, positive pressure horizontal ventilation allows us to bypass the roof altogether. This is the safest option for fire fighters when we are dealing with the "unknowns" of green roof construction and related eco-energy roof fixtures.

WRAP-UP

Chapter Summary

- Green construction is proliferating in response to environmental and energy concerns.
- The materials used in green construction are not necessarily "natural" materials.
- Do not equate green construction with safe construction.
- From a firefighting perspective, green construction can be categorized into four categories: eco-friendly materials, energy conservation, water conservation, and energy generation.
- Each green construction system and material presents different potential firefighting hazards; preplanning is key to locate, identify, and understand these dangers.

Key Terms

Biopolymers In terms of construction materials, a naturally produced plastic from renewable, living sources (e.g., starches, wood), instead of nonrenewable sources such as oil.

Building-integrated photovoltaics (BIPV) PV systems that are incorporated into the building itself in the form of either PV shingles or PV wall panel systems.

Cob A composite material composed of clay, straw, sand, and earth; similar to adobe; typically laid in courses.

Gray water Wastewater from industrial processes, laundries, and other sources.

Inverter A device used in a PV roof panel to convert DC into AC.

Off-grid systems PV systems that are not connected to a traditional public electrical grid; they are often located in rural areas.

Structural insulated panels (SIP) "Stud-less" wall assemblies using a core of polyurethane.

Structural insulated sheathing (SIS) Installed as an exterior sheathing in wood-frame dwellings, providing structural stabilization (similar to plywood and particleboard sheathing over wood studs), insulation, and a barrier to moisture.

Sustainable construction Construction that is deemed to be energy efficient and environmentally friendly; also known as green construction.

Trombe wall A set of glass exterior panels and concrete block wall with a void space in between (used in smaller buildings).

Case Study

As a fire lieutenant, you are taking your company out to preplan a new residential subdivision containing hundreds of new homes. Since each home contains PV roof panels, you see the opportunity to assess your company's knowledge of such systems.

1. A group of PV modules is known as a(n):

- **A.** Relay
- **B.** Inverter
- **C.** Array
- **D.** None of the above

2. True or False: PV semiconductor cells convert the sun's energy into AC.

3. A device used to convert DC into AC is known as a(n):

- **A.** Converter
- **B.** Inverter
- **C.** Current director
- **D.** Battery

4. True or False: Conductors within conduit from the PV array will be energized when the array is exposed to sunlight.

WRAP-UP

Challenging Questions

1. Identify the different green construction systems that might present a dead load hazard to fire fighters operating underneath them.
2. Develop a list of tactical objectives for dealing with a PV energy-generating system. Include safety concerns.