Mill The earliest form of heavy timber construction; a type of factory that emerged during the Industrial Revolution.

Scupper An outlet in a wall of a building for drainage of water from a floor or a flat roof.

Slow burning A characteristic of a building that should allow a fire in that building to be brought under control before the building itself becomes involved.

Type IV Heavy timber construction.

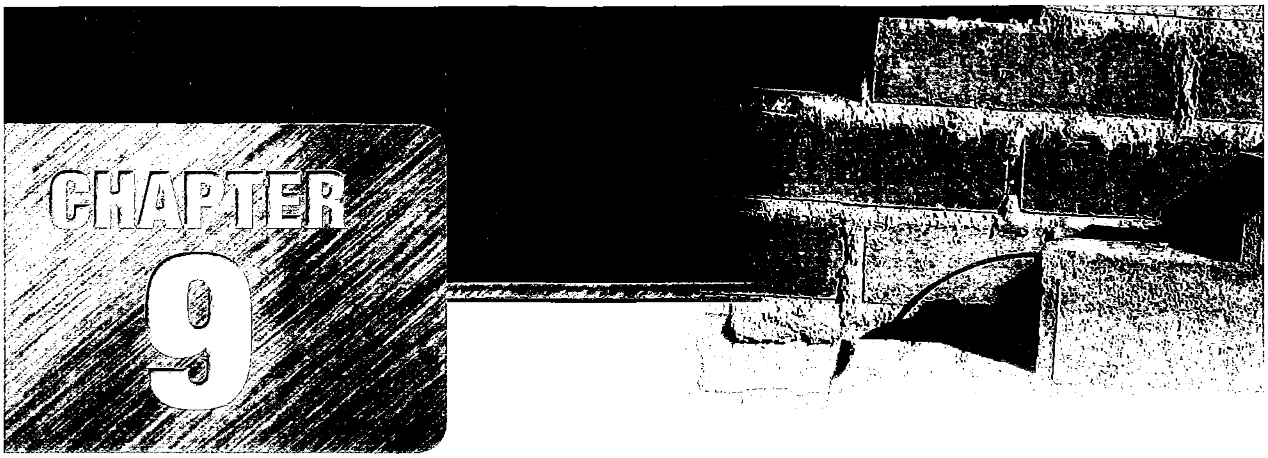
Case Study

You are a captain assigned to an engine company that is in the process of completing a preplan for an old textile mill that is currently being converted nto a new apartment building. The building is 4 stories high, 150 feet (45.7 m) in width, and 450 feet (137.2 m) in length. You take a walk through of the building, noting issues of concern for your firefighting efforts.

1. While walking across the second floor, you note wooden columns that have been cut at an angle on each corner. Which term describes this feature?
   - **A.** Corbelled
   - **B.** Laminated
   - **C.** Champhered
   - **D.** Dissected
2. On your preplan, you note that heavy timber construction is classified as which of the following?
   - **A.** Type III construction
   - **B.** Type I construction
   - **C.** Type V construction
   - **D.** Type IV construction
3. You notice that gypsum board ceilings are being installed in the apartments. Is that permitted? Yes or no?
4. You see that the old beams in the mill have fire cuts on their ends. Will they act like a lever on the exterior wall of the mill when they fall away during a fire? Yes or no?

Challenging Questions

1. What are some features of mill construction that may not be found in heavy timber construction?
2. You are the incident commander for a fire involving a 6-story, 100-year-old heavy timber warehouse in a heavily populated, urban neighborhood with numerous wood-frame apartments. Fire is quickly extending up through the building from the first floor. What are your concerns about a conflagration? How do you deal with the problem?



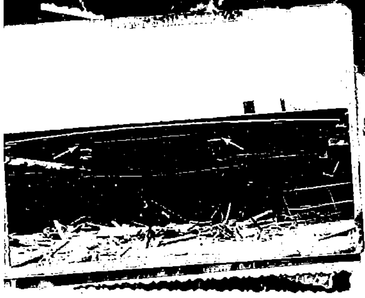
Ordinary Construction

OBJECTIVES

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

- Understand the details of ordinary construction, including features found in modern structures of ordinary construction.
- Understand how the structural stability of a masonry wall is compromised.
- Identify specific wall and wall component problems.
- Recognize collapse indicators.
- Identify the problems associated with interior structural elements.
- Identify fire hazards associated with roofs.
- Understand fire spread through void spaces of ordinary construction.
- Explain how masonry walls and fire doors act as fire barriers.

Case Study



gure 9-1 The deteriorated bowstring truss of of this abandoned laundry fell and killed o fire fighters in Chicago.

rtesy of NIOSH.

Understanding the potential for collapse of a structure during a fire is at the core of studying building construction. This potential can be multiplied by the addition of problems such as age, renovation, abandonment, and subsequent deterioration. Such was the case in December 2010 when the bowstring truss roof of a 1920s-era abandoned laundry of ordinary construction in Chicago collapsed on several fire fighters, tragically killing two of them (**Figure 9-1**). An investigation revealed that a rubbish fire in a room at the rear of the laundry had extended to the wood truss roof; the extent of this extension was not readily apparent to fire fighters. Some fire fighters reported that at floor level, there was very little visible smoke immediately prior to the collapse, which occurred soon after the fire was declared under control. It is likely that water leakage had rotted the trusses when the building was abandoned.

1. What is the potential for collapse of abandoned, unmaintained buildings?
2. Is it possible for a significant fire in a bowstring truss roof to remain hidden from fire fighters immediately below the truss?
3. How does the potential for collapse differ between abandoned and inhabited structures?
4. Which type of abandoned building marking system is used in your community?

Introduction

There have been some comments that this chapter is concerned with hazards that exist primarily "back East." It is true that many of the examples cited here occurred in older eastern cities, but many of the best photos that illustrate these examples were taken west of the continental divide. Those who built the structures of the East migrated westward and exercised their talents from Seattle to San Diego. The fact that a fire department has only a few of the buildings described in this chapter in its area is one reason to learn from the bad experiences of others, so that it may avoid these problems itself.

In addition, lateral transfer is becoming more common among the highest positions in the fire service. An ambitious junior fire officer cannot afford to neglect any aspect of this subject simply because that problem doesn't exist in his or her current department.

This chapter should be studied in conjunction with the chapters on every other type of construction. A wide range of construction characteristics—void spaces, balloon frames, tile arch floors, marble stairs, timbers, unprotected steel, plain and reinforced concrete—may be found in ordinary and other types of construction. Some elements may masquerade as being fire resistive.

Classifying Ordinary Construction

The term **ordinary construction** describes an almost infinite variety of buildings. In simpler days, it was generally known as brick and wood-joisted construction. Today, this construction uses a variety of walls and interiors. The chief common characteristic of ordinary construction is that the exterior walls are made of masonry. However, a few cast-iron-front buildings still stand, particularly in the Soho neighborhood of Manhattan (**Figure 9-2**).

The incorrect spelling or pronunciation of words such as masonry (not masonARY), lintel (not

LENtil), and spalling (not spalDING) reflects on the competence of fire professionals and underscores the need for accuracy in usage and pronunciation. Proper use of technical words or trade jargon helps to bolster the perception of technical knowledge and authority. For example, fire fighters should avoid using the term *brick building*. Buildings of different types of construction use bricks, both real and imitation. If you mean a building with brick load-bearing walls and wood joists, say *ordinary construction*.

Ordinary construction is classified as **Type III construction**. It can be described as "Main Street, USA." When Disneyland was created back in 1955, the organization wanted to build its version of Main Street, so it chose the appearance of typical brick-front commercial buildings from the 1800s. The actual structures in the Disney parks are imitation brick on steel frame and are fully sprinklered.

Although we often think of ordinary construction in terms of old "Main Street," there are many new structures being built of ordinary construction. One of the more common examples is the one-story **strip mall** with lightweight wood roof trusses and concrete block walls.

Figure 9-2 Built in the 1850s as commercial buildings, these buildings in lower Manhattan have decorative cast-iron-front walls. Even though these walls are not masonry, they are classified as ordinary construction.

In February 1989, two Orange County, Florida, fire fighters died in the collapse of a lightweight truss roof of a store in a strip mall. The trusses spanned 50 feet (15.2 m) front to back. The roof collapsed in less than 12 minutes. The fire was above the ceiling and did not appear to be threatening from the inside. The first-due engine was the only unit on the scene when the collapse occurred.

Masonry walls in ordinary construction may consist of brick, stone, concrete block, terra-cotta tile, adobe, precast, or **cast-in-place concrete**. The wall may be all of one material, different materials may be used in different areas, or different materials may be combined to form composite construction.

Today, load-bearing wall assemblies sometimes use open-cell polystyrene panels, in which rebar and concrete are inserted into the cells for structural strength. Wood joists are hung from these panels. Even though they are eventually covered by veneers, these plastic structural members add another layer of fire safety problems for fire fighters.

Most building codes used to have a provision for so-called **fire limits**. Within the fire limits, a structure could not be built unless the outer walls were constructed of masonry to limit fire extension. Wood-frame buildings were banned inside the fire limits. These regulations were established in many older cities only after major conflagrations occurred.

As we have seen, codes and standards divide types of buildings into five broad classes. Unfortunately, many of the buildings a fire fighter must cope with were built by people who used building materials that seemed best suited to their purpose or were readily available. Often, little or no thought was given to distinctions between types of construction as classified by building codes, the National Fire Protection Association (NFPA), or insurance underwriters.

Characteristics of Ordinary Construction

The simplest ordinary construction building consists of masonry bearing walls, with wood joists used as simple beams spanning from wall to wall. The joists usually are parallel to the street frontage of the building (or the smallest building dimension.) The roof may be similar to the floor in construction or it may be peaked by using rafters or trusses. In most cases, a **cockloft** (void space) separates the top floor ceiling from the roof. Ventilators for the cockloft are sometimes seen in the side walls Figure 9-3.

Bearing and nonbearing walls use similar construction materials and are often identical in appearance. In the typical downtown business or commercial building, the side walls are the bearing walls, whereas the front and back walls are nonbearing Figure 9-4.

The simple wood beam floor is satisfactory for buildings up to a practical limit of about 25 feet (7.6m) in width. For a wider building, or one with an irregular floor plan, interior masonry walls or a column, girder, and beam system must be provided. There is no limit to the ingenuity of builders. Many possible combinations of building materials are used. Columns may be wood, brick, stone, concrete block, steel, or cast iron. Different materials may be used for columns in the same building. Balloon-frame stud walls may provide intermediate support. Girders may be wood or unprotected steel. The connection systems that attach the beams to the girders and the girders to the columns are of almost infinite variety. It is in the weakness of these connections that the principal interior collapse potential is often found.

Figure 9-4 It is critical that responding fire fighters know the location of load-bearing walls within a structure, which is impossible to tell from the exterior of this building.

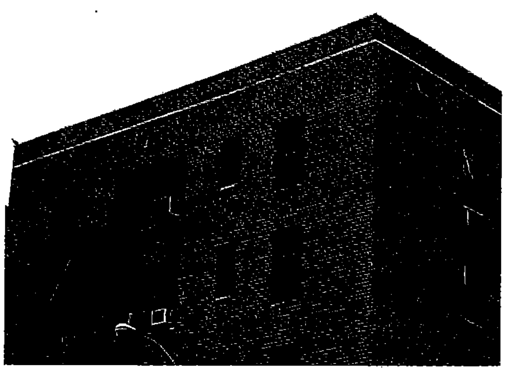


Figure 9-3 Although not common, some multiple dwellings of ordinary construction have cockloft vents between the top floor ceiling and roof deck; in this case, they are covered with metal weather shields.

Courtesy of Glenn Corbett.

As in wood construction, void spaces are an inherent part of ordinary construction. Some fire protection measures, such as embossed metal or tin ceilings, which were intended to prevent the extension of fire from the usable space to the void space, also prove to be barriers to the fire department's efforts to reach the fire once the fire penetrates the void space.

As a general rule, there is no effective fire separation within an ordinary construction building, either from floor to floor or within floors. Even where fire separations exist up through the regular floors of the building, they often are imperfect or nonexistent in attic spaces.

There is an inherent limit to the height of masonry buildings due to the necessity for increasing the thickness of the wall as the height of the building increases. The tallest old-style masonry bearing wall building in the United States is the Monadnock Building in Chicago Figure 9-5. It is 15 stories high,

Figure 9-5 Under today's standards, ordinary construction buildings are usually limited to no more than six stories, unlike the Monadnock Building shown here.

Photo courtesy of David K. Staub

and the masonry walls at the ground level are several feet thick. About the time it was built, steel-frame construction was developed, and masonry soon was being used only for fire-resistant panel walls, supported on the steel frame, and was not load bearing.

In recent years, high-rise brick or concrete block buildings with no wall thicker than 12 inches (30.9 cm), and medium-rise brick buildings with no wall thicker than 8 inches, have been developed, supplanting the traditional practice of ever-increasing wall thickness. These reinforced masonry structures depend in great measure on integration with reinforced concrete.

Masonry Construction Terms

Some of the principal terms used in masonry construction are defined here:

- **Adobe**: Bricks made of clay, water, and straw, dried in the sun. After the bricks are laid, the building is then parged (parging is defined later in this list) with a slurry of the same material.
- **Ashlar masonry**: Stone cut in rectangular units.
- **Cantilever wall**: A freestanding wall that is unsecured at the top. This wall acts like a cantilever beam with respect to lateral loads, such as wind or a hose stream. Precast concrete walls are very dependent on the roof for stability. If the roof is affected by a fire, these walls are likely to fall.
- **Cavity walls**: Hollow walls in which wythes are tied together with steel ties or masonry trusses.
- **Composite wall**: Two different masonry materials, such as brick and concrete block, used in a wall and designed to react as one under load (Figure 9-6).
- **Concrete masonry unit**: A precast hollow or solid structural block made of cement, water, and aggregates (CMU).
- **Coping**: The masonry cap on top of a wall (Figure 9-7).
- **Cornice**: A projecting decorative ledge at the top of a masonry wall.
- **Course**: A horizontal line of masonry.
- **Cross wall**: Any bracing wall set at a right angle to the wall in question.
- **Flying buttress**: A masonry pier at a distance from the wall and connected to it. Such buttresses resist the outward thrust of the roof. They are used mostly in Gothic architecture.

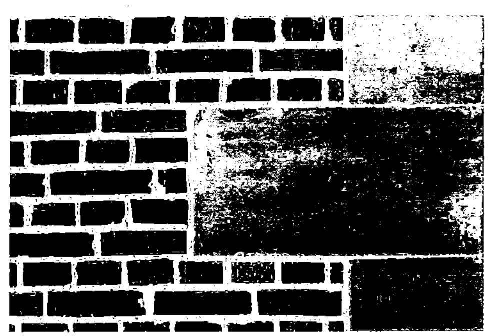


Figure 9-6 Used together, the components of this wall will support the load.

Figure 9-7 Rust-colored coping stones on the top of a stucco covered parapet wall.

Courtesy of Glenn Corbett.

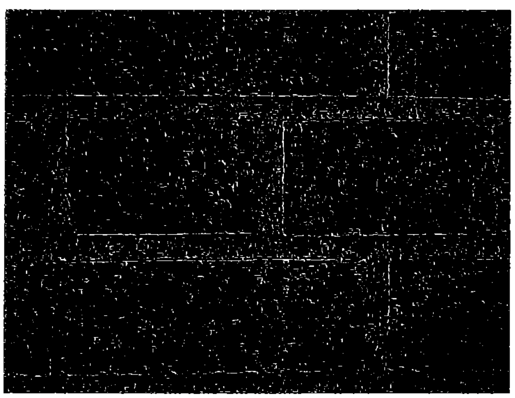


Figure 9-8 A header course of bricks (middle row).

Courtesy of Glenn Corbett.

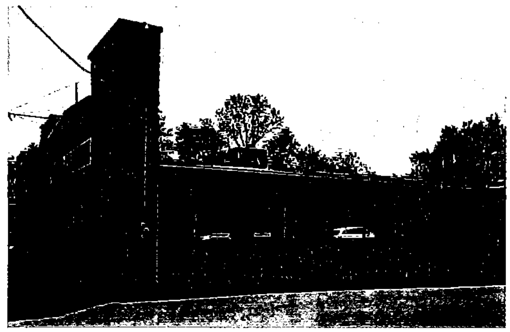


Figure 9-9 A commercial building with fieldstone walls.

Courtesy of Glenn Corbett.

- **Header or bond course**: Bricks laid so that the end is visible Figure 9-8.
- **Hollow masonry walls**: Two wythes of masonry with an air space between. The wythes are tied together or bonded with masonry.
- **Masonry columns**: Masonry bracing incorporated into unstable masonry walls; often called piers, buttresses, pilasters, or columns. These components may be built inside or outside the building. Where visible, they indicate where the wall is strongest, often where the concentrated loads are applied, and where *not* to attempt to breach the wall.
- **Parging (pargetting)**: The process of covering a masonry wall with a thin coat of concrete.
- **Rubble masonry**: Masonry composed of random stones Figure 9-9.
- **Rubble masonry wall**: A wall composed of an inner and outer wythe of coursed masonry. The space between is filled with random masonry sometimes mixed with mortar. Such walls are unstable to a lateral thrust.
- **Solid masonry walls**: Masonry units (either solid or hollow) laid contiguously with the joints filled with mortar.
- **Stretcher course**: Bricks laid so that the long side is visible Figure 9-10.
- **Terra-cotta tiles**: Made of clay and fine sand, terra-cotta is fired in a kiln. Terra-cotta is both structural and decorative and is used in ornamental facings Figure 9-11. Structural terra-cotta has been replaced to a large extent by concrete block.

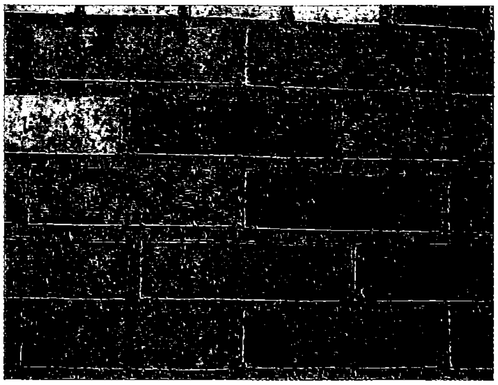


Figure 9-10 Stretcher courses of bricks.

Courtesy of Glenn Corbett.

Figure 9-11 The Filene's building in downtown Boston under extensive renovation. Note the clay terra-cotta tiles, which were used to enhance fire resistance over 100 years ago, underneath the exposed second floor.

Courtesy of Glenn Corbett.

- **Unreinforced masonry**: Ordinary masonry walls are not reinforced, so they have no resistance to lateral movement. As a consequence, they are very vulnerable to earthquake collapse.
- **Wythe**: A vertical section of a wall, one brick or masonry unit thick.

Renovation and Restoration of Ordinary Construction

Over the years, most old buildings have undergone extensive modifications. Usually, such modifications have had a detrimental effect on the structure from a fire suppression and protection point of view, creating collapse potential or interconnected voids from which fierce fire can burst out on the unwary.

This is not a new problem. The site of an 1890 fire in which 13 Indianapolis fire fighters were killed, the Bowen-Merrill Building, is now home to a restaurant frequented by many fire instructors attending the Fire Department Instructors Conference (FDIC). The building was essentially a front and back with the stores on the other two sides providing the side walls. Over the years, some interior walls on the first floor had been removed and iron poles placed above the joists to support the upper floors. Additionally an arch in the basement had been removed, further weakening the structure. A fire brought the building down on the fire fighters.

"Old news!" you say. In fact, within the past several years we have seen these conditions and many others in existing buildings. It is also important to note that alterations over the years, including reconstruction from fires that may have occurred many years ago, may cause one part of a building to be quite different from another. What you see on first observation may not be representative of the entire building. Furthermore, interior alterations and finish may make it difficult or impossible to determine the true nature of the building Figure 9-12.

A case in point is the dining hall at the National Fire Academy, which was used during the Civil War as a temporary hospital for victims of the Battle of Gettysburg. When the building was first taken over from St. Joseph's College, it was not too difficult to trace the growth of the building over the years by examining the basement and the attic. The more recent interior improvements have made it much more difficult to do so. Cast-iron columns mark the boundaries of the original structure.

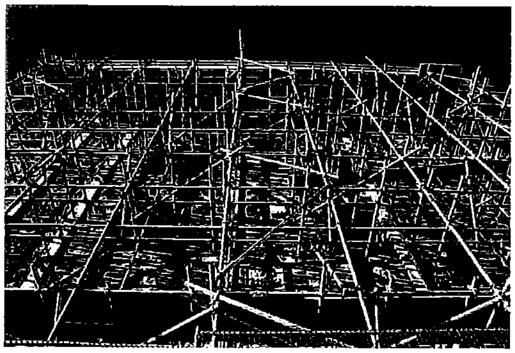


Figure 9-12 It is important for fire fighters to understand the history of the structures within their responding districts. What changes have been made over the years?

servation

Old buildings may be preserved for a number of reasons. They may have undeniably historic value, such as Independence Hall in Philadelphia, or they may be a part of our architectural heritage. They may be preserved to rehabilitate a specific neighborhood or a developer may fix up an old building to create an attractive apartment, shop, or office rental space.

In such projects, it sometimes seems as if the fire safety of the occupants has a lower priority than the preservation of the original structure. In any case, it is important to remember that fire fighter safety is left up to the fire department—in short, you are on your own.

The call for preservation of older multiple-unit dwellings from the 1800s in some urban areas has led to an unusual situation. The walls of these structures, typically brick, are retained while the entire core of the building, including floors, is gutted. The wood joist floors are replaced with lightweight steel joists in some areas, while others are retrofitted with lightweight wood trusses and lightweight wooden I-beams. It is critical that fire fighters take note of such changes and plan accordingly.

Branniganism

There is no magic formula for preventing or combating a fire in a historic vacant building. First, you should have an aggressive code enforcement division. Its goal should be to prevent a fire and work with preservationists to ensure that as many precautions as necessary are taken to reduce the threat.

The Owner's Rights

The right to own a building and to maintain it as one pleases is a fundamental right anchored in the U.S. legal system. Some laws have whittled away at this right, albeit rarely without legal challenge. Often only in the presence of clear evidence of existing public danger will the courts order an owner to repair or demolish a property.

It is certainly not a commonly held belief that the potential collapse of a building in the event of a fire is adequate grounds to infringe on the owner's rights. The fire department is left, then, with the duty of examining buildings for possible collapse and adjusting fire suppression tactics accordingly.

In addition to neglect of maintenance, alterations—with or without building permits—may prove just as deadly for fire fighters. A 2005 Bronx, New York, fire in an apartment building led to the deaths of two fire fighters and severely injured four other fire fighters when they all had to leap out of windows 50 feet (15.2 m) above the ground. Occupants on the top floor of the multiple-unit dwelling had illegally installed partitions in the unit, blocking the fire fighters' escape when the apartment flashed over. A New York State Supreme Court justice overturned a criminal conviction of the owners—the justice ruled that the prosecutors did not prove that the owners knew the partitions had been installed and, therefore, the owners could not be held accountable for the fire fighters' deaths.

Fire Resistance

The line between ordinary construction and early **fireproof** construction is not clear-cut because building development is evolutionary. Many of the hazards of early fireproof buildings can be found in ordinary construction. Unsupported marble stairs are a good example.

Portions of an ordinary construction building may have some degree of fire resistance, either initially or as a result of legal action. Some examples include installing a properly enclosed, fire-rated stairway in an old school or providing a fire-rated barrier around a special hazard such as a boiler room. Rarely does this piecemeal provision of fire-resistive features alter the fundamental nature of the building, however.

In some codes, **concrete topping** was required over first-floor wood floors for fire resistance or to provide a sanitary floor. This layer represents additional dead weight and may confuse fire fighters as to the true nature of the floor. It may also conceal the heat below. Concrete topping on the floor was a factor in at least two building collapses that led to multiple fire fighter fatalities.

Some additions or modifications may be truly fire resistive, particularly in public buildings. It is a principle of most building codes that the fire-resistive and non-fire-resistive portions of a building should be adequately separated. Unfortunately, there are a number of cases where this principle was not carried out.

Recent Construction

Many buildings constructed in recent years have departed from simple ordinary construction, though their development does not necessarily represent an improvement. In modern construction, a noncombustible void can accumulate explosive carbon monoxide gas as readily as a combustible void. A noncombustible void can contain combustible wiring and thermal insulation.

In addition, the use of solid sawn wood joists in earlier buildings of ordinary construction has been replaced by the use of lightweight wood trusses and wooden I-beams in new buildings of ordinary construction. This presents not only the problem of fire spread in the void spaces of these new buildings, but also the possibility of larger accumulations of explosive carbon monoxide. Many new strip malls and small business occupancies are constructed of lightweight wooden members.

Buildings of ordinary construction often use large amounts of wood "flourishes." In early 1991, a Los Angeles County, California, fire fighter suffered fatal injuries when a wooden façade collapsed. The use of wood truss roofs, wooden cornices, canopies, "colonial" belfries, combustible interior wall and ceiling finishes, and even wood veneer over masonry leaves few truly noncombustible commercial or institutional buildings.

The desire for wider spans and the availability of construction cranes have led to the widespread use of unprotected steel for roof framing. One office building is a case in point. The floors are of bar-joist construction with left-in-place corrugated metal forms and concrete topping. The ceilings are of lay-in tile. A casual inspection might indicate that the building is of fire-resistive construction, using floor and ceiling bar-joist assemblies. In fact, the building is of ordinary construction. It did not need to be fire resistive because the code does not require a fire-resistive building. The steel framing of the roof is unprotected steel. The roof itself is plywood. The ridge beam runs the length of the units. Given a fire in the wooden roof, enough heat would be generated to elongate the beam and push out the brick gable ends of the building.

In another building, steel beams run end to end through two openings in the fire walls, on which they are supported. The roof is plywood on wood trusses. The elongating steel would push down the end gables and might pull down the fire walls.

General Problems of Ordinary Construction

The problems presented to the fire department by ordinary construction can be divided into the following areas:

- The structural stability of the masonry wall
- The stability of the interior column, girder, and beam system
- Void spaces
- The masonry wall as a barrier to fire extension

These are not hard-and-fast divisions—they are all interrelated. An exterior collapse *will* usually cause an interior collapse. Conversely, the elongation of steel beams or an interior collapse may cause the walls to come down. A carbon monoxide explosion in a void space can demolish a building. A minor failure of an exterior wall may permit fire to extend to another building.

Discovery of Hazard

Many fire texts cite indications of building failure that may be observed on the fireground. Typical indicators include smoke or water flowing through walls, soft floors, a small partial collapse, walls out of plumb, and time since arrival on the scene. Although these are all good indicators, sometimes they are insufficient or, tragically, appear too late.

Early in Frank Brannigan's study of this subject, two books were noted as key texts: *Construction Failures* and *Building Failures*. Both of these excellent texts cover similar ground. The authors were consulting engineers who were often retained after a collapse to determine the cause of the failure. If an investigation after the fact could determine that the clues to impending disaster were evident before the disaster, perhaps the fire service could examine buildings beforehand and determine whether a particular building was likely to fail in a fire. These authors helped to move the consideration of fire-caused building collapse from anecdotal experience to analysis.

Many of the ordinary constructed buildings in a typical city were built before present members of fire departments were even born. There is still ample opportunity to study such buildings ahead of the time of fire and establish preplanned tactics to minimize the risk from collapse. Unfortunately, too many fire reports indicate that the fire fighters were completely unaware of situations that presented serious fire suppression and collapse problems.

In this text, many clues to potentials for disaster are given. The list of such signs could, of course, be almost endless. Use these examples as a guide to help you estimate hazards in buildings where your department must fight fire.

Some of the clues are evident from the street; others require detailed examination, which may not always be possible. In any event, be aware that an ordinary construction building, however sturdy and well maintained, was built without any thought as to what would happen to the building in the event of fire. By code definition, such buildings are non-fire resistive; they have no designed resistance to collapse in a fire.

Problems with Types of Walls and Wall Components in Ordinary Construction

Hollow or Cavity Walls

Hollow and cavity walls limit penetration by rain. Although there are no recorded cases, it is possible that carbon monoxide from a fire could accumulate in the hollow space or cavity and explode with disastrous results.

In one case, gas from a leaking main outside a building found its way into the hollow of a cinder block wall in a Florida supermarket. When filtered by seeping through the ground, natural gas can lose its artificial odorant (an additive to the otherwise odorless gas). Unaware of the gas, an employee of the Florida supermarket flicked his lighter and the gas exploded.

It is an accepted practice to place sheet or foamed-in-place plastic insulation in hollow walls. These plastics have various ignition characteristics. Burning plastic produces large quantities of smoke. If the source of smoke cannot be found, it would be wise to check for plastic insulation in the walls.

Hollow walls built of hollow terra-cotta tile present a special hazard. Originally the exterior and interior wythes were connected with steel ties. The tile industry has developed special tiles that can be used to connect the wythes. If either wythe starts to move, a tensile load is placed on a clay tile that has no tensile strength.

Composite Walls

Masonry walls were, for centuries, built only of bricks. In recent years, the composite wall—once incorporating hollow tile, now using concrete block—has been developed. Recall that both composite wall elements must react together under a load. When composite walls were first developed, bonding the wall together was accomplished by inserting brick headers and stretchers according to various design practices.

Uneven settlement between the brick and the block has caused header bricks to crack. Consequently, the **masonry wire truss** was developed. This wire truss is embedded into the mortar in specified courses. As a result, the header course is no longer necessary, and the appearance of a masonry bearing wall may be no different than that of a **veneer wall** of all stretchers. In some veneer walls, bats or half bricks were inserted to give the appearance of a bonded wall. Thus, it is often impossible to tell a bearing wall from a veneer wall by external appearance alone. Moreover, not all brick-and-block walls are composite. Brick may be veneered onto concrete block or cast concrete using the same ties that are used in brick veneer-on-wood construction.

Cast Iron

An intermediate step in the development of cast-iron-front buildings was the use of cast-iron columns and wrought- or cast-iron arches or lintels at the street floor level carrying masonry above the first floor. This architecture enables the builder to provide larger show windows or entranceways than would have been possible with masonry.

The small area of a masonry wall available for windows led to the acceptance of walls made of prefabricated cast-iron sections. Usually a unit was cast integrally in two sections. These sections were then bolted together at the crown to form the arch. There are few buildings with cast-iron fronts left, and the demolition of one today is regarded as an act of barbarism in some circles.

Over time, the cast-iron front may separate from the masonry side walls. Some walls are tacked onto the masonry with steel straps. The columns, like interior cast-iron columns, may transmit fire vertically.

Lintels

Arches and beams are the two ways to carry the wall above an opening. Such a beam is called a lintel. The lintel commonly used today is a steel "L" or channel section. When such sections were first used, the practice was to arrange the bricks above the lintel as a false flat arch. Later, the pretense of an arch was abandoned and the bricks above the window were set vertically. Today, the common practice is to carry the brickwork horizontally across the lintel. Steel lintels are tied tightly into the masonry wall. When heated, they elongate and the masonry can fail. Combustible wood lintels are also sometimes used Figure 9-13.

Figure 9-13 Wooden lintels used in masonry walls will have an early failure potential.

Imitation Brick

Some imitation brick is made by spreading a coat of gray concrete on lath. A coat of red concrete is then applied. The red concrete is cut away to expose the gray concrete in horizontal and vertical lines to simulate mortar joints.

Another method is to cement thin slices of brick onto panels of gypsum board. These layers are then mounted on a steel frame and joined together to give the appearance of a brick wall. Several bank branches have been built using this method. Imitation masonry is also created by applying a thin coat of concrete over blocks of cast foamed plastic. The exteriors of many of the buildings at Universal Studios in Orlando, Florida, are constructed in this way.

Structural Stability of Exterior Masonry Walls

Traditional fire service training on the subject of falling walls provides little real guidance in actual incidents. Although some trainers speak wisely of walls falling a fraction of their height, bricks can fly in all directions and great distances. If a single brick gets you, the fate of the rest of the wall is immaterial **Figure 9-14**.

Figure 9-14 Most fire service references will direct that a collapse zone should be set up at 1.5 times the height of the structure. When a brick wall fails and collapses, the bricks can injure fire fighters at much greater distances as seen resulting from this gas explosion.

General Collapse Indicators

Is it probable that a masonry wall will collapse during a fire? Some do; many do not. No study has been conducted to determine if there is a common pattern in fire collapses. There are, however, certain general indicators of probable collapse, some of which can be observed beforehand and noted in a prefire plan. Other indicators may be observed during a fire.

Collapse may be due to a variety of causes:

- Inherent structural instability, aggravated by the fire
- Failure of a nonmasonry-supporting element upon which some portion of the masonry depends
- Increase in the live load due to firefighting operations, specifically retained water
- Collapse of a floor or roof with consequent impact load to the masonry wall
- Impact load of an explosion
- Collapse of a masonry unit due to overheating
- Collapse of another building onto the building in question

Specific Factors That Can Lead to Collapse

Some of the signs of potential collapse are derived from building elements and materials. These can be observed prior to a fire and should be noted in the prefire plan.

Bricks and Mortar

Bricks have a reputation for toughness and permanence that can be misleading. When properly made, they can be a tough and long-lasting building material. However, poorly made bricks can deteriorate readily. Poorly made bricks absorb moisture and can fail due to freezing. Poor-quality brickwork is not uncommon.

Look for signs of poor brickwork in buildings. At times, brick defects are covered with parging (sometimes pargetting). This parging may be scored to look like brick. The parging itself may be falling off—often an indicator of poor brickwork.

Mortar that reacts chemically may "grow," forcing the masonry out of alignment. Parapet walls, which project above the roof line, are particularly subject to weather deterioration. Many such walls, as well as some chimney tops, consist of bricks held in place by gravity, with nonadhering mortar simply acting as a shim that is used to wedge a component into position.

As has been noted, the use of sand-lime mortar creates a potential failure hazard because it is water soluble Figure 9-15. Suspect any building built in the last century or early in this century of containing this type of mortar. To get rehabilitation tax credits, sand-lime mortar must be used to repair old sand-lime mortar buildings. Consequently, even currently restored buildings should be suspect. If a wall is torn down, look at the bricks. If they are clean with little mortar clinging, sand-lime mortar was used.

A number of nonfire collapses have occurred when water leaks washed out sand-lime mortar. The old Broadway Central Hotel in New York and the Empire Apartments in Washington, D.C., collapsed because of water leaks that washed out sand-lime mortar. A probationary fire fighter noted and reported the washout of sand-lime mortar at one of these fires. The building was cleared and it collapsed shortly thereafter.

Figure 9-15 Fire fighters directing streams onto a fire situation can wash this mortar out of the walls, causing the wall to fail and collapse.

Wood Beams

Wooden beams carry an amazing load. The destruction of the wood in a fire, in turn, may cause the failure of the otherwise impressive structure. This type of deadly construction is not apparent from the exterior, but can be detected only through competent prefire evaluations focusing on collapse potential. The practice of using wooden lintels in the interior portions of masonry walls, while showing substantial masonry arches on the exterior, is centuries old.

In a number of European buildings, heavy masonry walls are carried over openings on wooden beams. This technique is cheaper and faster than building full arches. The craftsmen who knew this technique immigrated to the United States and taught it widely; thus it has been seen across the country. Look closely at masonry buildings. Check the basement and the attic where the walls are exposed. Determine whether the wall over the openings for doors and windows is carried on masonry arches or on wood. If it is on wood, expect early failure. Stone barns have had fatal collapses resulting from fires attacking wooden lintels.

Cracks

Cracks, even if patched, indicate weakness in the wall that may be due to inadequate foundations. If there is a thrust against one part of the wall, the rest of the wall may not resist the thrust Figure 9-16.

A horizontal crack may indicate that the wall is being pushed out by steel roof beams that are elongating in summer heat. When the same beams contract in winter, the wall may be left out of plumb and the beams may have little bearing. This happened in the Knickerbocker Theater in Washington, D.C., in 1922. Steel trusses had elongated and contracted repeatedly over the years, pushing the hollow tile walls out of plumb. On a cold winter night, the trusses, then at minimum length, were bearing on very little of the wall. A 22-inch (55.9 cm) snowfall brought down the wall. Almost 100 people died.

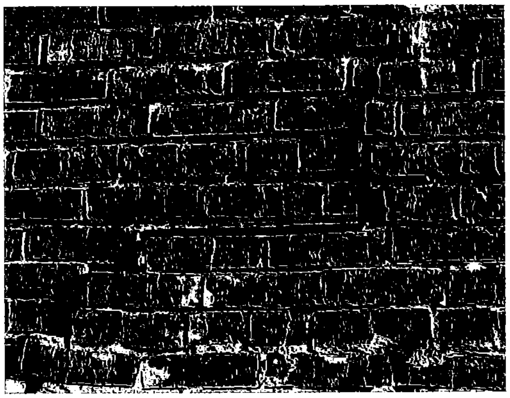


Figure 9-16 Any crack, no matter the size or if it has been patched, will prove to be a weakness in the wall.

Arches

A brick or stone may fall out of an arch. If any arch unit (vousoir) is out, there is no arch. The window or door frame then becomes an undesigned structural post and beam. Any added or shifting weight will cause the masonry to collapse.

Wall Weaknesses

All walls are inherently unstable. One stabilizing method uses intersecting or cross walls. Typically, the front and side walls are designed to brace one another. Often the walls are made of different materials, such as brick and stone or different types of brick, which expand and contract at different rates. Look at the wall joints; in many cases, the separation is readily apparent. Other ways to stabilize a wall include the use of the following:

- Buttresses or masses of masonry outside the wall
- Pilasters or columns built inside the wall
- Wall columns, built within the wall

In a concrete block wall, the wall columns may lid concrete blocks, concrete bricks, regular clay bricks, cast-in-place reinforced concrete, or steel. Often sizable holes are cut through walls. Until a proper lintel is installed, this gap represents a serious weakness in the wall. This often happens when building owners wish to create a usable space that spans two buildings or create a passageway between two basements to enlarge a storage area. Such an expansion in Manhattan in the 1980s led to the collapse of an entire building of ordinary construction on 9th Avenue.

Any construction work to create additional openings (e.g., windows, doors, walkways) should be done under the supervision of a structural engineer. Fire fighters are also warned to be especially careful when breaching brick walls (or any load-bearing wall for that matter) during firefighting and rescue activities for the same reason.

Steel Lintels

Steel lintels have been used for years without any protection for the steel. In recent years, there has been a great increase in fire loads and the rate of heat release of contents, due principally to plastics. Steel lintels have deformed and thrown bricks off the wall.

Reinforced-concrete lintels are commonly used in masonry walls. Because the building is not required to be fire resistive, the concrete is not required to be fire resistive. The bottom concrete may spall off, exposing the reinforcing rods, which provide the tensile strength to the composite structure, causing the lintel to fail. It is a common myth that concrete is inherently fire resistive. Concrete is inherently noncombustible. It can be formulated to be fire resistive.

Bracing

Braced walls are another basic sign that a wall is in distress Figure 9-17. (Their presence is signaled by stars, plates, channel sections, or other spreaders, or straps tying the front wall to the side wall.) The walls may be tied together across the building or tied to floor beams. Braces made of unprotected structural steel, or worse yet, of steel cable (complete failure at 800°F [427°C]) will fail at fire temperatures.

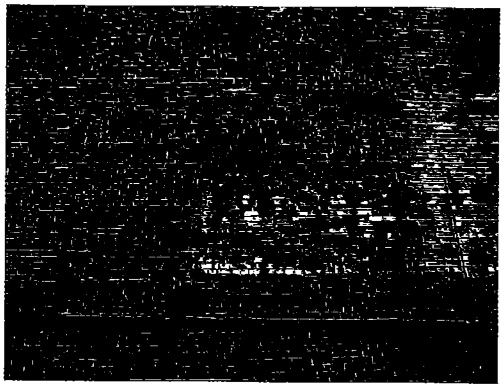


Figure 9-17 These ornamental stars should alert fire fighters to the instability of this wall. The cable itself has been proven to completely fail at 800°F (427°C).

Wooden walls are tied together in a similar manner. Failure of a steel tie caused the 1975 collapse of a wooden church wall that cost a Paterson, New Jersey, fire captain his life.

Braces are not always an indication of instability. Some buildings have walls that were tied to the floors to make the structure more rigid. Generally these can be identified by spreaders in a regular pattern.

In California and other earthquake-prone areas, bracing may be used either initially or as a retrofit to upgrade the earthquake resistance of unreinforced masonry walls. In this case, fire-caused failure of the steel may cause failure of the structure.

Eccentric Loads

Some walls carry an eccentric load, such as from a projecting sign Figure 9-18. This load must be counterbalanced, usually by tying the wall to the interior structure. A large abandoned garage with masonry walls and a wood truss roof had a projecting sign; the wall was tied to the roof trusses. The trusses and the roof burned. There were no contents. When the trusses weakened, the sign pulled the wall down, injuring 17 fire fighters. There was no anticipation of collapse.

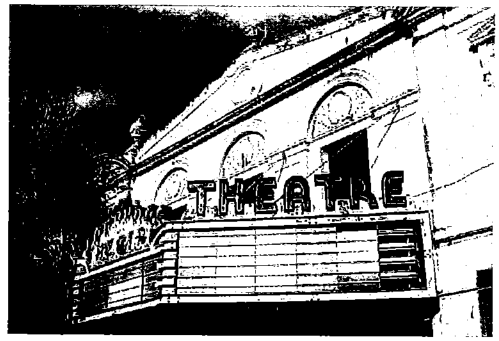


Figure 9-18 Eccentric loads like this one must be properly braced or the weight of the sign can pull the entire wall down.

Cantilevered beams can also project from a wall to form balconies. When confronted with a cantilever, the key question is, "What is happening to the other end?" Three New Orleans fire fighters died when a balcony collapsed and pulled down the wall. Cantilevered canopies and balconies are very common. Those supported on trusses or wooden I-beams are particularly dangerous.

Suspended beams that form canopies are quite common. They are secured by tie rods connected to the interior structure. If the connection fails, the canopy becomes an undesigned cantilever. As it falls, it will bring the wall down with it. Pictures of such a collapse in Long Beach, New York, show the parapet wall also being pulled down for about 50 feet (15.2 m). The collapse zone is not merely at the canopy, but the entire front of the structure. With suspended beams, the key question is, "What are the suspension rods tied to?"

The canopy support rods of a Washington, D.C., theater were tied to the roof trusses, and a multi-alarm fire occurred in the roof void of the building. Alert fire officers noted that the top of the front wall had been pulled out just short of the collapse point and cleared the area.

An Alabama overhanging façade attached to an auto body shop collapsed during a 2002 fire, killing a fire captain who was standing directly underneath it.

The subsequent investigation determined that the load imposed by the façade—which was composed of plywood, 2 × 4's, and asphalt shingles—had caused cracks in an underlying parapet wall, necessitating the use of steel rods attached to the building's roof to stabilize it laterally. When the roof collapsed, the parapet and façade fell as well.

Unvented Voids

Carbon monoxide gas trapped in unvented voids can detonate violently and blow down walls. In one incident, fire fighters were battling a blaze in an abandoned icehouse. Carbon monoxide accumulated in a 9-foot (2.7-m) cockloft and exploded, bringing down the rear wall. Thirty-nine people watching the fire from an apartment house died when the wall fell on the apartment house. A small boy who was saved from the rubble grew up to become a fire fighter.

Masonry walls are not designed to resist lateral impact loads. Consequently, explosions have blown down many masonry walls. In one fire, an explosion of coal dust blew down the five-story masonry curtain wall of a steel-framed building. Brick or masonry walls that separate one electrical transformer from another are often specially reinforced to resist lateral impact.

Planes of Weakness

It is difficult to get floor beams level in masonry buildings due to masonry irregularities. A simple method is used to solve this problem across the country, in buildings as much as 200 years old. A wooden beam is laid in the brick wall at the line of the bottom of the floor beams. The floor beams are then set on the wooden beam. This produces a level floor without shimming. The hidden danger occurs when the wood burns out and a plane of weakness (like the scoring to cut glass or gypsum board) is created in the wall. Even a modest lateral thrust may be enough to break the wall along the plane of weakness.

In one building, a horizontal plane of weakness was noted in a two-story wall under construction. A slot was left in the wall to accommodate a concrete floor yet to be poured. When the floor was poured, if the concrete was not worked well into the gap, a hidden weakness would be left in the wall. Such a weakness may cause a collapse. This weakness will give no warning during a fire.

It is possible to put a vertical plane of weakness into a building by cutting a chase into a wall. A chase is a passageway, usually vertical, cut into a masonry wall for a pipe or conduit. Close examination of the rear wall of an old building in Toronto disclosed an unusually weakened wall. The roof downspouts of the building were often damaged by trucks moving through the alley. A chase had been cut vertically down each end of the face of the wall, from the ceiling to grade. The downspouts were set into these chases, keeping them protected from exposure to damage. When chases are built into a wall during the initial construction process, they may represent a weakness, but at least the joints can be properly laid to forestall disintegration. In contrast, a chase cut into an existing wall presents a serious weakness. Downspouts that need protection from vehicles should not be recessed into a wall, but rather should be protected by masonry or cast iron.

In 1973, the Broadway Central Hotel in New York City collapsed. The investigation disclosed that 30 years earlier an unauthorized chase had been cut into the wall for a drain. The drain leaked water that washed out the sand-lime mortar. Without being able to cite any such experience, Frank Brannigan warned of this potential in the first edition of this text—two years before the collapse. This is just one example of how fire officers can identify a hazard by analysis, not experience.

Effects of Interior Structural Elements and Building Contents on Exterior Walls

The interior structure of a building may push down a wall in several ways. Wooden floor beams fitted tightly into the wall may act as a series of levers on the wall; when they collapse, they will pull the wall down. The usual solution is the "fire cut," in which the end of the beam is cut at an angle so the beam can fall out of the wall. This may save the wall but weakens the beam because there is less wood to burn. Floor beams are placed with an upward camber or rise, but over the years they may sag. To restore the upward camber, the fire-cut beams are sometimes turned upside down. This often results in a very small bearing surface of the beam on the wall.

In some areas, the beams are not set into the wall, but rather sit on a masonry ledge, corbelled out from the wall. In heavy timber construction, a cast-iron beam box may be inserted into the wall. The beam end is inserted into the box. If it falls out, there is no problem with the wall.

Appearances can be deceiving. The heavy masonry walls of a Montréal church were supported on an unprotected steel grillage of three I-beams bolted together. This grillage was supported by unprotected steel columns that extended down into the crawl space. Steel columns inserted into the wall rested on the grillage and supported the roof trusses. Thus, the wall was not actually a bearing wall, but rather a curtain wall. Nothing of this construction was evident. The wall appeared to be a typical solid masonry wall. When fire in the crawl space caused the steel columns to fail and drop the wall, two fire fighters died. Be careful of potentially fatal assumptions made on the fireground.

Effects of Fire Streams on Brick Walls

Some fire texts advance the concept that wall collapse is caused by cold water hitting a hot wall, causing unequal expansion. This hypothesis is suspect. Too many brick walls have been heated to high temperatures, struck by heavy cold streams, and survived. It is likely that that the factors mentioned previously—particularly the never-cited wooden components—are probably far more significant.

However, fire streams can damage brick walls. Older brick buildings have an exterior veneer like the surface of finish brick. A heavy stream can penetrate the veneer and strip it off the wall, sending deadly missiles in all directions. Heavy streams can rip loosened bricks, as from a deteriorated parapet. Very heavy streams, such as from fireboats, can smash through a brick wall.

Interior Structural Stability

In this text, interior and exterior collapses are discussed separately, although they are interrelated. An interior collapse of an overloaded floor can cause the walls to collapse. The collapse of an exterior wall into the structure or onto the adjacent structure may cause an interior collapse. The interior structure consists of floors, any necessary interior support for the floors, any suspended loads, and the roof.

Historically, consideration of interior structures assumed collapse in case of fire. Questions arose as to whether to design connections to permit easy collapse of girders (with self-releasing floors) to prevent collapse of columns or to design easy collapse of floors to prevent collapse of walls with fire-cut joists. The opposite point of view called for tying the building together tightly and disregarding the concept of releasing the floors in case of fire.

Fire-Resistive Combustible Assemblies

In recent years, combustible floor and wall assemblies of wood and gypsum board have been developed that can achieve fire resistance ratings in standard fire tests conducted in accordance with the American Society for Testing and Materials (ASTM) E-119, *Standard Test Methods for Fire Tests of Building Construction and Materials*. They are used to produce code-classified protected combustible structures.

Interior Structural Support Systems of Columns, Beams, and Girders

The list of inherent defects of interior supports is endless. Those that are most important to fire fighters, however, are found in the structures for which you are responsible. Observe, study, and ask questions.

In older masonry buildings, the interior walls, if not of masonry, are of balloon-frame construction. Balloon-frame wall-carrying interior loads may fail very early due to the small cross-sectional area of the studs. Masonry walls are usually much thicker than wooden walls. Brick and stone interior walls can also have all the defects of exterior walls except perhaps weathering. Stone walls and interior walls also may lose their strength due to spalling during a fire.

Adjustable steel jack posts or simple steel posts may be used to support overloaded beams. They are vulnerable to early failure. Interior merchandise racks in retail stores are often of very lightweight steel construction, and subject to early collapse.

Amateur builders often use water pipe for columns and beams, porches, and canopies. This is dangerous. Water pipe is designed for internal pressure. The metal removed to cut threads is replaced by the heavy collar around the fitting. As a structure, this connection is weak because metal has been removed where the shear load is greatest.

Interior masonry bearing walls may stand in the way of projected improvements, such as combining several rooms. If an opening is made in the wall, or if the wall is entirely removed, this arrangement will have much less stability and less inherent fire collapse resistance than the original brick wall.

Such alterations were major factors in the Washington, D.C., Empire Apartments collapse and the Vendome Hotel collapse in Boston Figure 9-19. A beam and cast-iron column unconnected to the beam were often used in these structures. In the remodeling of the Vendome Hotel in Boston, an air-duct opening was cut through the wall directly below a cast-iron column that supported a brick wall. Nine fire fighters were killed in the collapse in June 1972. In the Empire Apartments, the wall above an opening was supported on a beam cut into the old sand-lime masonry wall. Leaking water washed out the mortar, and the structure collapsed several fatalities.

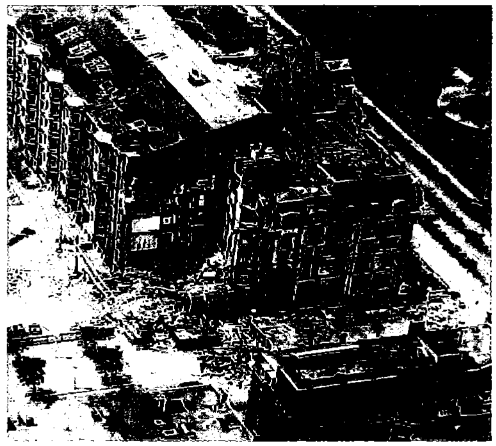


Figure 9-19 The Vendome Hotel collapse in Boston, MA.

Deficiencies of Materials

Structures originally built with heavy timber columns, girders, and beams are found reinforced with added steel in a variety of ways. In such cases, the failure of the steel may precipitate collapse. Assume that any structural support that was added after the building was built was added because it was absolutely necessary.

The addition of unprotected steel to a building with a wooden interior structure is sometimes apparent, but is often fully concealed. In one case, steel bar joists had been installed between each pair of wood joists to strengthen a building. This arrangement did not become apparent until the building's demolition. Many newly built ordinary construction buildings have some unprotected steel structural members.

In structures, wood beams may have been trussed initially or at a later date. This is usually accomplished by erecting a strut downward from the center of the beam and stretching tension rods from one end of the beam to the other, over the strut. The strut or the rods may fail first. This technique has been used where heavy loads are on the floor above, or where equipment such as belt drive shafts were suspended from the overhead, or to transfer a load formerly carried on a column.

A tea shop is located on the first floor of a commercial building in Chester, England. To clear the dining area of columns, wooden trusses were erected at the ceiling level to support the floors above. To the untrained eye, they appear to be decorations. A heavy fire in the dining area, however, might precipitate the collapse of the entire structure.

Connections in Ordinary Construction

Beam-to-Girder Connections

The only way to connect wood beams to wood girders and receive the full benefit of the time it takes the wood to burn through is to set the beams atop the girder. However, this is undesirable because it adds height to the walls. All sorts of systems were designed so that the top of the beam could be level with the top of the girder.

Old-time craftsmen are proud of their mortise and tenon joints. In such a joint, the beam was cut down from the top and up from the bottom to form a tenon or tongue. This was inserted through a mortise cut into the girder. A wooden dowel, or trunnel, was driven through a hole bored in the protruding end of the tenon. Another method of connection used notched beams on strips nailed to the side of girders.

The weakness of any method that reduces the size of the wood is readily apparent. The effective strength of the wood under fire attack is determined by the size of the thinnest portion, not the mass of the member as a whole.

Beam-to-Beam Connections

Beam-to-beam connections must be made whenever an opening is provided in a wooden floor. The joists that are cut to provide the opening, and thus do not reach to the girder or bearing wall, are connected to a header beam, which in turn is connected to trimmers. These connections are accomplished in various ways. Mortise and tenon joints are found in older buildings. Notched beams are also common. Metal **joist hangers** or stirrups and heavy steel or wrought iron straps shaped to receive the joist and nailed to the top of the header are used. Tests made years ago showed that such stirrups are dangerous, charring the joist and softening rapidly (Figure 9-20). More recently, very lightweight hangers have been developed for lightweight construction. The rapidity with which such hangers may fail in a fire is an important factor. The small mass of metal and the dependence upon nails do not inspire confidence.

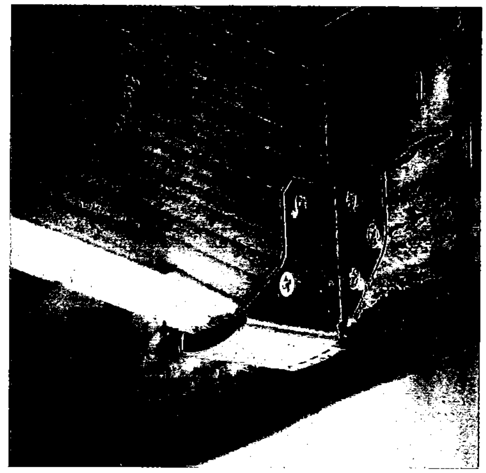


Figure 9-20 Joist hangers are points of weakness.

Beam-to-Column Connections

Buildings of ordinary construction present many options for connecting girders to columns. Self-releasing floors can be seen in most old interior mercantile buildings. The girder sits on a steel shelf that protrudes from the column. A scrap of wood or a **dog iron**, like a big staple, connects the girders and imparts some lateral stability under normal conditions. Although self-releasing floors may limit the collapse area, any system that is designed to precipitate collapse must be weaker and more likely to collapse. In any event, many of the buildings fire fighters must cope with are "vernacular" buildings, designed without benefit of professional engineers.

The principle that columns should set directly atop one another to carry loads to the ground as axially as possible has been widely violated. Where a column is offset, the girder on which it rests becomes a transfer beam and is subject to severe shear stresses unless it was designed as a transfer beam. Improperly loaded structural components are more likely to fail than similar components properly loaded.

Cast-Iron Columns

Cast-iron columns create many problems. Good practice dictated that the column be topped by a **pintle**, a solid iron pin of much smaller diameter than the column. The pintle passed through the gi-der, surrounded by wood, and then enlarged to the full width of the column above.

Pintles are often used to connect wooden columns end to end. In practice, the column passes through the girder at its full width. The ends of the girders are cut in a semicircle to make room for the column. Thus, a relatively small amount of wood rests on the cast flat shelf that extends from the top of the column. The loss of this wood or the softening of the cast-iron shelf could cause the initial collapse of the column.

Over the years, failures of cast-iron columns have been blamed for many serious collapses. It is true that cast-iron columns can fail, particularly if they are poorly cast so that the material is thin at one point. After looking at a number of buildings with cast-iron columns, it appears likely that the chief cause of their failure is the unsafe connections, rather than the questionable "cold water on red-hot cast iron" theory (although this is still a possibility). Often the cast-iron column is held in place only by gravity, so that the slightest lateral movement can cause it to kick out.

Interior Suspended Loads

Balconies, **mezzanines**, half stories, and other susp-ded loads, including merchandise racks, are very h lous (Figure 9-21). Suspended loads are becoming

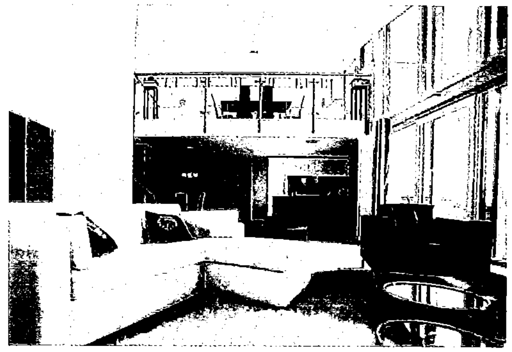


Figure 9-21 Often constructed directly above the ground floor and projecting as a balcony, these overhangs can become obscured by smoke and trap heat.

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more common as architects realize the space advantages of suspension over columns. In a fire, the loads in such structures may be obscured by smoke, and the suspension system may be subjected to temperatures hundreds of degrees higher than at floor level.

One grocery market was converted to a Japanese-type restaurant in which the guests sit around a grill where the chef performs as the food is prepared and cooked. Such a restaurant requires a heavy steel exhaust hood for each table. The hoods were suspended from the roof. Because of the added dead load, this roof is not the same working platform for fire fighters that it was when its only purpose was to keep the rain off the groceries.

Architects are realizing more and more the utility of hanging loads from the overhead. Interior designers are also prone to hanging heavy loads from the overhead. The overhead may be the floor above or the roof. For example, a supermarket designer wanted to have suspended shingled canopies over the checkout stands. In the resulting structure, the ends of steel rods are held by two 2×4s that extend across the bottom chords of bar joists. A fire overhead could either burn the wood away, letting the washer slip through, or cause the restrained bar joist to elongate or twist, dropping the canopy.

Another grocery supermarket was housed in an otherwise noncombustible building with a gypsum plank roof. The meat cutting area was in the rear of the structure. The health department required a washable gypsum ceiling rather than lay-in tiles. A substantial wooden structure was hung from the roof bar joists to support the gypsum board. The wood structure also supported the refrigeration units. An electrical fire occurred in the ceiling void. When a truck company was overhauling the completely extinguished structure, the company members were literally pulling the building down on themselves. Directing their attention to the hazard, Frank Brannigan asked the officer to back the fire fighters up and to have one fire fighter gingerly break away the gypsum board so he could get a picture of the poor-quality support. As the fire fighter touched the gypsum board, the entire refrigeration unit fell down.

Floors

Often, old buildings of ordinary construction housing a mercantile occupancy had open stairwells to permit unimpeded access for shoppers to move from floor to floor, including the basement. Of course, this allows fire to also travel unimpeded up through the building. In one case, heavy fire loading took the form of foam mattresses that were stacked to the basement ceiling.

When a stairway is actually relocated, the old opening is usually covered over. The closure is usually much lighter than the floor. In one observed case, 2×4s were used, whereas the floor was made of 3×10s. From above, the floor looks uniform. Such an opening has figured in at least one serious collapse.

In some store alterations, the upper floors are abandoned. The stairway is removed to provide ground-floor room. Often, a single sheet of metal is placed over the opening. A Washington, D.C., fire fighter died when he fell through a patch of sheet metal over an old opening.

A **light well** is a vertical shaft with windows that provides light and ventilation to enclosed rooms. A light well in an old **tenement** building was floored over. The new flooring was very light and collapsed under the applied load.

In past years, floors were made of subflooring and a finished floor. In more recent construction, floors are often a single thickness of plywood and carpeting. These floors are much more quickly consumed by fire.

Floor collapse can occur early in the fire. A National Fire Academy executive, Dr. Burton Clark, was a member of a local fire company and responded with the first unit to a townhouse fire. He made a primary search of the second floor on his hands and knees, testing the floor as he went. He went through the floor into a void below. Fortunately, the active fire had moved to another area.

Roofs

Fire departments are concerned about equipment such as ropes, aerial ladders, and aerial platforms because equipment failure can cost lives. Specifications are tightly written and acceptance and in-service tests are carefully monitored. However, there is one working platform fire fighters use that has cost many lives—the roof. One of the basic purposes of a roof is to keep out the rain and enclose the structure. A secondary purpose is to stabilize the walls. A roof is not designed or constructed as a fire department working platform. Generally, fire suppression tactics assume the stability of the roof until there is warning of collapse. In fact, there are a few warning signs, but they are often too little and too late.

Fire Characteristics of Conventional Wood Roofs

The discussion that follows chiefly concerns roofs supported on solid sawn rafters and beams. Metal deck roofs are discussed in the chapter that reviews noncombustible construction. The roofs of tilt slab concrete buildings are also discussed in the aforementioned chapter. The hazards of single-ply membrane roofs are discussed in the chapter that reviews concepts of construction.

The information identified in one prefire plan simply listed architectural roof types: flat, gable, hip, gambrel, shed, mansard, dome. Such information, although useful, is incomplete. Structural characteristics as well as the appearance of the roof must be known beforehand.

Solid sawn wood contains "fat"—wood not necessary to carry the imposed load. When only this part of the wood is burning, roof strength is not greatly affected. As it continues to burn, however, the beam gradually weakens, and the roof becomes spongy. This may or may not warn fire fighters to get off the roof in time to avoid disaster.

Roof Hazards

The best roof is one in which the roof beams rest on girders. Any sort of hangars or other metal connections make the roof more vulnerable to failure. In some localities, steel U channels have been used for rafters. The effect of elongation and failure should be evaluated.

Roofs apparently supported on heavy wood beams or laminated arches can be much less reliable than they appear. Long wooden beams are scarce. Apparent long beams are often several beams spliced together with metal connectors, which can heat up and burn out of the wood.

In a 90-year-old building being renovated in Orlando, Florida, the roof joists were exposed. The joists in the center section between the wood girders (any beam supporting other beams is a girder) were short and did not rest on the girders; instead, they were nailed to joists that overhung the girders. This use of such overhanging and drop-in beams is not uncommon. The nailed connections could fail very early in the fire and collapse the center section of the roof. Even if beams resist collapse, the roof boards may be burned away.

Energy conservation and rapid completion are two important considerations in today's buildings. Some roofs are made of large panels in which foamed plastic is sandwiched between sheets of plywood. Even if the plastic is inhibited to discourage combustion, it may melt away in a fire, allowing the roof panel to fall.

In an attempt to make use of natural light, corrugated glass fiber-reinforced plastic panels are made to the same dimensions as corrugated steel. A fire fighter could easily step through the plastic when visibility is poor. When exposed to fire, the plastic will burn away. The glass fiber matting, however, may stay in place and obstruct ventilation. In 2009, a Newark, New Jersey, battalion chief fell through such a panel during a nighttime fire, falling 22 feet (6.7 m) to the floor (Figure 9-22). The edge of the panel was flush with the corrugated steel panels, making it nearly impossible to distinguish it from the steel panels.

Ventilation tactics can accelerate collapse. Be aware that the impact of an axe may be the straw that breaks the camel's back. Some think that impact is avoided by the use of saws. Not so! There is no such thing as zero impact. A fire fighter stepping onto a roof as lightly as possible still imposes a momentary load on the roof at least twice his or her at-rest weight. Of course, cutting through structural load-carrying members can initiate collapse.

Excess live loads on roofs can accelerate collapse. In one case, three fire fighters ventilating a roof died in a collapse where there was heavy ice on the roof. When they opened the first hole, the roof beams were seen to be burning. This should have been a clear warning that much of the roof's normal resistance to

Figure 9-22 A Newark, New Jersey, battalion fire chief fell through a plastic skylight panel in this roof.

Courtesy of Frank Bellina.

collapse had already been expended. Unfortunately, they went on to open another hole.

Water trapped on a flat roof because of blocked drains has caused many collapses. Snow on a roof also has caused many collapses. Sometimes wind piles snow up in one area, causing a local concentrated load and resultant collapse.

Air-conditioners and similar equipment are often mounted on roofs. Sometimes grillage is added to the roof to support the additional load. If all the grillage is affected by the fire (as is usually the case), the extra support is ineffective in a fire. In some cases, equipment is erected on steel beams that are supported on exterior walls. This is a superior construction method, but the supporting beams should be watched for any signs of overheating and be cooled with hose streams if there is direct flame exposure.

Except for fire-resistive buildings, the roofs of buildings today have little or no inherent fire resistance to early failure. This even includes the roofs of noncombustible buildings. The typical non-fire-resistive roof today is usually supported on wooden I-beams, wood trusses, steel trusses, concrete T-beams, or in some cases, cored concrete slabs, which are susceptible to failure.

Second or even third roofs may be built over an original roof. At times, the reason is simply to improve the appearance of the building. A peaked roof is considered more attractive than a flat roof. Intractable leaky roofs are often overcome by adding an entirely new roof. A "rain roof"—covering a bowstring truss roof—was a factor in the deaths of six New York City fire fighters in a Brooklyn supermarket fire in 1978.

Lightweight Wood Truss Roofs

In 1991, a neon light started a fire in the gable end of a truss roof restaurant in Orange County, Florida. The staff and patrons of the restaurant were unaware of the fire. Patrons of a nearby restaurant gave the alarm. The first unit on the scene raised a ladder to the attic scuttle hole. The acting lieutenant noted that the fire was moving rapidly through the trusses, pushed by a high wind, so he ordered his unit out. The acting battalion chief ordered the building cleared. About 5 minutes later, a large section of the roof collapsed. Images of the restaurant show heavy equipment on the roof. There was a gypsum board ceiling on the bottom of the trusses, probably intended to protect the trusses for a few minutes from fire originating below. The ductwork was suspended below it, and a grid ceiling concealed the ductwork. This construction made the fire impervious to an interior attack.

In February 1999, three fire fighters were killed in the collapse of a lightweight wood truss church roof in Lake Worth, Texas. The collapse occurred only 10 minutes after the fire was reported. Fire fighters working on the roof, one of whom survived after falling completely through to the sanctuary below, reported that the roof deck felt firm just prior to the collapse. Heavy fire involvement of the trussloft led to extremely rapid failure of the trusses. The deadly lesson of this fire is this: working under or on a lightweight wood truss roof that is well involved in fire is extremely dangerous and must not be permitted.

Bowstring Truss Roofs

The bowstring truss gets its name from the curved shape of the top chord (Figure 9-23). Sometimes bowstring trusses are known as **arched trusses**. This can be confusing. The thrust of a truss is downward. In contrast, the thrust of an arch is outward, and usually resisted by a mass of masonry. Some arches are **tied arches** in which a steel tension rod ties the ends of the arch together to eliminate the need for the masonry. Early Arby's restaurants featured arched roofs; some of these arches were tied arches.

Bowstring truss roofs were very popular during the mid-20th century, having found their way into occupancies that desired open floor spaces like bowling alleys, supermarkets, and auto body repair shops. They have also been a killer of fire fighters, including the truss collapse during a 1988 fire in a Hackensack, New Jersey, Ford dealership. Five fire fighters lost their lives in this collapse, which originated in an unapproved auto parts storage area in

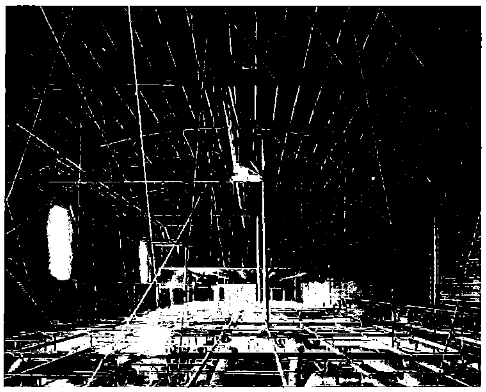

Figure 9-23 A bowstring truss roof.
Courtesy of David G. De Vries/Library of Congress.

th[illegible]ussloft. Although a major roof fire was evident t[illegible]e fighters on the roof, conditions just moments before the collapse indicated virtually no smoke in the auto repair bays below. The loss of these fire fighters led to New Jersey regulations that require placarding on buildings of truss construction.

It is important to note the observed conditions at this Hackensack fire and the fire in the abandoned Chicago laundromat described at the beginning of this chapter: there was little or no smoke visible at floor level while a fire was burning in the trusses above.

Treated Plywood Roofs

Treated plywood has been proposed as a fire barrier. Builders have long objected to the cost and leakage problems of parapetted fire walls. Many code authorities in the eastern United States accepted the use of fire-resistant treated plywood (FRTP) roofing extending 4 feet (1.2 m) on each side of the fire wall, which extended to the underside of the roof. Delamination of ordinary plywood permits fire extension over fire walls, compromising the reliability of this method.

At least some chemicals used in FRTP react and deteriorate in ordinary temperatures. This causes the roof to leak and it becomes unsafe, even for normal u[illegible] fire fighter or a worker walking on such a roof may fall into the structure. Unfortunately, in many cases, the FRTP was used not only along the fire barrier wall, but also randomly throughout the roof.

Void Spaces

As in frame buildings, void or concealed spaces are an inherent part of buildings of ordinary construction. The voids may be totally combustible, as in a wood joisted building with wood floors and lath and plaster ceiling. Partially combustible voids are exemplified by wood stud construction with gypsum interior finish.

During construction, requirements for firestopping may not have existed or may have been ignored. Even if firestopping has been installed, the execution may have been imperfect or it may have been removed to permit the installation of ducts or wires.

As has been noted, void spaces are a major firefighting problem. The existence of combustible voids has caused many serious losses even in sprinklered buildings because of failure to comply fully with NFPA 13, *Standard for the Installation of Sprinkler Systems*. NFPA 13 requires sprinklers in many types of combustible void spaces; certain small confined areas and those protected with special ignition resistance coatings are permitted. The fire can be extinguished only if it breaks out of the void or if the fire department breaks into the void. In January 2006, a five-alarm fire broke out in the old John Jacob Astor commercial building on Prince Street in New York. The fire spread throughout the structure through numerous void spaces, despite the fact that the building was alleged to have been fully sprinklered. If circumstances are favorable, expansion of steam (created by hose streams hitting burning material) into the void may accomplish extinguishment.

The fact that a particular void was not as noncombustible as similar adjacent voids was responsible for the fire loss of a new high school. Low-density combustible fiberboard had been applied to the studs behind gypsum wallboard on interior walls to provide acoustical treatment. A fire started by a plumber's torch found a fully combustible void space in a wall and extended quickly to the void space above the ceiling. The roof was an insulated metal deck. The noncombustible acoustical tile ceiling proved to be a hindrance to the fire department's efforts to deliver the water to the underside of the roof, the vital place to have absorbed heat.

Interior Sheathing

There is a concept, never definitively stated but acted upon nevertheless, that by providing a protective interior sheathing or finish for a structure, a substantial contribution has been made to the building's fire safety. Examples include placing sheet metal or gypsum board over combustible surfaces. This is true as long as the sheathing keeps a contents fire out of the structure. However, when the fire originates behind the protective sheathing or extends behind it, the protective sheath becomes a detriment to the firefighting effort.

Light Smoke Showing

The expression "light smoke showing" has too often been the first report of what turned out to be a disaster. It is important to recognize with fire that "what you see, ain't necessarily what you've got." Ordinary citizens and inexperienced fire fighters are generally unaware of the tremendous fire threat that can be concealed in voids. For example, three fire fighters died in a furniture store fire. Heavy smoke was reported showing from more than a mile away by responding units. Fire fighters operating inside found only light smoke. In fact, they dropped their 2.5-inch (6.4-cm) line in favor of extending a 1.5-inch (3.8-cm) line. Suddenly, fire burst out from a void and killed the three fire fighters. A number of other operational problems also contributed to this tragedy: unfamiliarity with the structure, a missing preplan, and a broken radio microphone.

In another instance, a fire broke out in an L-shaped one-story row of stores. The firefighting operations were at the short leg of the "L." A sewing machine store with fabric up to the ceiling was at the top of the "L," farthest from the visible fire. The store was absolutely clear. A brown spot appeared on the metal ceiling. Gradually, it turned red and the paint started to burn. Flaming paint fell on the fabrics and the store was soon fully involved. The entire process took fewer than five minutes.

Ceiling Spaces

Older buildings have much higher ceiling heights than those built today. False ceilings commonly are added to conserve heating and cooling costs and to modernize the building. It is not uncommon for a building to be modernized several times in the course of its lifetime with a new and lower ceiling each time.

Lowering the ceiling of old buildings is most easily accomplished by constructing a new ceiling. This provides a convenient void for the new utilities, air ducts, and so on. Firestopping is usually nonexistent in these situations. Vertical voids connect the horizontal voids so the building is honeycombed with what amounts to one big interconnected non-firestopped void. It seems as if authorities place almost magical trust in the use of fire-rated gypsum board to absolve all sins of omission and commission. In one particular case of a department store with three ceilings, code officials required the owner to extend the protection to all three "levels" as required by NFPA 13. This 100-year-old San Antonio structure became an "anchor store" in a large downtown mall.

Usual construction methods create a huge three-dimensional void across the ceilings. In the rehabilitation process, the buildings are gutted and apartments are created by removing and/or adding walls. Dropped ceiling frames are hung and the new interiors are lined with plasterboard panels. The walls are not firestopped at the ceiling line and the vertical stud spaces are unprotected above the ceiling. Old dumbwaiter and pipe shafts are retained for utilities. Such buildings burn furiously. Fire fighters have to pull down the ceilings to find the fire and occasionally are met by a carbon monoxide explosion.

Joist Spaces

Important void spaces in any multistory, wood-joisted building are the joist spaces. Containing many square feet of exposed fuel, these spaces are protected from hose streams by their construction and the ceiling below. The modern use of wood truss floors has immeasurably increased this problem. As the fire gains in volume, it spews torches of flaming gas out of every hole, opening, and utility service in the floor above.

Combustible Gases in Void Spaces

The ignition of combustible gases accumulated in voids within the building may provide the fuel for a devastating explosion, even though the building is ventilated in the accepted manner. The generation of carbon monoxide in concealed places can be as much as 50 times greater than what it would be in the open. The carbon monoxide flammability range is from 12.5 to 74%. Its ignition temperature is 1,128°F (609°C).

At a stable fire in New York in 1938, Frank Brannigan witnessed an explosion of carbon monoxide that had accumulated in the cockloft (the void between the ceiling and the roof). The violent explosion took place an hour and a half after the first alarm. It was presignaled by dense clouds of boiling black smoke. A longtime observer of fires noted, "It's going to blow." The blast caused the collapse of a side wall and the loss of one fire officer's life. There was actually a deflagration. Apparently, the gas–air mixture was just in the right proportion. The building had been vented according to standard procedures, but removing the skylights did not vent the cockloft. It was incomprehensible to the investigating committee that a backdraft explosion could occur 90 minutes after the first alarm in a vented building. It was reported that the wall simply collapsed.

Large Voids

Churches, schools, town halls, and other buildings often include vast void spaces. Often, there is a basement full of combustibles, nonfirestopped walls, and sometimes hollow columns. The voids are so extensive that handlines cannot reach the fire. Access for heavy-caliber streams is limited so there are large areas that cannot be reached by water. Some valuable fire protection features were never required by code. They resulted from provisions for some other purposes, and the fire protection benefit was unintended. An excellent example is windows at the front and rear of a building and skylights in the roof to let in light. These wall openings are absolutely necessary to the control of any advanced fire in a building of ordinary construction, but were never legally mandated.

In an effort to modernize the typical downtown store, designers often close up the front windows of the upper floors. Air-conditioning and fluorescent lights substitute for windows and skylights. The skylights and rear windows are closed up to foil burglars, and the often heavily fire-loaded upper floors become, in effect, one big inaccessible concealed space, completely impervious to fire department streams. In some cases, building and fire code authorities have recognized the fire department's problem and required fire department access panels. These are usually of limited size.

Many codes require sprinklers for inaccessible cellars or concealed spaces below mercantile buildings, so it is logical to press for sprinkler protection when the void is built above the first floor. The problem is the same. The sprinklers may prevent the loss of the building, but a substantial fire loss is almost inevitable.

Of course, the same problems of lightweight wood trusses discussed in the chapter on wood-frame construction are applicable to the truss voids of new buildings of ordinary construction: large void spaces within the collapse-prone trusses and lack of code-compliant draftstopping. As noted earlier, lightweight wood trusses are prevalent in strip malls and small office buildings.

Fire Extension

In ordinary construction, rarely is any provision made to prevent the extension of fire through the stairways and halls. Even if the stairways are enclosed in response to legislation passed after some terrible disaster, there are often many bypasses. The interconnected voids, pipe closets, utility shafts, and elevator shafts provide fire paths.

Interior Walls

Masonry buildings with spans greater than 25 feet (7.6 m) must have interior bearing walls. In older buildings, these walls are usually of balloon-frame construction unless made of masonry. Interior masonry walls can be distinguished from wooden interior walls by their greater thickness. Large wooden buildings also must have interior bearing walls, which usually are of balloon-frame construction in older buildings.

In large buildings of ordinary construction, masonry walls may provide the interior load-carrying structure. Sometimes closures of more or less adequate fire resistance have been provided at openings. These can be useful. However, because the purpose of the wall may not be to stop fire but only to carry the interior floor loads, it would be unusual to find such a wall carried through the attic space. The combustible attic may provide a path by which fire, initially confined to one section, may pass over the top of the wall.

Voids in Mixed Construction

Many buildings are composites of older sections, possibly frame or ordinary construction, and newer sections of protected steel or concrete construction. Unless the architect is aware of the hazard, or an alert fire department can present a convincing analysis of the total fire problem to the building department, the new fire-resistive addition may be completely at the mercy of the old building, particularly when the architect wishes to make the result look like one building.

In one case, an industrial building in New England appeared to be of fire-resistive concrete construction. The view of the building from an upper story of a hotel nearby shows that it was built around an older building with a huge peaked-roof attic on which air-conditioners are mounted. It is almost certain that the attic is of wood construction. This would be quite a surprise at a fire.

Cornices and Canopies

In the 1800s and early 1900s, many buildings were not complete without a cornice. A cornice is a structure of wood, metal, metal over wood, or masonry that tops the wall and projects from it. Collapse of cornices has caused many fire fighter fatalities and injuries.

The more functional architecture of the 1920s eliminated the use of cornices. In recent years, however, there has been another change in style and tastes. Cornices, fake mansards, overhangs (sometimes called eyebrows), and other projections are being installed on many new buildings and added to old buildings to improve their appearance. They are usually made of wood and sometimes poorly attached to the structure. These decorations present a collapse hazard. New decorative cornices are made of coated plastic polystyrene and are backed with plywood Figure 9-24.

Figure 9-24 Decorative cornices at the roof level of two buildings.

A noncombustible motel in Pennsylvania is decorated with a huge mansard that extends around the building. The fuel load of a motel room is sufficient to pour heavy fire out the window. This fire could ignite the mansard and destroy the motel. It would be interesting to ask the architect, "Did the owner give you a criterion that a single room fire should put the entire motel out of business?" This question might interest the owner.

Closely allied to the cornice is the sidewalk canopy. In some cases, this is of cantilever construction, thus providing a serious collapse potential. Even when not cantilevered, the cornice and canopy represent substantial loads, usually supported by combustible members.

Fire Barriers

Masonry Bearing Walls as Fire Barriers

A fire wall, by definition, is erected for the sole purpose of stopping a fire, and the truly adequate fire wall can often accomplish this function unaided. Masonry bearing walls may serve to stop the fire, but conditions generally make a bearing wall less than a fire wall. When defects are recognized, tactics may then be planned to take advantage of the assistance offered by the masonry wall. "Main Street, USA" is made up of buildings of ordinary construction, usually brick and wood-joisted, built side by side. If each building has a 12- or 16-inch (30.5- or 40.6-cm) unpierced bearing wall, these two walls together form a barrier to the passage of any fire that can be generated. The fire may go over or around such a pair of walls but not through it. Unfortunately, often the walls are pierced with openings for utilities or doorways when occupancies encompass both buildings.

Fire Doors

When openings have been made in walls to connect buildings, fire doors should be provided (Figure 9-25). The local code may not require them, however, and

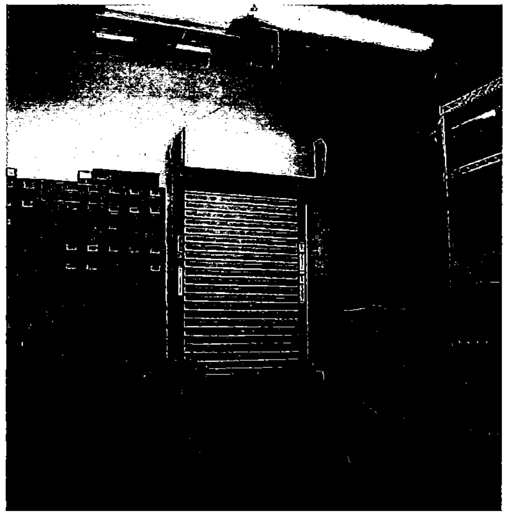

Figure 9-25 Automatic closing of rolling fire doors can be activated by fusible links at the top of the door opening, or by an electronic failsafe release device connected to an alarm system or local detectors.

Courtesy of Lawrence Doors.

even if installed they may be ineffective. In some cases, the originally planned openings were properly protected by fire doors, but additional openings were made later without proper protection. In one case, two older buildings in Virginia were combined to form a restaurant. The created opening was protected with a fire door. Alongside it there was an unprotected window so the manager could see the dining room from the office.

Fire fighters should be trained in how to inspect a fire door for proper operation. Particular attention should be paid to keeping the door path clear at all times of any displays or equipment or anything that would block the door. Prefire plans should indicate the presence of fire doors. It is a truck company's function to see that they are closed and latched properly. During a fire, pay particular attention when stretching hose through an open fire door—if the fire door closes behind you, you will lose water pressure and a means of egress.

In bygone years, adjacent buildings may have been connected by doorways at one or more floors. The fire department may be totally unaware of openings that were abandoned in the past when the occupancies were separated. The closure at an opening may be an ordinary door, an inoperative fire door with merchandise stacked against it, fiberboard lath and plaster, or properly constructed masonry to restore the full integrity of the wall.

Protection From Exposures

When one building is taller than its neighbor, the owner of the taller building may install windows in the upper stories overlooking the smaller building. Fire coming through the lower roof may extend to the adjacent building via the side windows (although modern building codes require wired glass or other types of protection of openings in new structures). Burning material may fall out of the upper windows onto the adjacent roof.

Old, hidden windows may provide a surprise path for fire to travel from one building to another. A key factor in a $1 million fire in Gloucester, Massachusetts, was a window in a brick building that had been boarded up. The window was next to the wooden exterior wall of a sprinklered department store. The fire entered the ceiling of the store above the sprinkler piping. The sprinklers collapsed and the store was lost.

If two buildings are not of the same depth, the rear windows of one and the side windows of the other may expose one another. In such a case, the rear exposure may require protection, even before the fire is attacked. Otherwise, a frontal attack may drive the fire out the back windows into the exposure.

Narrow alleys between buildings present difficult defense problems against exposures. Often sheet or corrugated steel, or steel-clad wooden fire shutters, protect windows facing the alley. Unfortunately, their worth is suspect. Wired glass is also of limited value against radiant heat.

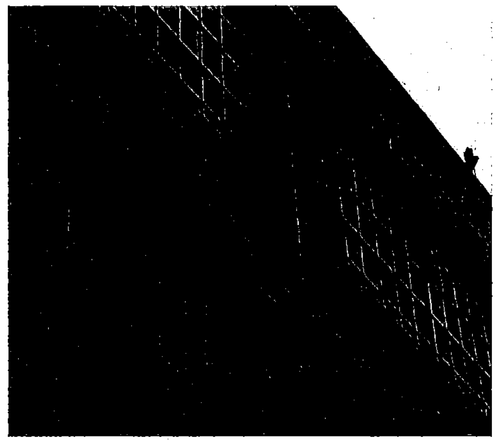

Figure 9-26 An exterior water spray system on a building to protect it from an exposure fire.

Courtesy of Tim Scroggins

At times, outside sprinklers or spray systems are installed to protect against exposure fires (Figure 9-26). The fire department should be fully familiar with their operation. In most cases, they must be turned on manually and the valve is located inside the building. The system should be tested at least annually because the "open" nozzles can become clogged. Ensure that the water covers the entire face of the building. The system will do the work of one or more engine companies in covering the exposure and without risk to personnel.

Party Walls

In many cities, it is quite common to erect **party walls**, structural walls that are common to two buildings. In the area of the original city of Washington, D.C., fire protection regulations issued by President George Washington required that masonry party walls be built, and that the builder of the subsequent building pay the first builder for half the cost of the wall.

Usually party walls are established by mutual contract between the owners. The Washington, D.C., situation is probably unique. In examining the building, determine the thickness of the wall. A party wall is thinner than two separate walls. Because the joists of both buildings are supported on the same wall, the builder often found it convenient to support the joists in the same socket. Sometimes the joists were overlapped to provide greater strength. Some codes forbade this practice.

A typical party wall fire extension occurred in Ottumwa, Iowa. The fire involved two stores separated by a party wall in which joists were lapped in common sockets. The fire in the original store was under control. No examination was made of the ceiling void of the adjacent store. Suddenly, the ceiling void of the adjacent store was found to be involved. A backdraft explosion drove the fire fighters out and the building was lost. The fire had passed into the ceiling void of the adjacent store by way of the joist openings.

Fireground Safety

Fire fighter safety at the scene is a critical factor that all departments must face—not just those charged with fighting fires in certain occupancies. One method that could significantly improve fire fighters' safety at the fireground is for the fire department to set up a Board of Building Review. Experienced fire officers who have studied building construction, assisted by consultants from the building department or private sources, could survey major buildings of ordinary construction and typical smaller buildings. Considering the available fire load, the type of construction, the nature of connections to adjacent buildings, water supplies, protection provided, and other relevant circumstances, an upper limit in minutes could be put on the time that fire fighters were permitted to stay in the building. The time rating of the building would be part of the prefire plan. The incident commander (IC) would reserve the right to order the fire fighters out before the expiration of the rated time, but strong restrictions should be placed on authority to keep fire fighters in the building after the expiration of the rated time.

The IC would be substantially relieved of an unfair responsibility (i.e., determining the boundary between stability and collapse under fire conditions). In a fire, the boundary between building stability and instability is a thin line. Ignorance of the boundary is no excuse when a failure occurs.

TACTICAL CONSIDERATIONS

1. Ordinary construction is brick masonry or noncombustible material on the exterior with interior dimensional lumber supporting the floors and roofs. It is found in a variety of structures, including apartment buildings, department stores, and light industrial structures. They are usually three or four stories, but can be as tall as seven stories. Three-story buildings usually do not have a standpipe. Four-story buildings or higher will typically have a Class I or Class III standpipe system.
2. In Type III ordinary buildings, the fire load consists of the contents and the combustible interior components of the building. With combustible material in the form of wood lath, wood furring strips, cross bridging, wood joists, and 2×4 wood studs, even a vacant Type III building will have enough of a fire load to produce a large fire. A rapid deployment of an interior attack line to the seat of the fire is necessary to prevent the structure from becoming involved. Void spaces need to be checked immediately after the fire is extinguished to stop or minimize structural involvement.
3. Ordinary construction from the 1950s and earlier typically used heavier lumber for interior structural members. Heavier lumber can withstand fire conditions longer than lightweight wooden assemblies, providing fire fighters with a wider margin of operational safety; 15 minutes is an accepted safe operational period. Remember, collapse of interior assemblies will make the exterior masonry walls less stable and more prone to collapse.
4. The major fire problem in ordinary construction is smoke and fire spreading throughout concealed spaces. The largest and most serious concealed space is the common cockloft between the highest ceiling and the roof. Rapid flame spread across this area has caused the destruction of thousands of buildings across the nation. Vertical ventilation, including the trench cut, is an effective tactic to stop the horizontal spread of the fire in long buildings.
5. With the historical preservation and renovations of older ordinary constructed buildings, concealed spaces have become larger and more numerous. The emphasis is on keeping the exterior façade as it was when it was built. There is more leeway to allow for modern and energy-efficient construction for the interior. For these reasons, the problem of concealed spaces in the brick-and-joist construction will always present a major hazard for fire fighters.
6. Other serious hazards to fire fighters with older ordinary construction are the parapet walls and cornices, some of which are very ornate, and all of which are extremely heavy. Usually located on the front side of the building, the parapet wall can collapse during structural firefighting. Over time, these walls are weakened by their constant exposure to the elements. Rain may wash away the mortar between the bricks, and freezing may cause cracks in the wall. Heavy master streams sweeping across the top of a burning roof can wash tons of loose bricks from the parapet wall down onto fire fighters below. The lateral force from heavy-caliber streams can topple the wall down a hundred feet on to the street. When the bricks hit, they can become projectiles. The collapse danger of the parapet wall is one reason why the area directly in front of the building is so dangerous, and why fire fighters should either move inside the doorway or away from the A side of the building altogether. Establish a collapse zone and look for other ways into the building.
7. More fire fighters have been killed in fires in ordinary construction than in any other type of construction. There is a variety of reasons, but one is simply age. Many of these buildings are over 100 years old. Because much of "Main Street, USA" is being lost to progress and urban sprawl, there is a push from historical societies to restore these dilapidated buildings rather than tear them down. Special loans are made available for those who wish to restore these old buildings. The primary emphasis is keeping the front façade in its original condition.

What's inside is often unknown—it can be original construction or a combination of new lightweight interior members. Remember, fire safety is not a priority in building preservation and restorations. Fire officers should become more analytical of the hazards of this type of structure, rather than relying on experience alone.

The firefighting forces of fire departments—not just the fire prevention division—should become involved in major building renovations and restorations. In this manner, fire fighters may make recommendations for improvements. In any event, fire fighters will be well aware of structural deficiencies after performing such inspections.

Many major cities, such as New York, Chicago, San Francisco, and Seattle, suffered "The Great Fire of..." around 1900. These great fires destroyed much of their downtown areas, which were populated with buildings that were constructed in the late 1[illegible]. These buildings were rebuilt with ordinary construction that was popular at the time. Because many of these "replacement buildings" still exist, it is important for fire fighters to understand the history of the buildings in their response districts. Prefire planning and training are essential. With new CAD system programs and mobile data computers, prefire information, drawings, maps, digital photographs, and informational updates can be disseminated throughout the fire department computer network from the cab of the inspecting fire company with the touch of a button.

Stay alert to alterations and new construction permits. Most fire departments have a system in place to notify the local fire companies of new construction projects happening in their district. Remodels can be harder to track because many are completed illegally without a permit. Pay attention to change of use (occupancy) construction projects.

When it's time for fire fighters to immediately evacuate the building, the department should have a recognizable signal, such as air horn blasts in addition to radio orders. The fire communication centers also have the ability to broadcast an "emergency evacuation tone" over all the radio channels on the fireground. Drills should be held on evacuation in real time. There is very little, if any, reaction time. Frank Brannigan saw a number of images of escaping fire fighters looking back—you should train personnel with the imperative, "Don't look back!" Look where you are going because there are many tripping hazards.

12. Many fire departments use electronic sirens on their apparatus, which usually have three settings: wail, yelp, and high-low. In cities such as Seattle, Washington, the wail and yelp are used while responding to emergencies. The "high-low" European siren is reserved exclusively for an emergency "abandon the building" tone. When the IC calls to abandon the building, the fire alarm center transmits a "high-low" tone on the fireground radio channel and the drivers of apparatus on scene turn on their "high-low" siren. The policy prohibits the high-low siren from being used during responses so it cannot be confused with any other signal.
13. Ordinary construction that houses food processing businesses is required by many health department codes to have a concrete topping over the first floor to provide a sanitary floor and to seal it from rats and mice. This additional dead weight may confuse fire fighters as to the nature of the floor. If there is a basement fire, the concrete topping may also conceal the heat below. Concrete topping on the floor was a factor in at least two building collapses that caused multiple fire fighter fatalities, including a fire in Seattle, where four fire fighters died when the heavy floor collapsed into the burning basement. The dimensional lumber that was supporting the floor burned out in approximately 20 minutes. Whenever you're responding to a commercial fire in a food processing facility, for example, that usage should raise a flag. You're probably dealing with a concrete floor, so remember to quickly check to see if anything is burning below the first floor.
14. If fire fighters must pass under a burning cornice or canopy, use a solid stream to knock off wood about to fall and drive the fire back. This may buy a short amount of time during which it is somewhat safer to pass under the cornice.
15. A possible wall collapse must be in the forefront in the constantly changing evaluation of the fire problem assessed by the fireground commander. If good prefire planning has been done, information on possible weak points in the walls will be available. In any event, a sector officer should be assigned to monitor wall stability. Remember, an exterior collapse will usually cause an interior collapse. Conversely, the

elongation of steel beams can push out an exterior wall and cause it to come down.

16. Once you have a wall collapse, the building is telling you it's giving up to the fire. This building no longer has any value and is not worth fire fighters getting injured or killed. Withdraw all crews from the building and regroup. The situation needs to be reassessed. If there are no parts of the building that have any value, you must switch to a defensive strategy. One specific tactical objective that sometimes results in futility is the trench cut. When the IC calls for a trench cut, the IC is essentially setting up a fire break—similar to a fire break established during a wildland fire. On the fire side of the trench, you're essentially writing the building off. On the opposite side of the trench, you're indicating: "Here is where we're making a stand because this part of the building is worth saving." The problem develops when crews initiate the trench cut too close to the fire. This is a labor-intensive and time-consuming operation. If you don't have enough personnel making the cut, the rapidly advancing fire will force crews to abandon the operation before the trench is completed. Another problem develops when the trench isn't long enough. The trench cut needs to extend from wall to wall; an incomplete trench will allow the fire to pass underneath the uncut part of the roof to the rest of the attic space. Finally, a trench cut needs to be backed up with a hose line. As the fire vents out the trench, there is still radiant heat attacking and preheating the unburned part of the roof and attic space. The only way to protect this area is with water.
17. The IC must be able to predict time-consuming tasks and have sufficient resources available to complete the task to have the desired effect on the fire.
18. Know your collapse indicators. Bricks have a reputation for toughness and permanence that can be misleading. Poorly made bricks are not uncommon. They absorb moisture and can fail due to freezing. Walls may come down in several ways. The worst or most dangerous collapse is when the wall breaks at ground level and falls straight out along the full height. Bricks and other debris will fly farther than the standard collapse zone (1.5 times the height of the building). In one case, bricks were measured to have traveled as far as 200 feet (60.9 m) away from the wall.
19. There should be strict control of the number of personnel in or close to the collapse zone. One way to establish a collapse zone is to use uncharged fire hose. There are hundreds of feet available at a fire scene. This provides a clear line of demarcation so there is no mistake. Though fire fighters like being up close to the action, it doesn't take four or five fire fighters to operate a portable deluge set. In fact, the equipment can be left unattended, but this "one spot" delivery is rarely effective. A heavy stream nozzle can be directed with special equipment or by means of radio signals, thus providing effective delivery without much risk to fire fighters. New apparatus are now being equipped with remote control master streams and deck guns.
20. Fire fighters directing hose streams against older brick buildings can wash out the mortar, causing the wall to fail or collapse. Watch out for leaning brick chimneys or chimneys pulling away from the structure. Be especially careful around freestanding chimneys after a fire. The safety officer should take note of this and notify the IC. A radio message should be transmitted on the fireground so all companies are aware of the safety hazard. Use flagging tape or uncharged fire hose to mark off a collapse zone and make all fire fighters aware of it.
21. Examine a wall before breaching it. If it is deteriorated, don't breach it because the entire wall may come apart. If you are breaching a wall and you find materials different from the rest of the wall, such as brick, steel, solid concrete blocks, or reinforced concrete, you are probably into a wall column and under a major load. Immediately cease operations, reposition someplace else, and start again.
22. When breaching a wall, make a triangular cut with the apex at the top. Do not cut a straight line across the top of the opening. Masonry units mortared together are not designed to hang upside down, so this action can lead to a collapse. Available shoring material (e.g., wood timbers, raker shores) should be used as soon as possible to support the opening in the wall. It's a good idea to note the location of existing construction sites. Also, have a prearranged agreement with the local lumber yard for quick access to shoring materials.
23. Whenever materials are combined in the structural support system, the fire characteristics of the weakest component should govern assessment of the collapse

potential. A building system is only as strong as the weakest connection. Never get into a position where lightweight interior structures, such as a rack storage or scaffolding, can collapse behind you.

Rundown theaters and auditoriums often have marquees that extend over the sidewalk and main entrance. Try and look for other entrances into these structures if they have been left abandoned and vacant for some time. If the front entrance must be used, consider shoring up the marquee overhang with one or two ground extension ladders as a temporary safety measure.

Steel beams, although not normally found in buildings of ordinary construction, may be used as replacement beams for sagging wooden beams. Steel elongates when heated. For example, a 100-foot (30.5 m) steel beam reaches 100 feet and 9 inches (30.7 m) at 1,000°F (538°C). Elongating I-b--ms and trusses have pushed down many walls. Th(use of elongating steel collapse is rarely reported after a fire because all that is evident at that time is failed steel. Material that absorbs water, such as carpet, bulk cardboard, large rolls of paper, and fibrous material, should be stored at least 1 foot (30.5 cm) away from masonry walls to allow for expansion. Expanding water-soaked material can push the walls out, causing a collapse. Though this precaution is enforced during a fire prevention inspection, it can pay big tactical dividends to fire crews operating at 3:00 in the morning.

Even where prefire planning was not accomplished, much can be learned at the time of the fire and deduced from a good knowledge of similar buildings. Walls that are obviously deteriorated, braced, or tied certainly indicate that a floor collapse will probably bring the walls down. Watch for the ornamental stars that indicate walls are in distress.

The volume of the fire gives clues about how long the floors will last. Ordinary wood-joisted floors are not formally rated by any standard fire resistance test. Recent simulated (laboratory) basement fire tests indicate an *exposed* 2×10 solid wood joist lasts 18 minutes. The attachment of a ½" (12.7 mm) gypsum board ceiling raised the endurance to 44 minutes.

Fire fighters should not be working on any roof structure that is on fire. In such a case, the roof will shortly self-vent. When vertical ventilation is perf--med, the attic space is filled with hot, "oxygen-deficient" smoke and gases. This means there is no fire...yet. Fire fighters must realize that ventilation increases the air flow to the fire. Wherever you cut the vent hole, that's where you're bringing the fire. A roof structure not involved before ventilation may quickly become involved soon after the roof is opened. Part of the vertical ventilation strategy entails redirecting where you want the fire to go.

29. The truck company officer also serves as the roof safety supervisor, with the responsibility of determining whether the roof is safe to use as a working platform during vertical ventilation operations. Departments without designated truck personnel still have to perform vertical ventilation. The most experienced member should direct the cuts and serve as the roof safety supervisor to determine when it is time to get off the roof. Always take a roof ladder to the roof; even when operating on a flat roof. The roof ladder may be needed to climb over a parapet wall or be used as a secondary means of emergency egress to an adjacent roof. Once the vent hole is cut, it is time to get off the roof.
30. A ventilation opening acts like a chimney. Chimneys exhaust smoke and heat, but they also accelerate the fire.
31. If a roof is deemed unsafe to work from as a platform, but rooftop ventilation is still critical to the offensive strategy, consider working from an aerial ladder or sectional types, which permits a bucket to be placed down on the roof.
32. Collapsing roofs often bring down masonry walls. When a roof collapse is anticipated, fire fighters should be withdrawn beyond the wall collapse zone.
33. Training officers and company officers must make every effort to present the invisible hazards of void spaces to their fire fighters with as much importance and drama as the live, visible fire.
34. Heavy volumes of boiling smoke that persist even after the visible fire has been well controlled indicate fire in a void. However, light smoke or no fire at all does not necessarily mean that there is no fire in the void spaces. In 1986, two fire fighters in Biloxi, Mississippi, were killed in a residential boarding house fire. The initial attack was over and the fire had appeared to be knocked down. The two fire fighters reentered the structure without a hose line; when fire busted out of a second-floor void space, they were killed. Always open and check the attic

and void spaces after the fire has been knocked down. The thermal imager is one of the most important lifesaving technological advances to assist fire fighters in searching for victims and checking for hidden fires.

35. In the case of row buildings, expect extension to the adjacent exposures. Get them opened up early and get charged hose lines into position inside the exposed buildings. If a shortage of personnel does not permit such lines to be staffed, leave the charged lines in place with a patrol. In too many cases, a fire department has suddenly found that the fire has extended; by the time operations can be rearranged, the exposed building might be fully involved.
36. Fire takes the path of least resistance. In addition to laying hose line at a row building, you can place positive-pressure blowers and pressurize the adjacent B- and D-side exposure buildings. If the fire building has a sufficient vent hole in the roof, by making a hole in the ceiling to the attic space of the exposure buildings, you can pressurize the attic space and reverse the horizontal spread of smoke and hot gases, channeling them back out the vent hole of the fire building. Anticipate the possible extension of fire as a result of collapse.
37. Fire fighters should be trained in how to inspect a fire door for proper operation. Particular attention should be paid to keeping the door path clear at all times of any displays, storage, equipment, or anything that would block the door from closing and latching. Prefire plans should indicate the presence of fire doors.
38. Fire units should never pass through a sliding or overhead rolling door without blocking it open temporarily. Closed sliding fire doors can be very difficult to open; overhead rolling doors may be impossible to open. A sudden burst of fire may trigger the door and the fire fighters could become trapped. If crews are operating hose lines beyond the door, they will suddenly lose water and may be trapped on the fire side of the door. If they have advanced beyond the door with an uncharged line, the door will prevent water from reaching the nozzle when water is called for. In both scenarios, fire fighters may become trapped on the fire side of the door with no way to protect themselves from fire.
39. In buildings more ornate than warehouses, fire doors may be artfully concealed. In one Rochester, New York, building, an overhead rolling fire door is concealed in the ceiling. The tripping fusible link is not conspicuous. The door lies across the attack path of the first-due engine company. Should a door like this activate after a sudden burst of heat, this door will come down like a giant hose clamp on crews' hose lines. Thus, whenever crews cross the threshold of a large rolling fire door, they must wedge it open.
40. Teach newer, inexperienced fire fighters that the purpose of a large fire door is to confine the fire to the space or building of origin. By design, if a fire is large enough to activate a large rolling fire door, the building is writing off property contents on the fire side of the door. If a crew is sent to the adjacent building or space to protect the exposures and prevent the fire from extending beyond the fire door, it may mean entering the building with a charged hose line and simply waiting—either for interior crews to extinguish the fire or for the fire to burn itself out.
41. Waiting is not easy for aggressive fire fighters. In one example, inexperienced fire fighters were manning a 2 ½" (6.4 cm) exposure line in a smoke-free, low-heat environment and felt like they had nothing to do. They realized the seat of the fire was just on the other side of the fire door. Because interior crews were having trouble finding the fire, they felt compelled to act. They concluded if they opened the D-side fire door, they would be at the seat of the fire, could quickly extinguish the fire, and would be heroes for saving the day. They had no idea of the fire behavior and thermal dynamics they were about to encounter. The crew split because it took two fire fighters to slide back the giant fire door. Superheated smoke and fire immediately started spreading horizontally across the ceiling. The radiant heat was so intense that they could not tolerate the thermal assault. They also could not move the 2 ½" (6.4 cm) hose line fast enough to push back the fire. The crew was forced to back out and the fire extended into the exposure building.
42. Fire fighters operating hose lines in a narrow alley are in serious danger. Because you cannot establish a collapse zone in an alley, study the problem in advance. Lines directed downward from the roof of the exposed building or ladder pipes directed into the alley from the street are two methods of attack. If there is a way to operate from a protected area off

the alley, that would be best. Many times there are covered entryways or covered ramps to underground parking off the alley for the C-side exposure building. You can also make entry from the next block. Take your exposure lines through the building back toward the alley. This tactic gets lines into position to support the strategy of attack and allows your crew to set up from a rear door or windows and operate from a safe position.

Extension through party walls is sometimes hard to detect. Examination of the adjacent premises early in the fire may show nothing. It may take time for the fire to work its way through. Smoke, which might ordinarily give cause for alarm, goes unnoticed in the general smoky condition of the fire. Without some evidence, officers are often reluctant to order the necessary opening of ceilings. When the need becomes evident, it is often too late. Thermal imagers have made it easier to detect hot spots without needlessly damaging property.

Tabletop drills have always been effective because they give an aerial perspective of an incident. But how effective would they be if you had to lay your head against the table? The incident command post (ICP) is usually set up in front of the building or at the nearest street intersection. Some ICs are comfortable running an incident from the inside of a command vehicle, and even insist on this arrangement because there is less distraction. On large multijurisdiction incidents, you do not have a choice. However, on a normal fire response, you need your eyes for initial and ongoing size-ups. Sometimes a floor or roof of an adjacent building can help you with a better vantage point to realize what's going on or what's going wrong. An overpass or a bridge located higher than the roof line of the involved buildings can also be helpful. If it is not practical for the IC to set up there, have a deputy IC or company officer be your aerial sector to give you a "bird's-eye view" update on the situation.

45. With mobile data computers, helmet cameras and apparatus-mounted cameras can be used to transmit digital video to the ICP in real time. Local news stations, many of which have helicopters, can also feed live video directly to the ICP for an aerial perspective of the ongoing incident. Local and state agencies may have stationary security video cameras mounted throughout a community and on highways, many of which have remote control spanning capabilities. If a fire incident is within the lens range of the camera, the video can be streamed to the ICP in real time.

WRAP-UP

Chapter Summary

- The term *ordinary construction* describes an almost infinite variety of buildings.
- In simpler days, ordinary construction was generally known as brick and wood-joisted construction. Today, this construction uses a variety of walls and interiors.
- The chief common characteristic of ordinary construction is that the exterior walls are made of masonry with combustible frame members.
- Ordinary construction is classified as Type III construction.
- Over the years, most old buildings have undergone extensive modifications. Usually, such modifications have had a detrimental effect on the structure from the fire suppression point of view, creating collapse potential or interconnected voids from which fierce fire can burst out on the unwary.
- Many buildings constructed in recent years depart from simple ordinary construction; this is not necessarily an improvement.
- In modern construction, a noncombustible void can accumulate explosive carbon monoxide gas as readily as a combustible void.
- The problems presented to the fire department by ordinary construction can be divided into the following areas:
  - The structural stability of the masonry wall
  - The stability of the interior column, girder, and beam system
  - Void spaces
  - The masonry wall and fire wall as barriers to fire extension
- Many fire texts cite indications of building failure that may be observed on the fireground:
  - Typical indicators include smoke or water flowing through walls, soft floors, a small partial collapse, walls out of plumb, and time since arrival on the scene.
  - Although these are all good indicators, sometimes they are insufficient or too late.
- The interior structure may push down a wall in several ways.
- Fire departments are concerned about equipment such as ropes, aerial ladders, and aerial platforms because equipment failure can cost lives. However, there is one working platform fire fighters use that has cost many lives—the roof.
- Fire fighter safety at the scene is a critical factor that all departments must face—not just those charged with fighting fires in certain occupancies.

Key Terms

Adobe Large, roughly molded, sun-dried clay units of varying sizes.

Arched truss A truss with an arched upper chord and a straight bottom chord, with vertical hangers between the two chords.

Ashlar masonry Stone cut in rectangular units.

Cantilever wall A freestanding wall unsecured at the top that acts like a cantilever beam with respect to lateral loads, such as wind or a hose stream.

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.

Cavity wall Hollow wall in which wythes are tied together with steel ties or masonry trusses.

Cockloft Void space between the top floor ceiling and the roof.

Composite wall Two different masonry materials, such as brick and concrete block, used in a wall and designed to react as one unit under load.

Concrete masonry unit Precast hollow or solid structural block. Sometimes referred to as cinder block.

Concrete topping Concrete placed over the first-floor wood floors for fire resistance or to provide sanitary floors.

Coping The masonry cap on top of a wall.

Cornice A projecting decorative (ledge) at the top of a masonry wall.

Course A horizontal line of masonry.

Cross wall Any wall set at a right angle to any other wall; the walls should brace one another.

Dog iron Connects the girders and imparts some lateral stability under normal conditions; resembles a big staple.

Fire limit Older code provision that would not allow a structure to be built without the use of exterior masonry walls that would limit fire extension.

Fireproof Material applied to structural elements or systems that provides increased fire resistance; usually serves no structural function.

Flying buttress Masonry pier at a distance from the wall and connected to it that resists the outward thrust of the roof.

Header or bond course Bricks laid so that the end is visible.

Hollow masonry wall Two connected wythes of masonry with an air space in between.

Joist hanger Metal angle or strap used to support an individual joist against a beam or a girder.

Light well Small court commonly placed in large buildings to admit daylight into interior areas not exposed to an open view.

Masonry column Masonry bracing incorporated into unstable masonry walls; also called piers, buttresses, pilasters, or columns.

Masonry wire truss Wire truss embedded into the mortar in specified courses, making the header course no longer necessary.

Mezzanine A low-ceilinged story located between two main stories; usually constructed directly above the ground floor, often projecting over it as a balcony.

Ordinary construction Buildings in which the exterior walls are noncombustible or limited combustible, but the interior floors and walls are made of combustible materials.

Parging (pargetting) Application of mortar to the back of the facing material or the face of the backing material.

Party wall A structural wall that is common to two buildings.

Pintle Square metal device used to transfer loads of columns on upper floors by passing the loads through intervening beams and girders to metal column caps on the column below.

Rubble masonry Rough stones of irregular shapes and sizes, used in rough, uncoursed work in the construction of walls and foundations.

Rubble masonry wall A wall composed of an inner and outer wythe of coursed masonry. The space between is filled with random masonry sometimes mixed with mortar. Such walls are unstable to a lateral thrust.

Solid masonry walls Masonry units (either solid or hollow) laid contiguously with the joints filled with mortar.

Stretcher course Bricks laid so that the long side is visible.

Strip mall Modern one-story retail occupancy building that typically has a lightweight wood truss roof and concrete block walls (Type III construction) or steel bar joists and a metal deck roof with a masonry wall (Type II construction).

Tenement Multistory working-class apartment buildings constructed in the 1800s and early

WRAP-UP

1900s, often substandard in terms of fire safety and health.

Terra-cotta tile Made of clay and fine sand and fired in a kiln.

Tied arch Arch in which a steel tension rod ties the ends of the arch together to eliminate the need for the masonry.

Type III construction Ordinary construction.

Unreinforced masonry Ordinary masonry walls are not reinforced, so they have no resistance to lateral movement.

Veneer wall A wall with a masonry facing that is not bonded but is attached to a wall so as to form an integral part of the wall.

Wythe A single continuous vertical wall of bricks, one masonry unit in thickness.

Case Study

While riding in charge of the truck company, you decide to take the crew out for a tour of the new strip mall that has gone up on the east side of town. On the way over, you talk to the crew about the hazards associated with strip malls and ordinary construction.

1. Masonry walls in ordinary construction may consist of ________________.

A. concrete block
B. terra-cotta tile
C. precast concrete
D. all of the above

2. Which term best describes a freestanding wall unsecured at the top?

A. Composite wall
B. Cantilever wall
C. Cavity wall
D. Hollow masonry wall

3. True or False: Assuming this strip mall was constructed using lightweight wood trusses, you can rely on the presence of code-compliant draftstopping to prevent horizontal fire spread.

4. Cornices found on new strip malls are likely made of:

A. Wood
B. Metal
C. Stone
D. Polystyrene

Challenging Questions

1. Describe the basic characteristics of an ordinary construction building.

2. Why is the term *brick building* improper?

3. Identify the indicators of structural collapse.

4. Identify the paths of fire spread through void spaces.

5. You are a battalion chief in command of three engine and two ladder companies for a reported fire in a one-story, unsprinklered supermarket with a bowstring truss roof. Upon arrival, you note light smoke in the store but no fire. You are advised that store employees noted smoke coming from the ceiling HVAC diffusers 10 minutes earlier. A ladder company on the roof reports moderate smoke coming from scuttle openings on the roof. What are your safety concerns? What overall strategy would you employ to deal with the fire?

Noncombustible Construction

OBJECTIVES

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

- Understand the difference between noncombustible and fire-resistive construction.
- Identify the different types of steel building components and their characteristics.
- Describe the use of masonry, including concrete, in noncombustible buildings.
- Describe different types of steel structural systems.
- Describe the hazards of a metal deck roof fire.
- Understand the hazards of high fire loads in unprotected steel structures and ways to improve the situation.

Case Study

Figure 10-1 The Memphis dollar store fire, in which the roof collapsed at the rear of the building.

Courtesy of NIOSH.

In 2003, an arson fire broke out in the rear office of a "dollar store" (with items for sale ranging from clothing to automotive supplies) in Memphis, Tennessee (**Figure 10-1**). Constructed of unprotected steel bar joists supported by concrete block walls, the 8,900-square-foot (826.8 m^2) building was divided by a concrete block wall into two areas. The sales area, approximately 100 feet (31 m) deep, was at the front of the building; a smaller storage and office space was located at the rear of the store. The roof deck consisted of a corrugated steel deck covered with ¾" fiberboard and asphalt. A suspended ceiling was installed in the sales area, while the bar joists were exposed in the rear storeroom and office.

Fire fighters entered the front of the store and noted a light smoke condition. Other fire fighters entered the structure through a rear door, going into the storeroom. The fire fighters in the storeroom encountered moderate smoke conditions; when they opened the door to the office, they were met with heavy fire conditions. Handlines were stretched through the front door, and fire fighters were assigned to the roof for ventilation as smoke conditions worsened.

One fire fighter was directed to open up the drop ceiling in the store. As he conducted this task, the fire intensified in the ceiling void and blew down a number of ceiling tiles and HVAC diffusers onto fire fighters below (believed to be the result of a backdraft). At about the same time, a portion of the bar-joist roof in the storeroom collapsed; two fire fighters—one in the storeroom and one in the sales area—became trapped, ultimately succumbing to the effects of the fire.

1. What are the effects of a drop ceiling in terms of locating a fire?
2. How can backdrafts occur in a void space consisting of a drop ceiling, bar joists, and a built-up metal deck roof?
3. Which type of fire load is necessary to initiate the collapse of steel bar joists?
4. How many buildings of this type exist in your community?

Introduction

Both Type II noncombustible construction (covered in this chapter) and Type I fire-resistive construction (covered in the chapter that discusses fire-resistive construction) use construction materials that will not support combustion—namely, steel and concrete. What, then, is the difference between noncombustible and fire-resistive construction? The answer is simple—the level of fire resistance (fire rating) assigned to the structural frame, walls, floors, and roof. Noncombustible construction has little or no fire resistance for its structural members, while fire-resistive construction has moderate to heavy fire resistance.

Noncombustible construction also differs from fire-resistive construction in that its allowable area and height (discussed in the chapter that reviews building and fire codes) are much smaller than the corresponding criteria for fire-resistive construction. Many noncombustible buildings are 1–3 stories in height, with the maximum height being 12 stories for certain types of occupancies. Fire-resistive construction, by comparison, is permitted to be of unlimited height.

Although the use of concrete is found in some buildings of noncombustible construction, noncombustible construction relies heavily on the use of steel for its structural system, including the roof and floor framing. In this chapter, the focus is on steel because it is the most prevalent material of choice. Nevertheless, many actual examples of fire-resistive construction can be cited that use steel for their framing systems. These buildings will have high levels of fire resistance (protection) for the steel.

The use of concrete in Type II construction is typically limited to exterior walls and shaft enclosures. For example, many strip malls use concrete block as exterior load-bearing walls. Similarly, warehouses of tilt slab construction (discussed later in this chapter) often use large exterior wall panels of concrete. Concrete block or panels are used to provide fire-rated enclosures of stair and elevator shafts. In addition, concrete is often used to construct a fire-rated floor assembly in Type II construction. A detailed discussion of concrete can be found in the chapter on fire-resistive construction.

Steel is the most important metal used in building construction. It is widely available and relatively inexpensive in the United States. Without it, construction would be limited to massive all-masonry buildings with arched floors or masonry wall-bearing buildings with wooden floors.

Steel is tremendously strong. Its **modulus of e[illegible]icity** (a measure of its ability to distort and r[illegible]e) is about 29 million pounds per square inch (psi)—far more than any other material. Steel's compressive strength is equal to its tensile strength. Its shear strength is about three-quarters of its tensile strength. This great strength enables steel members of relatively small mass to carry heavy loads, particularly when used in trusses. Fire resistance, however, is a function of mass. Such strong but lightweight members have little inherent fire resistance.

Fire Characteristics of Steel

Steel has several important characteristics to consider regarding its behavior in fire. The characteristics that concern fire fighters are:

- Substantial elongation can take place in a steel member at ordinary fire temperatures (about 1,000°F). This elongation may cause the disruption of other structural components, such as masonry abutting the ends of the steel. If the steel cannot elongate because of restraint, it will buckle or overturn. This can be significant when other components rest on a steel member.
- At higher temperatures (above 1,300°F [704°C]), steel members may completely fail, bringing about a collapse of the structure.
- Cold-drawn steel, such as steel tendons used for tensioned concrete and for excavation **tie-backs** and elevator cables, will fail at about 800°F (427°C).
- Steel is a good thermal conductor, so it transmits heat readily. Heat can be transmitted by conduction through walls to combustible materials.

Unwarranted Assumptions

The fact that steel is noncombustible leads to unwarranted confidence in its "fireproofness" and suitability for all applications where fire is a problem. "I never would have believed it" is a common reaction by otherwise well-informed people when they see the ruins of an unprotected steel building.

Water on Hot Steel

The heat evolved by a fire can be **triaged**—that is, considered and treated according to priority needs. In reverse priority, this heat can be classified as follows:

- *Heat leaving the structure.* Let it go. Every British thermal unit (Btu) that leaves is one less Btu to keep the fire going. This is sometimes contradicted by the "Chicken Little" school of firefighting, which apparently believes that the sky can catch fire and the world will come to an end.
- *Heat being evolved from contents that are burning.* This is of secondary importance. This concept often comes as a surprise to those whose sole objective is to "put the wet stuff on the red stuff." Contents partially damaged are, in effect, totally destroyed. In fact, much of overhauling consists of throwing out partially or very limited damaged contents.
- *Heat being absorbed by contents or structural elements that will be ignited or caused to fail.*

> This heat is the most important heat to be removed. In the case of unprotected steel, failure can occur early in a fire and the consequences can be catastrophic.

The fire department's heat removal medium is water. It seems apparent that water should be used to remove the destructive heat from the steel. Unfortunately, there is a fairly widespread myth in the fire service that water should not be thrown on heated steel because of possible dire results—this is simply not true.

If the steel is elongating, the cooling effect of water draws it back to its original dimensions. Many drawbridges, elongated by the summer sun, refuse to go back into position until the bridge is cooled with water or diminished sun. If the steel is failing, the water simply freezes it in whatever shape it is currently in. When these statements were published in the first edition of this text in 1971, they were questioned by several people. The American Iron and Steel Institute assured that this was correct.

A Texas fire department was observed fighting a fire in a steel hay shed. All attention was given to throwing water on the hay. No attention was paid to cooling the steel, and the shed was severely damaged. There is no value in burned, wet hay.

Definitions

Some necessary definitions of steel construction members are given here:

- **Angles**: These steel members have two legs at right angles to one another. They are L-shaped in cross section.
- **Bars**: Plates fewer than 6 inches in width. Bars are also made square or round.
- **Box columns**: Large hollow columns built from steel plates.
- **Box girders**: Square or rectangular steel girders that are hollow, like box columns, and used to support other beams in buildings. Large box girders are used to construct bridges Figure 10-2.

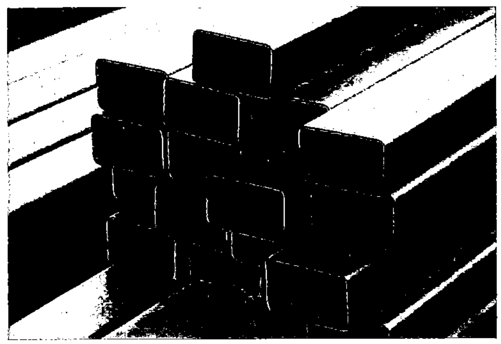

Figure 10-2 A set of rectangular box girders.

- **Castellated beams**: Wide flange beams that have been cut in half in a zig-zag pattern and then welded back together offset, creating new, deeper beams Figure 10-3.
- **Channels**: Steel structural components that have a square U-shape cross section.
- **I-beams**: Beams shaped like the letter "I". The top and bottom of the "I" are called flanges and the stem is called the web. The top flange resists compression, while the bottom flange resists tension. The web is necessary to keep the top and bottom apart. This principle has been copied in lightweight wooden I-beams. Composite beams also exist that include wooden flanges and corrugated steel web.
- **Plates**: Flat pieces of steel.
- **Purlins**: Beams, usually channels, set at right angles to trusses or roof rafters to provide support for lightweight roofing.
- **Rolled or built-up members**: Steel structural members can be either rolled or built up. Rolled members are one solid piece of metal. Built-up members are made up of different sections riveted, bolted, or welded together. A girder built from steel plate with angles riveted on each side of the top and bottom to form flanges is often called a plate girder. A column made of vertical units connected with

Figure 10-3 A castellated beam in a parking garage.

Courtesy of Glenn Corbett.

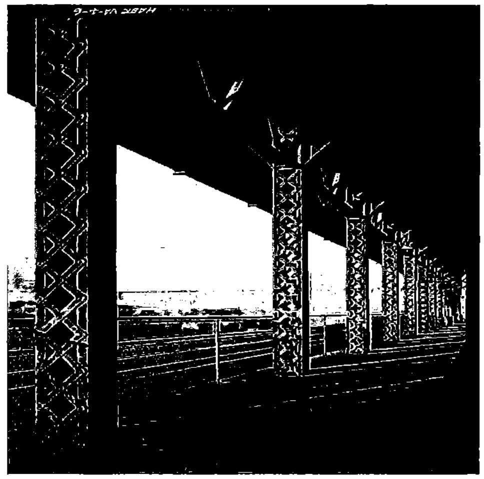

Figure 10-4 A lattice column.

Courtesy of Jack Boucher/Library of Congress.

diagonal pieces is called a **lattice column** (Figure 10-4).

- **Spandrel girders**: Girders that tie wall columns together in a framed building. They also carry the weight of the panel wall, which can be considerable when masonry is used. In addition, spandrel girders sometimes are connected to the columns and stiffened to help resist wind shear.
- **Tees**: A standard I-beam cut lengthwise through the web forms two such beams with T-shaped cross sections. If the end of the cutoff web is thickened, it is called a **bulbtee**.
- **Tubes**: Steel structural members that are rolled in cylindrical, square, or rectangular shapes. They are most often used as columns. Some circular steel columns can be made fire resistive by filling them with concrete. There are hazards with these Lally columns.
- **Wide flange shapes**: I-beams that have flanges wider than those found in standard I-beams (Figure 10-5). Some are H-shaped and, because they are square, are more suitable for columns. The letters "WF" are part of the designation of wide flange shapes.

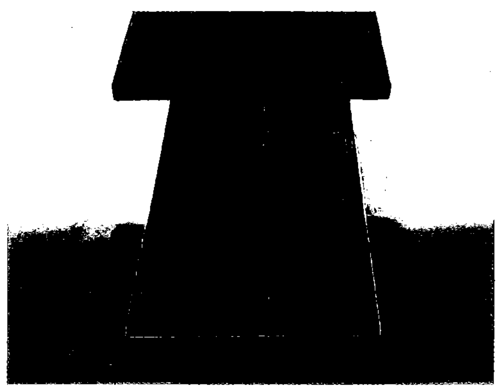

Figure 10-5 Wide flange beams have more structural support than do standard I-beams.

Courtesy of Jason Roe, All Metals Incorporated.

- **Zees**: Members with a Z-shaped cross section. They are not often used in structures. Short lengths of "Z" sections, fitted over the edge of a subway platform, provide a base to shift a subway car away from the platform. As steel technology developed, mills were built that could roll larger and larger sections. Therefore, built-up structural members of a size for which rolled members are used today are typically found in older buildings.

Steel as a Construction Material

Often the first structure that comes to mind when steel is mentioned as a construction material is the high-rise building. The development of steel framing as an engineering technique made it possible to erect tall buildings. The combined use of steel and concrete in high-rise buildings is discussed in the chapter on specific occupancy-related construction hazards.

The variety of steel shapes available has led to a specific nomenclature for specifying structural steel members. The following abbreviations are used for different-shaped steel members:

- C: channels
- CB: castellated beams
- L: angles
- S: America Standard (I-beam)
- W: wide flange beams and columns
- WT: structural tees

In addition, these abbreviations are used along with a set of numbers on architectural blueprints to designate a member of a specific size. The first number in this set refers to depth of the member (in inches), while the second number refers to the weight of the member per foot of length (in pounds), for all shapes except angles. For example, W 12 × 96 designates a wide flange beam or column that is 12 inches deep and weighs 96 pounds per foot of length. Remember the importance of the depth of a beam—the deeper it is, the larger the load it can carry. In the case of angles, three numbers are used to identify the steel member. The first two refer to the nominal depths of the two "legs," and the last number refers to the thickness of the legs. For example, an angle designated L5 × 3 × 0.375 indicates an angle with two legs, one measuring (nominally) 5 inches and the other 3 inches. The two legs are each 3/8″ (9.5 mm) thick.

The strength of steel, the consistency of its structural characteristics, and its ability to be connected to other structural elements so that loads can be adequately transferred are all important to the use of steel as a building material. Only a few specialized buildings, such as fiberglass buildings that are "invisible" to electromagnetic radiation or less affected by corrosive atmospheres, are built without steel.

The effect of fire on steel can be crucial to the stability of almost any building during a fire. Steel fire escapes are provided on many buildings. If they are in good condition, they can be useful not only in the evacuation of occupants, but also for fire department access. Steel reinforcing bars and cold-drawn steel tendons are vital to concrete construction in providing the tensile strength that concrete lacks. Steel is also used in concrete flooring systems. Corrugated steel provides "left in place" forms, which are often designed to react together with the concrete under load, thus forming a composite.

Steel is used to repair failures in concrete buildings. Even when a building is required to be fire resistive, the added steel is often improperly installed. In one case, an alert fire fighter noticed unprotected steel columns being installed and painted to match the walls in a fire-resistive-rated concrete mall. The building department was notified but did nothing for years, until a building permit was requested for another job.

Steel Buildings

Steel framing is used for many commercial and industrial buildings, usually of one-story construction. To achieve a peaked roof, the framing may consist of columns and beams with triangular trusses. The columns may support deep parallel-chord trusses spanning wide areas, with smaller trusses, often called **bar joists**, spanning the main trusses to support a flat roof **Figure 10-6**. Space frames (three-dimensional trusses) provide huge clear spans in some modern buildings.

Figure 10-6 Roof bar joists.

Courtesy of Glenn Corbett.

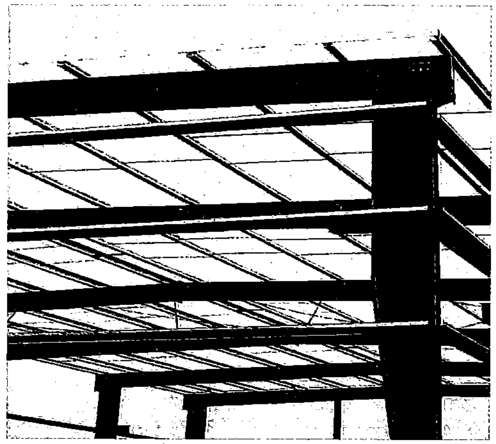

Figure 10-7 In the rigid frame, the column is narrow at the base and tapers to its widest point at the top where it meets the roof rafter. Note the lightweight purlins on top of the rafter (acting as a girder), which will support the roof deck.

The steel in such buildings is almost universally unprotected. At best, such buildings can only be classified as noncombustible. In fact, steel is rarely protected from the effects of fire until the building is of such height or size (or occupancy in some cases) as to be required by law to be fire resistive.

Protected noncombustible sprinklered construction is found more commonly. In such buildings, major structural elements are provided with some fire resistance, but not enough to qualify the building as fire resistive. The concept is that the protected members will resist collapse until the sprinklers can control the fire.

Rigid frames are a cousin to the arch and are used to achieve wide clear spans. In the rigid frame, the column is narrow at the base and tapers to its widest point at the top where it meets the roof rafter (beam) Figure 10-7. This rafter is also tapered so that it is narrow at the ridge and wide where it joins the column. It is the specific type of connectors—which resist movement—that gives this type of structural frame its rigidity. This wide haunch resists the outward thrust of the roof. Rigid frames are sometimes tied together under the floor to keep the legs from moving outward. If there is a basement, and the ties are exposed to a basement fire, failure of the ties may cause failure of the building.

Rigid frames can provide clear spans of about 100 feet (31 m). The area of the structure can be increased indefinitely by using Y-shaped columns, common to both frames. If such a column is distorted by fire, the area of damage may be doubled. Rigid frames can also be built of reinforced concrete or laminated wood.

Many steel-framed buildings are prefabricated. The Butler Company is a prominent manufacturer of steel "prefabs." Such buildings are often referred to as "Butler buildings," regardless of the manufacturer. Originally, the lightweight steel-framed building was exclusively for industrial use, but in recent years, schools, churches, and many other types of buildings have been built with similar designs Figure 10-8.

Huge Spans

When huge spans (in some cases, well over 100 feet [31 m]) are achieved by using rigid frames, trusses, or space frames, collapse can be sudden and tragic. In buildings with huge spans, adjacent bents are

Figure 10-8 This Washington, D.C., Fire Department reserve apparatus building is a Butler building, incorporating an exterior insulation finishing system (EIFS) and masonry into the exterior walls.

Courtesy of Butler Manufacturing.™

tied together to resist wind load. Tying the steel units together, however, means that if one part of the building is distorted by fire, torsional or eccentric loads beyond the designed capacity may be placed on the balance of the building. This can start the progressive collapse of the building, often far beyond the area involved in fire. As a matter of fact, the better the building is tied together to resist wind load, the more likely it is to suffer progressive collapse due to fire distortion.

Designers are working wonders in developing wide-span trusses made up of very light sections. Recently, a hangar was built in Spain with a span clearing 787 feet (239.9 m), 272 feet (82.9 m) deep. The push to design large open areas with a minimum of mass is fraught with the potential for disaster. Designs may be pushed beyond the limits of steel. Hasty field changes or errors in construction can have catastrophic consequences. The weather-related collapses of the C.W. Post Auditorium in 1978, a 171-foot-span (52.1 m) steel and **aluminum** space dome located on Long Island, New York; the Hartford Civic Center in 1978, a 300-foot-span (91.4 m) steel space frame; and the Kemper Auditorium in Kansas City, Missouri, in 1979, a 324-foot (98.8 m) steel truss roof suspended from a space frame, caused no fatalities. Considering the thousands of people who had occupied these buildings, it is easy to see that there was a disaster potential that could dwarf the problems faced by rescue personnel in the Kansas City Hyatt Regency Hotel skywalk collapse in 1981, in which 113 people died and 186 were injured.

Very deep parallel-chord trusses have been used as floor beams in hospitals. Engineers borrowed a medical term and called the space produced by such trusses **interstitial space**. The hazard of such huge spaces is the temptation to use them for storage, maintenance shops, and the like. Such voids are dangerous. Automatic sprinklers should be required in them.

Heavy parallel-chord trusses have been used as **transfer beams**. A transfer beam is used to laterally relocate the vertical load of columns to clear an area, such as in a hotel ballroom. The trusses are often hidden in partition walls or ceilings.

There are also true trussed arches. The arch of a steel-arch bridge is often a truss. The arch is a compression structure. In this unique case, the top and bottom chords are both under compression.

Exterior Walls of Steel-Framed Buildings

A steel-framed building can be provided with a variety of walls. Some common wall materials and their fire characteristics are described here:

- **Cement-asbestos board**: This material is noncombustible and is often used for friable construction. Friable construction is used where an explosion is a possibility. It will break away readily, relieve the pressure, and not provide missiles during an explosion. Although such a scene appears to have great devastation, the loss is much less than would occur in a building that was not designed to resist the blast (e.g., regular construction). Concern for asbestos hazards may require monitoring before overhauling or investigating a fire where cement-asbestos board is involved. (Transite™, a trade name of such material, is often used as a generic name.) Some sandwich boards of cement-asbestos "bread" and low-density fiberboard "meat" are used in steel-framed buildings as well; fire can burrow into the fiberboard and smolder.

- **Glass fiber-reinforced plastics**: Although glass fiber is noncombustible, the resinous binder most often used with it is flammable. This is not generally known, and the material is often thought of as noncombustible. Some reinforced plastic panels with good fire characteristics are available, but they would not be permitted in buildings of noncombustible construction.
- Aluminum: This material is noncombustible, but has a low melting point and little mass per unit of area, so it disintegrates rapidly in a fire. This characteristic is not always a disadvantage. In some instances, it may provide needed venting and access for hose streams to the interior of the building.
- **Precast prestressed concrete panels**: Panels of this type are erected in large sections, and their collapse can be particularly hazardous to fire fighters. When you are examining buildings that use precast prestressed concrete panels, study the relationship of the steel frame to the wall. If the steel expands under fire conditions, will it deflect the wall section from the vertical? If deflected, will the wall section fall freely or will it be restrained from falling? Precast concrete panels formed the side walls of McCormick Place, the large Chicago exhibition hall destroyed by fire in 1967. Distortion of the steel roof in the fire pushed the wall sections out of alignment and several of them collapsed.
- **Masonry walls**: The most common walls for unprotected steel-framed buildings are made of concrete block or a composite of concrete block and brick. Natural or artificial stone walls are also seen. Usually, the walls are only curtain walls. The exterior surface may show unbroken masonry; the interior wall may show panels of masonry between steel wall columns whose interior surface is approximately flush with the masonry. In other designs, the wall is independent of the steel frame and is tied to it only for wind resistance. Occasionally in framed construction, one wall, or part of one wall, is a bearing wall. In either case, it is important to analyze the effect of the expansion of the steel frame on the wall. For instance, if a girder rests on a bearing plate, it may be free to slide and, therefore, will disturb only masonry above. In contrast, a beam tied to a girder that is incorporated longitudinally into a wall may, by pushing on the beam, bring down all or a substantial part of the wall.

  Sheet steel-walled buildings are sometimes "improved" by covering the steel with a brick veneer. Any movement of the steel would likely bring down the brick because its stability depends entirely on the steel. The signs of masonry deterioration, which were mentioned in the chapter that discussed ordinary construction, are equally important in the steel-framed building. However, the absence of deterioration does not decrease the possibility of collapse of the masonry. A very probable cause of collapse is a steady lateral push by expanding steel.
- **Galvanized steel walls**: These walls are an industrial standby in applications where heat conservation is not important. Sometimes the metal is weather protected by an asphalt coating—so-called **asphalt asbestos protected metal (AAPM)**, often called Robertson protected metal (RPM), one proprietary name. The tar coating is combustible and would not be permitted in noncombustible buildings.
- **Metal panels**: Prefabricated metal panels are often made up in a sandwich construction to provide one unit combining thermal insulation and interior finish (Figure 10-9). In earlier construction, low-density fiberboard will be found. Later, mineral and glass fibers were used. Today, plastics are most often employed for this purpose. Even when the outer layers are noncombustible, the insulation, vapor seal, or adhesive in the panels may be combustible. It may be necessary to open such panels far from the main

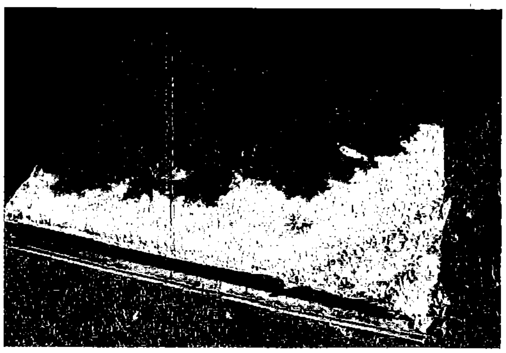

Figure 10-9 A damaged insulation panel from a cold storage building fire composed of polyurethane with metal cladding.

Courtesy of Glenn Corbett.

fire area if the interior of the panel becomes ignited. It is recommended that fire fighters overhauling such a structure work slowly and patiently, and cut with a circular saw rather than with an axe to avoid excessive destruction.

In one type of construction, polyurethane insulating panels are protected by gypsum board and stainless-steel sheathing. It is quite possible that, many years hence, alterations will be undertaken by persons not aware of the insulation. A cutting torch may be used, and a smoky, destructive fire may result.

Aluminum sandwich panels with foamed polyurethane are also available. Underwriters Laboratories, Inc. lists some of these materials as having low flame spread ratings, but their "smoke-developed" ratings may be quite high. Metal wall panels can be used on any framed building and, in fact, are used on many concrete buildings.

The design of panel walls, the method of installation, and the degradation of insulation or expansion of metal under fire conditions are some of the reasons the closure of the wall panel to the floor slab can fail and permit the extension of fire from floor to floor. This can be particularly significant in high-rise buildings beyond the range of effective ground attack.

Prefabricated metal panels forming the front wall of some motel rooms have neoprene gaskets between the panel and the wall separating the rooms. A fire in one room would quickly destroy the gasket and extend toxic gases and fire to the adjacent rooms.

- **Light gauge steel-framed wall**: The use of lightweight galvanized steel studs for exterior walls has surged (Figure 10-10). Shaped like the letter "C," these studs are held in place with U-shaped tracks on top and bottom. A variety of exterior finishes are applied to these steel-framed walls, including brick veneer, EIFS, and stucco. In some cases, these walls are load bearing.

High-Rise Framing

For many years, steel framing stood unchallenged as a method for high-rise buildings. (This statement applies to both "short" high-rises of Type II noncombustible construction and "tall" high-rises of Type I fire-resistive construction.) In recent years, concrete

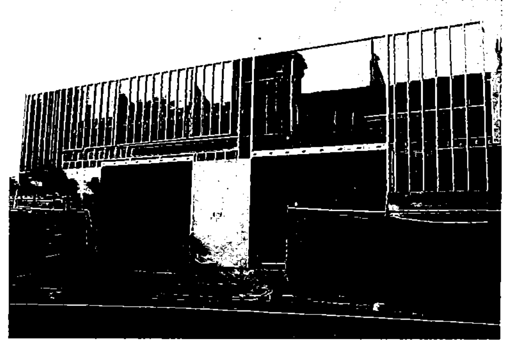

Figure 10-10 A light gauge steel-framed exterior wall under construction.

Courtesy of Glenn Corbett.

is finding more use for framing high-rise buildings, and the two materials compete. In Chicago, the reinforced concrete South Wacker Tower is 946 feet high. The principles of construction are the same, however, and much of what is discussed here applies equally to concrete-framed high-rise buildings.

When steel-framed buildings were first built, builders were hesitant about publicizing the fact that it was the frame that supported the building. Traditionally, most people associated strength and permanence with solid masonry. Consequently, tons of brick, stone, and terra-cotta, all structurally unnecessary, were loaded onto framed buildings. The heights of buildings were also suspect. Rather than arrange the exterior so that vertical lines led the eye upward, as is common today, buildings were belted with masonry corbels or trim. Different materials were used on successive floors, and all possible architectural devices were used to reduce the apparent or perceived height of the building.

The masonry served another purpose in early construction. The **spandrel space** (the distance between the top of one window and the bottom of the one above) was made of masonry. It was sufficient to prevent the extension of fire from floor to floor on the outside.

Today, the pendulum has swung the other way. Glass and metal exterior panels are common, and the firestopping capabilities of such members are dubious. High-rise buildings should be evaluated for the dependability of perimeter firestopping. Tactical plans should be developed to deal with the problem.

Tilt Slab Hazards

There is special hazard in tilt slab construction (also known as tilt-wall construction or tilt-up construction)—that is, buildings in which the roof holds the tilted-up concrete wall panels in place (Figure 10-11). This method of construction is found in industrial buildings that are very popular around the country. When these structures are being constructed, the builder carefully braces the walls with tormentors or braces. This is required for stability until the roof is in place and tied in, thus stabilizing the building.

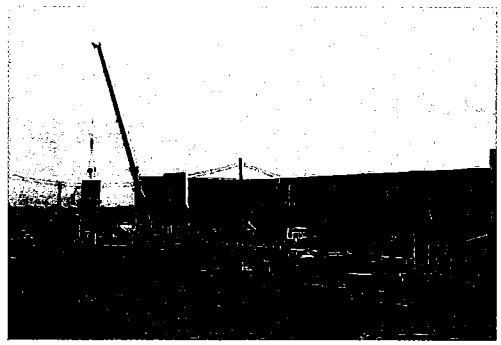

Figure 10-11 Precast wall panels, delivered to the construction site on a flatbed trailer, being lifted prior to being "tilted" into place.

Courtesy of Glenn Corbett.

Although a roof of steel joists is the most common, the roof may be of any type of construction. If the roof is being lost in the fire, however, fire fighters should be wary of wall collapse, as has happened in warehouses from California to New Jersey. Wood roofs may simply burn away, leaving the concrete panels freestanding as a vertical cantilever. Concrete may spall from the bottom of T-beams, exposing the tendons to their failure temperature. Steel may elongate significantly before failing. This elongation may push the walls down.

In tilt slab construction, examine openings in the wall carefully. Ordinary-size doors are usually placed in an opening cast into a panel. Loading doors may take the full width of a panel. The concrete panel above may be suspended from the roof and subject to collapse.

If the building is sprinklered, make careful observations of the density and volume of smoke. If heavy smoke is being generated, then the sprinklers are probably not controlling the fire, and the roof is vulnerable. Massive and, in some cases, total-loss fires in a number of sprinklered warehouses have been especially disturbing to those familiar with the exemplary record of successful sprinkler operation.

Steel-Framed Buildings Under Construction

Except for the problem of breaching shear walls around elevator shafts, the method of wind bracing in a building is of no concern to fire fighters after the building is completed. While the building is under construction, however, wind forces must be resisted because the building is not fully connected. Often, cables are strung diagonally across the steelwork, and at times these braces are not properly installed. If there are no high winds, nothing happens.

Plastic Design in Steel Construction

In an effort to seek economical steel design and to compete with concrete, plastic design has been developed. The typical steel-framed building is pinned. In a pinned building, loads are delivered to the nearest columns. In plastic design, the connections are built to transfer loads beyond the column. This is analogous to monolithic construction in concrete. Because of the rigid connections, a load that might be locally excessive is redistributed over the structure. As a result, the weight of steel in the building can be decreased. Beams are lighter and columns are smaller than they would be otherwise. This is of more than academic interest. The lighter the steel, the less fire resistance. Thus, the provision and maintenance of adequate fireproofing for the steel is even more important in a plastic designed building than in one of conventional design.

More on the Fire Characteristics of Steel

Steel Conducts Heat

The fact that steel transmits heat is well known. A suit of armor is noncombustible—but no one would ever attempt to fight a fire in it. Despite this, many building codes previously required so-called **tin ceilings**, which are actually embossed steel, in certain occupancies (Figure 10-12). These can transmit fire in either direction.

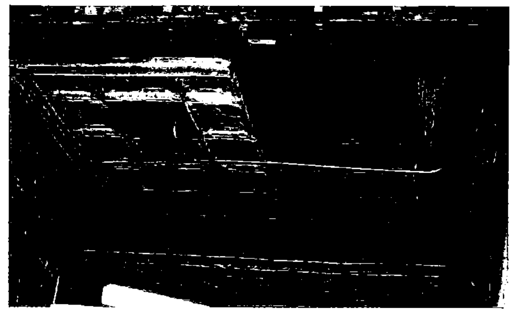

Figure 10-12 Although tin ceilings are typically installed in Type III ordinary construction, they illustrate the heat transfer characteristics of metal.

Courtesy of the estate of Francis L. Brannigan.

In earlier years, sheet steel doors were commonly used on vaults, some of which still guard valuable governmental and private records. The chief disastrous result of using steel doors could be the loss of records. Across the country, businesses and homeowners alike seem to rest secure in the knowledge that their vital records are "protected" in uninsulated steel files. Tin boxes are often sold in stores as fire-resistant chests.

The conductivity of steel can be a factor in spreading fires. For example, heat was conducted through **steel expansion joints** in a concrete floor at a fire in a multistory post office. Mail bags resting on the joints in the concrete floor were subsequently ignited by the heat.

In many cases, steel sheets directly attached to combustible surfaces to provide fireproofing have acted to transmit or retain heat. In one case, a steel plate was attached to the wood-joisted ceiling above the end of a rotary kiln in a building of ordinary construction. When it was ordered to be removed, plant personnel were surprised to find that all the wood behind it had carbonized to charcoal.

It is generally understood that metal smoke pipes that lead from a furnace or stove to a chimney or metal stock must have clearance from wooden members. However, this concept is often ignored in the case of other metal ducts that may have fire in them, despite requirements to the contrary. Grease ducts are a good example. A grease duct fire often extends to adjacent combustible construction by conduction.

Ships are not buildings, but the practice of using ships as buildings, like the Queen Mary in Long Beach, California, is growing. A number of ferry boats have been converted into restaurants. Ships have steel walls known as **bulkheads**. Many people associated with ships confuse noncombustibility with nonconductivity. Typically, welding operations will be performed on one side of a bulkhead without any concern for heat transmission through the steel to ignite combustible material on the other side. This can cause a problem when the other side is covered with wood paneling, which could be ignited from within the concealed space behind the paneling.

Self-storage facilities built of steel have many of the characteristics of ships (Figure 10-13). The Tualatin Valley, Oregon, Fire and Rescue Department fought a stubborn fire in a self-storage building that involved 97 units. Some of the units contained flammables and explosives. The fire spread from unit to unit by conduction and radiation. Scalding steam was generated when water hit the hot steel sheets.

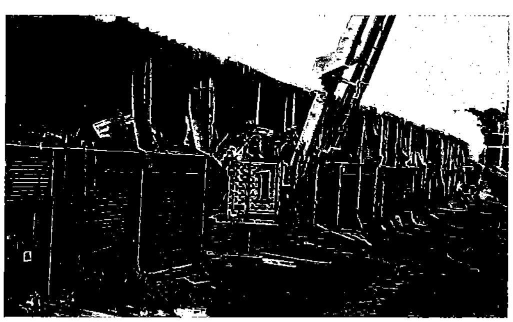

Figure 10-13 Self-storage facilities have similar characteristics to those of ships, including the extensive use of heat-conducting steel, allowing fire to spread from unit to unit through conductive heat transfer.

Steel Elongates

Steel will expand 0.06 to 0.07% in length for each 100°F (37.8°C) rise in temperature. The expansion rate increases as the temperature rises. Heated to 1,000°F (538°C), a steel member will expand 9 1/2 inches (24 cm) over 100 feet (30.5 m) of length. As you will see in the next section, at temperatures above 1,000°F (538°C), steel starts to soften and fail, depending upon the load.

Elongating steel exerts a lateral force against the structure that restrains it. If the restraining structure is capable of resisting the lateral thrust, the expanding steel structure may be even stronger, at least for a period of time. Some floor assemblies have a different fire resistance rating depending on whether they are restrained or unrestrained.

If steel beams are restrained, as by a masonry structure, and the temperature of the fire is sustained at around 1,000°F (538°C), the expansion of the steel may cause the displacement of the masonry, resulting in a partial or total collapse. A one-story commercial building in Dallas was constructed of concrete block walls and a steel-joist roof; the steel joists were restrained by the walls. A metal deck roof fire sent heat rolling through the roof void. Elongating bar joists pushed down the walls, dropping six fire fighters into the structure. Fortunately, all six were rescued.

In hot, fast fires, failure temperatures are reached rapidly and the lateral thrust against the wall is minimized. In a one-story and basement noncombustible building, a heavy girder was supporting a one-wythe-thick decorative brick wall in the reception lobby. There was a hot fire in the basement. The steel beam attempted to elongate but could not because of the presence of the restraint. It then took the only other course available to it to absorb the increased length—it twisted, dropping the wall completely across the lobby. Fortunately, no one was in its path. This overturning can be anticipated when unprotected steel girders are used to support wooden floors in combustible buildings.

Steel Fails

When steel is raised to temperatures above 1,000°F (538°C), it starts to lose strength rapidly (Figure 10-14). Temperatures above 1,000°F (538°C) are quickly reached in fires. Recognizing this, the standard fire test used to test building materials and assemblies (described in the American Society for Testing and Materials [ASTM] E-119) reaches 1,000°F (538°C) in 5 minutes. Recent tests conducted by the National Institute of Standards and Technology (NIST) of a typical basement room fire reached 1,500°F (816°C) in 5 minutes, reflecting the presence of today's heavy plastic fire loads rather than any special significance of basements.

In standard fire tests of the fireproofing of steel columns, the column fails when a temperature of 1,200°F (649°C) is exceeded at one point or 1,000°F (538°C) is exceeded on the average in the column. How fast the fire temperature will be achieved in the steel varies. The principal variable is the weight or mass of the steel unit. For instance, a bar joist or lightweight steel truss will absorb heat very rapidly. In a fire equivalent to the standard test fire, the bar joists generally will fail in about 7 minutes. In one observed fire in a one-story and basement bar-joist building, the bar joist–supported floor was collapsing before the people could get out of the first floor. Very heavy steel sections might have survived longer. Fireproofing is sometimes found in low-rise multistory buildings and certain occupancies of Type II construction.

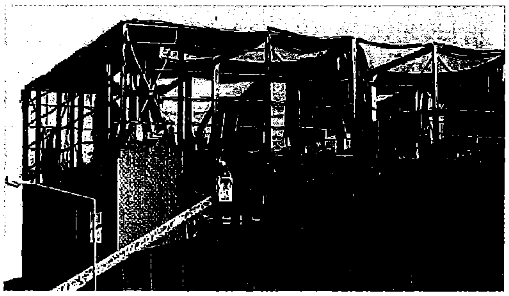

Figure 10-14 Steel will begin to lose its strength at temperatures of 1,000°F (538°C).

The amount of ventilation may also be a significant factor. It appears that if a fire is well ventilated, the temperature in the steel may be less than if the fire is confined. This may help to explain observed differences in the effect on steel in different fires. The heavier the steel is loaded, the faster it will fail.

Overcoming the Effects of a Fire on Steel

A number of options are open to the designer to deal with these characteristics of steel as they relate to fire risk:

- Ignore the problem.
- Rely on inadequate code enforcement.
- Take a calculated risk.
- Protect (insulate) the steel.
- Protect the steel with sprinklers.
- Protect the steel with an internal water cooling system.
- Locate the steel out of range of the fire.

Ignoring the Problem

The potential for fire damage to steel buildings is not clearly understood. Often, unwarranted confidence is placed on the fact that the steel is noncombustible. A major insurance carrier found it necessary to conduct demonstrations of actual fires for plant managers in which the only fuel was the hydraulic oil in presses to show the seriousness of the fire problem to plant managers without any fire experience.

In one case, a metal building intended as a site for thawing frozen drums of uranium residue was under construction at an atomic energy facility. The shed and all the roller conveyors were destroyed by a fire. The only fuel was the 1-inch fiberboard lining of the building. The builder was astonished—and chastened: he had been so convinced that there was no fire problem that he had not insured the job.

Steel Highway Structures and Bridges

Bridges and overpasses on highways provide a good example of unprotected steel that is vulnerable to an occasional gasoline or oil truck fire. Such fires can result in enormous damage, possibly accompanied by major traffic disruptions. A bridge on the Trans-Canada Highway in Nova Scotia was damaged when struck by a fuel truck that exploded. The bridge was out of service for 69 days and the repairs cost $350,000.

The Chicago Fire Department fought a truckload of magnesium on fire under a concrete overpass. The structure was protected by hose streams as the fire burned out. The bridge was saved.

Seventy years ago, when prefire planning was generally unknown, the New York City Fire Department developed very specific preplans to get water as soon as possible onto fires on the East River bridges, recognizing the vulnerability of the unprotected steel. If assigned units are unavailable when incidents involving these bridges occur, the dispatcher must cover them and notify the replacement units of their specific function to be performed.

The Hazards of Concentrated Fire Loads

Even when average fire loads are low, an unprotected steel building may be endangered by a highly concentrated fire load in one area. Occupants then break up the big open space to meet operation needs. Although unprotected steel industrial buildings are usually only "one-high story," it is not uncommon to find a mezzanine built into the building to provide office or storage space.

The term *one-high story* is used to designate buildings of greater than usual height from floor to ceiling. A description such as "one equals five" describes a one-story building of a height equal to five ordinary stories. Often a mezzanine within such a building is built entirely of wood (not permitted in a noncombustible building but often done without a building permit). Where problems such as noise, temperature, pilfering, or privacy exist, structures may be built within the building to provide office space, lunch rooms, a controlled environment, privacy for secret processes, or security for valuable merchandise. Unfortunately, such structures are often combustible. The structure then represents a hazard not only to the building, but also to the contents that it is designed to protect.

Experiment halls at research facilities are often built of lightweight steel construction to provide the greatest free floor area at the least cost. The steel is usually unprotected; the fire load is expected to be minimal. In recent years, however, the practice of purchasing ordinary house trailers to use as offices or to house telemetry equipment inside such halls has grown. From the fire protection point of view, they provide a serious potential source of heat. When grouped closely together, the trailers represent exposures for one another, increasing the possibility of a serious loss in the event of a fire.

Prefabricated metal buildings are sometimes used in place of the trailers. Often these are of sandwich construction with an insulator placed between the inner and outer walls. The nature of the insulation should be determined. Many kinds of insulation present severe fire problems.

Excavation Bracing

Because of the requirement for underground parking, building excavations are now being made much deeper than in previous years. When a hole is opened in the ground, the earth under the adjacent structures may tend to shear sideways into the hole, causing a structure to collapse. Often it is necessary to shore up the excavation. Such shoring literally holds up the neighborhood.

Rows of vertical steel beams called soldier beams are driven into the ground. They are tied together by a horizontal beam called a **waler**. Diagonal columns called **rakers** brace the entire structure. These columns may be loaded to twice the load that would be permitted if they were permanent structures. They are, therefore, subject to early failure in a fire—and the consequences of such a failure could be catastrophic.

An excavation is often loaded with combustibles, such as plywood, plastic, and fuel. This array of rakers is a nuisance in the erection of the building. If ground conditions permit, tiebacks are used. With this technique, cold-drawn steel cables are inserted in holes driven into the rock and anchored with epoxy. They are then tensioned, similar to posttensioned concrete. The end of the cable sticks out, so it can be easily heated in the event of a fire. If the tensioned portion of the cable reaches 800°F (427°C), it will fail.

The unprotected steel tower crane is similarly vulnerable. This hazard does not appear to be covered in any code, but it should be explained to the building department and to the builder. "Nothing like that has ever happened. You guys are always thinking up busy work," is a likely response to this warning. However, the fire department will be in a much better position if the disaster occurs.

The Redmond, Washington, Fire Department, with the help of mutual aid units, fought a fire in a fire-resistive concrete building under construction. The fire heated the tower crane and put it as much as 4 inches out of plumb. If uncontrolled, this shift in balance could have caused a collapse. Heavy hose streams reduced the out-of-plumb gap to 2 inches, averting such a disaster.

Buildings Under Construction

During construction, steel that will later be fireproofed may be unprotected for extended periods.

When the first World Trade Center was under construction, original plans to use fire-retardant treated plywood for formwork were scrapped in favor of ordinary plywood and $1 million in savings. When fire protection of the project was discussed at a National Fire Protection Association (NFPA) meeting, the Chief of the New York City Fire Department, John O'Hagan, warned the Port Authority of New York and New Jersey about the hazard of such a "7-block-long lumber yard" to the structural steel of the World Trade Center. Fortunately, no fire occurred.

Relying on Inadequate Codes

Building codes generally classify steel buildings as "unprotected noncombustible," or "protected noncombustible." In this latter case, major columns and beams have some protection. The word *protection* is often confused with *sprinkler protection*, but actually refers to physical protection of the steel with gypsum board, spray-on fireproofing, or the like.

In studying a potential fire in an unprotected steel building, the first consideration should be the basic type of construction. Column, girder, and beam construction is used for both single-story and multistory construction. If a masonry bearing wall is substituted for some of the exterior columns, the building is wall bearing. Column and girder buildings are characterized by relatively short spans, so the failure of one column may affect only one portion of the building. As with all such generalizations, however, watch for the exceptions.

A Maryland church is built of steel columns that support steel roof trusses. The roofing is wood. The 40-foot-high curtain walls, which do not carry the load of the roof, are composite brick and block. Should there be a severe roof fire, the heat absorbed by the roof steel would cause it to elongate, pushing the columns out of alignment. The moving columns might bring down the walls.

Another unfortunate assumption about fires is that they will only burn upward. Fuel in a church balcony might include hymn books and cushions of foamed plastic. A fire in these fuels would readily burn down into the void. A fire involving the wooden balcony or the metal deck roof could well cause the steel framing to move and thus cause one of the brick-veneered walls to fall. A well-advanced fire in such a structure should be treated with caution.

Steel High Above the Floor

In some building codes, steel used to support roofs at a certain distance above the floor (usually about 20–30 feet [6–9 m]) does not require protection. Atria roofs over 55 feet (16.8 m) are given this exemption as well. It is generally believed that flame impingement is not likely at this height. The concept is probably valid if there is no significant fire load in the area below the steel. Such a situation is unlikely, however. For example, the situation that existed at Chicago's McCormick Place is far more common.

The McCormick Place Fire

McCormick Place was a huge Chicago exhibition hall built in 1960. It burned on January 16, 1967, with a loss of $154 million (Figure 10-15).

The main exhibit area of McCormick Place provided a clear area of 320,000 square feet (29,729 m^2). The roof was supported on 18 steel trusses, each 60 feet (18.3 m) on center. Each truss had a 210-foot (64 m) central span and a 67-foot (20.4 m) cantilever on each side from the column to the exterior wall. The trusses were 16 feet (4.9 m) deep at the column, tapering to 10 feet (3 m) at the center of the building. They were made of heavy steel members.

The columns were trusses themselves. In accordance with the previously mentioned provisions common to many building codes, the columns were fire protected up to a height of 20 feet (6.1 m) above the floor. The roof trusses were unprotected.

The exterior walls consisted of freestanding steel columns supporting precast concrete sandwich wall panels. The sandwich consisted of concrete interior surfacing, foamed plastic insulation, and exterior sculptured concrete.

Figure 10-15 The 1967 Chicago McCormick Place fire.

At the time of the fire, preparations were being completed for the exhibit of the National Housewares Manufacturers Association. Exhibit booths crowded the floor, with some exhibits being two stories high. The fire loading at the same time has been estimated at 80,000 to 120,000 Btu per square foot. In addition, the combustible material, both by nature and arrangement, was fast burning, and provided a high rate of heat release. Fortunately, the fire started in the early morning hours. The loss of life might have been staggering had the fire occurred during the day.

The fire was discovered early, but soon spread beyond the capabilities of the maintenance employees. There was about a 6-minute delay in the alarm. A second alarm was transmitted on arrival. The first-due engine company had penetrated the hall a few feet when they heard a great roar as the flames approached. At this time, their water supply failed. It became known later that the hydrants in the area that were out of service were the responsibility of the exhibit hall management. In retrospect, at least one close observer thought this was a blessing. Had the water been available, it would have made little or no difference to the loss, but it is possible that a number of fire fighters would have been in serious danger while advancing lines into a collapsing building.

Within a half hour after the start of the fire, portions of the massive roof trusses began to fail. The failing trusses pushed out a number of the wall panels, making close approach hazardous. Several of the panels collapsed.

Based on the size and occupancy classification of the building, the construction of McCormick Place apparently met the fire protection requirements of the Chicago Building Code and most other widely recognized building codes. Most contemporary codes would classify the building as an assembly occupancy. However, at the time of the fire, it more closely resembled a mercantile occupancy such as a department store, discount house, or shopping center. In this type of occupancy, different fire protection measures would have been required by most modern building and fire codes.

If McCormick Place was viewed as a mercantile occupancy, modern building codes would have required a building of this size to be equipped with an automatic sprinkler system throughout. Additional or supplementary fireproofing of the structural members would not have been required.

Automatic sprinklers installed throughout the exhibit areas probably could have limited the spread of this fire and enabled the fire department, with a properly operating water supply, to bring it under control with a minimum of damage.

A building that can accommodate 50,000 people and is the equivalent of a tinder-dry forest cannot be protected by mere compliance with codes that did not contemplate such a building. Neglecting installed equipment and assuming that employees would take proper emergency action also critically affected fire protection at McCormick Place. At least this point became apparent after the fire. But how apparent is it to your local armory, hotel ballroom, or exhibit hall management? Is your fire department satisfied that the extent of their responsibility is to see to it that all "rubbish" is removed and all fire code "exhibit" requirements are being met?

The New McCormick Place

In the new McCormick Place, structural steel is protected with directly applied fireproofing delivering 1-hour fire resistance. The entire building, except electrical enclosures and enclosed stair towers, is sprinklered. Sprinkler systems protecting the high fire load exhibit area are hydraulically designed to deliver 0.30 gallons per minute (gpm) (1.1 Lpm) per square foot over areas as large as 6,000 square feet (557.4 m^2). Ninety-eight percent of the floor area can be reached with 100 feet (30.5 m) of hose from standpipes. Elaborate provisions have been made for smoke venting. Supervisory control has been provided for water supply. Training programs for employees and prefire planning with the Chicago Fire Department are provided.

Important Test Experience

Testing undertaken at Underwriters Laboratories, Inc., in the aftermath of the McCormick Place fire examined whether sprinklers would have controlled the fire. The data developed in these tests is worth examining, especially as it relates to the temperatures developed at quite ordinary fires.

The fire tests were conducted in a building 30 feet (9.1 m) high, the height above a floor at which it is presumed that steel in the roof needs no protection. The fuels used were lightweight, readily combustible materials typical of those used for exhibition hall displays. Plywood, tempered hardboard, cardboard cartons, and packing materials made up the fire load average of 20 pounds per square foot. The materials had a high surface-to-mass ratio and thus would produce a fast, hot fire. The display material was set up over a 20 by 30 square-foot (6.1 m by 9.1 m) area. Thus, the total weight of combustibles was about 12,000 pounds (5443 kg), which would yield almost 100 million Btu if completely consumed. This was a rugged test, but not unrealistic.

The first of the test fires is of great interest. The plan was to keep the sprinklers turned off for 6 minutes after ignition, corresponding to the reported gap between ignition and time of discovery of the McCormick Place fire. The report gives no indication that even the experienced engineers running the test had any qualms about the plan of holding back the water for 6 minutes. After 5 minutes and 45 seconds, temperatures of 1,500°F (816°C) were recorded at the ceiling. The sprinklers were turned on at this time to avoid damage to the test facility.

Steel beam temperatures were monitored by thermocouples **peened** into the surface. A bar joist at the ceiling reached 1,540°F (838°C) and an I-beam reached 1,355°F (735°C) at a little over 5 minutes. Temperatures at the ceiling level exceeded temperatures in the booth area by a slight margin.

The fire load used in the test cited is not excessive in either quantity or rate of heat release. There are many unprotected steel buildings with such a great fire load that collapse will have started prior to the arrival of the fire department, even with prompt alarm and normal response.

Despite the McCormick Place fire and the tests cited above, buildings are still being designed in accordance with the concept that steel needs to be fireproofed only below a certain height. Plans should include the necessity of using hose streams to cool affected steel.

Taking Calculated Risks

The lack of fire protection for unprotected steel may reflect a calculated risk taken by the building's developers and managers. For our purposes, there are three classes of calculated risks:

- Financial or economic
- Engineering
- Forget it

The basis of the calculated risks must always be closely examined.

Financial Calculation

One calculation for a government-owned building went like this: This noncombustible building is of low value and is slated for demolition in the 5-year plan. In the meantime, it is used for the reserve storage of foamed plastic shipping containers. The value is low and the loss of the containers would not hamper production. The cost of any special protection could not be justified. "In case of fire—let it go."

Engineering Calculation

Here's an example of an engineering calculation: The fire load in this noncombustible building is minimal. Unpackaged noncombustible heavy metal sections are stored on pallets. The combustible load averages about 2 pounds per square foot and is dispersed. There is no apparent source of ignition. No special protection is recommended. This calculation is adequate.

The steel industry is in constant competition with the concrete industry. When steel is required to be fire proofed, the cost shows up as a line item in the budget. The cost of fire-resistive concrete, in contrast, is buried in the cost of the concrete. This gives concrete a competitive advantage.

Some steel-framed parking garages are large enough to require fireproofing under some codes. The steel industry conducted fire tests to demonstrate that steel-framed parking garages do not require fire protection of the steel. As a result, some codes permit unprotected steel to be used if a substantial portion of the garage is open to the air, which permits the escape of heat. This engineering calculation could not be applied to the parking garage in a Texas city in which the floors are supported on bar joists, rather than on heavy steel.

In another example, a steel garage was built over a railroad track that carried flammable liquid tank cars. It was decided rightly that the steel columns of the garage should be protected. This was done literally—the columns and steel directly at the track were protected. If a fire occurs, however, it will roll out beyond the protected elements and destroy the building. The same sort of questionable engineering was seen on a Canadian car–passenger ferry. Originally, a deck was fitted out with passenger cabins. The overhead steel in the cabin area was spray-applied with fire protection. The beams extended out to form the overhead of the outside deck, but this steel was not protected. When the cabins were removed to make more space, the entire area was enclosed. The newly enclosed steel was not protected. Thus, only half the length of each beam is protected; the other half is bare.

Forgetting It

In taking "calculated risks," keep in mind the well-known computer programmers' acronym GIGO—garbage in, garbage out. No calculation is any better than the information used in it.

Fire protection interests are often hampered by management obsessed with the short-term results. Industrial managers may defer fire protection expenditures to show a better quarterly profit picture. Politicians may vote to defer the expense of sprinkler installation to erect a new structure that will carry a bronze plaque.

Some managers are fond of using a calculated risk as an excuse to do nothing, particularly when the cost of providing protection interferes with other objectives. They get upset when it is pointed out, however, that they do the calculating while others take the risk.

Insulated Metal Deck Roof Fire Problems

In August 1953, the General Motors transmission plant at Livonia, Michigan, burned Figure 10-16. Its loss of $32 million was the largest industrial fire loss to that date. The metal deck roof was the principal contributing factor to the destruction of the plant.

Metal deck roofs consist of metal sheets laid over steel bar joists. The sheets are crimped together, making a joint that is not gas-tight. Usually insulation is added—often a low-density fiberboard, although plastics currently are making inroads into this application.

Insulation that has absorbed moisture is useless, so it must be protected from moisture driven through the roof by capillary attraction. An adhesive is also necessary to secure the insulation to the roof deck and to prevent loss of the roof covering in a windstorm. A bituminous (asphalt) coating serves as the adhesive and sometimes as a moisture-stopping vapor barrier. On top of the insulation are successive layers of bituminous (bitumen) material and roofing felt or fiberglass mats. From the presence of these successive layers comes the term *built-up roof*. While the construction of "hot applied" built-up roofs using tar kettles and hot asphalt still occurs, roofs of this type are now typically "cold applied" using fiberglass sheets with special adhesives. Some roofs are built with a layer of concrete laid on the corrugated metal and the roof built up above the concrete. Such roofs are not of concern here.

Figure 10-16 The Livonia, Michigan, General Motors fire in 1953.

In recent years, the "rubber roof" (composed of ethylene propylene diene monomer [EPDM]) has increased in popularity in Type II construction (although this roof may also be found in other types of construction). It is composed of a single ply of this rubber-like material (to minimize water leakage in the roof) laid over fiberboard and plastic insulation, held in place with metal fasteners, seam tapes, and flammable adhesives.

A five-alarm wind-aided fire in Brooklyn in the 1990s highlighted a number of problems with this construction technique, including the fire's ability to spread like a brush fire; burning sections of the roof were picked up by the wind and deposited downwind, starting new fires. The entire 750-foot (228.6 m) length of the roof was consumed in about half an hour. The lessons of this fire include the application of heavy-caliber streams ahead of the fire; checking for extension inside the building in the form of a flaming, dripping liquid coming through the metal deck seams and falling on to combustibles below (the same problem as a metal deck roof fire in a traditional built-up roof); the need to apply cooling streams to the underside of the roof deck to prevent this problem; and the significant safety concern of ensuring that no fire fighters are placed in the path of the fire.

Another relatively new type of roof is the modified bitumen ("mod bit") roof. In this construction technique, a traditional built-up roof is modified by the addition of synthetic polymers to reinforce the roof. The sheets of the roof may be laid down with adhesives liquefied by a propane torch; more recently, a cold application technique has been developed to lay down these sheets.

Approved roof is the accepted term for roofing that meets a testing lab (e.g., Underwriters Laboratories, Inc.) standards for roofing resistant to the propagation of fire from building to building by flying brands. A roof can be listed but still be a combustible metal deck roof—the two problems are entirely different. The listing points out that fire under the roof is not a consideration.

When a fire occurs below a combustible metal deck roof, the metal deck heats up. Tests show that exposure to a temperature of 800°F (427°C) for 5 minutes is enough to start the process. The heat is conducted through the deck to the bituminous adhesive; this adhesive liquefies and then vaporizes. The gas cannot escape through the roofing material, so it forces itself down through the joints in the deck. When the gas mixes with the air below, it ignites from the fire below.

Such a gas fire rolls along under the roof, heating additional roof areas, which generate more gaseous fuel. Almost unbelievable quantities of thick black smoke are generated. This type of fire becomes self-sustaining, independent of the original fire, and spreads rapidly in all directions.

The roofing insulation and some of the roofing felt may burn, showing fire on top of the roof. This is of little consequence; the problem is at the underside of the roof.

Two solutions are available to the builder to prevent such occurrences:

- Use Factory Mutual Class I roofing or a UL Classified Roof. These have been tested in accordance with NFPA 256 and will not provide self-sustained combustion—the problem with the ordinary combustible metal deck roof.
- Provide adequate automatic sprinkler protection for the roof, even though the contents may be noncombustible. If a ceiling is installed, the sprinklers must be located above and below the ceiling. Several buildings have sprinklers above and below the ceiling.

Fires of Interest

In 1985, U.S. taxpayers suffered a $195 million loss in a fire at a production building at Tinker Air Force Base in Oklahoma City. The fire was started by roofers. The sprinklers were below a wire lath and plaster ceiling. The water did not hit the underside of the roof deck, and the fire burned unimpeded. An attempt was made to cut the fire off by removing the built-up roofing, but the fire passed the cuts.

Even Class I roof construction, if combustible, may not always be acceptable. For example, a fire in a large concentrator building at the Wabush Mines complex in Labrador, Canada, badly damaged a metal deck roof 90 feet (27.4 m) above the floor. Investigators theorized that even if the roof had been of Class I construction, damage still would have been severe. Failure of unprotected steel supports undoubtedly would have let the roof sag, exposing to the fire asphaltic materials in the built-up covering over the roof insulation.

The term *Class I* may be taken to mean "completely satisfactory under all circumstances" by persons not fully familiar with this subject. If a Class I roof has any combustibles at all, it may not be satisfactory for use over a high-value installation, such as an area filled with computers. Total noncombustibility should be sought in such a case.

The Atomic Energy Commission (AEC) studied the problem of fire protection for thousands of acres of metal deck roofs covering some of the most vital production plants in the United States. Many proposals were examined. The final decision was to add sprinklers to the plants. Over $20 million was spent on sprinklers and water supply. A fire occurred in an AEC facility in Paducah in a sprinklered building; it was confined to the area of origin. The fire was a very hot chemical fire, and the sprinkler operation caused a steam cloud that rolled through the plant. Over 2,000 sprinklers opened, causing a water flow of millions of gallons. Thereafter, all sprinklers in these plants were replaced with higher temperature sprinklers in order to drastically lower the number of sprinklers that would open.

An Unrecognized Problem

Careful reading of fire reports indicates that the metal deck roof is a factor in many losses where its significance is not understood by the fire suppression group. In May 1977, the Beverly Hills Supper Club in Kentucky burned with a loss of 164 lives Figure 10-17. An extensive study of the circumstances of that fire indicated that a significant factor in the huge loss of life in the Cabaret Room was the tremendous amount of black, choking smoke developed by the fire in the metal deck roof. The initial investigators discounted the possibility of fire moving through the voids because they were cut up by walls. It is true that the roof was pierced by parapetted walls. The building had been added to many times, but undoubtedly there were penetrations through the walls. A metal deck roof fire does not need a big opening. A tongue of flame passing through a small hole, impinging on the metal deck of the next section would be sufficient to extend the fire. (Factory Mutual tests on metal deck roof assemblies have shown that it takes only 800°F (427°C) for 5 minutes for heat impinging on the surface of steel decking to start a self-sustaining roof fire. This fire is independent of the original fire.)

Figure 10-17 The Beverly Hills Supper Club in Kentucky, May 1977.

It is not at all clear that if the Supper Club building had been sprinklered according to the usual practice, a substantial fire could have developed. Under typical practice, the void would be regarded as noncombustible and left unsprinklered. Because it was above the ceiling insulation, a separate dry-pipe system would have been required to prevent freezing. Of course, had code requirements for exits and fire resistance been met (a fire-resistive structure would not have had a metal deck roof), there would probably have been few lives lost.

It appears that in most jurisdictions, an ordinary combustible metal deck roof would be permitted on a noncombustible building. Sprinklers below the ceiling in such a building will not protect against a metal deck roof fire moving through the void. However, they might prevent a contents fire from reaching the metal deck roof. They would also operate on contents fires started by dripping, flaming tar.

Four elderly persons lost their lives in a one-story nursing home in Dardenelle, Arkansas, in 1990. The building had been described as a protected noncombustible structure by the Arkansas Department of Health. The building had a combustible metal deck roof. Extremely thick black smoke, typical of a metal deck roof fire, drove the staff from the west wing. The NFPA Fire Investigation Report declared that "flammable vapors from the heated roof assembly contributed to the fire extension in the concealed space, and the smoke and toxic gases generated in the concealed space filled the occupied patient rooms."

Fighting a Metal Deck Roof Fire

Frank Brannigan first became aware of the metal deck roof problem in 1946. A fire occurred in a 250-foot (76.2 m) section of a 1,500-foot (457.2 m) by 100-foot (30.5 m) warehouse at the Marine Corps

Supply Depot in Norfolk, Virginia. The warehouse was loaded with field supplies. The fire originated in the center of the section, involving stock on both sides of the center aisle. Brannigan was supervising handlines inside the building, hitting fire in the burning stock. Blue flames extended down six feet or more from the underside of the roof, accompanied by dripping, flaming tar. When the heat and tar became hazardous, the streams were directed upward to put out the fire. The fire fighters made a "good stop," cutting the fire off right in the piles of stock 20 feet (6.1 m) high.

The pictures of the building, however, told a different story. The roof was gone from fire wall to fire wall, and it appeared as if the fire department had played no effective part in stopping the fire, but that rather the fire walls had done the job. After much discussion and study, the conclusion was that the roof had burned overhead, independently of the main body of fire in the contents.

It appeared that a fire involving a metal deck roof could be controlled only by the continuous application of water to the underside of the roof. By cooling the steel, the tar would be prevented from generating gas. Literally, the fire would be extinguished by removing the fuel.

The chance to try the plan came in about 15 months. In a similar warehouse section, the Marines had built a plywood office, a sick bay, and theater, while the balance of the area was loaded with combustible stock. Like the first fire, this fire was well advanced upon fire fighters' arrival, and an immediate second alarm was sounded.

Looking up along the underside of the roof, from the door at the end opposite the fire, Frank Brannigan observed the characteristic blue waves of fire several feet deep advancing rapidly. A hose wagon with deck pipe was ordered into the building, taking a position in the center aisle opposite the door. The orders were to direct a master stream at the underside of the roof, keep it moving, and ignore the burning contents. The operation was successful. The warehouse looked as if a knife had cut through the roof and walls; the building was lost only in the area where the huge body of initial fire had done its work before arrival.

Metal Decks on Nonmetal Buildings

Metal deck roofs are not found exclusively on steel-framed buildings. Many are built on masonry buildings and more recently wood-frame buildings, but the problem remains the same. In December 1970, in Kensington, Maryland, fire fighters responded to a serious fire in the contents of a one-story building housing a janitor supply business. There was heavy smoke, and the ceiling was not visible through the smoke. The chief felt hot tar dripping on his neck. Later he said: "I immediately thought metal deck roof, and though we couldn't see the overhead, we directed a big line up to the ceiling area to cool everything." When the smoke cleared away, the fire fighters were able to see and photograph icicles of chilled tar hanging from the joints in the steel.

Types of Protection for Steel Structures

Prefire planning for steel structures must begin with a determination of the type of protection provided for the steel. Steel structures can be divided into four types:

- Unprotected
- Dynamically protected
- Passively protected
- Passive/dynamic combination protection

Unprotected Steel

Unprotected steel structures can be extremely hazardous because of the potential for early collapse. Trusses are covered elsewhere in this text, but the story of a fatal collapse should serve as a grim warning of the dangers of buildings in which clear spans are achieved by unprotected steel trusses.

Four fire fighters lost their lives in the collapse of a Wichita, Kansas, automobile showroom that occurred about 10 minutes after they arrived. The showroom had repair bays that required large open areas and was built of lightweight steel-truss construction. Fire was visible to units turning out, and a second alarm was transmitted immediately. This fact alone should have signaled caution. A large amount of heat was being produced and the steel would absorb the heat. Early collapse should have been anticipated. Unfortunately, the fire fighters followed the standard aggressive offensive procedure of advancing a handline to the seat of the fire.

Through constant training, personnel can become accustomed to the need to cool all heated steel. The quantity of water needed at any point is not excessive. Water supplies for spray systems designed to protect tanks and steel supports from flammable liquid spill fires are calculated on a requirement of 0.25 gallon per minute per square foot. It is most important to cool all the steel that is within reach of hose streams and to give special attention to columns. The stream should be kept moving; overcooling in one spot obviously means undercooling, perhaps disastrously, someplace else. It is important that the stream reach the steel. When a long reach is required, a solid stream tip might be better than a fog tip (even on the fog tip's most solid setting). A fog stream may absorb a greater amount of heat in penetrating the flame zone. Converting all the water to steam as it passes through the fire, leaving none to cool the steel, is not the best use of water, particularly when the fire is uncontrollable.

A Washington, D.C., junkyard consisted of several identical unprotected steel buildings joined together without walls. A fire in wastepaper exposed two identical steel girders above the fire. One was successfully cooled with a master stream. The other, shielded by the first one, heated, overturned, and dropped the roof. Fire fighters conditioned to hit the fire sometimes neglect to protect the steel—clearly a mistake in this case.

Safe locations for cooling the steel should be preselected. Personnel should not be endangered by being placed in the collapse zone, which may cover a much greater area than the fire zone.

Water Damage

The use of water in the manner urged here might bring the criticism of unnecessary damage. However, the damage potential was created by the person who placed the combustible loading in a thermoplastic building. If the building can be saved, it will probably be possible to save some of the contents. If the building collapses, the contents are lost, too. In this day of close attention to municipal revenue sources, note that it is the building—rarely the contents—on which the tax base rests.

To the argument that "we never throw water except when we see fire," the reply can be offered that "If the owners had sprinklered the building, as they should have, water would be discharged on the steel, whether or not the sprinklers could see fire."

Where cooling-stream tactics are deemed necessary to prevent collapse, it would be beneficial to explain them to management in advance. Then, if the tactics are successful, the water damage to contents may be severe. The necessity of using the tactics might not be apparent after the fire, and the fire department may find itself ridiculed or even sued.

The possibility of severe water damage from hose streams might cause management to take a second and closer look at providing automatic sprinklers. The secondary objective of the preplanning for any major hazard should be to reduce the severity of the hazard.

Curiously, this also works in a reverse way. Highly protected risk (HPR) insurance companies usually require sprinklers for combustible metal deck roofs, even over noncombustible contents. This mandate often surprises management, who in turn may decide that it would be better to install a more costly roof that would not sustain combustion, so as to avoid the initial cost and maintenance of sprinklers.

Dynamic Fire Protection

Dynamic protection is generally accomplished with various types of automatic sprinkler systems. In some cases, a building is simply conventionally sprinklered, though this system may not be adequate to protect the steel.

It is important for the fire department to know whether the sprinkler system is adequate for the fire load. Rolled paper has been the fuel for a number of fires that destroyed sprinklered steel buildings. In one case, the building collapsed on the piles of paper, but the sprinkler pipes didn't break and the sprinklers operated continuously.

Hydraulically calculated sprinkler design can produce water flows adequate for the fire load, but this is no guarantee of success. Sometimes the procedure is used to design the system down to the bare minimum to keep costs low. Increases in fire loads overwhelm the system.

Heavy structural steel is sometimes protected by special lines of sprinklers. Flammable liquid hazards have long been covered by deluge sprinkler systems. More recently fog/foam systems have been installed to provide a foam blanket over the flaming liquid on the floor.

Passive Fire Protection

Passive fire protection is provided by protecting steel in one of the ways discussed earlier in this chapter. If a building is rated as fire resistive, two considerations are vital:

- Is the legally required level of fire resistance adequate for the fire load as it exists in the building?
- Has the protection of steel been completely provided, and is it maintained?

If the answers to these two questions are negative, three other critical questions should be asked:

- Is there any legal relief?
- Is it up to the fire department simply to do the best it can in the event of a fire?
- If the fire department estimate of the situation indicates potential or inevitable disaster, who, if anyone, is notified?

All personnel who perform inspections should be made aware of the requirements for fire resistance as applied to specific buildings. The manner in which fire protection of steel can be degraded by the actions of persons completely unfamiliar with its vital purpose is also crucial.

As noted, sprayed-on fireproofing and membrane protection are the two methods most likely to be degraded. Sprayed-on protection is often removed by mechanics accomplishing other work or disposing of an asbestos hazard. The fire department should insist on its being replaced with an adequate safe material. Sprayed-on protection is also vulnerable to being washed away by hose streams. Caution should be exercised when returning to areas from which the fire department was driven away by the fire—hot steel as a result of missing fireproofing can still collapse even after the fire is out. Spray-on fireproofing is discussed in further detail in the chapter that reviews fire-resistive construction.

There are numerous ways a membrane ceiling can be tampered with, so a prefire plan for any building in which one is installed should draw special attention to the possibility that collapse might occur. This is particularly a possibility where steel columns are unprotected in the plenum space.

One scenario for catastrophic damage to a column or columns could go like this: An interior stockroom has a characteristically high fire load. A ceiling tile has been removed for replacement, is being used elsewhere, or the ceiling fails. The column is heated to failure along a limited length and the column drops a foot or two. The effect would be staggering.

The fire department should be aware of the extent to which membrane fireproofing is permitted under the local code. Discussions should be held with the building and fire department and local installers to reinforce the need for strict adherence to installation details as specified by the manufacturer's listing. In one case, poke-throughs for wiring permitted a fire to spread to several floors. There was extensive collapse of bar joists.

All must be aware of the difference between fire resistance or flame spread listings of tile and the fire-rated tile as part of the fire resistance system of the floor and ceiling assembly. Similar-appearing tile is often used in these two quite different categories.

Not all suspended ceilings are a part of the fire resistance rated system. The ceiling may be installed for any reason, such as to reduce the room volume for better air-conditioning, to hide ducts and pipes, to conceal an old ceiling, for acoustical treatment, and so on. At one fire, it was found that the fire-resistive membrane was provided by suitable lath and plaster, that the visible tile ceiling was only acoustical, but that to install the tile ceiling, many holes had been punched in the fire-resistive ceiling to accommodate the support wires.

If the ceiling, including light fixtures and air diffusers, is an integral part of the fire resistance rating of the building, the owner and occupants should be put on notice that the fire department or building department must be consulted before any changes are made. Inspecting and preplanning personnel must be aware of the hazard of tampering with the ceiling and should check them during inspections, with an appropriate item provided on checklists.

Passive/Dynamic Protection

Protected combustible construction combines partial static protection of the steel with automatic sprinklers. One major insurer approves a spray-on coating that does not meet the standard for rated fire resistance, but would insulate the steel for a period of time that might be adequate to permit the sprinklers to control the fire.

Code Problems

In any discussion of prefire planning, it is difficult to separate firefighting procedures from fire protection requirements for steel structures or proper maintenance of the passive or dynamic protection.

The fire department must develop competence in the many facets of the overall problem. It is impossible for all officers to be equally competent and informed. One person or a small group should be designated to develop expertise in each relevant area. Becoming familiar with current and past local building and fire codes, and most importantly, the manner and degree of this enforcement, are prime areas of concern to effective fire departments.

Some building officials are less than enthusiastic about fire department interference in "their business." Incredibly, in one metropolitan-type county, fire inspectors were not permitted to inspect a building until the certificate of occupancy was issued. This practice not only ignores the hazard of fires in buildings under construction, but also allows many defects to be hidden from view in a completed building.

Some fire prevention managers are equally unenthusiastic about any interest by fire suppression managers in "their business." The ultimate fiasco is to have information that is vital to fire suppression locked up in fire prevention office files at 3 a.m. when a fire occurs.

Code Variances

Building and fire prevention officials sometimes assume that they have the authority to grant exceptions to the code, based solely on their own undocumented action. Actually, codes do not permit waivers to specific requirements but do permit the use of alternative, equivalent methods. Political influence or worse may be involved when unapproved variances are undertaken. All modifications to requirements of the code should be fully documented, meet the intent of the code (including the level of protection), and the fire suppression forces should be involved in the process. It is possible that the beneficiary of the unrecorded variance may at some future date drag the municipality into a lawsuit. Without proper documentation, the municipality is very likely to be found liable.

Preplanning Your "McCormick Place"

With the advantage of hindsight and a study of the McCormick Place fire, consider a possible preplan of a fire in an unprotected steel building being used as an exhibit hall. For discussion purposes, assume the building is a typical armory (i.e., brick-bearing walls with unprotected steel trusses supporting the roof). Also assume there is a balcony running down both sides that is used for sports events but not for exhibits. Recommendations for automatic sprinklers have not been carried out. No money is available. The state will not permit the city to dictate to it, and most of the time the fire load is low.

The first move might be to set up a "bruising battle" for either sprinkler protection or denial of permission for the facility to house high fire-load exhibits. This battle is set up not to be won, but rather with the full expectation that it will be lost. In losing, however, the fire department may gain some concessions. Without being too specific, get in writing an agreement that the fire department can take whatever steps necessary to protect life and property during exhibits. Having beaten back the greater financial threat, the managers of the armory can only be magnanimous and yield a point to the fire department. When they learn the proposed precautions, they may be quite upset, but the fire department has the written agreement. In such a public battle, it is not the fire department that is willing to risk the lives of our citizens.

Consider a worst-case scenario in this armory. Suppose an exhibition such as a housewares, home, or furniture show is scheduled. Calculations of the combustibility of typical exhibits together with the floor area indicate that a fire with a high rate of heat release would develop. The surface-to-mass ratio of the material and its arrangement will provide a fast fire with early high-heat release at a rapidly increasing rate. The same fuel load in a more restricted area might give off heat more slowly due to restricted airflow, but an unlimited supply of oxygen can be assumed in the exhibit hall.

The fact that a hot, fast fire is anticipated indicates a more severe test of the structure than a slower fire. The radiant energy of a fire is proportional to the fourth power of the absolute temperature (actual thermometer reading in degrees Kelvin plus 459); thus a 2,000°F (1093°C) absolute fire of 20 minutes' duration could have a radiant energy potential 16 times that of a 1,000°F (538°C) absolute fire of the same duration. Because of the large void above the bottom chord of the trusses, a huge smoke and heat storage area is provided, and for quite some time there might be little smoke to protect the bottom chords of the trusses from radiant heat. If a bottom chord fails, the truss fails.

On first glance, such a plan appears ridiculous. "Fire fighters and equipment cannot be tied up to fight a fire before it happens. The precautions would upset the patrons of the show. We never did anything like that before. Who will pay for the time? We have a fire, we call you, you come. That's the way it's always been."

However, this concept may not be as farfetched as it seems. Instead of overhead piping, perhaps the concept of an alternative automatic system is feasible.

The Alamodome in San Antonio has installed just such a system. Flame detectors at roof level "view" the floor below. When the safeguards built into the system are satisfied that there is a serious fire, water is started from the two closest of six fixed nozzles located around the perimeter of the area.

The suggestions made above thus are no longer in the realm of fantasy. If a fixed system can be installed, it is certainly reasonable to improvise a similar system. For example, a department store in San Jose, California, has a fabric roof protected by sprinklers suspended from the roof cables.

If the building is sprinklered, study the potential water supply requirements, particularly the possibility of the opening of more than 20 sprinklers. It might well be advisable to make a standby hookup to the sprinkler system Siamese connection so that the supply could be augmented in terms of both quantity and pressure immediately upon the start of a fire.

Be Proactive

Frank Brannigan recalled lecturing to Navy personnel, "There is no law saying you must have a fire before you open a can of foam. Foam can be used to suppress a flammable liquid hazard before the fire starts." Although it was a revolutionary idea then, the use of foam to control a flammable liquid spill is now commonplace.

There is nothing the human intellect resists more than a new idea. Step by step, logic leads inexorably to the practical solution—prepare for fire before it happens. Learn from those fires that have occurred.

Fire fighters should be eternally curious. Just about everything that happens has some impact on the fire protection situation. Evaluate it and take action to contain or perhaps eliminate any problem.

TACTICAL CONSIDERATIONS

1. Fire-resistive and noncombustible construction, both of which use steel and concrete, may lead new recruits to believe that they shouldn't expect a significant fire. Not so! There are more hazards to fire fighters in Type II construction than just the fire. Make that clear to new recruits. They need to know the difference between Type I and Type II construction. Type II construction—especially nonsprinklered Type II buildings—are actually more dangerous because little or no fire resistance protection for their structural steel members is provided. Fire resistance is a function of mass. Strong but lightweight steel members have little inherent fire resistance.
2. If you are a student of building construction and fire, certain temperatures are worth memorizing. Probably 80% of the fire service knows the temperature recommended for baking cookies (350°F [177°C]), but how many fire fighters and company officers know the temperature at which substantial elongation can take place in a steel beam? It is about 1,000°F (538°C). This temperature is easily attained at any structure fire. The elongation can push out masonry walls abutting the ends of the steel, causing a roof or wall collapse. If the steel cannot elongate because of restraint (such as an exposure building), it will buckle or twist, causing a roof collapse.
3. Everyone knows that water boils at 212°F (100°C), but what is the temperature at which steel members may fail under their own weight, bringing about collapse? Temperatures above 1,300°F (704°C). You must know this to operate safely on the fireground when dealing with a building using steel as structural components.
4. Steel is a good thermal conductor of heat. Heat can be easily transmitted by conduction through the cold-drawn steel cables often used in tensioning concrete, excavation tiebacks, and elevator cables. These cables can fail at about 800°F (427°C). Fire fighters riding in elevators should have this temperature memorized or take the stairs.
5. In a noncombustible building, if the fire cannot be quickly located and extinguished (remember—putting the fire out eliminates all kinds of problems), the next important tactic is applying water to cool the exposed steel. Cooling the steel stops the detrimental effect of the heat and helps maintain the structural integrity of the building. Some incident commanders (ICs) are concerned with water damage, but if the building is sprinklered and the system is operating, water damage is taking place whether the fire department is on scene or not. Keep your priorities straight: life safety, followed by incident stabilization, and then property conservation. The effects from high temperatures on steel happen quickly. If you lose the building to structural collapse due to failure of steel members, does it matter how much water is being dumped into the building? At this point, it is probably a surround-and-drown defensive operation.
6. Plans for cooling steel should provide for a safe location that personnel can operate from. If a safe position is not practical, consider unmanned hose streams or unmanned monitors. Aerial ladder pipes are ineffective while the roof is intact because the roof will operate as designed—it will shed and keep water out of the building. If this is the case, aerial master streams should be shut down because they rob water pressure from ground-level appliances that can still be effective in controlling the fire.
7. If it becomes too dangerous to cool the steel, pull fire fighters back, establish a collapse zone, and change to a defensive strategy. Notify the building owners of the probable outcome of such a fire. Don't risk your fire fighters on buildings that no longer have any value.
8. In the case of unprotected steel, if temperatures in excess of 1,000°F (538°C) are reached (easily attainable in major structure fires), failure can occur early in a fire and the consequences can be catastrophic. It is still important to try and remove the heat, however. Vertical rooftop ventilation operations can be time-consuming depending on the roofing material, unforeseen obstacles, crew resources, available equipment, and the speed and experience

of the assigned crew. A metal deck roof with a significant fire below is a very dangerous place. Roof ventilation in such cases should be avoided. The fire department's fastest and safest heat removal medium is water. Water should be used to remove the destructive heat from the steel. If the steel is elongating, the cooling effect of the water will draw it back to its original dimensions. If the steel is failing, the water will simply freeze the steel in whatever shape it is currently in.

9. It's often difficult for fire fighters and officers to believe how fast unprotected steel can be destroyed. The distortion of steel due to fire can weaken the integrity of the building so that it may no longer support superimposed or its designed loads. Unexpected stresses, particularly torsional, may be created by buckling, which lead to structural failure if the condition is not reversed. This condition can be reversed only with the application of water. Structural steel that has been sufficiently cooled by water can retain the same structural strength of steel that has not been exposed to fire.
10. During new construction of Type II noncombustible buildings and Type I fire-resistive buildings, the practice known as "field bolting" may be used, in which temporary bolts are placed instead of permanent rivets. Whether at 2:00 p.m. or 2:00 a.m., most fire fighters would be unlikely to be able to spot the difference or identify this condition. Fire fighters should carefully examine temporary bracing before going up to extinguish a fire in a steel building under construction, particularly when the incident occurs in conditions of high winds. Consider giving a wide berth to field-bolted structures during high winds.
11. If you have exposed steel, then the building is in the early phases of construction. Once the civilian life hazard has been mitigated, there isn't much property value at stake yet. It's not worth risking fire fighters' lives over steel framing. Because many noncombustible buildings are likely to be 1 to 3 stories in height, with the maximum being 12 stories in height (fire-resistive buildings are even higher), consider using elevated master streams operated from the perimeter. This type of cooling sustains the structural integrity of steel.
12. Elongating steel bar joists may potentially push a block wall out of alignment. If fire fighters can determine which way the trusses run, this is critical information that needs to be passed on to the IC. This can often be determined by using thermal imagers (TIs). By scanning the roof with a TI, whether it is on fire or not, the trusses will be visible on the screen. For example, if the trusses run from side B to side D, the elongation will take place from B to D, so the walls in danger of being pushed out are the B and D walls. The IC can establish collapse zones or cordon off access to these sides of the building.
13. When cooled steel shrinks back to its original position, the trusses may potentially pull away from the walls, thereby causing a roof collapse due to truss failure. The point to remember is to use the reach of the hose stream to cool the steel from a safe position. A 2 ½"(64 mm) hose line is best. The more gpm delivered along with reach, the faster the cooling effect. A 2 ½" (64 mm) hose line can easily throw a horizontal stream for more than 80 feet (24.4 m)—a lot of reach.
14. Stay alert. Be aware of the hazards to fire fighters who are fighting the fire in an unprotected steel building. Steel fire escapes still exist on the exterior of older buildings all around the country. If they have been well maintained and certified (every 5 years per code), they can be useful not only for the evacuation of occupants, but also for fire department access. Some exterior standpipes run up adjacent to the fire escape and can be accessed only from the fire escape landings. These standpipes are exposed to the elements all year round, however, so they age faster than interior standpipes. The tie rods supporting the standpipes are vulnerable to temperatures above 800°F (427°C). Therefore, it is essential that these fire escapes be inspected on a regular basis and certified by a structural engineer every 5 years. You may have to trust their structural integrity with your life.
15. A prefire plan for a metal deck–roofed building should be based on taking a safe position where all areas of the underside of the roof can be reached with heavy stream appliances. Do not hesitate to throw water onto smoke, even though the target will probably be obscured—it's still there and needs to be cooled.

16. You cannot cut off a metal deck roof fire by implementing vertical ventilation. The fire can move very fast. Tests show that only huge vent holes—far beyond the capability of fireground tactics—would be effective in such a case.
17. Working on a roof over a metal deck roof fire would be extremely dangerous. An article discussing collapse of wood trusses makes the point that wood trusses collapse, whereas steel trusses sag. This is not necessarily a better alternative because the sag may cause fire fighters on the roof to slide downward on a slick, liquid tar surface. For this reason, you should place a secondary ladder for escape. In fact, feel free to throw additional ground ladders on every side of the building if extra personnel are waiting for an assignment. Ground ladders at an incident aren't doing any good stored on the apparatus.
18. A ladder pipe or ladder tower master stream directed downward onto a traditional built-up roof is useless. Such traditional built-up roofs are doing what they are designed to do—shed rain and keep it out of the building. The fire is always many feet beyond the point at which the roof is opened up. A fire that can be seen on the top of the roof is in the fiberboard, the plastic insulation, or the upper layers on a built-up roof and is unimportant. That part of the roof no longer has any value. If you stop the progressive heating of the "frying pan" from underneath with hose streams, the roof fire will die out or decrease to easier manageable proportions. "Rubber roofs" in which the roof surface itself is on fire, in contrast, call for the use of aerial master streams because they are the only way of stopping the fire.
19. When construction operations present unacceptable hazards to unprotected steel, fire departments are well advised to put the building owners on notice—even if there is no applicable code.
20. Preplans should provide for the rapid cooling of all exposed steel in an excavation fire. Apparatus placement and operating positions should take into consideration the fact that adjacent buildings might collapse into the excavation. The occupants of such buildings should be evacuated.
21. Fire departments should survey all highway structures for vulnerability from building fires. Prefire plans for buildings that expose highway structures should take into account protection for these structures; the highway structure may be far more valuable than the building on fire. In such a case, cooling the steel of the highway structure might be more important than trying to extinguish the building fire. Unorthodox tactics, such as driving the fire down into the building, may be necessary.
22. Accidents under highway structures and underpasses may result in massive fires. Fire departments should preplan to protect the steel (or concrete) and anticipate a flammable liquid fire in addition to a vehicle fire. An adequate water supply must be planned for. Generally, the water must be delivered by units located off the highway. Water used with foam to suppress the fire may not be as effective as using the water to cool the steel and concrete of a bridge structure. The best tactic depends on the value of the structure and the ability to maintain an uninterrupted water supply.
23. When faced with a massive fire involving highway structures, consider making mutual aid requests of nearby airports. Often, airport fire departments can send a crash truck to help extinguish a large vehicle on a major highway. This apparatus may carry as much as 3,000 gallons (11,356 L) of water, 300+ gallons (1,136+ L) of foam, and 500 pounds (227 kg) of Purple K powder (PKP) dry chemical ready to disburse from its turrets.
24. If water is used to cool steel and mixes with burning gasoline, it may produce a flowing stream of fire. Will the fire flow harmlessly down the road or will it enter a storm drain and potentially cause environmental damage to nearby streams and watersheds—or start a fire further away? Could the burning stream enter the sewer system or flow into nearby buildings? In the latter case, crews may have to build a dike to contain the runoff and extinguish it with foam. If no exposures are threatened and there are no environmental hazards, it may be best to let this stream burn. Once the fuel is consumed, the fire will go out.

WRAP-UP

Chapter Summary

- Steel is the most important metal used in building construction. Without it, construction would be limited to massive all-masonry buildings with arched floors or masonry wall-bearing buildings with wooden floors.
- Steel has several important characteristics to consider regarding its behavior in fire:
  - Substantial elongation can take place in a steel member at ordinary fire temperatures (about 1,000°F [538°C]). This elongation may cause the disruption of other structural components.
  - At higher temperatures (above 1,300°F [704°C]), steel members may fail, bringing about a collapse of the structure.
  - Cold-drawn steel such as steel tendons used for tensioned concrete and for excavation tiebacks and elevator cables will fail at about 800°F (427°C).
  - Steel is a good thermal conductor, so it transmits heat readily. Heat can be transmitted by conduction through steel to combustible materials.
- The strength of steel, the consistency of its structural characteristics, and its ability to be connected to other structural elements so that loads can be adequately transferred are all important to the use of steel as a building material.
- To achieve a peaked roof in a steel-framed building, the framing may consist of columns and beams with triangular trusses.
- A number of options are open to the designer to deal with the characteristics of steel as they relate to fire risk: ignore the problem; rely on inadequately enforced codes; take a calculated risk; fireproof (insulate) the steel; protect the steel with sprinklers; fireproof the steel with an water cooling system; or locate the steel out of range of the fire.
- The metal deck roof is a factor in many losses where its significance is not understood by the fire suppression group.
- Steel structures can be divided into the following types:
  - Unprotected
  - Dynamically protected
  - Passively protected
  - Passive/dynamic combination protection

Key Terms

Aluminum A lightweight metal that is both malleable and nonmagnetic. This material has very good conductivity. This noncombustible material has a low melting point and little mass per unit of area, so it disintegrates rapidly in fire.

Angles Steel members that have two legs at right angles to one another.

Asphalt asbestos protected metal (AAPM) Asphalt coating that is combustible and used as a weather-protective coating on galvanized steel walls.

Bar joist A joist that generally runs in the same direction as a beam and forms a lightweight, long-span system, used as floor supports and built-up roofing supports.

Bars Plates fewer than 6 inches in width; may be square or round.

Box column A large hollow column built from steel plates.

Box girder A large girder, which is hollow, like a box column, and often used for highway bridges.

Bulbtee A tee where the end of the cutoff is thickened.

Bulkhead An upright partition that divides a ship into compartments and is meant to prevent the spread of leakage or fire.

Castellated beam A wide flange beam that has been cut in half in a zig-zag pattern and then welded back together in an offset manner, creating a new, deeper beam.

Cement-asbestos board Noncombustible material often used for friable construction.

Channel Steel structural component that has a square U-shaped cross section.

Galvanized steel walls Walls made of weatherized steel. Can conduct heat easily.

Glass fiber–reinforced plastic A composite material made of plastic reinforced with glass fibers.

I-beam Beam shaped like the letter "I".

Interstitial space Void space made by utilizing deep parallel-chord trusses.

.tice column Column made of vertical units connected with diagonal pieces.

Light gauge steel-framed wall An exterior wall constructed with lightweight galvanized steel studs.

Masonry walls The most common walls for unprotected steel-framed buildings; made of concrete block or a composite of concrete block and brick.

Metal panel Prefabricated metal structure that is often made up in a sandwich construction to provide one unit combining thermal insulation and interior finish in a steel-framed structure.

Modulus of elasticity A measurement of the ability of steel to distort and restore.

Peened (peening) Embedded into the surface.

Plates Flat pieces of steel.

Precast prestressed concrete panels Concrete panels that are precast and brought to the construction site.

Purlins Beams set at right angles to trusses or roof rafters to provide support for lightweight roofing.

Rakers Diagonal columns that brace an entire structure.

Rolled or built-up members Steel structural members; rolled members are one solid piece of metal; built-up members are made up of different sections riveted, bolted, or welded together.

Spandrel girders Girders that tie wall columns together in a framed building.

Spandrel space Distance between the top of one window and the bottom of the one above.

Steel expansion joints A metal connection that allows for movement of floors.

Tee A standard I-beam cut lengthwise through the web forms two such beams with T-shaped cross sections.

Tiebacks Cold-drawn steel cables inserted into holes driven into the rock and anchored with epoxy. Also refers to braced sheeting used in soil walls to protect against collapse.

Tin ceiling Embossed steel; will transfer heat in either direction.

Transfer beam Used to laterally relocate the vertical load of columns to clear an opening area.

Triage To evaluate and categorize.

Tube A steel structural member that is rolled in cylindrical, square, or rectangular shapes.

Waler A horizontal beam that ties rows of soldier beams together.

Wide flange shapes I-beams that have flanges wider than standard I-beams.

Zees Members with a Z-shaped cross section.

Case Study

During some down time at the firehouse, you decide to talk with your fire fighters about steel frames and some catastrophic incidents that have happened in the last 60 years. You explain that we must learn from past experiences and that if we can understand how buildings are put together, we can understand how they will come apart.

1. What is a W 12 × 22 steel member?
   - **A.** A wide flange beam with a weight of 22 pounds
   - **B.** A wide flange beam with a depth of 22 inches
   - **C.** A structural tee with a weight of 12 pounds
   - **D.** A structural tee with a depth of 22 inches
2. McCormick Place used unprotected steel roof trusses. We know from research that steel will expand _______ % in length for each 100°F rise in temperature.
   - **A.** 0.06 to 0.07
   - **B.** 0.07 to 0.08
   - **C.** 0.08 to 0.09
   - **D.** 0.09 to 0.10
3. The General Motors transmission plant fire in Livonia, Michigan, is a good example of a:
   - **A.** deadly collapse of a walkway.
   - **B.** tilt wall collapse.
   - **C.** mechanic knocking off spray-on fire-proofing.
   - **D.** metal deck roof fire.
4. An abbreviation for a "rubber roof" is:
   - **A.** EFIS
   - **B.** EIFS
   - **C.** EISF
   - **D.** EPDM

Challenging Questions

1. Detail the differences between noncombustible and fire-resistive construction.
2. Describe how a building of tilt slab construction is constructed and the associated hazards when it is exposed to a fire.
3. Identify and describe the general ways of protecting steel from the heat of a fire.
4. Describe the indicators and hazards of a metal deck roof fire in an unprotected steel joist warehouse as well as the techniques to deal with the problem.
5. You have been assigned to the bureau of fire prevention. You attend a meeting of architects, engineers, and building code officials concerning the design and construction of a new convention center in your city. As a follow-up to the meeting, you are to prepare a list of concerns that you have about the new structure. What specific fire protection and firefighting concerns would you have?