CHAPTER 13

BUILDING CONSTRUCTION

Dave Dodson, Lead Instructor, Response Solutions

OUTLINE

STREET STORY

A firefighter's worst fear is being trapped in a collapsing building and burning to death. Real-life encounters become implanted in our memory. It is one thing to read or hear about certain occurrences, it is another thing to have lived through one.

As a chief officer arriving at a fire scene, I encountered a large body of fire on the top floor of a three-story building. The first-due companies were initiating an offensive attack. My initial reaction was that the tactics being employed were correct. I surveyed the scene by doing a 360-degree walk-around of the building. I realized that conditions were not improving. I contacted the interior sector officer, and he informed me that interior conditions were deteriorating. I had noticed the following collapse indicators in my size-up: a large volume of unabated fire despite the aggressive interior attack; heavy smoke conditions indicating that the fire was probably attacking the building's structural supports; the ordinary constructed building contained a corbelled brick cornice, which added an eccentric load to the bearing wall supporting it; and lack of progress in the interior attack.

I had witnessed similar indicators in previous collapses. I ordered the units to withdraw from the building, set up a collapse zone, and initiated a defensive attack. The building's masonry wall collapsed shortly after the units' removal. The ensuing investigation found that the collapse occurred due to the combination of the collapse indicators.

Knowledge of building construction is vital before firefighters can attempt to fight a fire within a structure. Each type of construction contains inherent problems or positive features that can impede or assist in our ability to control a building fire. Examine the building. If it contains collapse indicators, decide their potential impact on the building's stability. If in doubt, it is better to err on the side of safety. Remember that once all civilians are removed from a structure, the life safety of firefighters is our utmost consideration.

—Street Story by James P. Smith, Deputy Chief, Philadelphia Fire Department, Philadelphia, Pennsylvania

OBJECTIVES

After completing this chapter, the reader should be able to:

- Describe the relationship between loads, imposition of loads, and forces.
- List and define four structural elements.
- Identify the effects of fire on five common building materials.
- List and define the five general types of building construction.
- List and define hazards associated with alternative building construction types.
- List five building collapse hazards associated with fire suppression operations.
- List five indicators of collapse or structural failure that might be found during fire suppression operations.

INTRODUCTION

Many fire departments pride themselves in their ability to launch aggressive interior structural fire attacks. Unfortunately, many firefighters are injured and killed when that same structure collapses, **Figure 13-1.** Often, buildings collapse without a "visual" warning such as sagging floors and roofs, leaning walls, and cracks. To keep from getting trapped in a collapse, firefighters must understand the types of structures they enter from the perspective of how the buildings are assembled, what materials are used, and how buildings react to fire. Additionally, firefighters must understand how fire travels through a building and choose appropriate tactics to stop the fire before key structural elements are attacked by the fire. Many firefighter fatality investigations conclude that fire departments need more training and education on building construction and the effects of fire on buildings. This chapter introduces several key topics regarding building construction and how fire affects buildings. It is important to note, however, that this chapter is merely an introduction. Firefighters must bridge the information in this chapter with a long-term commitment to study and research building construction and, more importantly, to explore the buildings within their jurisdiction.

Figure 13-1 This collapse happened seconds after firefighters were repositioned.

Streetsmart Tip Firefighters must realize that most of the buildings they will work in are already in place, and it is very difficult to determine the type of construction and fire-resistive rating by driving by or standing in front of a structure. Conducting in-service inspections, and securing the building owner's permission to walk through a building and get an "inside view" are ways of learning more about the structures in a particular jurisdiction.

If new construction is being conducted in a firefighter's response area or jurisdiction, contact the building department and secure a set of the plans. The fire department should be involved in the plan review process; however, this is not always the case. Also, take photographs of how the building is built and what materials are used for future training references. Many new materials and construction methods are introduced regularly. Firefighters should find out what materials are in the buildings in their jurisdictions.

This chapter begins by exploring some basic terms and mechanics of building construction, and then examines structural hierarchy and fire effects on materials. That information is then applied to classic and new construction types. The chapter concludes with a look at collapse hazards associated with structural fires.

BUILDING CONSTRUCTION TERMS AND MECHANICS

Firefighters need a basic understanding of certain terms and concepts associated with building construction. Obviously, buildings are constructed to provide a protected space to shield occupants from elements. The building must be built to resist wind, snow, rain, and still resist the force of gravity. Additionally, the intended use of the building can add a tremendous amount of weight, placing more stress on the building's ability to resist gravity. In building terms, these elements create building **loading**. Loads are then *imposed* on building materials. This imposition causes stress on the materials, called *force*. Forces must be delivered to the earth in order for the building to be structurally sound. With this basic understanding, we can start to define terms and mechanics.

Types of Loads

Loads can be divided into two broad categories as it relates to building construction: **dead loads** and **live loads**. Dead loads include the weight of all materials and equipment that are permanently attached to the building. Live loads include equipment, people, movement, and materials not attached to the structure. Dead loads and live loads can be more specifically described using the following terms:

Concentrated load: A concentrated load is a load that is applied to a small area, **Figure 13-2.** An example of a concentrated load is a heating, ventilation, and air-conditioning (**HVAC**) unit on a roof.

Distributed load: A distributed load is a load applied equally over a broad area, **Figure 13-3.** Examples of this include snow on a roof or a hoist attached to numerous roof supports.

Impact load: Impact load is a load that is in motion when applied, **Figure 13-4.** Crowds of people, fire streams, and wind gusts are examples of impact loads.

Figure 13-2 The steel stairs and air-conditioning unit apply a concentrated load on this roof structure. Also note the potential instability of the air-conditioning unit placed on cement blocks.

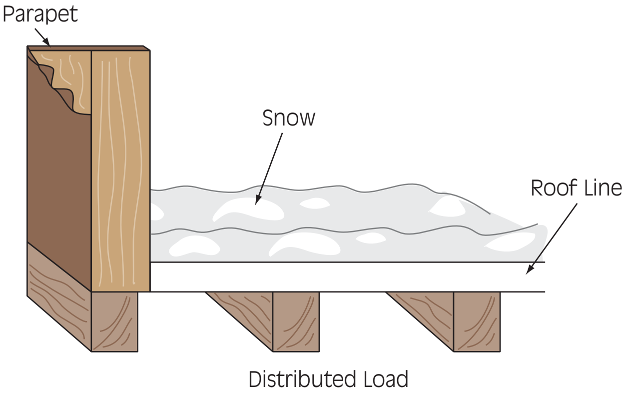


Figure 13-3 The weight of snow is a distributed load on this roof structure.

Figure 13-4 This ladder pipe operation is applying an impact load to the wall of this structure. As the wall weakens, it will eventually collapse. *(Photo courtesy of William H. Schmitt, Jr.)*

HISTORICALLY SIGNIFICANT BUILDING COLLAPSES

Contributed by Dave Dodson

Many firefighters have been killed as a result of building collapse during firefighting operations. With each of these tragic losses, lessons can be learned. The following is a brief look at some of the more significant collapses. Each of these events should be researched to find all the contributing factors that led to the event. The italicized lessons are perceptions that are shared in the spirit of preventing firefighter injuries and death.

New York City, 1966

Firefighters responded to a commercial structure fire only to discover that the building shared a basement with another building. The concealed fire advanced rapidly and undetected. The ensuing firefight trapped and killed twelve firefighters. *It is vitally important to preplan buildings prior to a fire event. Older buildings may have access ways sealed from adjoining buildings. Shared utilities and other hidden voids can facilitate fire spread.*

The Boston Vendome Hotel Fire, 1972

Nine firefighters died during overhaul of a fire in an old, remodeled hotel. The investigation revealed that a masonry wall had been breached to make way for an air duct. Just above the breach, a column carried the load from floors above. A corner of the five-story building collapsed, trapping the firefighters. There were no obvious signs of impending collapse. *The Vendome building was brought back from disrepair in 1971, and many alterations were made that were unknown to the fire department. Firefighters should take an interest in the construction activities in and around buildings. Remodeling and restoration can compromise structural elements.*

Detroit, Abandoned Building, 1980

A fire was reported in a large, abandoned building that was scheduled for demolition. Responding firefighters found "light smoke" showing. The fire escalated rapidly due to the poor interior conditions and wide-open spaces. One firefighter died while trying to escape. Two other firefighters died when a firewall collapsed. *Abandoned buildings are much like a building under construction. Firefighters cannot take anything for granted. Rapid fire spread and suspect integrity should be the order of the day. Defensive operations must respect collapse zones.*

Hackensack, New Jersey, Ford Dealer, 1988

A fire was discovered in the attic space above an automobile repair garage. Responding firefighters launched an aggressive attack. The bowstring truss roof space was being used as a parts storage area, placing additional load on the structure. During firefighting operations, the roof collapsed, trapping and killing five firefighters. *Fighting fires in truss spaces is like playing Russian roulette. Trusses help form a wide, open space beneath. Clear spans are a warning sign of quick collapse should the truss space be involved in fire. Where there are no occupants to rescue, firefighters should reduce their risk and fight fire from safe attack points.*

Orange County, Florida, 1989

Firefighters responded to a fire in a single-story commercial structure. Interior conditions were described as light smoke and no heat. The fire had gained headway in a truss space above the ceiling. The tile-covered roof collapsed twelve minutes after firefighters arrived and killed two firefighters. *A fire can be roaring over firefighters' heads without them being aware. Firefighters should routinely inspect the ceiling space above their heads for fire. Once fire or heavy, dark smoke conditions are found in truss spaces, tactics should change. Tile roof coverings are quite attractive but show very little signs that the roof supporting them is about to collapse.*

Brackenridge, Pennsylvania, 1991

Firefighters were attempting to attack a fire in the basement of a large commercial building with concrete floors supported by steel columns. During the attack, the floor collapsed, trapping and killing four firefighters. *Basement fires present many difficult challenges to firefighters. Limited access, trapped heat and smoke, and the storage nature of basements must be factored in fire attack. Unfinished basements allow the fire to attack the floor above and floor supports rather quickly. Unprotected steel exposed to fire will soften quickly, leading to collapse.*

(continued)

HISTORICALLY SIGNIFICANT BUILDING COLLAPSES (CONTINUED)

One Meridian Plaza, Philadelphia, Pennsylvania, 1991

Three firefighters died when they became disoriented and ran out of air while fighting fire in the high-rise building. The fire started on the twentieth floor and ran up to the thirtieth floor where a sprinkler system extinguished the fire. Although the firefighters did not die from a collapse, this event is significant in that fire officers feared a catastrophic collapse due to stress cracks found in the concrete stair towers and withdrew their firefighters. *There are many lessons learned from this event. The fatality and fire investigation details many building construction issues associated with high-rise firefighting. It is available from the U.S. Fire Administration (http://www.fema.gov/usfa).*

Mary Pang Fire, Seattle, Washington, 1995

An arson fire in a multiuse commercial building caused the deaths of four firefighters when a portion of the floor collapsed. The building had been altered several times, and a lightweight "pony wall" had been used to replace a portion of a load-bearing wall. The building had a confusing layout including entry points at two different elevations (like a walkout basement). The advanced fire was not apparent from the "front" side of the building. An aggressive interior attack was under way when the floor collapsed. *Buildings that have gone through several owners and occupancy changes should always be suspect. Prefire planning helps uncover hazards that could change firefighting tactics. Firefighters should make a habit of reporting fire and building conditions and observations.*

Stockton, California, 1997

Two firefighters died when a home addition collapsed during interior firefighting operations. The homeowners had built a large, two-story clear-span addition on the back of the home. Firefighters entered the front of the building and found a heavy fire and dense smoke conditions. *Homeowners do not necessarily follow established building practices and codes when making additions. A "360" prior to fire attack can uncover significant hazards when "reading" the building. Firefighters cannot preplan every home, so they must rely on their ability to read buildings and read smoke conditions.*

World Trade Center, New York City, 2001

Terrorists hijacked two large airliners and hit the twin towers of the World Trade Center. The Fire Department of New York (FDNY) responded and began the biggest rescue effort in fire service history. The high-rise towers collapsed, killing 343 of FDNY's bravest. Thousands of civilians also died in the collapse. *Steel high-rise construction relies on fire-resistive coatings to protect the steel. The combination of burning jet fuel and the trauma of the aircraft strikes rendered the steel unprotected. Failure came much quicker than the four-hour time limit prescribed for Type I fire-resistive construction found in high-rises. Firefighters should never rely on fire protection time ratings when making decisions for fire attack. History will always remember that the FDNY firefighters died trying to rescue trapped civilians. They have the undying respect of people throughout the world.*

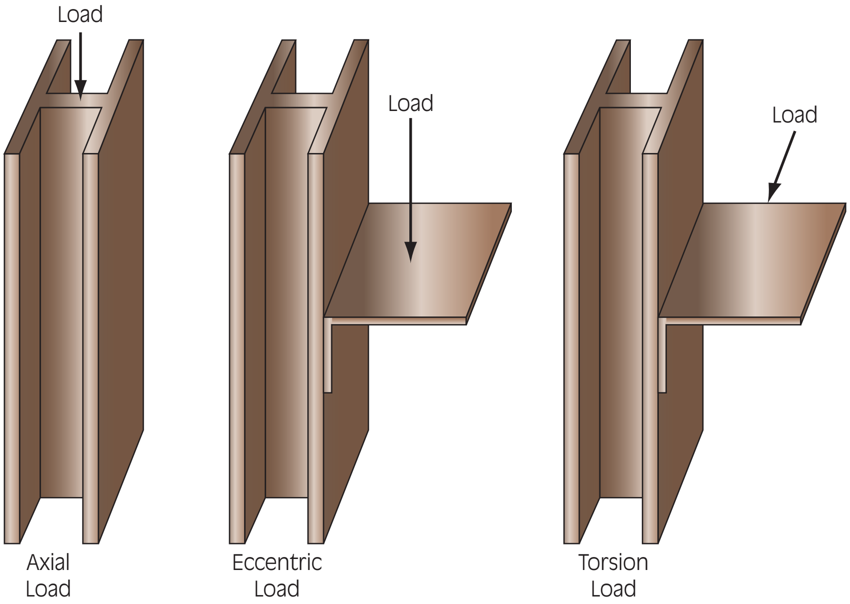
Design load: Design loads are loads that an engineer has planned for or anticipated in the structural design.

Undesigned load: Undesigned load is a load that was not planned for or anticipated. Buildings that are altered or are being used for occupancy other than original intent create an undesigned load. One common example is a residential structure that is converted to a print shop or legal office. These buildings were not designed to hold the additional live loads caused by the change in occupancy.

Fire load: A fire load is the number of British thermal units (Btus) generated when the building and its contents burn. It is important to note that the construction industry does not recognize *fire load* in its vocabulary—it is a fire engineering term.

Imposition of Loads

Loads must be transmitted to structural elements. This is called *imposition of loads.* Terms associated with imposition include axial load, eccentric load, and torsional load, **Figure 13-5.**



Application of Loads

Figure 13-5 There are three types of loads that can be transmitted through a structural member: axial, eccentric, and torsional.

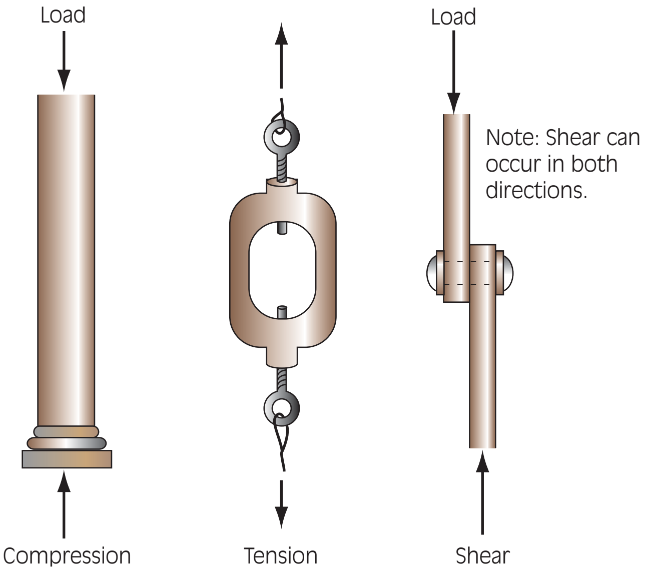
An **axial load** is a load that is transmitted through the center of an element and runs perpendicular to the element. **Eccentric load** is applied perpendicular to an element and, subsequently, does not pass through the center of the element. **Torsion load** is a load that is applied offset to an element, causing a twisting stress to the material.

Streetsmart Tip As a building burns, the structural elements decompose and lose their strength. This causes a change in the forces and the way the design loads are applied, leading to structural failure and collapse.

Forces

Loads imposed on materials create stress and strain on the materials used to make the element. Stress and strain are defined as forces applied to materials. These forces are defined as compression, tension, and shear, **Figure 13-6.** In **compression**, forces tend to push materials together. **Tension** occurs when forces tend to pull a material apart. **Shear** occurs when a force tends to "tear" a material apart—the molecules of the material are sliding past each other.

All loads—and the forces they create—must eventually pass through the structure and be delivered to the earth through the foundation of the building. Under normal conditions, structures will resist failure. Under fire conditions, the materials used to resist forces start breaking down. Eventually, gravity takes over and pushes the building to the earth.



Types of Loads

Figure 13-6 Loads are applied to a structural member as compression, tension, and shear forces.

The time it takes for gravity to overcome the structure during a fire is not predictable. A number of variables determine the amount of time a material can resist gravity and fire degradation. These include:

- Material mass
- Surface-to-mass ratio
- Overall load being imposed
- Btu development (fire load)
- Type of construction (assembly method)
- Alterations (undesigned loading)
- Age deterioration/care and maintenance of the structure
- Firefighting impact loads
- Condition of fire-resistive barriers

Streetsmart Tip **Surface-to-Mass Ratio**: **Surface-to-mass ratio** is defined as the exposed exterior surface area of a material divided by its weight. In simple terms, smaller, lighter structural members will have a large surface with small mass when compared to larger structural members capable of carrying an equal load. A 3- × 14-inch solid wood beam may carry the same design load as six 2- × 4-inch parallel chord trusses. The trusses have much more wood surface exposed and are more likely to ignite and burn rapidly.

The larger the surface area, the smaller the mass, the quicker it will burn or fail. Also, in combustible construction, the large surface area provides more fuel for the fire. Surface-to-mass ratio may also be applied to lightweight steel or pre-engineered buildings. These lightweight structural steel members will absorb heat quickly, and the steel elements will lose their strength and fail, causing collapse.

STRUCTURAL ELEMENTS

Buildings are an assembly of structural elements designed to transfer loads to the earth. Structural elements can be defined simply as beams, columns, and walls. Each of these elements must be connected in some fashion in order to effectively make the load transfers to the building foundation, which delivers the building live and dead loads to earth.

Beams

A **beam** is a structural element that delivers loads perpendicular to its length. Obviously, something must support the beam—usually a wall or column. It stands to reason that beams are used to create a covered space. In doing so, the beam is subjected to an eccentric load. This load causes the beam to deflect. The top of the beam is subjected to a compressive force whereas the bottom of the beam is subjected to tension, **Figure 13-7.** The distance between the top of the beam and the bottom of the beam dictates the amount of load the beam can carry. I beams are very typical and usually refer to the use of steel to form a beam. The top of the I is known as the top **chord;** the bottom of the I is called the bottom chord. The material in between is known as the **web.** There are numerous types of beams although the principal method of load transfer remains the same. A few types of beams include:

- **Simple beam:** A beam supported at the two points near its ends.
- **Continuous beam:** a beam that is supported in three or more places.
- **Cantilever beam:** A beam that is supported at only one end—or a beam that extends over a support in such a way that the unsupported overhang places the top of the beam in tension and the bottom in compression.
- **Lintel:** A beam that spans an opening in a load-bearing masonry wall—such as over a garage door opening. In wood construction, the same beam is often called a *header.*
- **Girder:** A beam that supports other beams.
- **Joist:** A wood framing member used to support floors or roof decking. A **rafter** is a joist that is attached to a ridge board to help form a peak.
- **Truss:** A series of triangles used to form a structural element that in many ways is really a "fake" beam. That is, a truss uses geometric shapes, lightweight materials, and connections to transfer loads just like a beam. Trusses will be covered in detail later in this chapter.
- **Purlin:** A series of wood beams placed perpendicular to steel trusses to help support roof decking.

Columns

A **column** is any structural component that transmits a compressive force parallel through its center. Columns typically support beams and other columns, **Figure 13-8.** Columns are typically viewed as the vertical supports of a building; however, columns can be diagonal or even horizontal. The guiding principle is that a column is totally in compression.

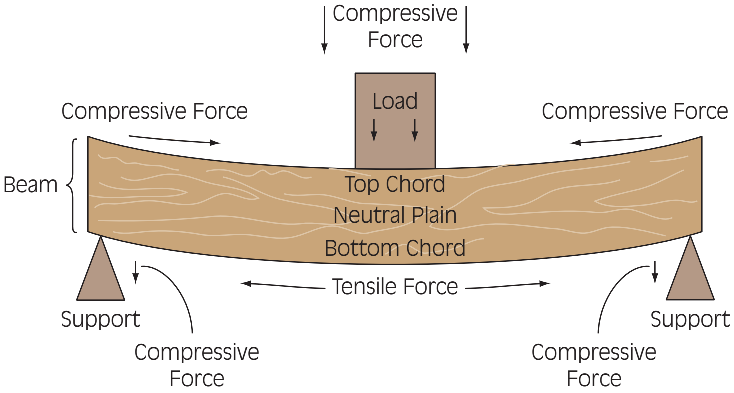


Figure 13-7 A beam transfers a load perpendicular to the load—creating compressive and tensile forces within the beam.

Walls

A wall is also a component that transmits compressive force through its center. Simply put, a wall is a really long, but slender, column. Walls are subdivided into two categories: **load-bearing** and non-load-bearing. A load-bearing wall carries the weight of beams, other walls, floors, roofs, or other structural elements as well as the weight of the wall itself. A non-load-bearing wall need only support its own weight. A partition wall is an example of a non-load-bearing wall.

Connections

As mentioned previously, beams, columns, and walls must be connected in some fashion in order to effectively transfer loads. Often, the connection is the weak link as it relates to structural failure during fires. The connection point is often a small, low-mass material that lacks the capacity to absorb much heat, thereby failing quicker than an element that has more mass such as a column or wall. Connections fall into three categories: pinned, rigid, and gravity. Pinned connections use bolts, screws, nails, rivets, and similar devices to transfer load. Rigid connections refer to a system where the elements are bonded together such that all the columns (or load-bearing walls) are bonded to all the beams. Typically, failure of one element will cause the loads to be transferred to other elements. Gravity connections are just that—the load from an element is held in place by gravity alone.

Figure 13-8 This column is supporting a beam, flooring, and another column. Columns are subjected to compressive forces.

Together, structural elements defy gravity and make a building sound. A series of columns and beams used to hold up a building are often referred to as the *skeletal frame. Post and beam* describes the same concept. Beams resting on walls are simply called wall-bearing buildings. One factor that has not been discussed is the suitability of the materials used to form structural elements. The next section covers these materials and how they act during fires.

FIRE EFFECTS ON COMMON BUILDING CONSTRUCTION MATERIALS

Many factors determine which material is used to form structural elements. Quality, cost, application, engineering capabilities, and adaptability all play in the suitability of a material. In some cases, the material chosen for a structural application

TRIBUTE TO THE OL' PROFESSOR

Contributed by Dave Dodson

Francis L. Brannigan is a true friend to the fire service. For over thirty-five years Mr. Brannigan has shared his knowledge of fire and, more specifically, effects of fire on buildings. His book *Building Construction for the Fire Service* (see the Additional Resources section at the end of this chapter) is a must-read for any firefighter and critical reading for anyone wanting to promote into fireground decision-making positions.

The fire service has affectionately called Mr. Brannigan the "Ol' Professor." His teachings have saved untold numbers of firefighters. I will never forget my first exposure to Mr. Brannigan. It was at a national conference in Cincinnati. The Ol' Professor was teaching a daylong class on steel buildings. As a young and inexperienced firefighter, I was all ears. The class taught me two things. First, I had much to learn about fire effects on building construction. I was way behind in my knowledge, and the Ol' Professor motivated me to make a never-ending knowledge quest to understand buildings. Second, I realized that reading buildings and reading smoke were the keys to rescuing people and putting the "wet stuff on the red stuff."

Over the years, Mr. Brannigan has coined many powerful—and lifesaving—phrases. These bits of advice have remained part of the teachings of many fire instructors. Among my favorites:

Trusses

"BEWARE the TRUSS!"

"A truss is a truss, is a truss . . ."

—in reply to the notion that a bowstring truss is more dangerous than other trusses.

"The bottom chord of a truss is under tension—It's like you hanging on a rope. If the rope gets cut, you will fall. So it is with a truss."

"Failure of one element of a truss may cause the entire truss to fail—failure of one truss can cause other trusses to fail."

Columns

"The failure of a column is likely to be more sudden than failure of a beam."

"The slightest indication of column failure should cause the building to be cleared immediately."

On Collapses

"There is a tendency among those concerned about building stability to make light of partial collapse . . . a partial collapse is very important to at least two groups—those under it and those on top of it!"

"From an engineering point of view, (lightweight, trussed) buildings are made to be disposable . . . we don't make disposable firefighters!"

In response to those who claim a building collapsed without warning during a fire:

"The warning is the brain—in your ability to understand buildings and anticipate how they will react to a fire."

The fire service is indebted to the Ol' Professor. Thanks for all you have done!

---

needs to meet fire resilience criteria. Regardless, the firefighter needs to understand how these materials react to fire. In the past, the fire service looked at the characteristics of four basic material types: wood, steel, concrete, and masonry. Each of these materials can be found together or separately. Each material reacts to fire in a different way, **Table 13-1.** Now, advanced material technology has found its way into structural elements. Buildings are being assembled using plastics, graphites, wood derivatives, and other composites. This section covers the four basic building materials as well as some of the new composites.

Wood

Wood is perhaps the most common building material. It is used in millions of residential and commercial buildings. Wood is relatively inexpensive, easy to manipulate, and a replenishable natural resource (although that can be argued). Wood has marginal resistance to forces compared to its weight, but it does the job for most residential and small commercial buildings. Wood also burns—and in doing so gives away its mass. The more mass a section of wood has, the more material it must burn away before strength is lost. This is true of native wood—that is, wood that

Performance of Common Building Materials under Stress and Fire

MATERIAL	COMPRESSION	TENSION	SHEAR	FIRE EXPOSURE
Brick	Good	Poor	Poor	Fractures, spalls, crumbles
Masonry block	Good	Poor	Poor	Fractures, spalls
Concrete	Good	Poor	Poor	Spalls
Reinforced concrete	Good	Fair	Fair	Spalls
Stone	Good	Poor	Fair	Fractures, spalls
Wood	Good w/grain; poor across grain	Marginal	Poor	Burns, loss of material
Structural steel	Good	Good	Good	Softens, bends, loses strength
Cast iron*	Good	Poor	Poor	Fractures

*Some cast iron may be ornamental in nature and not part of the structure or load bearing.

TABLE 13-1

has been cut from a tree. Engineered wood can react differently when exposed to heat from a fire. Engineered wood includes a host of products that take many pieces of native wood and glue them together to make a sheet, longer beam (trees only grow so tall!), or stronger column. Plywood delaminates when exposed to fire. Some newer wood products such as composites, which are discussed later in this chapter, present safety concerns for all firefighters.

Steel

Steel is a mixture of carbon and iron ore heated and rolled into structural shapes to form elements for a building. Steel has excellent tensile, shear, and compressive strength. For this reason, steel is a popular choice for girders, lintels, cantilevered beams, and columns. Additionally, steel has high factory control. It is easy to change its shape, increase its strength, and otherwise manipulate it during production.

As it relates to fires, steel loses strength as temperatures increase. The specific range of temperatures depends on how the steel was manufactured. Cold drawn steel, like cables, bolts, rebar, and lightweight fasteners, loses 55 percent of its strength at 800°F. Extruded structural steel used for beams and columns loses 50 percent of its strength at 1,100°F. Structural steel will also elongate or expand as temperatures rise. At 1,000°F, a 100-foot-long beam will elongate 10 inches. Imagine what that could do to a building. If a beam is fixed at two ends, it will try to expand—and likely deform, buckle, and collapse. If the beam sits in a pocket of a masonry wall, it will stretch outward and place a shear force on the wall—which was designed only for a compressive force. *This could knock down the whole wall!*

Because steel is an excellent conductor of heat, it will carry heat of a fire to other combustibles. This can cause additional fire spread, sometimes a considerable distance from the original fire.

Caution Steel softens, elongates, and sags when heated, leading to collapse. Cooling structural steel with fire streams is just as important as attacking the fire.

Concrete

Concrete is a mixture of portland cement, sand, gravel, and water. It has excellent compressive strength when cured. The curing process creates a chemical reaction that bonds the mixture to achieve strength. The final strength of concrete depends on the ratio of these materials, especially the ratio of water to portland cement. Because concrete has poor tensile and shear strength, steel is added as reinforcement. Steel can be added to concrete in many ways. Concrete can be poured over steel rebar and become part of the concrete mass when cured. Cables can be placed through the plane of concrete and be tensioned, compressing the concrete to give it required strength. Cables can be pretensioned (at a factory) or posttensioned (at the job site). *Precast concrete* refers to slabs of concrete that are poured at a factory and then shipped to a job site. Precast slabs are "tilted up" to form load-bearing walls—thus the term *tilt-up construction.*

All concrete contains some moisture and continues to absorb moisture as it ages. When heated, this moisture content will expand, causing the concrete to crack or spall. **Spalling** refers to a large pocket of concrete that has basically crumbled into fine particles, taking away the mass of the concrete. Reinforcing steel that becomes exposed to a fire can transmit heat within the concrete, causing catastrophic spalling and failure of the structure. Unlike steel, concrete is a heat sink and tends to absorb and retain heat rather than conduct it. This heat is not easily reduced. Concrete can stay hot long after the fire is out, causing additional thermal stress to firefighters performing overhaul.

Masonry

Masonry is a common term that refers to brick, concrete block, and stone. Masonry is used to form load-bearing walls because of its compressive strength. Masonry can also be used to build a **veneer** wall. A veneer wall supports only its own weight and is most commonly used as a decorative finish. Masonry units (blocks, bricks, and stone) are held together using **mortar**. Mortar mixes are varied but usually contain a mixture of lime, portland cement, water, and sand. These mixes have little to no tensile or shear strength. They rely on compressive forces to give a masonry wall strength. A lateral force that exceeds the compressive forces within a masonry wall will cause quick collapse of the wall.

Streetsmart Tip **Masonry Walls Collapse:** Masonry has very little lateral stability, and in many cases the roof or floor structure of a building holds the walls in place. Steel beams or joists will expand during a fire, creating lateral loads that the walls were not designed to withstand. In addition, wood roof structures will burn away or collapse during a fire, leaving little lateral support. The effects of the fire, pulling forces of the collapsing wood structure, or the force of a hose stream may cause the wall to collapse. Remember, the designer and contractor did not plan for the building to burn down.

Figure 13-9 Prior to a fire, the effects of age will take their toll on masonry walls. How stable is this wall with joint deterioration and lack of full mortar bond?

Brick, concrete block, and stone have excellent fire-resistive qualities when taken individually. Many masonry walls are typically still standing after a fire has ravaged the interior of the building. Unfortunately, the mortar used to bond the masonry is subject to spalling, age deterioration, and washout. Whether from age, water, or fire, the loss of bond will cause a masonry wall to be very unstable, **Figure 13-9.**

Composites

New material technologies have introduced some interesting challenges for the firefighting community. Composites are a combination of the four basic materials listed above as well as various plastics, glues, and assembly techniques. Of particular interest are the many wood products that are widely used for structural elements.

Lightweight wooden I beams (joists) are nothing more than wood chips that are press-glued together into the shape of an I beam, **Figure 13-10.** While structurally strong (stronger than a comparable solid wood joist), the wooden I beam fails quickly when heated. Actually, no fire contact is required. Ambient heating causes the binding glue to fail, leading to a quick collapse. The bottom of a beam is under tensile forces. If the bottom of the beam falls off, due to glue failure, the beam will immediately snap and collapse.

New products, known as FiRP (fiber-reinforced products) are becoming common in the construction industry. FiRP can be plastic fibers mixed with wood to give the wood increased tensile strength. As with most plastics, fire exposure can cause quick failure as the plastic melts.

The mixture of steel and wood as a structural element can cause rapid collapse because steel expands

Figure 13-10 To save on materials and cost, the use of composites or engineered wood structural members is becoming popular. Shown here is a typical wood I beam with 2- × 3-in. flanges and a ⅜-in. structure board web. In addition to providing a large surface-to-mass ratio, the flanges and web are fastened with glue, which may deteriorate quickly under fire conditions.

Figure 13-11 A composite truss. Rapid heating will cause the steel to separate from the wood chords.

(A)

(B)

Figure 13-12 These are wall panels that are load-bearing (A). Expanded polystyrene is sandwiched between OSB sheets. Fire can easily enter the wall space. (B) Failure of the wall panel will cause instability in the roof structure.

faster than wood. This causes stress at the intersection of the two materials, **Figure 13-11.**

Structural insulated panels (SIP) are another interesting composite. This technique is characterized by large wall panels made of expanded polystyrene sandwiched between two sheets of oriented strand board (OSB). OSB is a sheet of wood chips bonded by glue, **Figure 13-12A** and **B.** The OSB is covered with a typical wall finish. It is anticipated that a fire will cause rapid deterioration of the load-bearing panel.

To review, this chapter has so far explored the basic terminology, mechanics, elements, and materials used in the construction of buildings. It has also discussed a bit about how fire attacks materials and causes failure. The next section explores the various methods used to assemble buildings.

TYPES OF BUILDING CONSTRUCTION

Over time, five broad categories of building construction types have been developed to help classify structures. These categories give firefighters a basic

Types of Construction from NFPA 220

	TYPE I		TYPE II			TYPE III		TYPE IV	TYPE V	
	443	332	222	111	000	211	200	2HH	111	000
Exterior Bearing Walls—										
Supporting more than one floor, columns, or other bearing walls	4	3	2	1	0	2	2	2	1	0
Supporting one floor only	4	3	2	1	0	2	2	2	1	0
Supporting a roof only	4	3	1	1	0	2	2	2	1	0
Interior Bearing Walls—										
Supporting more than one floor, columns, or other bearing walls	4	3	2	1	0	1	0	2	1	0
Supporting one floor only	3	2	2	1	0	1	0	1	1	0
Supporting roofs only	3	2	1	1	0	1	0	1	1	0
Columns—										
Supporting more than one floor, columns, or other bearing walls	4	3	2	1	0	1	0	H[1]	1	0
Supporting one floor only	3	2	2	1	0	1	0	H[1]	1	0
Supporting roofs only	3	2	1	1	0	1	0	H[1]	1	0
Beams, Girders, Trusses & Arches—										
Supporting more than one floor, columns, or other bearing walls	4	3	2	1	0	1	0	H[1]	1	0
Supporting one floor only	3	2	2	1	0	1	0	H[1]	1	0
Supporting roofs only	3	2	1	1	0	1	0	H[1]	1	0
Floor Construction	3	2	2	1	0	1	0	H[1]	1	0
Roof Construction	2	1½	1	1	0	1	0	H[1]	1	0
Exterior Nonbearing Walls	0	0	0	0	0	0	0	0	0	0

🟨 Those members that shall be permitted to be of approved combustible material.

[1] "H" indicates heavy timber members; see text for requirements.

Source: Reprinted with permission from NFPA 220, *Types of Building Construction*, copyright © 1995, National Fire Protection Association, Quincy, MA 02269. This reprinted material is not the complete and official position of the National Fire Protection Association on the referenced subject which is represented only by the standard in its entirety.

TABLE 13-2

understanding of the arrangement of structural elements and the materials used to construct the building. Unfortunately, these broad classifications are dangerously incomplete for firefighters and may lead to deadly assumptions about the makeup of a building. As stated before, firefighters need to explore the buildings within their jurisdiction to determine how buildings are assembled.

It is important to note that buildings are built to meet certain codes. These codes are designed to give occupants time to escape during a fire. Concrete is **fire resistive**—meaning it has some capacity to withstand the effects of fire. Other materials, like steel and wood, need fire-resistive assistance to give occupants a chance to escape. Building codes outline **fire-resistive ratings**, occupancy classifications, and means of egress based on five general types of buildings. The features of each type of construction will be discussed shortly, but first it is important to understand fire resistance for structural elements. **Table 13-2** outlines the number of hours that a structural element needs to be protected for the five types of construction. Simply put, firefighting time is not part of the fire-resistive and building construction equation. Fire-resistive ratings are established in a laboratory. In the real world, fire resistance ratings could "underperform" due to many factors. For example, a structural element with a two-hour fire rating may fail in thirty minutes if it was not assembled correctly or if improperly inspected. Fire resistance for structural members can be achieved by various methods including drywall (gypsum wallboard), spray-on coatings, and concrete, **Figure 13-13.** Aging, alterations, and wear can damage fire-resistive methods to the point that structural elements have no fire resistance protection.

Figure 13-13 This parking garage is of Type II construction. The protective coating applied to the structural steel may increase the fire-resistive rating, but note that the unprotected corrugated metal flooring and interior steel structure are not protected. These unprotected structural members may fail early in a fire. *(Photo courtesy of William H. Schmitt, Jr.)*

The following paragraphs outline the basic definition of each building type, its general configuration, and some historical fire spread problems associated with each. Also included are some construction methods that do not fit into the five common types.

Type I: Fire-Resistive

Type I fire-resistive construction is a type in which structural elements are of an approved noncombustible or limited combustible material with sufficient fire-resistive rating to withstand the effects of fire and prevent its spread from story to story. Concrete-encased steel, **Figure 13-14,** monolithic-poured cement, and steel with spray-on fire protection coatings are typical of Type I, **Figure 13-15.** Generally, the fire-resistive rating must be three to four hours depending on the specific structural element. Fire-resistive construction is used for high-rises, large sporting arenas, and other buildings where a high volume of people are expected to occupy the building.

Most Type I buildings are typically large, multistoried structures with multiple exit points. Fires are difficult to fight due to the large size of the building and the subsequent high fire load. Type I buildings rely on protective systems to rapidly detect and extinguish fires. If these systems do not contain the fire, a difficult firefight will be required. Fire can spread from floor to floor on high-rises as windows break and the next floor windows fail, allowing the fire to jump. Fire can also make vertical runs through utility and elevator shafts. Regardless, firefighters are relying on the fire-resistive methods to protect the structure from collapsing. The collapse

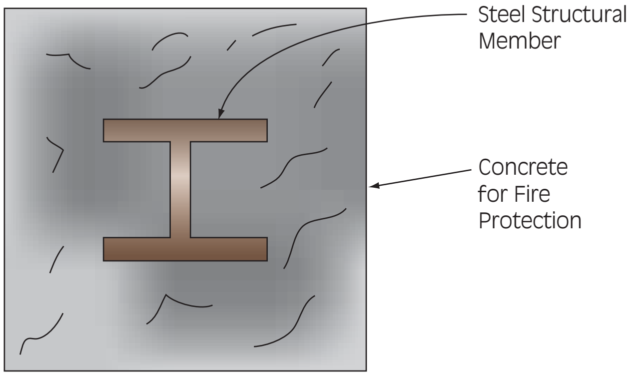


Figure 13-14 To achieve a Type I fire-resistive rating, structural steel members are encased with concrete to prevent failure from the effects of a fire.

Figure 13-15 A typical Type I building, with structural members designed to resist the effects of fire for three to four hours. This building is of reinforced concrete construction.

Figure 13-16 Buildings of Type II construction will have structural elements with little or no protection from the effects of fire. Remember, in the event of a fire, these unprotected steel structural members may fail and collapse with little warning.

of fire-resistive structures can be massive, as we are reminded from the World Trade Center collapse in New York City.

Type II: Noncombustible

Type II noncombustible construction is a type in which structural elements do not qualify for Type I construction and are of an approved noncombustible or limited combustible material with sufficient fire-resistive rating to withstand the effects of fire and prevent its spread from story to story. More often than not, Type II buildings are steel, **Figure 13-16.** Modern warehouses, small arenas, and newer churches and schools are built as noncombustible. Because the steel is not required to have significant fire-resistive coatings, Type II buildings are susceptible to steel deformation and resulting collapse. Fire spread in Type II buildings is influenced by the contents. While the structure itself will not burn, rapid collapse is possible from the content Btu release stressing the steel.

Suburban strip malls with concrete block load-bearing walls and steel roof structures can be classified as Type II. Fires can spread from store to store through wall openings and shared ceiling and roof support spaces. The roof structure is often of lightweight steel that fails rapidly. More often than not, the fire-resistive device used to protect the roof structure is a dropped-in ceiling. Missing ceiling tiles, damaged drywall, and utility penetrations can render the steel unprotected. These buildings may have combustible attachments such as facades and signs as well as significant content fire loading.

Type III: Ordinary

The term **Type III ordinary construction** is often misapplied to wood frame buildings. By definition, ordinary construction includes buildings where the load-bearing walls are noncombustible, and the roof and floor assemblies are wood. Most commonly, this is load-bearing brick or concrete block with wood roofs and floors. Ordinary con-


Figure 13-17 Buildings of Type III, ordinary construction, are common throughout North America. These typical "Downtown USA" buildings provide many challenges to firefighters, such as void spaces and common walls allowing rapid fire extension and little structural protection, with early collapse during firefighting operations.

struction is prevalent in most downtown or "main street" areas of established towns and villages, **Figure 13-17.** Firefighters have long called ordinary construction "taxpayers." This slang is derived from landlords who built buildings with shops and/or restaurants on the first floor with apartments above in order to maximize income to help pay property taxes. Newer Type III buildings include strip malls with block walls and wood truss roofs, **Figure 13-18.**

Ordinary construction presents many challenges to firefighters. In older buildings, numerous remodels, restorations, and repairs have created suspect wall stability and hidden dangers.

Firefighter Fact Sagging or bowing load-bearing walls are often pulled back in alignment by tightening a steel rod that runs through the building from wall to wall. A small interior fire can elongate this steel and cause catastrophic wall failure. These buildings can be spotted by decorative stars or ornaments (called *spreaders*) on the outside brick wall.

Ordinary construction has many void spaces where fire can spread undetected. Common hallways, utilities, and attic spaces can communicate fire rapidly. Masonry walls hold heat inside, making for difficult firefighting. Wood floors and roof beams are often gravity fit within the masonry walls. These can release quickly and cause a general collapse, leaving an unsupported masonry wall. Older Type III buildings have structural mass; therefore, they burn for a long time.

Type IV: Heavy Timber

Type IV heavy timber construction can be defined as those buildings that have block or brick exterior load-bearing walls and interior structural members, roofs, floors, and arches of solid or laminated wood without concealed spaces. The minimum dimensions for structural wood must meet the criteria in **Table 13-3.** Heavy timber buildings, as the name suggests, are quite stout and are used for warehouses, manufacturing buildings, and some older churches, **Figure 13-19.** In many ways, a Type IV building is like a Type III—just larger dimension lumber instead of common wood beams and trusses.


Figure 13-18 One of the most common uses of Type III, ordinary construction, is the "strip mall" with masonry walls and lightweight steel or wood trusses. Common problems associated with this type of construction are void spaces allowing for rapid fire extension and collapse of lightweight structural elements.

Heavy Timber Dimensions

TYPE OF ELEMENT	USE	SIZE
Column	Supporting floor load	8- × 8-in. minimum any dimension
Column	Supporting roof load	6-in. smallest dimension, 8-in. depth minimum
Beams and girders	Supporting floor load	6-in. width and 10-in. depth minimum
Beams, girders, and roof framing	Supporting roof loads only	4-in. width minimum, 6-in. depth minimum
Framed or laminated arches	As designed	8-in. minimum dimension
Tongued and grooved planks	Floor systems	3-in. minimum thickness with additional 1-in. boards at right angles
Tongued and grooved planks	Roof decking	2-in. minimum thickness

TABLE 13-3

Figure 13-19 Type IV buildings, heavy timber construction, have large wood structural elements with great mass. The mass of these structural members requires a long burn time for failure. The connections, usually steel, are the weak points in this type of construction.

Some firefighters mistakenly call Type IV buildings "mill construction." Mill construction is a much more stout, collapse-resistive building that may or may not have block walls. A new Type IV building is hard to find. The cost of large-dimension lumber and laminated wood beams makes this type of construction rare.

Fire spread in a heavy timber building can be fast due to wide-open areas and content exposure. The exposed timbers contribute Btus to the fire. Because of the mass and large quantity of exposed structural wood, fires burn a long time. If the building housed machinery at one time, oil-soaked floors will add more heat to the fire and accelerate collapse. Once floors and roofs start to sag, heavy timber beams may release from the walls. This is accomplished by making a fire-cut on the beam, and the beam is gravity fit into a pocket within the exterior load-bearing masonry wall, **Figure 13-20.** As the floor sags, it loses its contact point with the wall and simply slides out of its pocket without damage to the wall. It is important to recall that a free-standing masonry wall has little lateral support and requires compressive weight from floors and roofs to make it sound.

Type V: Wood Frame

Type V wood frame construction is perhaps the most common construction type. Homes, newer small businesses, and even chain hotels are built primarily with wood, **Figure 13-21.** Older wood frame buildings were built as **balloon frame**—

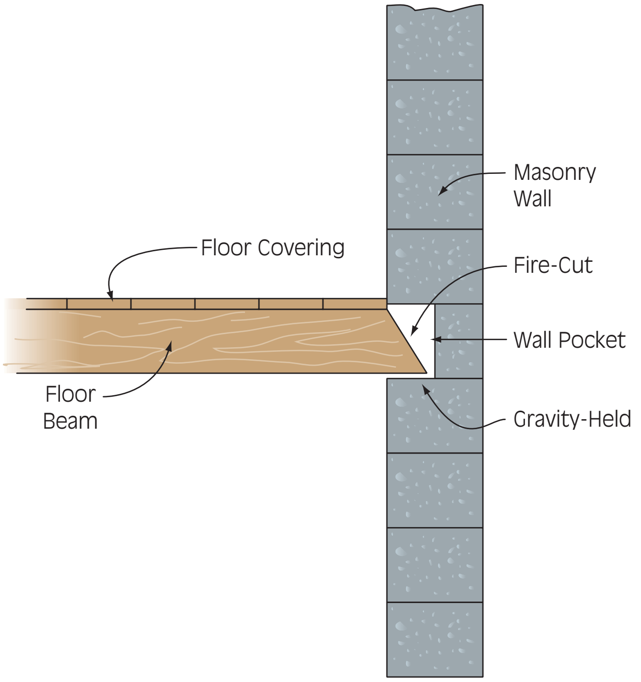


Figure 13-20 Wood and heavy timber beams were often "fire-cut" so that a fire-damaged, sagging floor would simply slide out of the wall pocket in order to preserve the wall.

Figure 13-21 The wood frame structure, Type V construction, is the most common type of construction in North America.

that is, wood studs ran from the foundation to the roof and floors were "hung" on the studs. As can be envisioned, fire could enter the wall space and run straight to the attic. In the early 1950s, builders started using a **platform framing** arrangement where one floor was built as a platform for the next floor. This created **fire stopping** to help minimize fire spread. Newer wood frame buildings utilize lightweight wood trusses for roofs and floors. This is akin to a "horizontal balloon frame" that can allow quicker lateral fire spread. Coupled with high surface-to-mass wood exposure, collapse becomes a real possibility, **Figure 13-22.** Some codes require truss spaces to have fire stopping every 500 square feet. Even with this fire stopping, it remains dangerous to step onto the 500 square feet where the fire is. Wood frame structures may appear more like a Type III ordinary building because of a brick-wall appearance. Remember, brickwork may be a simple veneer to add aesthetics.

To protect structural members from a fire, wood frame construction typically uses gypsum board (drywall or the brand name Sheetrock). Once finished, wood frame buildings typically have many rooms that can help compartmentalize content fires. Fire that penetrates wall, floor, or attic spaces becomes a significant collapse threat, especially in newer buildings. Often, the only warning that fire has penetrated these spaces is the issuance of smoke from crawl space vents, gable end vents, and eaves.

Other Construction Types

As mentioned earlier, the five broad building types can actually lead to dangerous assumptions. Newer construction and alternative building methods may not fit cleanly into one of the above types. Some buildings are actually two types of construction. For example, a particular restaurant located in Colorado is built as a Type II noncombustible yet is topped with a large wood frame structure to hide rooftop HVACs and cooking vent hoods, **Figure 13-23A** and **B.** The square feet space of the false dormers and wood frame structure exceeds that of most homes.

New lightweight steel homes resemble wood frame homes. These buildings are actually a "post and beam" steel building with lightweight steel studs to help partition the home. OSB is added to the studs to help make the house more "stiff" and increase wind-load strength, **Figure 13-24.** Another interesting construction type uses foam blocks to make a form for a lightweight concrete mud mixture. The concrete is not contiguous—there are many voids, utility runs, and foam block spacers (made of plastic or galvanized steel), **Figure 13-25.** These structures are called "ICF" or insulated concrete formed." However, it is important not to be fooled by any claims that these buildings are concrete or are less combustible. In reality, these composite buildings are assembled with plastics, polystyrene, lightweight steel, and lightweight concrete. When finished, these buildings may resemble wood frame or even ordinary construction.

(A)

(B)

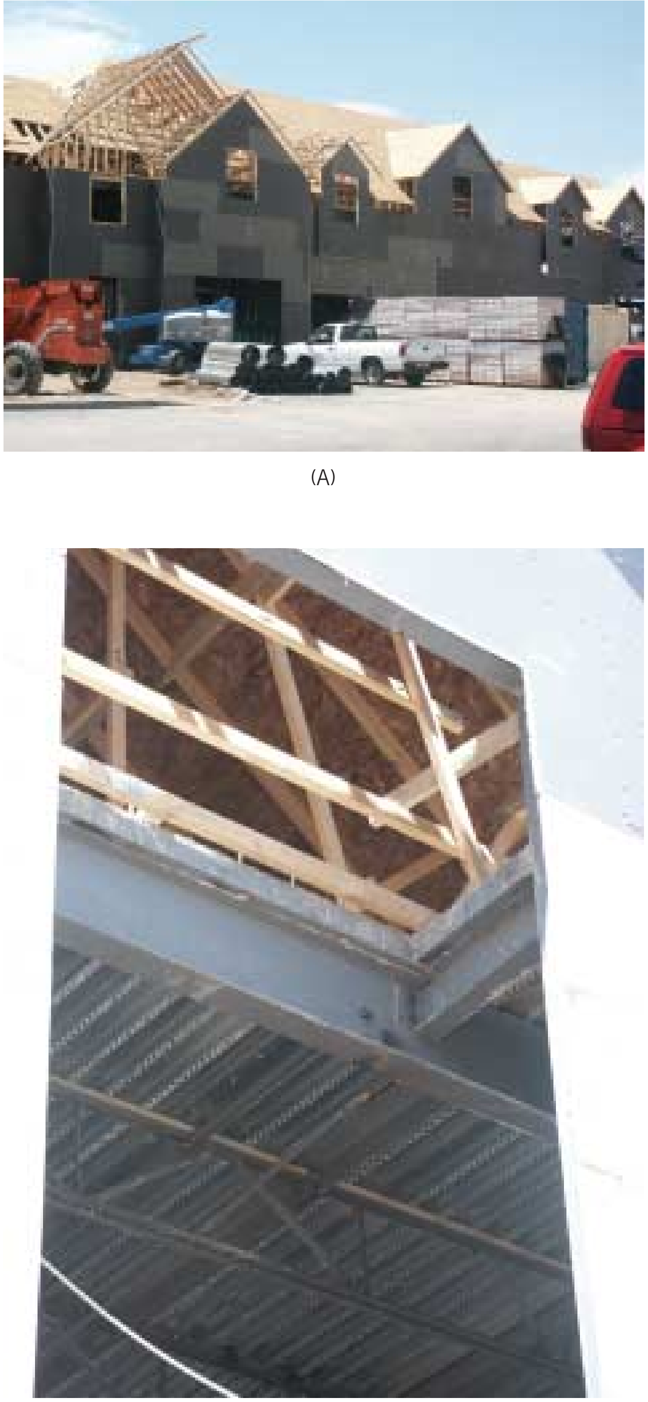
(C)

Figure 13-22 (A, B) Note the void spaces at the first and second floor levels and in the attic area that are created by the use of truss systems. (C) The building after it was completed. Firefighters should survey the buildings in their area before they are completed.

Extended window and door jambs are clues that indicate the wall is thicker than that of typical wood or masonry built buildings.

The fire service has very little research information on the stability of these new types of buildings during fires. One thing is certain: Firefighters should expect rapid collapse due to the low-mass, high surface-to-mass exposure of structural elements.

Manufactured buildings can be defined as those structures that are built at a factory and then trucked to a job site. These building are quite light with little mass. Where a stick-built home uses 2 × 4 or 2 × 6 lumber, the manufactured home uses 1 × 2 and 2 × 2 lumber. These buildings use galvanized strapping to give required strength. In any case, these buildings burn quickly and collapse equally fast.



(A)

(B)

Figure 13-23 (A) The decorative roof assembly is a Type V wood frame structure while the occupancy space is Type II noncombustible. (B) This building uses two types of construction.

Figure 13-24 This lightweight steel home is built similar to a Type V. OSB sheeting gives the steel rigidity to torsional loads like wind.

Relationship of Construction Type to Occupancy Use

Before considering the basic types of construction, many officials and builders first look at the anticipated use of the building—its occupancy type. **Occupancy classifications** are called many different names around the country, but they are usually broken down into five basic arenas: residential, commercial, business, industrial, and educational. Each of these general occupancies has a number of hazards that firefighters must understand, **Table 13-4.** Remember, a building may have been built for one type of occupancy only to be sold and converted to another occupancy type for which it may not have been designed. Firefighters should go out and explore the buildings in their community.

(A) (B)

Figure 13-25 (A) This wall is a load-bearing foam block unit filled with a lightweight concrete mud mix. (B) Note the black plastic spacers that will fail early in a fire.

Typical Hazards Associated with Occupancies

OCCUPANCY	TYPE OF CONSTRUCTION	HAZARDS
Residential	Type V, most common	Fire loading, truss construction, owner alterations, rapid fire extension in void spaces
Commercial	Type III, most common	Fire loading, truss construction, rapid fire extension in void spaces, unknown occupancy change
Educational	Type II, most common	Unprotected structural steel, collapse, high fire load in some areas
Business	Types II and III, most common	Unknown change in occupancy, high fire load, difficult to ventilate
Industrial	Types I and II, most common	Hazardous materials, difficult to ventilate

TABLE 13-4

COLLAPSE HAZARDS AT STRUCTURE FIRES

It cannot be overstated that firefighters have to understand the buildings in their jurisdiction. Constant reading, study, and site visits will help them “read” buildings. Reading buildings is essential to anticipating collapse proactively. This section addresses some specific collapse threats that the fire service has experienced throughout history and the importance of understanding buildings and how they react at structure fires.

Figure 13-26 Wood trusses provide a large surface-to-mass ratio, fuel load, and void spaces—three of the worst conditions a firefighter will encounter during structural firefighting operations.

Figure 13-27 A typical parallel chord truss. The gusset plates on this truss are pressed into the wood. In addition to the decomposing of the wood element, the light-gauge steel plates will deform and pull away from the wood under fire conditions.

Trusses

Truss roof collapses have killed many firefighters. As stated previously, a truss is actually a fake beam. A truss uses geometric shapes (the triangle) to create a structural element similar to a beam. A wood truss can actually be stronger than a like-sized solid wood beam, and does so with less material, **Figure 13-26.** It is this loss of material and subsequent increase in exposed surface area that make them so vulnerable during fires. Trusses rely on each and every part of the truss to carry a portion of the imposed load. Like a beam, the top of the truss (called the top chord) is typically under a compressive force. The bottom chord is under tension. In between the two chords, connecting members (the web) transfer the two forces creating stress and strain. Failure of one part of the truss will likely cause the whole truss to fail. This distributes the weight of the failed truss to other trusses—which may not have the capacity to take that weight—thereby starting a domino effect collapse. Trusses come in many styles and shapes. Bowstring truss, parallel chord truss, and open web joists are some of the more common names. Trusses are also classified by the type of material used in assembly.

Wood Trusses

Wood trusses are an assembly of many pieces of wood. Some may even be press-glued particles. These pieces are connected using **gusset plates**. A gusset plate is a simple galvanized steel plate (very thin) with perforations punched into the plate. The perforations are used to pierce into wood fibers to hold pieces together. These perforations only penetrate the wood a fraction of an inch (3/8 inch is typical), **Figure 13-27.** During fires, the steel gusset heats up and transfers heat into the very wood fibers that are being held. If the heating is slow (like a smoke-filled attic), the wood decomposes, allowing the gusset plate to fall out. If the heating is fast, like sudden exposure to flame, the steel expands too quickly for the wood and the gusset simply pops out. Either way, truss failure is imminent. Sometimes the truss gingerly stays together because of the weight of roofing or flooring materials, yet a sudden force, like a walking firefighter, will cause the truss to disassemble and suddenly collapse.

Wood trusses are mass-produced at a factory where quality control may not be adequate. Further, the truss gusset plates may vibrate or be damaged while being delivered to a job site. Once on the job site, contractors may use shortcuts to lift the truss into position, furthering the damage to gusset plates.

Steel Trusses

Steel trusses are no less susceptible to collapse than wood trusses. Like wood, steel trusses are an assembly of pieces—typically angle iron for the chords and cold-drawn round stock for the web. The pieces are tack-welded together to form the truss unit. While not a true joist by definition, many call the common steel truss an open web steel joist, **Figure 13-28.** The term *bar joist* is also used to describe an open web steel joist. These trusses expose a large surface area to heat during fires. Given the lack of mass, the truss heats quickly and will soften and expand. The expansion can cause wall movement. (Remember, masonry walls must be loaded axial with compressive force.) Lateral movement can cause wall collapse. If the wall does not move, the steel truss will twist and buckle to allow expansion. It is very important to keep steel trusses cool.

Figure 13-28 Unprotected open web steel joists present a large surface area to absorb the heat of a fire, expand, and collapse. Structural steel will lose 50 percent of its strength at temperatures of 1,000°F.

Figure 13-29 Lightweight floor truss systems have many void spaces. This could be called "horizontal balloon frame."

Void Spaces

Trusses create large void spaces. The area between the chords of trusses will allow fires to spread horizontally, **Figure 13-29.** Some codes require fire stopping in floor truss spaces but may allow wide-open attic spaces. Fires can start in void spaces due to electrical and other utility problems. In Type III ordinary construction, voids are numerous. Some voids may pass through masonry walls, causing fire spread from one store to the next in a row of buildings. The obvious collapse danger with void spaces is that the fire may be undetected with simultaneous destruction of structural elements.

Roof Structures

The roof of a building can be flat, pitched, or inverted. Many factors help determine how and why the roof is built the way it is. Sometimes the roof is designed just to hide rooftop HVACs. Other times the roof shape is designed to shed snow, accommodate a vaulted ceiling, or merely give the building character, **Figure 13-30.** As it relates to

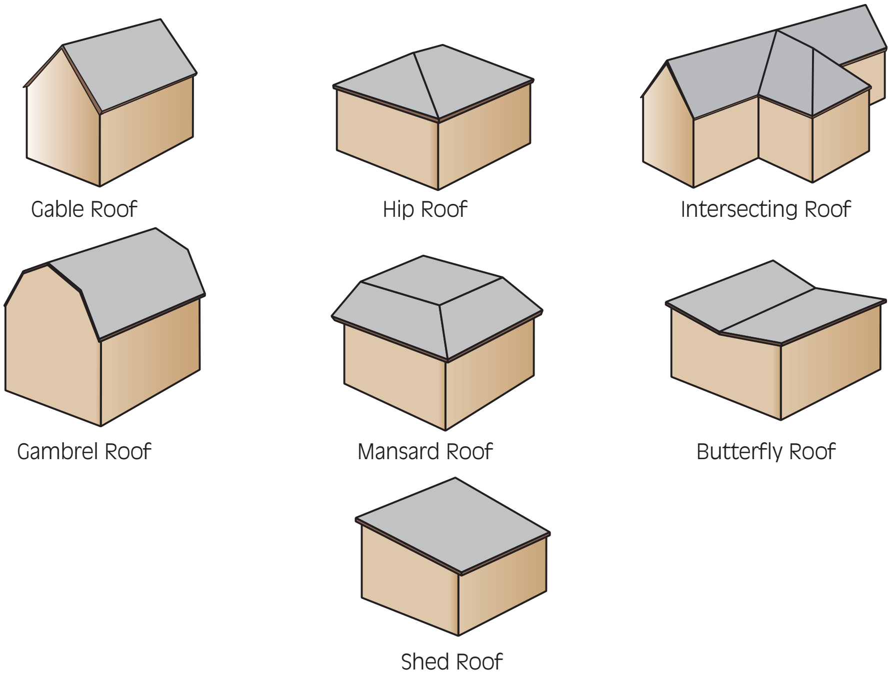


Figure 13-30 Some common roof framing styles used in wood frame or ordinary construction.

structural collapse, the roof style may allow a large volume of fire to develop. Other roofs, like the mansard, have many concealed spaces. Dormers are protrusions from a roof structure. Dormers can be used to introduce daylight into a roof space that is converted into a living space, **Figure 13-31.** Other dormers are actually aesthetic (false) and can fool ventilation crews attempting to relieve heat from a roof space.

Stairs

First arriving firefighting crews rely on internal stairways to help gain access for rescue and fire attack. For years, firefighters have found stairways to be durable and a bit stronger than other interior components. This is a dangerous assumption in newer wood frame buildings. Stairs are now being built offsite and simply hung in place using light metal strapping, **Figure 13-32.** Additionally, stairs are being made using lightweight engineered wood products that fail quickly when heated. Remember, press-glued wood chip products can fail from the heat of smoke—no flame is required.

Figure 13-31 An internal view of dormers in a mansard roof. Fire can run through the many voids between the exterior and the roof.

Parapet Walls

A **parapet** wall is the extension of a wall past the top of the roof. Parapets are used to help hide unsightly roof equipment and HVACs and give a building a finished look. Typically masonry, these walls are free-standing with little stability. Collapse may be caused by the failure of the roof structure, **Figure 13-33.** Business owners hang signs, utility connections, and other loads on the parapet. During a fire, the steel cables and bolts holding these will weaken and subsequently pull down the parapet, **Figure 13-34.**

Figure 13-32 This prefab stair assembly is hung in place by thin metal strapping. Note the staples and plastic shims that can quickly fail under fire conditions.

Figure 13-33 This is the scene of a typical "parapet" wall failure common in Type III ordinary construction.

Figure 13-34 This electrical service entrance and weather head may be the eccentric load causing an early failure of this parapet wall.

Collapse Signs

Firefighters must rely on building material knowledge, building construction principles, and an understanding of fire effects on buildings in order to predict or anticipate collapse. Waiting for a visual sign that a building will collapse is dangerous, especially in newer buildings. There are, however, some factors and observations that can be used to help anticipate collapse. These include:

- Overall age and condition of the building
- Deterioration of mortar joints and masonry
- Cracks, in anything
- Signs of building repair including reinforcing cables and tie-rods
- Large open spans
- Bulges and bowing of walls
- Sagging floors
- Abandoned buildings
- Large volume of fire
- Long firefighting operations—remember gravity?
- Smoke coming from cracks in walls
- Dark smoke coming from truss roof or floor spaces (Brown smoke indicates that wood is being heated significantly; black smoke means combustibles have ignited or are near ignition.)
- Multiple fires in the same building or damage from previous fires

Buildings under Construction

Buildings are especially unsafe during construction, remodeling, and restoration. The word *unsafe* applies not only to fire operations but also to rescues, odor investigations, and on-site inspections. Buildings need only meet fire and life safety codes when they are completed. During construction, many of the protective features and fire-resistive components are incomplete. Additionally, stacked construction material may overload other structural components. This is not to say contractors are using unsafe practices, but to underscore that exposed structural elements, incomplete assemblies, and material stacks will contribute to a rapid collapse if a fire were to develop.

Streetsmart Tip **Beware of Buildings under Construction:** A building as a complete unit has a number of interdependent parts. During construction, these parts may not be fully connected (steel), may not be at their full design strength (concrete), and may lack any type of fire protection (gypsum board or concrete). Also, many structural elements may be held in place by scaffoldings, false work, or forms. Because of this, a building under construction is exposed to early collapse due to the effects of fire or other elements such as high winds.

Historical building restoration and general remodel projects in buildings are similar to buildings under construction. Firefighters may find temporary shoring up of walls, floors, and roofs while other structural components are being updated, replaced, or strengthened. Contractors may use simple 2 × 4s to temporarily shore up heavy timber, leading to disastrous results during fire conditions. The best approach for firefighters to take when responding to fires in buildings under construction is to be defensive. They should make sure everyone is out and accounted for and then attack the fire from a safe location. A building under construction can be replaced—a firefighter's life cannot.

Preparing for Collapse

There are no time limits for firefighting operations within a building. Tests have shown that the age-old "twenty-minute rule" used by previous fire officers is no longer accurate. Roofs and walls can collapse within minutes of fire involvement given certain conditions. An overloaded (due to improper storage or other factors) truss can collapse immediately when heated.

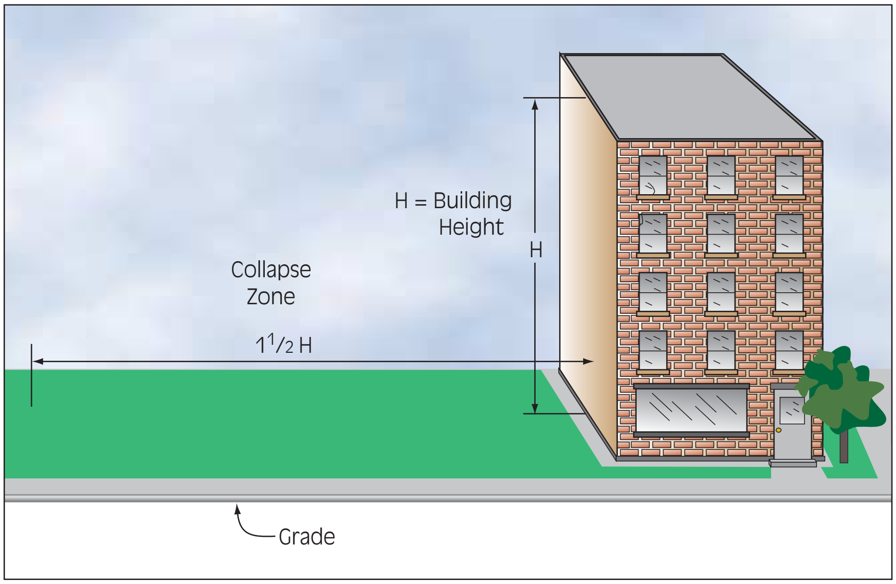


Figure 13-35 A minimum collapse zone should be 1½ times the height of the building.

Streetsmart Tip **Collapse:** Every firefighter must understand two rules about structural collapse during fire operations. The first is that the potential for structural failure during a fire always exists. Do not set artificial time limits based on experience. The second rule is to establish a **collapse zone,** as shown in **Figure 13-35,** which is an area around and away from a building where debris will land if the building fails. As an absolute minimum this distance must be at least 1½ times the height of the building. The walls may crumble into a pile or they may tip out the full height of the building. Also you need to provide extra room for cascading debris.

Once a building has been searched for occupants, the risks firefighters take to control the fire should be reduced—after all, it is now a property issue. Many firefighters have been killed fighting interior fires, only to have the building torn down after the investigation. Outside (defensive) firefighting operations can be equally dangerous if firefighters wander into the **collapse zone**, **Figure 13-36.**

Figure 13-36 These photos show the effects of fire on a masonry wall. Note the debris and distance the bricks fell away from the building. Firefighters should always establish a collapse zone, as shown in Figure 13-35.

Lessons Learned

Many firefighters have been killed as a result of building collapse from structural fires. To prevent future deaths, firefighters must understand the buildings in which they fight fires. This understanding comes from a long-term commitment to read and study building construction information. Additionally, firefighters must get into buildings within their jurisdictions to survey and explore the way buildings are assembled, remodeled, and used in the real world. Knowledge of building construction starts with an understanding of loads, forces, and materials found in the structural makeup of buildings. Firefighters also study the effects of fires on materials and construction types. The five classic types of construction are being challenged by new construction methods. Trusses are used in virtually all new buildings. Trusses have high surface-to-mass characteristics that rapidly absorb heat and subsequently fail quickly. Failure of one truss can cause failure of other trusses. There are no rules for how long a building will last while on fire. Many factors determine when materials and construction design fail and gravity pushes down the building. Buildings under construction are losers from a firefighting point of view—they collapse quickly.

KEY TERMS

Axial Load A load passing through the center of the mass of the supporting element, perpendicular to its cross section.

Balloon Frame A style of wood frame construction in which studs are continuous the full height of a building.

Beam A structural member subjected to loads perpendicular to its length.

Cantilever Beam A beam that is supported at only one end.

Chord The top and bottom components of a beam or truss. The top chord is subjected to compressive force; the bottom chord is subjected to tensile force.

Collapse Zone The area around a building where debris will land when it falls. As an absolute minimum this distance must be at least 1½ times the height of the building.

Column A structural element that is subjected to compressive forces—typically a vertical member.

Compression A force that tends to push materials together.

Concentrated Load A load applied to a small area.

Continuous Beam A beam that is supported in three or more places.

Dead Load The weight of the building materials and any part of the building permanently attached or built in.

Design Load A load the engineer planned for or anticipated in the structural design.

Distributed Load A load applied equally over a broad area.

Eccentric Load A load perpendicular to the cross section of the supporting element that does not pass through the center of mass.

Fire Load The amount of heat energy released when combustibles burn in a given area or building—expressed in British thermal units (Btus).

Fire Resistive The capacity of a material to withstand the effects of fire.

Fire-Resistive Rating The time in hours that a material or assembly can withstand fire exposure. Fire-resistive ratings are usually provided for testing organizations. The ratings are expressed in a time frame, usually hours or portions thereof.

Fire Stopping Pieces of material, usually wood or masonry, placed in stud or joist channels to slow the extension of fire.

Girder A large structural member used to support beams or joists—that is, a beam that supports beams.

Gusset Plate A connecting plate used in truss construction. In steel trusses, these plates are flat steel stock. In wood trusses, the plates are either light-gauge metal or plywood.

HVAC Acronym for heating, ventilation, and air-conditioning unit. HVACs are typically a rooftop unit on commercial buildings. Buildings may have one or dozens of these units.

Impact Load A load that is in motion when it is applied.

Joist A wood framing member that supports floor or roof decking.

Lintel A beam that spans an opening in a load-bearing masonry wall.

Live Load The weight of all materials and people associated with but not part of a structure.

Load-Bearing Wall Any wall that supports other walls, floors, or roofs.

Loading The weight of building materials or objects in a building.

Mortar Mixture of sand, lime, and portland cement used as a bonding material in masonry construction.

Occupancy Classifications The use for which a building or structure is designed.

Parapet The projection of a wall above the roofline of a building.

Platform Framing A style of wood frame construction in which each story is built on a platform, providing fire stopping at each level.

Purlins A series of wood beams placed perpendicular to steel trusses to help support roof decking.

Rafter A wood joist that is attached to a ridge board to help form a peak.

Shear A force that tends to tear a material by causing its molecules to slide past each other.

Simple Beam A beam supported at the two points near its end.

Spalling Deterioration of concrete by the loss of surface material due to the expansion of moisture when exposed to heat.

Surface-to-Mass Ratio Exposed exterior surface area of a material divided by its weight.

Tension A force that pulls materials apart.

Torsion Load A load parallel to the cross section of the supporting member that does not pass through the long axis. A torsion load tries to “twist” a structural element.

Truss A rigid framework using the triangle as its basic shape to emulate a beam.

Type I, Fire-Resistive Construction Type in which the structural members, including walls, columns, beams, girders, trusses, arches, floors, and roofs, are of approved noncombustible or limited combustible materials with sufficient fire-resistive rating to withstand the effects of fire and prevent its spread from story to story.

Type II, Noncombustible Construction Type not qualifying as Type I construction, in which the structural members, including walls, columns, beams, girders, trusses, arches, floors, and roofs, are of approved noncombustible or limited combustible materials with sufficient fire-resistive rating to withstand the effects of fire and prevent its spread from story to story.

Type III, Ordinary Construction Type in which the exterior walls and structural members that are portions of exterior walls are of approved noncombustible or limited combustible materials, and interior structural members, including wall, columns, beams, girders, trusses, arches, floors, and roofs, are entirely or partially of wood of smaller dimension than required for Type IV construction or of approved noncombustible or limited combustible materials.

Type IV, Heavy Timber Construction Type in which exterior and interior walls and structural members that are portions of such walls are of approved noncombustible or limited combustible materials. Other interior structural members, including columns, beams, girders, trusses, arches, floors, and roofs, shall be of solid or laminated wood without concealed spaces.

Type V, Wood Frame Construction Type in which the exterior walls, bearing walls, columns, beams, girders, trusses, arches, floors, and roofs are entirely or partially of wood or other approved combustible material smaller than the material required for Type IV construction.

Undesigned Load A load not planned for or anticipated.

Veneer A covering or facing, not a load-bearing wall, usually with brick or stone.

Web The portion of a truss or I beam that connects the top chord with the bottom chord.

REVIEW QUESTIONS

1. What are three ways loads are imposed on materials?
2. List the three types of forces created when loads are imposed on materials.
3. Name three kinds of beams.
4. Explain the effects of fire on steel structural elements.
5. How does a masonry wall achieve strength?
6. List and define the five common types of building construction. Give an example of each type that is located in your district or response area.
7. List the three parts of a truss and explain what forces are being applied to each.
8. List three buildings in your district or response area that have truss construction.
9. List how fire affects the four more common building materials in use today.
10. Diagram and label four different roof shapes.
11. List and describe eight conditions or observations that might indicate potential structural collapse.

Additional Resources

Brannigan, Francis, *Building Construction for the Fire Service,* 3rd ed. National Fire Protection Association, Quincy, MA, 1992.

"High Rise Office Building Fire, One Meridian Plaza, Philadelphia, PA," Technical Report Series, Report #049, U.S. Fire Administration, Washington, DC.

"Without Warning, A Report on the Hotel Vendome Fire," Boston Sparks Association.

Building Construction for Fire Suppression Forces—Wood & Ordinary. National Fire Academy, National Emergency Training Center, Emmittsburg, MD, 1986.

Angle, James; Harlow, David; Gala, Michael; Maciuba, Craig; and Lombardo, Williams; *Firefighting Strategies and Tactics.* Delmar Learning, a part of the Thomson Corporation, Clifton Park, NY, 2001.

Diamantes, David, *Fire Prevention: Inspection & Code Enforcement,* 2nd ed. Delmar Learning, a part of the Thomson Corporation, Clifton Park, NY, 2003.