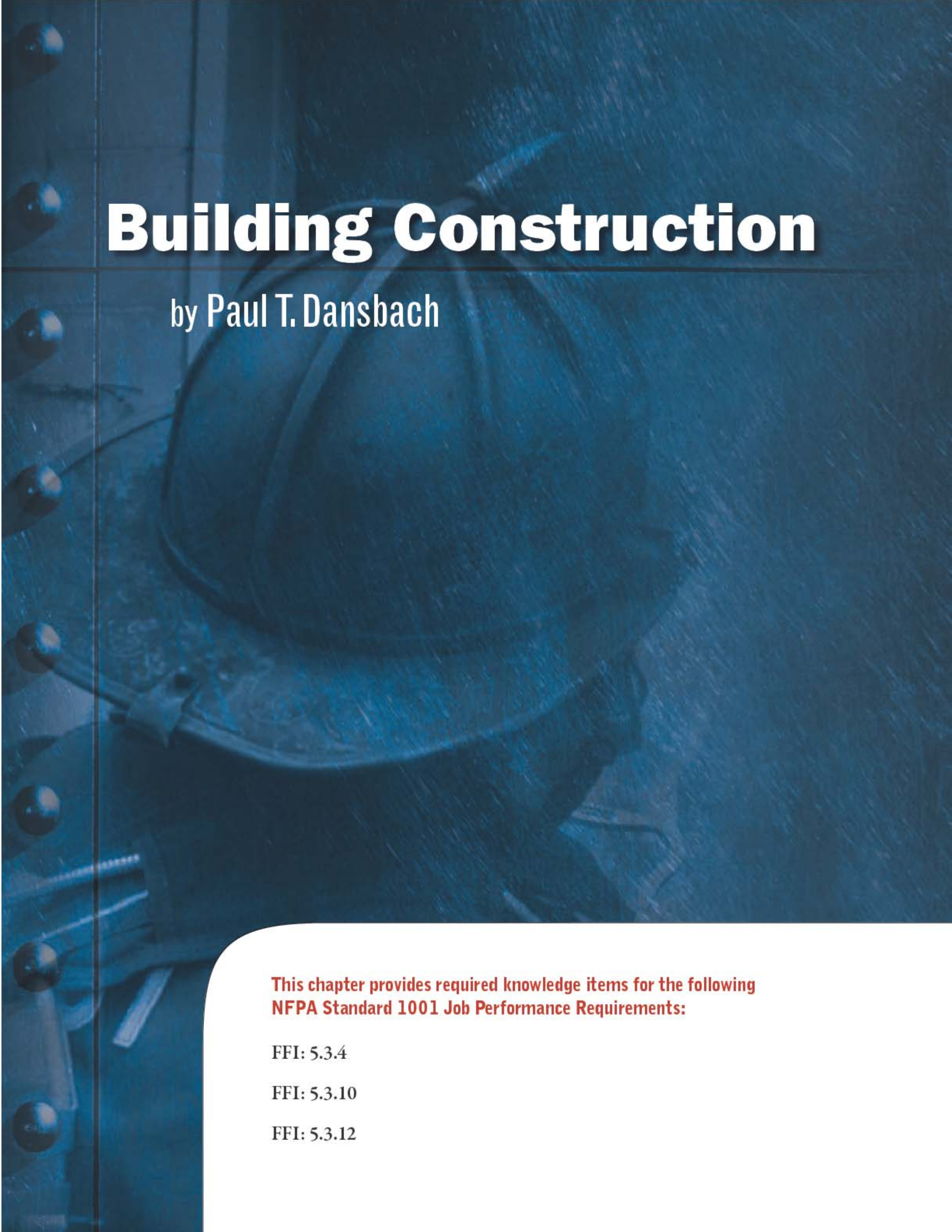

Building Construction

by Paul T. Dansbach

This chapter provides required knowledge items for the following NFPA Standard 1001 Job Performance Requirements:

FFI: 5.3.4

FFI: 5.3.10

FFI: 5.3.12

OBJECTIVES

Upon completion of this chapter, you should be able to do the following:

- Identify the types of forces and loads that impact building construction materials
- Identify and describe the basic types of building materials
- Identify and describe the five common types of building construction
- Identify the basic structural components in a building
- Identify factors affecting structural stability of a building
- Describe the hazards associated with light-weight and truss construction
- Identify the indicators of collapse
- Describe the impact of new building construction technology on the fire service
- List actions to take to limit injury or death to personnel in the event of a structural collapse

INTRODUCTION

This chapter begins your study of building construction (fig. 7–1). By the end of this chapter, you will understand the basic concepts of building construction as they relate to firefighting. To be successful as a firefighter or fire officer, the study of building construction must be an ongoing and perpetual learning experience. From the beginning of firefighting, firefighters have been called on to extinguish fires in buildings. Much of what you learn in your formal Firefighter I and II training programs centers on safe and efficient fireground operations. Fighting a fire in a building is inherently dangerous: The building and its structural integrity is attacked and weakened as the fire burns. Much has changed in firefighting since the beginning of organized firefighting, but one aspect remains the same: To successfully extinguish most struc-

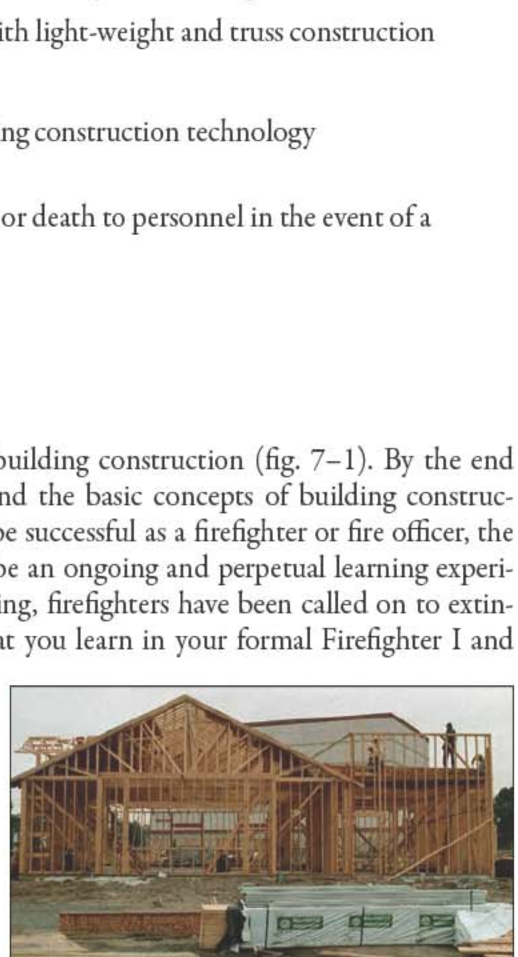

Fig. 7–1. A wood frame building

ture fires, a crew of firefighters must enter the building, locate the fire, and extinguish the fire by directing a stream of water from the nozzle onto the burning material. Your success and safety largely depend on your knowledge and understanding of building construction.

FORCES AND LOADS ACTING ON A BUILDING

Forces and how they apply to a building

A **force** is any action that maintains or alters the position of a structure or a part of a structure. Essentially, it is a push, pull, twist, or a combination of these exerted on an object or a structural member. Generally, there are four types of forces that can be applied to a building or its components:

1. **Compression**: the action of squeezing or pushing of a component, a **load** or weight imposed on a structural column that result in a compressive force when applied to the column (fig. 7–2). A compressive force may shorten the structural component.

Fig. 7–2. The studs supporting the floor joists in this wood-frame wall are in compression.

2. **Tension**: the action of stretching or pulling of a component. The threaded rod in fig. 7–3, which supports the stairway's intermediate landing, is in tension. Many members, which are in tension, are supported by attachment to a structural member above (fig. 7–4). A **tensile** force applied to a structural member may lengthen or stretch the member in tension; members in tension often fail by breaking apart or failing at the connection points.

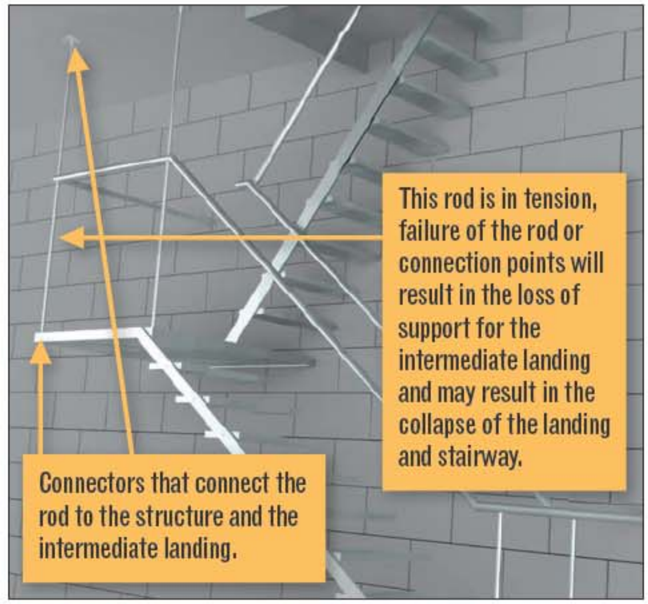

Fig. 7–3. Tensile force applied to a structural component

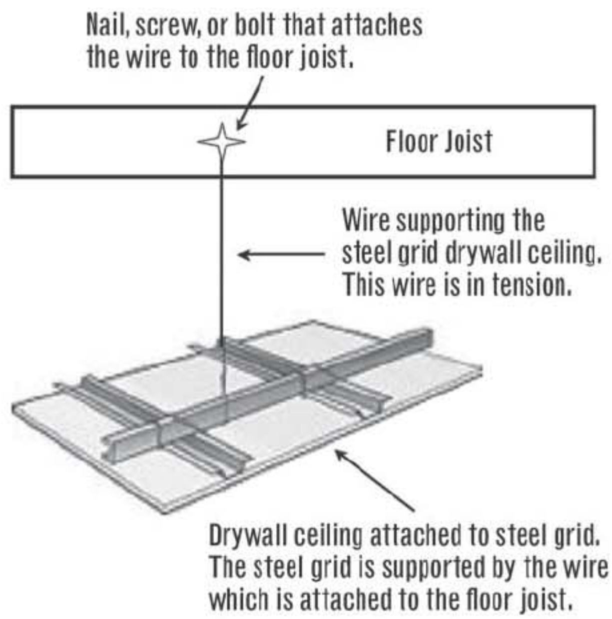

Fig. 7–4. The wire that supports the drywall steel grid is in tension and is attached to the floor joist above.

3. **Torsion**: the action of twisting a building component such as a nut on a bolt. Torsional force is commonly expressed in terms of **torque**.

4. **Shear**: a condition or force causing two structural members to slide past each other in opposite directions (away from or toward each other). Significant shear forces can cause structural members to fail at their connection points (fig. 7–5).

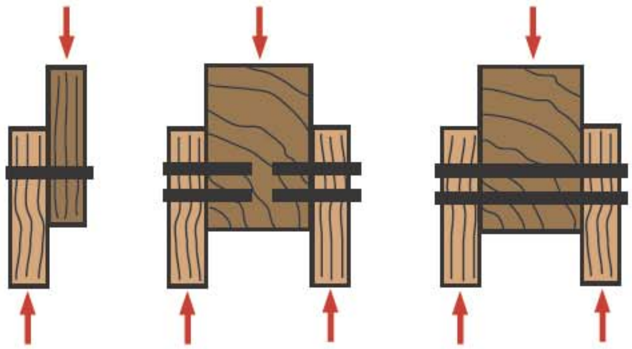

Fig. 7–5. These connections are typical connections in a wood-frame building: a shear force is applied to the connection. If the connection fails, the parts of the connection will slide past each other.

Loads applied to a building

Loads are basically the forces applied to a building from a variety of sources, such as the weight of the contents of a building (occupants, their possessions, and equipment), as well as **external forces** such as environmental effects (weather, earthquakes, etc.).

Loads may be imposed on a building's structural members in one of three different ways: axially, eccentrically, or torsionally. **Axial loads** pass through the center of a particular section or supporting member at a right angle to the cross section of the supporting member (fig. 7–6).

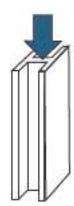

Fig. 7–6. An axial load is imposed on the column as the load passes through the center of the column.

Eccentric loads are imposed on a structural member at some point other than the center section of the supporting member (fig. 7–7).

Finally, **torsional loads** are parallel to the cross section of the supporting member, typically a column that does not pass through the long axis of the structural member (fig. 7–8).

Fig. 7–7. The parapet wall is eccentrically loaded with a cornice (a decorative wall projection attached to the top of many apartment buildings.) This load does not pass through the center of the wall.

Fig. 7–8. Torsional loads are delivered at a right angle to the supporting member and usually result in a twisting of the member. Torsional loads are common in collapses when the designed structural function of the structural members is upset.

The following terms are also used to describe specific types of loads:

A **designed load** is a load that the building designer or structural engineer has calculated into the building based on sound engineering principles. The structure can carry or withstand all the design loads that are applied to a given building or structure. Several of the loads explained in the following text are easily calculated and required by code to be calculated to ensure the building can withstand the various loads.

Design loads vary based on geographic regions. For example, a roof structure designed for a building in a New England state should be able to carry a much greater load, to support the weight of snow, than a roof structure in southern California, where it does not snow. A building in Florida is designed to withstand a much greater wind load, to endure hurricanes and tropical storms, than a building in a northwestern state, where such weather events are unlikely. A building in San Francisco is designed to withstand an earthquake; however, a building in Washington, DC, is not designed to the same standards, where the threat of an earthquake is much less.

Undesigned loads are loads that a designer or structural engineer did not anticipate or calculate. Undesigned loads are often the result of unauthorized construction, such as when a building owner fails to obtain the necessary approval and permits, or work performed by untrained or unscrupulous contractors. Through the history of fire service, firefighters have been injured and killed in buildings that were renovated or altered in this manner. An undesigned load could be the placement of heating, ventilation, and air conditioning (HVAC) units on the roof of an older building without considering the additional load on the roof support structure (fig. 7–9).

Fig. 7–9. The installation of air conditioning units on a roof without consideration of the extra weight being added to the roof is an example of an undesigned load.

A **live load** is a nonfixed (sometimes moving) variable load that is added to the structure, including people, materials, and other transportable items.

A **dead load** is the load of the building itself—the structural components, building utilities, interior finishes, and any other components that are built in or permanently attached to the structure. The dead load may change through the life of the building as the result of renovations and alterations to the structure.

Environmental loads include snow, rain, wind, and earthquakes. Code requirements for these loads vary based on geographic region (fig. 7–10).

An **impact load** is a force delivered in motion such as a blow or force delivered by an object in motion striking a fixed object (e.g., an axe striking a roof). Impact loads are the opposite of a force applied slowly and maintained over an extended period of time.

A **static load** is a relatively unchanging load, which may be delivered over an extended period.

Dynamic loads display significant dynamic effects or are in motion when applied to a building, including strong earthquakes, gusting winds, and loads applied by the fast movement of water or waves.

A **concentrated load** is applied to a relatively small area, such as a steel column bearing on the building's **footing** or an air conditioning unit on the roof of a building.

Fig. 7–10. An unusually heavy snow load caused the collapse of this bowstring truss roof. The fire department was dispatched to this collapse as an activated fire alarm. When the collapse occurred, the building's automatic sprinkler piping was broken and the resulting water flow tripped the fire alarm system. Note the large area of collapse as the result of the failure of only one of the bowstring trusses.

A **distributed load** is a load distributed over a large area of the supporting surface, supporting a uniform load over the area (e.g., ballast stone applied on a rubber **membrane roof**).

A **fire load** is the total amount or quantity of combustible material stored or used in a building, including combustible building contents and furnishings not built into the building (fig. 7–11). Previously, this load was expressed in pounds per square foot of combustibles or in the combustible's heat energy potential by British thermal units (Btu). Today, however, fire load is more commonly measured in terms of the heat release rate of the building's furnishings and contents (refer to chapter 5, Fire Behavior for a description of heat release rate).

Fig. 7–11. Fire loads will vary from building to building. Flammable liquids, which are used or stored in the building, will present a higher fire load. The wooden structural members of the building also contribute to the fire load.

HOW COMMON BUILDING MATERIALS ARE AFFECTED BY FIRE

The various building materials used to construct a building are affected by fire in various ways. Some materials burn and lose mass as they burn, and others, which are noncombustible, lose their strength as they are heated. Table 7–1 details how common building materials are affected and how the materials react to the heat from the fire.

UNDERSTANDING STRUCTURAL COMPONENTS

FFI 5.3.4, 5.3.10 To understand building construction features and hazards, the firefighter must understand the buildings components, the names given to the components, and what function each component serves in the structure. The following text reviews some of the most common building components and their function.

Arch

Arches are constructed in two basic shapes: round or curved arches and flat arches. The most common arches are round or curved and usually carry forces in compression in one direction only. Arches can fail when the adjoining wall, which helps the arch resist horizontal forces, fails and flattens out. Wooden arches may fail when they cannot support the imposed load because of the loss of mass or the burning away of the arch.

Beam

A **beam** is a horizontal supporting member that transfers weight from one location to another and from one structural component to another. A beam may support floor joists and transfer the weight of the floor joists in a horizontal direction to an exterior wall. A simple beam is supported at two points, whereas a continuous beam is supported at three or more points. Wood beams fail as the result of loss of mass; the beam burns away to a point where the beam can no longer support the load imposed on the beam and a collapse occurs. Steel beams fail because of the loss of strength from the exposure of the fire's heat, and they may sag or warp and drop the beam's load. Steel beams elongate from exposure to the fire's heat. When the steel beam is restrained in a supporting wall, the elongation may push the supporting walls out of plumb and cause the outward collapse of the supporting wall; then the load supported by the beam collapses. A 100-ft-long (30.5-m) steel beam heated evenly to 1,000°F (538°C) elongates 9 in. (229 mm).

Cantilever beam. A **cantilever beam** is supported at one end only (e.g., a balcony, which is supported by attachment to the structure at one end). A wood-cantilevered beam may fail because of loss of mass after being exposed to the fire, or the connections may fail, releasing the cantilevered beam from its support.

I-beam. An **I-beam** gets its name from the cross section of the beam, which is shaped like an I. Today, I-beams are known as **wide flange beams**, because the dimensions of the top and bottom flanges have increased in horizontal dimension; however, it is still called an I-beam in the fire service. The I-beam consists of a top and bottom flange separated by a vertical component called the **web**. I-beams are most commonly found in the form of steel and are used in steel frame buildings to support floors and roofs of these buildings. Lightweight wood floor joists are also manufactured in the shape of an I-beam and are often referred to as engineered wooden I-beams.

Girder

A **girder** is a structural support member usually found in the horizontal position. A girder is supported by a wall and/or columns and supports beams or joists.

Lintel

A **lintel** or **header** is a horizontal beam that usually supports the wall above an opening in a wall such as a window or door. It may be wood, steel, or masonry.

Column

A **column** is a vertical structural element that transmits the load imposed on the top or side of the column to another structural element at the base of the column. The load imposed on the column causes a compressive force on the column. The column may impose a concentrated load on the member supporting the column. Shorter columns tend to fail by crushing, whereas long, slender columns tend to fail by buckling. If connections are made to the column along the vertical length of the column, the connections increase the load-carrying ability of the column and reduce the potential for the column to fail.

Table 7–1. Effect of heat and fire on common building materials [FFI 5.3.12] [FFII 6.3.2]

Material	Common uses in buildings	Reaction when exposed to fire and heat
Wood	Often used in wood frame buildings as the primary structural elements (exterior and interior wall studs, floor joists, and roof rafters), ordinary-constructed buildings (interior wood studs, floor joists, and roof rafters), and buildings constructed using mortise and tenon connections (post and beam buildings).	Wood loses mass as the material burns, and the loss of mass weakens the wood member until it fails. The mass of the wood member is reduced to make the connection, when these connections are attacked by fire, they are usually the point of failure.
Structural steel	Structural steel is used in many forms. The common structural elements include columns, beams, and bar joists. It is the primary structural element in noncombustible buildings. When used as a structural element in fire-resistive buildings, the steel must be protected from the fire's heat. Structural steel may also be found in different forms in wood frame and ordinary construction.	As structural steel is heated, the steel loses strength and expands (lengthens). Once the structural member reaches the yield point (because of high temperature and resultant loss of strength), the structural element fails. The strength of structural steel varies from piece to piece, depending on the age of the steel and the ingredients added to the steel. Steel manufactured early on in the steel age is weaker than steel used today. Industry advances have lead to the development of stronger steel by using different compounds in the manufacture of the steel.
Cast-in-place concrete	Cast-in-place concrete is used in footings, foundations, and grade beams, as well as cast-in-place floors, walls, and columns.	Cast-in-place concrete is a great insulating material, because it is a dense noncombustible material. As with other masonry materials, the cast-in-place concrete is subject to spalling when exposed to high temperatures. If the cast-in-place concrete is a reinforced concrete element, and the spalling exposes the steel reinforcing bars or cables, the steel loses strength and the entire slab of concrete may be in danger of collapse.
Concrete block	Concrete block is found in foundation walls, interior and exterior bearing walls, and interior nonbearing walls.	A great insulating material, it is often used in building to construct fire walls or fire separation wall assemblies, because concrete block resists the passage of fire. As with other masonry materials, the concrete block is subject to *spalling* (fragments of concrete dislodged under the heat of a fire) when exposed to high temperatures.
Cast iron	Structural columns that support floors and roofs are made of cast iron, as are building facades. Cast iron is found in buildings constructed in the late 1800s through the 1920s.	Cast iron may fracture or spall when exposed to high temperatures or when heated and cooled rapidly, such as if cooled by a hoseline operating on the fire.

Truss

A **truss** is a structural component using one or more triangular units to attain stability. The truss consists of **top** and **bottom chords** and **intermediate web members** that connect the top and bottom chords of the truss. Three common types of trusses are available: heavy timber wood truss, lightweight wood parallel-chord or peaked truss, and steel **bar joist** truss (figs. 7–12 and 7–13). Trusses are used to create large open floor areas where the use of columns or interior walls is undesirable. All trusses have large **surface-area-to-mass ratio** that leads to poor performance and early failure of the truss under fire conditions. When a truss fails, the resulting collapse area is large because of the span between the walls supporting the trusses and spacing between the trusses.

Floor truss. A **floor truss** is a lightweight wood parallel-chord truss used in wood-frame construction (fig. 7–14). Trusses are manufactured using 2 × 4–in. (51 × 102–mm) lumber as the top and bottom chord of the trusses. The chord may be spliced from smaller lengths of 2 × 4-in. (51 × 102–mm) lumber and spliced together using a splice plate or finger joint to piece the chord together.

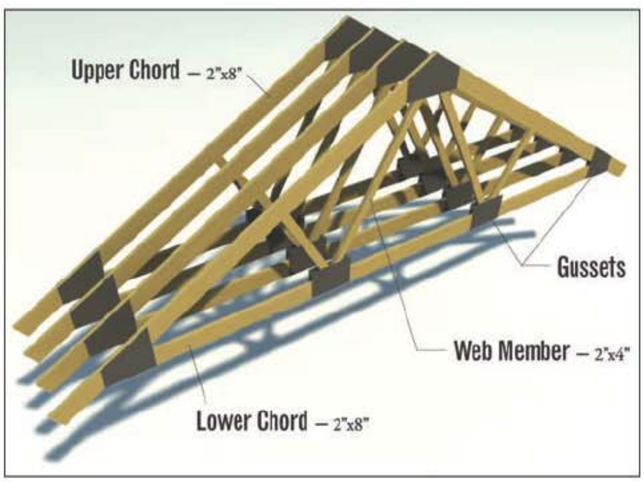

Fig. 7–12. Components of a lightweight peaked-roof truss.

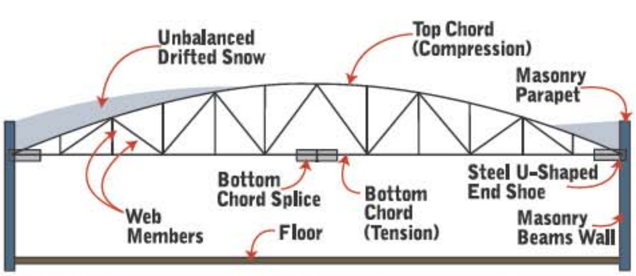

Fig. 7–13. Components of a heavy-timber bowstring roof truss.

Fig. 7–14. Use of lightweight wood parallel-chord truss members in a floor system. The use of floor trusses creates a large combustible void space. Buildings framed with dimensional lumber, which use 2 in. x 10 in. (51 mm x 254 mm) floor joists, will not have this combustible void space.

The web members of the truss are also made from 2 × 4-in. (51 × 102–mm) lumber that separates the top and bottom chord with geometric shapes; web members are connected to the top and bottom chord with gusset plate connectors or finger-joint glue connections. Theses members are used in a series to support floors and ceiling loads.

Wooden I-beam

Wooden I-beams, sometimes referred to as **engineered wood joists**, are engineered floor joists manufactured with a top and bottom chord and a web member between the chords, separating them. The top and bottom chords are made of laminated lumber and are typically 2 in. × 3 in. (51 mm × 76 mm) or 2 in. × 4 in. (51 mm × 102 mm) in dimension. A **dado** or groove is located in the center of the long axis of the top and bottom chord, and the web member is glued in place between the top and bottom chords (fig. 7–15).

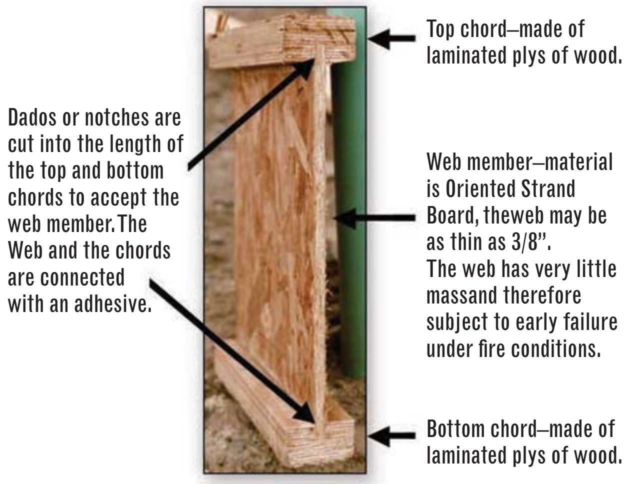

Fig. 7–15. The components of a wooden "I" beam. Math has replaced mass in the manufacture and use of engineered wood structural components. The 3/8" web on a wooden I-beam has greatly reduced the burn time for this component before collapse occurs. The fire service is experiencing a greater number of floor collapses that are injuring and killing firefighters.

The web member is a piece of **oriented strand board (OSB)**, which is typically between ⅜ and ½ in. (10 and 13 mm) thick. Theses members are used in a series to support floor and ceiling loads.

Joist

A **joist** is a parallel framing member used in a series to support floor and ceiling loads. Joists span between and are supported by bearing walls or **girders** or beams.

Rafter

Rafters are a series of sloping roof framing members that support the roof sheathing and roof covering. A rafter is supported by the outside walls at the low point of the roof and is connected to the ridgepole at the uppermost point of the roof. Rafters in buildings constructed with a flat roof may also be referred to as **roof joists**.

Ridge beam or ridgepole

A **ridge beam** or **ridgepole** is the uppermost horizontal framing member of a roof system located at the peak or uppermost point of the roof. Rafters are connected to the ridge beam or ridgepole on opposing sides.

Wall types

Load-bearing wall. **Load-bearing walls** are commonly constructed of wood, brick, structural steel studs, concrete block, and poured-in-place concrete. A load -bearing wall supports its own weight, the floors above it, and the walls or floors above, and sometimes the roof of the building. Load bearing walls can be exterior and interior walls.

Non–load-bearing wall. A **non–load-bearing wall** may be used to separate an area of a building into smaller rooms or individual spaces. A non–load-bearing wall supports no load other than itself and the weight of the finish materials attached to the wall. Non–load-bearing walls may be constructed from common materials including but not limited to wood-frame members and steel studs with an interior finish of drywall or concrete.

Curtain wall. A **curtain wall** is an exterior non-load-bearing wall of a building. The curtain wall is attached to the building or structure by its floors or columns. Curtain walls pass in front of the building **floor slab**. The space between the curtain wall and the floor slab may be a path for fire extension if the space is not properly **fire-stopped** (sealed with a fire-resistant barrier). Curtain walls are constructed of different materials; lightweight curtain wall panels are constructed of **heavy gauge steel stud** with a form of gypsum board attached to the steel stud and finished with a cementitious exterior finish material. These wall panels may contain some form of combustible foam insulating material.

Another form of a curtain wall panel is the large precast concrete wall panel with a decorative finish on the exterior exposed surface. Aluminum frame window systems are usually installed between the curtain walls. These **precast panels** may be attached to the steel frame of the structure by mechanical fasteners such as bolts or may be welded in place. The alternating horizontal bands of curtain wall and window systems that wrap around buildings usually identify office buildings. Residential and hotel occupancies usually have less window area than office buildings.

Parapet wall. The parapet wall is the part of an exterior wall that extends above the roofline of the building. It may or may not be on all sides of the building. Typically, if the parapet walls are part of the original construction, they are constructed of the same materials as the exterior walls of the building. A common alteration to change the façade of a building is to add a parapet wall on the front of the building. Often, the addition of a parapet wall on an existing building with exterior masonry walls uses wood or steel studs. The most dangerous type of parapet wall is a freestanding parapet on only one side of the building that is constructed of masonry (fig. 7–16). Masonry firewalls that separate buildings or parts of buildings that extend through the roof of a building are also parapet walls. Identifying this wall on the roof is a way of locating firewalls in the building.

Fig. 7–16. Freestanding parapet walls are the most dangerous parapet walls, as they do not intersect at any corner. If the roof of the building were to collapse during a fire, the freestanding portion of the wall may become greater and therefore less stable.

Roof types

Roof shapes are known by common names, with which firefighters should become familiar. More importantly, firefighters should learn the operational and collapse hazards as well as the fire spread potential of each roof type (fig. 7–17).

Flat. On a **flat roof** the members supporting the roof decking are horizontal or have a slight pitch. The building may have a cockloft, which is the space between the ceiling and the underside of the roof deck, or the ceiling interior finish material may be directly attached to the roof rafters. In buildings where an interior finish was unnecessary, the roof structure is open to the interior of the building.

Shed or single pitch. A **shed** or **single-pitched roof** is built in a single sloped plane that slopes from between parallel walls of different heights. The interior features of the roof are very similar to those found with a flat roof.

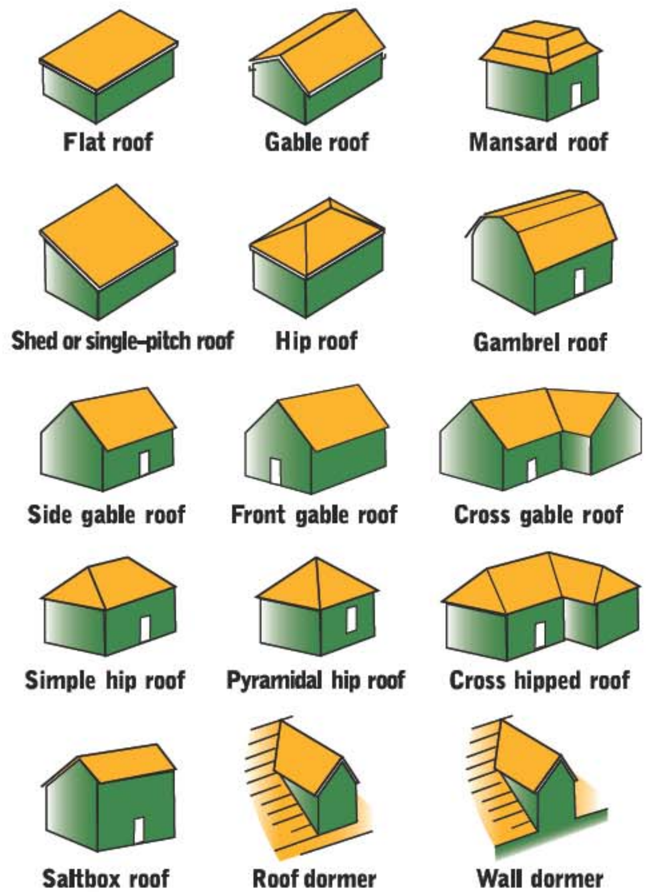

Fig. 7–17. Different types of roofs

Gable. Gabled roofs are identified by the straight slope falling from ridgepole at the highest horizontal point on the roof to opposite sides or walls of the structure. The roof rafters rest at the low end of the roof on an **exterior bearing wall**; the point at which the roof lands on and extends past the exterior bearing wall is known as the **eave**. Gable roofs are most commonly found on wood -frame buildings or ordinary-constructed buildings. The roofing material is typically some form of asphalt or fiberglass shingle. The roof shape creates a peak or triangle on the side walls or the front and rear walls of the building. Wall areas between the slope of the roof are known as the gable walls.

Hip. **Hip roofs** have three or more sides that slope to the exterior walls of the building. The hip roof may or may not have a ridgepole, depending on the size and shape of the building. Most commonly, hip roofs have sloping roof sections on all four sides of the roof. Any side of the building that has a sloping roof and an eve around the roofline is a bearing wall that supports the roof structure. Hip roofs have hips and maybe valleys. The hip is formed where two sides or parts of the roof meet and form an outside or external corner. The intersection where the sides of the sloping roof meet at an inside corner is known as the **valley**. Both hips and valleys typically start at the roof eve and continue up to their ridgepole.

Gambrel. A **gambrel roof** is similar to a gabled roof in that it is made up of two sides that slope away from the ridgepole; however, a gambrel roof begins at the ridgepole with a slight pitch and changes to a steeper pitch. The point where the roof changes slope is parallel to and lower in elevation from the ridgepole. The gambrel roof design allows for greater habitable space or floor area in the story directly below the roof structure. It is commonly found on barns and is sometimes called a **barn roof**. The walls to which the roof slopes are bearing walls that support the roof.

Mansard. A **mansard roof** is similar to a hipped roof in that the roof structure has at least three sides that slope to the exterior walls of the building. A mansard roof has two separate and distinct pitches. The slope or roof pitch that starts at the ridgepole or the flat part of a roof has a low or slight slope. Where the roofline intersects the exterior wall, the roof slope changes to a steep slope and vertically extends down along the exterior wall of the building, perhaps as much as two stories. The construction of a mansard roof may create a combustible void space where fire may extend to spread rapidly both vertically and horizontally. This roof style can also create a tremendous collapse potential because of how the roof structure is attached to the exterior walls of the building.

Saltbox. A **saltbox roof** is a form of a gabled roof where the sloping sides of the roof are asymmetrical. This roof style is used in buildings when the roof must end at two different stories of the building. For example, on a two-story building, one side of the roof slopes to and is supported by the two-story side of the building, and the opposite slope of the roof slopes to and is supported at the first story. The ridgepole on a saltbox roof is parallel to the supporting walls but may not be centered on the building. The walls to which the roof slopes are the bearing walls that support the roof structure.

Dormers. **Dormers** are small structures that rise up out of the roof to provide light, ventilation, and increased usable floor space on the story directly below the roof. Dormers are classified by their roof shape (shed, hipped, gabled, flat, etc.). Dormers are further classified into two classes based on their locations and means of support. A roof dormer extends up from the main roofline, like a small house with its own walls, roof, and window. Only the rafters or other roof structures such as lightweight wood roof trusses support the roof dormer. A wall dormer extends up from the roofline at the roof-to-wall junction and is supported partly by the exterior wall of the building, the same exterior wall supporting the main roof structure.

STRUCTURAL HIERARCHY AND FIREFIGHTER SAFETY

Certain structural components are more important than others. The term **structural hierarchy** determines which structural components are most important, factored with locations of the structural members within the building (fig. 7–18). Columns are some of the most important structural members in a building, and the column's vertical location in the building is also a factor. For example, in a four-story building, a column that fails in the basement affects the entire column line up through the building. In turn, this affects the beams on each floor supported by the column line, so the resulting area of collapse is likely to be extensive. In the same building, if a column fails on the uppermost floor of the building, the resulting area of collapse is likely to be contained to the top floor and the roof area, resulting in a much smaller area of collapse. These principles do not apply to buildings constructed with any form of trusses, because the collapse hazard associated with trusses is more severe.

Firefighters should study the collapse of Boston's Vendome Hotel, which occurred on June 17, 1972, causing the deaths of nine firefighters. The Vendome Hotel was under renovation to change the hotel into a multifamily dwelling when the fire occurred. The fire was under control and firefighters were overhauling and securing equipment when several floors and walls of the seven-story hotel collapsed without warning.

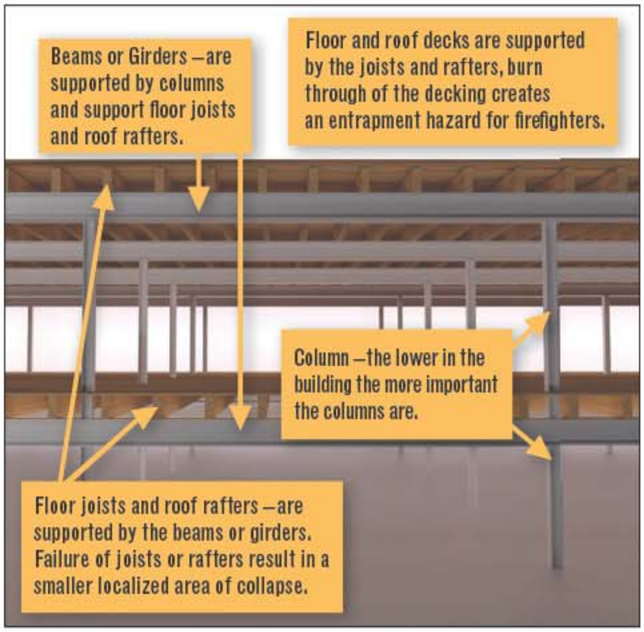

Fig. 7–18. The components and the importance of the components in terms of structural hierarchy

Factors affecting structural stability

FFII 6.3.2 Several factors affect the structural stability of the building. The building's structural stability is the building's ability to resist collapse. Remember, a collapse event may be a minor collapse caused by the loss of structural stability of one or more structural members.

The condition of the structural components of a building may vary and are sometimes deteriorated due to exposure to weather, lack of maintenance, or a combination of factors. For example, deterioration can be found when the ends of a wood timber truss rot because of water leaks in the roof system over the years. The wood slowly deteriorates, and this condition goes unnoticed. When a fire occurs in the building, the truss ends fail quickly as the fire burns through the deteriorated wood.

The mass of the structural elements will also be a significant factor in the structure's ability to resist collapse. Older buildings, especially wood-frame buildings and mill buildings, were constructed with many wooden structural parts. The beams, studs, and joists in the buildings had a fair amount of mass or cross-section value. In other words, there was some **fat** built into these buildings, and the fat of the **dimensional lumber** (2–4 in. nominal thickness) allowed for a certain amount of burn time before the building sustained a structural failure. In today's buildings, especially the lightweight wood-frame buildings that employ floor and roof trusses and engineered lumber such as plywood I-beams, the fat has been removed, resulting in the elimination of any burn time for the building. Another way of looking at the issue is that through engineering and mathematical calculations, the building industry has been able to eliminate the mass of the structural components. Math has replaced mass, making lightweight wood-frame buildings much more dangerous for firefighters. If anyone describes a building to you as a safe building for firefighters because the building is constructed using engineered structural components, disregard those comments as pure myth. Engineered structural components use the least amount of material to carry a predetermined load over a maximum specified span or at the least expense to the developer or property owner. Many firefighters have lost their lives in buildings constructed of engineered structural components.

Another factor affecting structural stability is the fire loading of the building. A rapidly developing fire with high heat output damages the structural components faster than a small fire with a lower heat output. The type of construction plays a major role in this equation. For example, consider two fires in a noncombustible constructed building with a steel bar joist roof. The first fire occurs in an occupancy involving the storage of baled rags and cardboard. The bales are tightly bound, and the fire has a slow rate of heat release that produces a considerable smoke condition. The low rate of heat release prevents the bar joist roof system from collapsing or failing as quickly as a fire in the same building involving the ignition of flammable liquids. The fire involving the flammable liquids rapidly develops and releases a significant amount of heat that causes early failure of a bar joist roof system. Determining the fire load and fire behavior at all fire incidents is an important part of an ongoing size-up.

CONSTRUCTION CLASSIFICATIONS

NFPA Standard #220, *Standard on Types of Building Construction* and the *International Building Code,* classifies buildings into five classes based on the materials used in a given building and the fire-resistiveness of the structural members of the building. The following text details the five construction classifications, materials used to construct these buildings, common occupancies found in the construction classes, and hazards associated with the construction classification. The classifications are as follows:

Type I:	Fire-resistive construction
Type II:	Non-combustible construction
Type III:	Ordinary construction
Type IV:	Mill or heavy timber construction
Type V:	Wood-frame construction

Fire-resistive construction

In **fire-resistive construction**, the structural members including columns, beams, and sometimes floor slabs are protected from the fire's heat to prevent the loss of the structural element's integrity. The level of fire resistance, measured in an **hourly fire rating**, is high compared to Type II noncombustible construction (described in the following text), which has little or no fire resistance.

Early fire-resistive buildings were constructed primarily of masonry materials, most commonly poured or cast-in-place concrete. Buildings constructed of **steel skeleton frame** used a variety of materials to encase or protect the structural steel from the heat of the fire. These materials include cement plaster, clay tile, **asbestos**, layers of **gypsum board**, and spray-on fireproofing materials (fig. 7–19).

Buildings or occupancies constructed of fire-resistive materials include high-rise buildings, mid-rise residential structures, hospitals, old-style warehouses, or cold storage buildings (fig. 7–20).

Pre–World War II buildings of fire-resistive construction tended to have smaller floor areas compared to modern high-rise buildings. These buildings relied on openable windows for ventilation and had fewer accommodations for heating, ventilating, air conditioning (HVAC), and technology. Many pre–World War II high-rise buildings were constructed with true fire tower stairs that vented to the exterior of the building, which effectively prevented smoke from entering the stair towers. The floor areas were smaller and there was greater **compartmentation** of the floor areas in the forms of rooms and offices. This resulted in slower fire spread and smaller fire areas. Pre–World War II high-rise buildings were constructed with heavier materials, which created mass within the structure.

Fig. 7–19. This photo details the use of a spray on fireproofing material on structural steel columns and bar joists. The material is a mixture of an insulating material and cement. The cement binds the insulation together and ensures that the fireproofing adheres to the building component. This material is easily removed by other construction trades and results in a lapse of protection.

Fig. 7–20. A poured-in-place fire-resistive constructed building. This construction is also sometime called monolithic construction as the poured concrete forms into one piece. Detailed here are the building columns and floor assemblies, poured into the concrete columns and floor steel reinforcing bars. (Courtesy of Glenn Taldelore)

Post–World War II high-rise buildings started using more modern, often lighter building materials. This in effect reduced the mass of the structure. More modern high-rise buildings are often constructed with the lightest weight materials available. The features of modern high-rise buildings include the use of steel bar joist floor systems and curtain wall systems (fig. 7–21).

The buildings are constructed with tremendous accommodations for technology-based business systems and rely on the building's HVAC systems to heat and cool the building, because the buildings do not have any openable windows. Eliminating the need for openable windows allowed the size of the floor area to increase tremendously.

Fig. 7–21. A curtain wall system being installed on a building. The wall panel passes in front of the floor slab and does not support any part of the building other than itself. Curtain walls may be responsible for fire extension between floors if the wall space is not properly fire-stopped at each floor level.

Modern high-rise office buildings are typically constructed using a **center core floor plan**, in which utilities, elevators, bathrooms, and exit stairways are built near the center of the building and are typical on every floor. This method of construction provides the greatest flexibility for the building owner in terms of making the floors available for lease. The floor areas of modern high-rise buildings have much less compartmentation than pre–World War II high-rise buildings (fig. 7–22).

Open office plans using **low-rise** office partitions or cubes create large mazelike fire areas on the floors of these buildings. The open floor plan also allows for faster fire development and a much larger fire area. There have been several notable fires in modern high-rise buildings such as the First Interstate Bank in Los Angeles, California, and the One Meridian Plaza building in Philadelphia, Pennsylvania. As a student of the fire service, take the time to research some of these fires; the articles, reports, and other documents are invaluable to you in your studies. See table 7–2.

Fig. 7–22. Fire-resistive constructed hotels will have the greatest amount of compartmentation because the size of the hotel room will limit the fire area. In this photo the space between the block walls will be further reduced by a non-bearing wall sub-dividing the space into two hotel rooms between the block walls.

Noncombustible construction

In **noncombustible construction**, the structural members are of **noncombustible materials** and have little or no fire resistance. The materials are typically structural steel, concrete block, poured concrete, and cold-formed steel structural elements. This class of construction may also be known as **limited combustible construction**. A major difference between fire-resistive construction and noncombustible construction is that in fire-resistive construction the structural steel must always be protected from the fire's heat. During the early stages of construction, you may be unable to determine the class of construction until the fireproofing material is applied to the steel. The collapse hazard of these buildings is due to the lack of structural steel protection. As the structural steel is heated, the steel loses strength; and when the steel member reaches the yield point, it cannot support its load and a collapse occurs (fig. 7–23).

Table 7–2. Fire spread potential of fire-resistive buildings

Fire-resistive buildings' fire spread potential based on occupancy and construction features (by increasing fire spread potential)	
1 High-rise hotels	These occupancies have the least fire spread potential. The rooms are typically the smallest fire areas found in any high-rise residential occupancy (fig. 7–22). The wall that separates the hotel room from the corridor and the adjoining rooms usually is a fire separation wall that contains the fire to the hotel room of origin.
2 Mid- and high-rise age-restricted and public housing multiple dwellings	These occupancies contain the smallest square footage of multiple dwelling buildings. Typically, the dwelling unit or fire area is between 800 and 1,400 sq ft (74 and 130 sq m). The walls separating the dwelling unit from the corridor and the other dwelling units are usually concrete block; or they may be other fire-rated walls that create a fire separation wall, containing the fire to the dwelling unit. The greatest threat of fire extension in these buildings is the dwelling unit entry door. If the door is left open when the occupants flee, the fire extends into the corridor. This may prevent other occupants from exiting and create high heat and dense smoke conditions in the corridor, making entry onto the floor by firefighting crews more difficult.
3 Mid- and high-rise multiple dwellings	The dwelling units many range in between approximately 1,000 and 2,000 sq ft (93 and 186 sq m) The fire separations and fire spread risk is the same as described above in #2.
4 Mid- and high-rise luxury multiple dwellings	These buildings and dwelling units have the greatest fire spread potential of all multiple dwelling buildings for two reasons. First, they contain the largest square footage within the dwelling unit. The dwelling unit may be 2,000 to several thousand square feet. Additionally, the dwelling unit may also have two levels, meaning there is an interior stairway that leads to the second floor of the apartment within the apartment. The dwelling unit is separated from the corridor and other dwelling units as described in #2. The two-level dwelling units also have the potential for vertical extension to the second floor within the dwelling unit. In some cases, the only access to the second floor of these dwelling units is via the interior stairway within the dwelling unit. This type of dwelling unit presents many different operational concerns to firefighters.
5 High-rise office buildings	The office occupancy has the greatest potential for fire extension. The fire area is defined by the size of the tenant space. The stairways are separated by fire-rated walls, but the tenant separation walls and the walls that separate the tenant space from the corridor may not be fire rated. If one tenant occupies the entire floor area, the fire may spread throughout the floor.

Fig. 7–23. A one story, non-combustible warehouse under construction. The roof system is supported by unprotected steel columns and bar joist trusses. These buildings are very prone to early collapse as the heat of the fire attacks the steel and the steel reaches its yield point and fails.

Common occupancies and buildings made of noncombustible construction are office buildings up to five or six stories high, large single-story warehouse buildings, and smaller two- and three-story storage buildings, such as the self-storage buildings that have become popular over the past 20 years or so. Noncombustible buildings have a variety of exterior wall systems. The exterior walls may be concrete block. The concrete block wall is not a bearing wall; it is only used as a wall in-filled between steel columns and beams and is a nonbearing wall that supports only itself. Another wall is called a **curtain wall**, because the curtain wall panels hang by attachment to the building's steel structure (fig. 7–24). The curtain walls may be made from various materials, such as concrete slabs that may weigh several tons. Wall panels are constructed of **cold-formed steel studs** to which a gypsum material is applied, followed by a stucco-type finish. The space between the curtain walls is then in-filled with windows or glass mirror panels. Steel panels or steel siding is a common exterior wall material that is often found on warehouse buildings.

Fig. 7–24. This office building is a non-combustible constructed building with a glass curtain wall system. This wall system makes identifying the number of floors in the building extremely difficult if not impossible from the exterior.

Another common wall system on warehouse buildings is a **tilt-slab** wall system (fig. 7–25). These wall systems are dangerous under fire conditions. In most structural systems, the walls or columns support the roof of the building. When a building is constructed with tilt wall systems, a skeleton frame of structural steel is erected. The wall panels (usually equal to the full height of the building) are poured either on- or off-site and delivered to the site to be erected. The panels are supported on the bottom by the building foundation or footing and attached to the steel skeleton frame at the roof level to hold the walls in their vertical position.

If a fire occurs, the connections that attach the walls to the steel frame at the roofline may fail and release the wall panels. *The stability of the walls is dependent on the roof structural system.* These panels are then likely to fall out away from the building, but experience has shown some fall into the building. There is little predictability. These walls will always collapse at a 90° angle. Therefore, firefighters must maintain a proper collapse zone that exceeds 100% of the height of the building when operating at buildings with tilt wall panels.

Typically, the roofs of noncombustible buildings are flat with steel decking supported by steel beams or steel bar joist trusses. The roofing system consists of a rigid or semi-rigid insulating board and some form of membrane roofing material, such as built-up layers of asphalt roofing paper applied with hot tar, or a rubber membrane roof system that is sealed at the seams with an adhesive material. The roofs may be covered with small stones known as slag that are raked into a layer of hot tar. For a rubber membrane roof, the roof covering may contain larger rounded river stones that range in size from approximately a golf ball to a baseball. The river stones provide ballast to the membrane roof and add weight to the roof.

The lightweight structural systems add steel bar joist roof systems to the collapse dangers associated with tilt wall panels. Such systems make noncombustible buildings some of the most dangerous buildings the firefighter encounters.

Fig. 7–25. Exterior tilt-slab wall of a noncombustible warehouse occupancy. In tilt slab construction, the exterior wall system relies on the roof for support. If a fire causes the roof to collapse, there is a tremendous likelihood that the walls will collapse next.

Ordinary construction

Ordinary construction consists of exterior masonry load-bearing walls and wood joist floors and roof (fig. 7–26). The interior bearing walls may be either wood frame, or, when required, a firewall constructed of masonry. This class of construction may incorporate some type of roof truss. Typically, buildings along old, downtown Main Street USA are made of ordinary construction. These buildings typically range from one to four stories in height.

Fig. 7–26. Ordinary-constructed buildings are made of masonry exterior walls, wood joist floors, and a wood roof structure. When the building has a storefront, the opening for the storefront windows is created with columns and beams. The steel columns and beams may be steel or cast iron. In the photo, the columns and beams support the total weight of the second and third floors, the roof structure, and the weight of the exterior masonry walls. (Courtesy of Christian P. Dansbach)

The term **taxpayer** has been applied to the one- and two-story buildings that line the streets of some older commercial districts; these taxpayers are cheaply constructed ordinary buildings. The "taxpayer" definition can vary among different regions. In some areas, it means a building erected on a property by the property owner for rental purposes, to generate a revenue to pay the property taxes. In others areas, taxpayers are a general classification of mixed-use buildings that contain a business on the first floor and apartments or living spaces on the upper floors.

The modern **strip mall** of retail stores has replaced its ancestor, the taxpayer (distinctive differences between the two are discussed further in chapter 31: Advanced Fire Attack). Strip malls are also often of ordinary construction with lightweight wood roof trusses and concrete block walls (other strip malls that use steel bar joists for roofs and concrete block walls are usually classified as Type II noncombustible construction).

Common uses of occupancies with this type of construction include older multiple dwellings, garden apartments, as well as commercial and manufacturing buildings. Manufacturing occupancies in ordinary -constructed buildings should not be confused with mill or heavy timber buildings. Ordinary-constructed buildings housing manufacturing occupancies usually have fewer square feet and stories than mill or heavy timber buildings.

Ordinary-constructed buildings that require large open floor areas may be constructed with timber truss roofs (fig. 7–27). This construction feature creates a combustible void space where the fire can intensify without being noticed by firefighters. A large volume of fire may be present in the void space created by the trusses, while conditions on the floor below the truss can be habitable with a light smoke condition. Firefighters must be able to recognize this construction feature and operate safely in these buildings. This construction feature may lead to conflicting reports between the interior crews and the roof crew. The roof crew is in a much better position to identify the fire conditions in the truss space; so when conflicting reports arise, the roof report is the better report to judge fire conditions.

Fig. 7–27. Common ordinary-constructed buildings that are constructed with truss roofs include bowling alleys, automobile dealerships, gymnasiums and churches. In this photo, you can identify the strong areas of support in the brick columns built into the exterior walls. (Courtesy of Christian P. Dansbach)

In multistory multiple dwellings, there are several construction features that permit rapid vertical and/or horizontal fire extension. These construction features include light and air shafts, dumbwaiter shafts and vertical openings created by plumbing waste and vent lines, and openings for steel channel rails in larger buildings.

Light and air shafts extend from the roof down through the building and terminate at the first or second floor level. The light and air shafts allow natural light and ventilation into rooms and apartments near the center. The shaft contains windows; if a fire in an apartment on one side of the shaft extends into the shaft, then due to the proximity of the windows in the shaft, the heat may cause the windows to fail and allow the fire and smoke to extend into the nearby apartments. An **open shaft** is open to one side of the building and easily identifiable from that side of the building; a **closed shaft** is enclosed on all sides and cannot be identified from street level. A fire extending in the shaft and showing above the roof may be mistaken for a fire burning through the roof. A report from the roof crew or identification of the shaft from another side of the building is necessary to determine if the fire is through the roof or extending from the light and air shaft.

Vertical fire extension in any building is always a paramount concern to firefighters. The location of the plumbing waste and vent lines in multiple dwellings creates significant potential for vertical fire extension. The buildings are constructed using typical floor plans, placing the bathrooms and kitchens on each floor in line vertically and resulting in the plumbing waste and vent lines serving all the apartments in that line. The openings created to install and maintain these lines produce a void space running the vertical distance of the building from the basement to and through the cockloft to the roof of the building (fig. 7–28).

Fig. 7–28. There is no fire-stopping or blocking installed around the bathtub waste line on the floor above. From the floor below, we can see the bottom of the bathtub. Fire that starts or extends to the combustible ceiling/floor space will rapidly extend vertically through the building.

Other structural features in some ordinary-constructed buildings are channel rails, which are used in buildings requiring larger square footage. The channel rails form an interior steel frame that supports the floors of the buildings. To determine if channel rails have been used in the construction of a building, an examination of the unfinished areas of the basement of the building will reveal the channels. The steel columns and horizontal beams are often exposed. The space around the channel rails may create a void space for fire to travel, which is especially concerning if the fire originates in the basement of the building.

Dumbwaiter shafts are another means of rapid vertical fire extension that firefighters should be aware of when operating in ordinary-constructed multiple dwellings. Dumbwaiter shafts contain either a mechanical or a manual lift intended to move material from one floor to another floor so the occupants need not carry materials up and down the stairs. The dumbwaiter shafts open on each floor at varying locations. The opening in the basement or the first floor is in a common area accessible to all the tenants, whereas on the upper floors the opening may be in the public hallway or in the dwelling unit. A small enclosure housing the operating mechanism of the dumbwaiter is located on the roof directly above the shaft.

In many older buildings, dumbwaiters are no longer used and may have been sealed up, concealing the original location of the shaft. The housing on the roof is sometimes removed and the roof sealed over the top of the shaft. The abandoned dumbwaiter shafts have been used over the years to run new building utilities such as new electric wiring, telephone and cable wiring, and even new plumbing lines. The new utilities easily run the shafts because the shafts are void of any fire-stopping, making the utility run of several stories an easy task for the contractor. It is for the same reason that rapid vertical fire extension is possible through the abandoned dumbwaiter shafts. For example, the old dumbwaiter shafts landed in the kitchen of each dwelling unit. The old doors have been removed and a single layer of ½-in. drywall has been secured over the door opening. If a fire occurs in a kitchen on the lower floor and extends into the abandoned dumbwaiter shaft, the fire rapidly extends vertically to the kitchens sharing the shaft as well as the cockloft of the building.

Heavy timber or mill construction

Heavy timber or **mill buildings** were designed and used as manufacturing buildings during the industrial revolution era for the manufacturing of products and goods. These buildings may have changed in use and occupancy or have been renovated during the life of the building, but the underlying support structure remains the same (fig. 7–29). The buildings were constructed of exterior brick walls, wood joisted floors, and massive interior wood columns and beams (more than 5 in. [127 mm] in any dimension).

The buildings have large open floor areas, even up to an entire block long. If the building floor areas are subdivided, they are subdivided by firewalls that separate the floor areas of the building. Openings in the firewalls contain rolling horizontal or roll-up vertical fire doors for protection. The firewalls may be easily identified from the exterior of the building by the protruding brick wall that extends above the roof of the building (fig. 7–30).

Fig. 7–29. A typical floor of a mill or heavy timber building; notice the large cross-section dimensions of the columns and beams, the wide-open area that permitted the movement of goods and materials. This area was also the top floor of the building as evidenced by the rows of skylights that allowed natural light to enter the building. (Courtesy of William P. Dansbach)

Fig. 7–30. Mill buildings may have large open floor areas and firewalls that sub-divide the floor areas of the building. In the photo, you can see the firewalls extending above the roof of the building. Mill buildings typically had many large openable windows to allow for natural light and ventilation. (Courtesy of Courtney A. Dansbach)

The buildings contain large open areas to facilitate the movement of raw materials used in manufacturing products. Multistory buildings contain a large freight elevator used for the movement of the raw materials and finished products. The freight elevator shaft represents significant firefighting challenges. The shaft is open, allowing the rapid vertical movement of smoke and heat as well as vertical fire extension. Firefighters operating on floors above the fire should identify the open shaft and be aware of rapidly changing conditions. The open elevator shaft also creates a fall potential for firefighters operating in the building. Even simple tasks conducted in light or limited smoke conditions in low lighting can be deadly if a firefighter falls into the shaft.

Through the years as the manufacturing operations have moved out of these buildings, the buildings have been converted to different uses. The newly established uses in these building have changed the hazards faced by firefighters. Common uses include conversion to residential occupancies, mercantile shops and restaurants, and warehousing ranging from large commercial warehouse space to self-storage facilities. In the conversion to residential occupancies, the building layout and arrangement drastically changes as many rooms are constructed and the entrances to the buildings and dwelling units are altered. Additionally, many concealed spaces are created as chase walls, and new ceilings are installed to conceal the various utilities installed to serve the residential occupancy. As with all void spaces, this alteration creates an avenue for fire and smoke to spread through the building (fig. 7–31). This concealment is not permitted by most building codes but still occurs.

Fig. 7–31. In this photo, a mill building is being renovated and a window is being added in the exterior wall. Notice the thickness of the exterior wall, the size of the interior column, beam, and floor joists. The original building had no ceiling other than the underside of the floor above. If during the renovation a ceiling is added under the floor joists (this is not permissible under most building codes), a combustible void space will be created. (Courtesy of William P. Dansbach)

Conversions to warehouse space may present challenges to the building's automatic sprinkler system if the system is not modified to meet the fire load and wall arrangement presented by the new storage occupancy. Failure of the automatic sprinkler system to control the fire requires the firefighters to manually extinguish the fire. The restaurants and mercantile shops mean higher occupant loads where the original designs did not intend occupancy by the general public. Sometimes, the conversion of a mill or heavy timber building may illegally create combustible void spaces. Modifications to such buildings often result in the rearrangement of the exits and access points to the building, and mazelike conditions from the floors of smaller tenant or occupant areas.

Wood-frame construction

This section of the chapter reviews **wood-frame construction**. Four separate and distinct classes define the features, methods, and hazards associated with each class of wood-frame construction. The four classifications of wood-frame construction are as follows: **post-and-beam** or **braced frame**, **balloon frame**, **platform frame**, and **lightweight wood frame**.

Post-and-beam. This is wood-frame construction in which the frame of the structure is formed by vertical wood posts (located at each corner of the building) connected to horizontal beams (located at each floor level) that support the floors (fig. 7–32). The walls between the beams are vertically filled in by 2 × 4 wood studs. This method of construction uses **mortise and tenon connections** to connect the beams to the posts and the floor joists to the beams.

Fig. 7–32. This photo details a post and beam building. Notice the vertical post at the corners and the horizontal beams at the floor level. (Courtesy of Tim Hetzel)

A mortise and tenon connection consists of tenon (tongue) cut onto the end of the beam that is inserted into the mortise (hole) cut into the post (figs. 7–33 and 7–34). This type of connection removes a significant amount of the cross-section value or mass of the structural members. Up to two-thirds of the beam's mass may be removed to create the tenon. As with any wood structural member, fire resistance and collapse resistance is a function of mass. Simply put, how much wood is there to burn before collapse occurs? The more wood the more burn time before collapse occurs. The mortise and tenon connection at each floor level makes post and beam construction susceptible to an **inward** or **outward collapse** when the first floor of the building is involved in fire. When the mortise and tenon connection at the first-floor ceiling level and second floor's floor is attacked by fire and can no longer support the weight of the floor or floors above, an inward or outward collapse occurs.

Fig. 7–33. This photo details the mortise and tenon connection where the post is connected to the beam, the connection is secured with dowel-like pegs called *trunnels*. The mortise and tenon connection is the weakest point in the framing system as 2/3 of the mass is removed from the beam and 1/3 of the mass is removed from the post to create the connection. (Courtesy of Tim Hetzel)

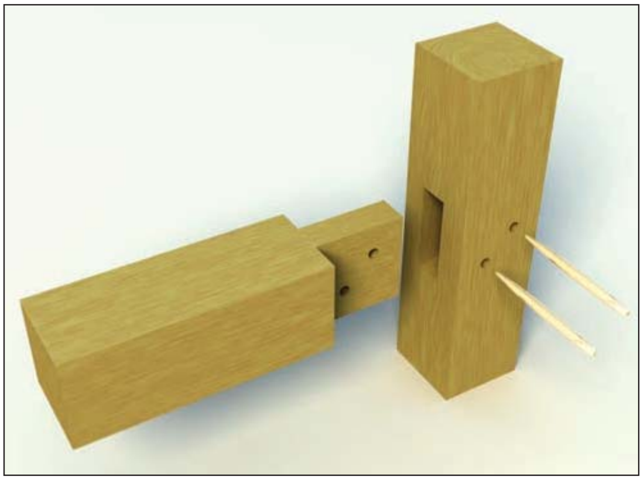

Fig. 7–34. This diagram details how a mortise and tenon connection is constructed. Notice the amount of mass removed from the beam to create the tenon. This makes this part of the connection the weak point in this connection. A wood peg or trunnel is driven into holes to secure the connection.

Fig. 7–35. In a building that is balloon framed, the exterior wall studs run from the basement to the attic without fire stopping. This photo looks up the wall as it passes the second floor joists; note the lack of fire stopping and the ease with which the duct work was run in the wall. This vertical void space becomes a chimney for the fire to travel from the basement to the attic.

Balloon-frame. Balloon-frame construction was a method employed from the mid-1880s to World War II. This type of construction employed the use of 2 × 4 wood framing members for the exterior and interior walls. The major fire problem with this type of construction is that the exterior wood stud walls are supported in the basement on the foundation plate, and the opening between the stud bays is an open vertical channel. The studs extend the full height of the exterior wall, terminating in the attic or top floor of the building (fig. 7–35). The void created by each stud bay allows for rapid vertical fire extension, especially when the fire originates in the basement (fig. 7–36). As a fire starts and continues to grow, two basic laws of physics create conditions for this rapid fire extension: The heat produced by the fire is more buoyant that the surrounding air; and whenever there is an increase in temperature in a confined room or space such as a basement, pressure increases. These factors allow the heated products of combustion, which are naturally rising to the ceiling, to be forced up through the void spaces created by the balloon framing and result in rapid vertical fire extension. Additional void spaces are found in balloon framing. Both load bearing and nonbearing interior walls may be balloon frame. Since the point in the framing system where the floor joists connect to the exterior and interior walls is not fire-stopped, this opening allows any fire running vertically in a wall to travel the horizontal concealed space created by the flooring and the interior finish applied as a ceiling.

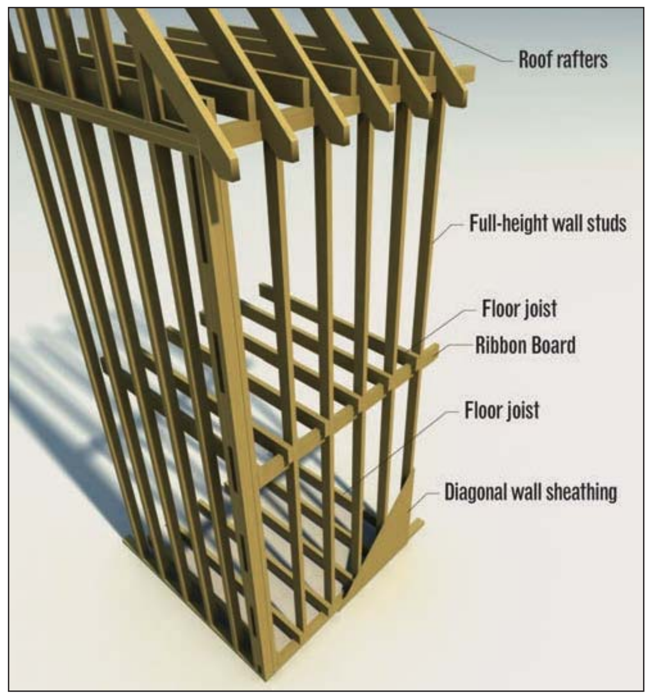

Fig. 7–36. The void spaces created by the 2 x 4–in. (51 x 102–mm) wood studs that run from the basement to the attic. These void spaces result in rapid vertical fire extension.

Platform frame. This method was introduced in the post–World War II construction boom and is still employed today. Traditional platform-frame construction used dimensional lumber such as the 2 × 4–in. (51 × 102–mm) for the interior and exterior frame walls, 2 × 8–in. (51 × 203–mm)for the floor joists, and at least 2 × 6–in. (51 × 152–mm) for the roof rafters. This construction method greatly differs from balloon frame in that the buildings are constructed one story at a time, so the construction method provides **inherent fire-stopping**. After the foundation is completed, the first floor framing is erected and the floor joists extend to the outer edge of the foundation. The subfloor is laid on top of the floor joists, completing the first-floor system. The next step constructs one story of 2 × 4–in. (51 × 102–mm) walls, a bottom 2 × 4–in. (51 × 102–mm) plate is laid horizontally on the subfloor, the walls are erected, and a double 2 × 4–in. (51 × 102–mm) top plate is run horizontally at the top of the first story of studs. This method is employed for interior and exterior walls. The floor of the next story is then constructed on the top of the first floor framing system, extending to the outer edge of the exterior wall framing. Each subsequent floor is constructed in the same manner (fig. 7–37). This framing method therefore provides inherent fire stopping because this construction method has eliminated combustible void spaces that penetrate the floors (fig. 7–38). An area of concern for firefighters is where building utilities (e.g., plumbing drain and vent pipes, HVAC ducts, and electric and communication cable) are run through the floors and walls. The installation of these utilities often results in removing parts of inherent fire stopping in the form of the top and bottom framing plates to run the various utilities. An avenue of fire extension from one floor to the floors above is created if the utility runs are not properly fire-stopped after the installation of the utilities. Experience has shown that in most instances, these penetrations are not properly fire-stopped. Firefighters may identify areas of potential vertical fire extension by locating vent pipes that penetrate the roof and subsequent vertical locations down through the building where fire extension is likely.

The interior finish of a platform-frame building is likely to be some form of drywall or gypsum material. In the beginning years of platform-frame construction, a material known as **rock lath** was used as the interior finish material. The rock lath was a gypsum board material, 16 in.- (406 mm-) to 2 ft- (0.6 m-) wide boards that had holes every couple of inches. The rock lath was installed on the walls and ceilings, and one or more coats of plaster were applied to the rock lath to complete the interior finish. This material, or a form of this material, may still be found in homes where the owner or designer prefers a plaster interior wall finish. There are many different types of drywall installed in wood-frame buildings. The most common form of drywall installed in dwellings is easily breached and removed by firefighters.

Fig. 7–37. In a building constructed of platform-frame construction, each story is built on top of the floor below. Notice the floor joists of the first and second floors extend to the outer edge of the framing, creating inherent fire stopping. (Courtesy of Robert Moran)

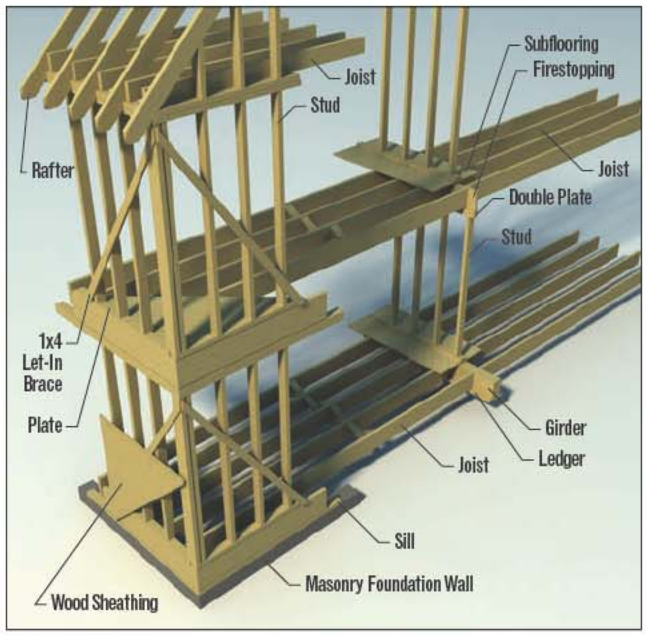

Fig. 7–38. The platform-frame method of construction. Note the inherent firestopping built into the building when one floor and one story of walls are constructed at a time.

Lightweight wood-frame construction. This is any wood-frame construction using lightweight engineered structural components, including lightweight parallel floor trusses, lightweight peaked-roof trusses, and engineered wood I-beams (fig. 7–39). These structural components have been used in the construction industry since the late 1960s; but the proliferation of townhouse and condominium construction in the 1980s saw a tremendous use of lightweight wood structural components. This will continue as the construction industry seeks ways to build more efficiently and economically (but not more fire safe), and natural resources such as wood becomes less available. These structural components have been engineered to carry the greatest load over the greatest span using the least amount of material necessary to carry the imposed load.

The connections in trusses make them dangerous under fire conditions. The trusses are connected with a steel gusset plate that only penetrates the wood between ⅜ and ½ in. The heat from the fire is conducted into the wood through the steel gusset plate and begins to decompose the wood fibers, which affect the connection's strength. Additionally, the steel gusset plate will be deformed and may warp from the heat of the fire, pulling out of the wood truss, and causing the connection and possibly the entire truss to fail (fig. 7–40).

The engineered wood I-beams are constructed of manufactured lumber; the top and bottom chord are laminated plies of lumber that create the top and bottom flange. The web of the beam is OSB, which begins to fail when exposed to the fire's heat as the resins and glues vaporize and allow chips of wood in the OSB to delaminate. From the exterior, a lightweight wood-frame building may be difficult to identify, because the exterior may appear as any other wood-frame building. Lightweight wood-frame buildings are constructed in the same manner as platform-frame buildings: one story at a time. The major difference that makes these buildings so prone to early collapse and so dangerous to firefighter is the use of lightweight wood, parallel-chord floor trusses, and peaked-roof trusses. Using these elements creates numerous combustible void spaces that can be large; there the fire can extend, grow, and destroy the structural support of the floor or roof system.

Most wood-frame buildings have an exterior siding of wood, aluminum, vinyl, composite hardboard or stucco, brick veneer, or another form of a **cementitious** finish. Many older wood-frame buildings may have **asphalt siding** (essentially, thin asphalt shingles that often look like bricks), sometime referred to as **gasoline siding** because of the combustibility and rapid fire development, which occurs over the surface of the siding. In closely built neighborhoods, fires involving this type of siding have been responsible for fire extension to the exposures. Often, the asphalt siding has been sided over with a more modern siding material. This can be a hazard when the fire extends to the siding material and the newly installed material burns away, exposing and igniting the asphalt siding.

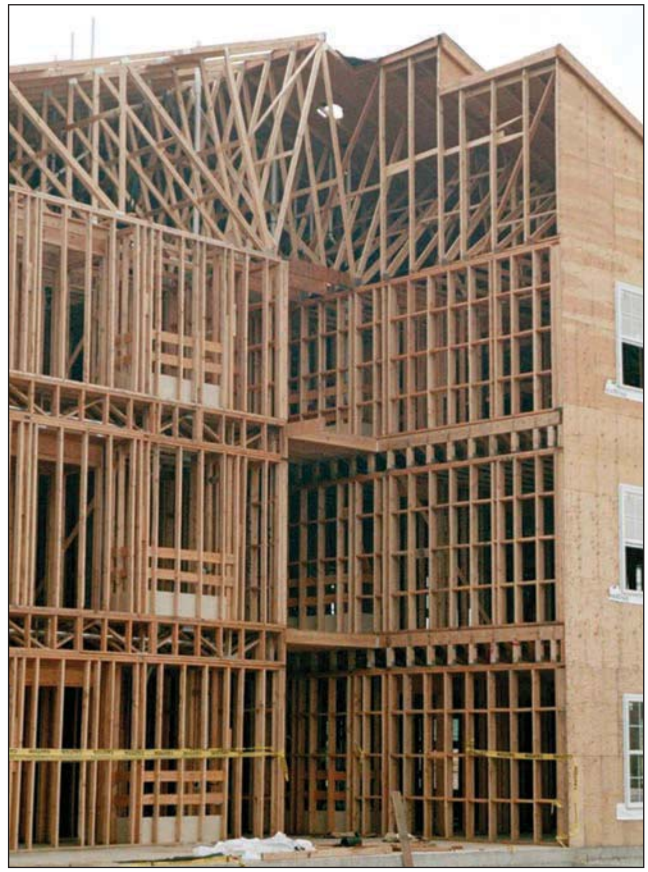

Fig. 7–39. This photo details the many combustible void spaces that will be found in buildings constructed with lightweight parallel-chord floor trusses and peaked-roof trusses. Note the floor system in the center public corridor is a different floor system and may be dimensional lumber such as 2 x 8–in. (51 x 203–mm) floor joists which are attached to the ends of the floor trusses and separates the floor systems on each side of the public corridor. (Courtesy of Courtney A. Dansbach)

Fig. 7–40. The lack of penetration of the teeth on the gusset plate allows it to warp and twist out of the truss. Loss of strength in the connection will lead to the failure of the truss.

Building alterations

Many buildings are altered at one time or another. In many cases, buildings have been renovated more than once, and each renovation increases the potential for hazards to firefighters. Common firefighting problems created by renovations include the creation of combustible void spaces, changes to the structural hierarchy of the building, overloaded structure, and changes to the exterior of the building. A common practice during renovation is to create combustible void spaces by lowering ceilings, furring out walls to facilitate the installation of building utilities from floor to floor, and the creation of combustible void soffits to facilitate the installation of buildings utilities horizontally through the structure (figs. 7–41 and 7–42).

Changes to the structural hierarchy of the building often result when the building is renovated (fig. 7–43). The removal of bearing walls or columns and replacement of the bearing walls and columns with other load-carrying components may result in a design incapable of carrying the load brought to bear on the new structural member. A common renovation involved removing a masonry load-bearing wall from the first floor of a multistory ordinary-constructed building and replacing it with a series of columns and beams to support the load of the floors and walls above. The new columns and steel beams may not be capable of supporting the load if a fire occurs, and the steel beams and columns are affected by the heat from the fire. Failure of the columns and beams in this situation may cause the bearing wall and the floors and roof it supports to collapse.

Fig. 7–41. A kitchen renovation that results in the creation of combustible void spaces when the framing for the cabinet soffit has been installed without first installing drywall on the wall and ceiling behind the soffit. Should the fire extend into the combustible void space created by the soffit, the fire will extend horizontally throughout the soffit and vertically in any non-fire-stopped void spaces in the wood framing.

Fig. 7–42. A dropped ceiling of 2 x 4s and drywall has been constructed below the original plaster and lathe ceiling. When checking for fire extension, firefighters must recognize this feature and continue to open the ceilings until they have exposed the underside of the floor or roof above. In this photo, the task was not completed as only the dropped ceiling has been removed leaving the plaster and lathe ceiling intact.

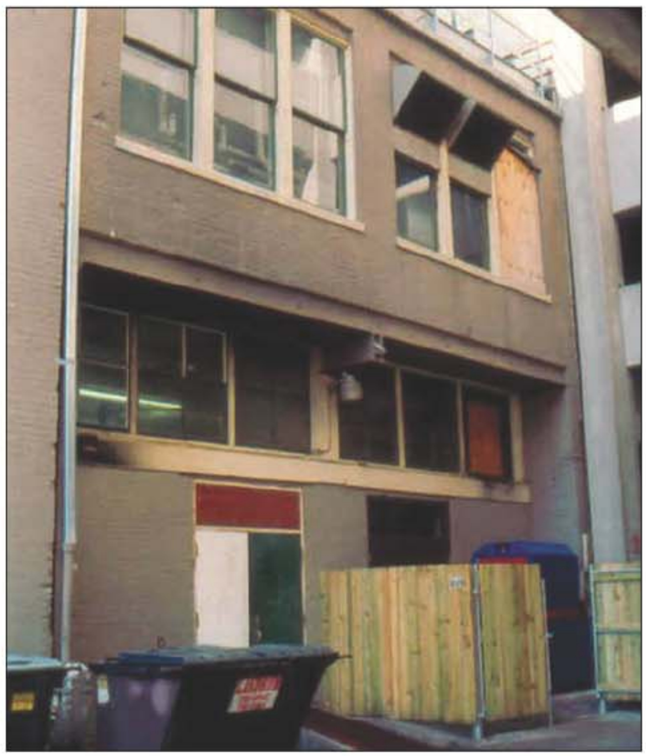

Fig. 7–43. A building in which the first floor exterior masonry wall has been removed and set back into the building from its original location. This renovation has changed structural support of the second floor and roof and the second-floor brick exterior wall. These components of the building had been supported by a masonry wall and are now supported by steel columns and beams. This renovation has changed the structural hierarchy of the building and has changed the collapse potential of the wall. The steel beam will be heated and may fail much sooner than the original masonry wall.

NEW TECHNOLOGY IN BUILDING CONSTRUCTION

One of the greatest challenges facing the fire service is the technological advances in the construction materials. The changes are the result of less raw material being readily available such as lumber and steel; the economic desire to construct more cost-effective buildings, lighter materials, and man-made materials have reduced the cost by decreasing the time to complete a given part of the building.

The advancements in building construction and materials technology have come at great cost to the fire service (fig. 7–44). The changes in construction materials have generally resulted in use of lightweight structural elements in the construction of buildings since the mid-1970s. Materials and structural components, such as lightweight wooden floor and roof trusses, mean a developer can expend less material to support existing loads using structural members capable of spanning greater distances than standard dimensional lumber. This is an example where math, the engineering of wood trusses, has replaced mass, the amount of wood in dimensional lumber (a 2 × 10–in. [52 × 254–mm] floor joist). Using or adding engineered structural components to the buildings has resulted in a considerably reduced period of safe operating in these buildings during firefighting operations.

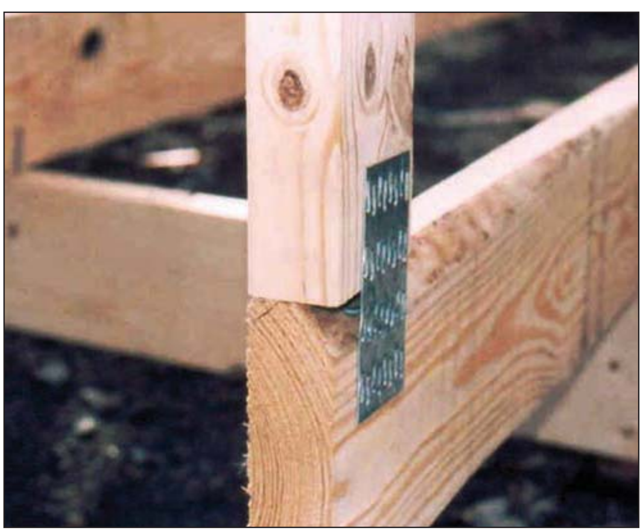

Fig. 7–44. The lack of quality control has lead to the truss being delivered to the construction site with one entire row of the connecting teeth of the gusset plate not being secured into any part of the wood truss. The heat from a fire will quickly attack these connections; this connection being less secure than the remaining gusset plates is likely to fail very early in the fire.

Another example of new material is the increased use of OSB (previously discussed); OSB is used in place of plywood in many applications such as exterior wall sheathing on wood-frame buildings. OSB is also used as a web member in wooden I-beams, which have replaced standard dimensional lumber in most wood-frame buildings as floor joists and roof rafters. The fire hazard of wood I-beams is again the lack of mass to the structural member. The OSB web of the wooden I-beam of at least 1½ in. (38 mm) is only ⅜ in. (10 mm) thick; compare to a 2 × 10–in. (52 × 254–mm) joist that has a nominal thickness. This results in a difference of 1⅛ in. (29 mm) in the mass of the structural member. Another factor affecting the burn time is the use of adhesive or bonding agents in the production of the OSB. These bonding agents are typically resins and wax; the greater part of the components are resins, and the wax is added to provide a degree of water resistance to the material. When the OSB that is the web of a wood I-beam is exposed to the heat, the resins and wax vaporize; as the materials vaporize, the OSB begins to degrade, delaminate, and lose structural integrity and the resins and wax add fuel to the fire. There are many documented cases where the collapse of lightweight wood floor and roof systems have killed and injured firefighters.

Another example of building designers using less and lightweight materials in Type II buildings is the replacement of steel I-beams with lightweight steel trusses (also known as **steel bar joists**). Trusses are examples of math replacing mass: geometric shapes in the truss design are mainly responsible for the support of a given load. The replacement of steel I-beams with trusses produces a building that is lighter weight. The structure's footings need not support the load of the steel I-beams, only the weight of the trusses.

Many advancements have been made in the manufacture of **gypsum board** or **drywall**. For many years, all-purpose, moisture-resistant, and fire-rated drywall were the most common types a firefighter would encounter. These types of drywall were easily opened up or removed when used in the building. Fire-rated assemblies that employ multiple layers of drywall to construct a fire-rated assembly require significant effort to breach or open up. Drywall is now available that has been reinforced with materials that make it difficult or impossible for firefighters to breach or remove the walls. **Impact-resistant drywall** is manufactured with fiberglass and other materials that make the finish of the drywall harder and therefore more difficult to open or breach. Drywall manufacturers also laminate drywall with other materials such as OSB or sheets of Lexan® plastic to make the drywall impenetrable. These different types of drywall may be found in various occupancy types. Impact-resistant drywall is found in schools and other locations, where durability of the wall is desired, and the use of impact-resistant drywall may also reduce cost by replacing a concrete block wall with a steel stud wall with impact-resistant drywall as the interior finish. **Laminated drywall** may be found on the walls of high-value occupancies such as jewelry stores in malls to prevent unauthorized entry into the occupancy by breaching the walls. Laminated drywall may be found in any location where security is a concern to the owner or occupant. Firefighters should be aware of occupancies that have been constructed with these types of drywall, because opening or breaching walls with these types may be difficult or impossible.

The exterior finishes on many recently constructed buildings appear to be a stucco or cement plaster finish, when in fact the exterior wall finish is a system known as an **exterior insulation and finish systems (EIFS)**. These appear to be typical cement plaster finishes used as an exterior finish material for many years. The EIFS is a lightweight synthetic wall cladding that includes foam plastic insulation and thin synthetic coatings that produce a finish that appears to be a stucco finish. The EIFS may be installed over a concrete block wall or oversheathing that has been applied to wood or steel studs. The application of any stucco-like wall finish makes identifying the type of construction more difficult from the exterior of the building. The foam component in the exterior wall system is likely to be combustible; and should the fire extend to or involve the wall system, firefighters may be faced with a challenging fire because it may extend through the wall system and require significant overhauling to be controlled and extinguished.

Another part of the building that has seen changes is the roof covering. For many years, flat roofs were covered with a **built-up roof** covering. Built-up roofs employed a fiberboard insulation panel, a base sheet of roofing materials and several layers or roofing felt (paper). The roof felt is applied and lapped over each other to provide multiple plies of roofing. The roofing felt was applied by hot asphalt tar mopped out onto the roof surface and then was rolled out into the hot asphalt. More recent roofing materials include synthetic rubber membrane that provides a watertight roof covering. One form of the synthetic roof coverings is an EPDM (ethylene propylene diene M-class) rubber. The seams in the rubber membrane are sealed with a flammable adhesive. The roof covering may be fully adhered to the roof, held in place by **mechanical fastening**, or covered with stone to act as ballast to prevent the roofing material from lifting in high winds (fig. 7–45). Firefighters may have to remove the ballast stones to access the roof covering. Additionally, the ballast stone will add a significant weight to the roof structure.

Firefighters should be constantly aware of changes in construction materials and methods. They should also know how these changes affect firefighting in the building as they conduct pre-incident inspections of buildings under construction or renovation in their jurisdiction.

Fig. 7–45. The ballast stones are placed on the roof to prevent the roof covering from lifting and are not secured to the roof. These stones make footing on these roofs difficult. The stones also add weight to the roof structure and create surface tension that slows down the drainage capability of the roof.

INDICATORS OF COLLAPSE

FFI 5.3.12 **FFII 6.3.2** An important aspect of the study of building construction is to understand the indicators of collapse and the collapse potential of the various types and forms of construction. There are numerous visual indicators (identified in the following text) of an impending collapse that could cause failure of a building or part of a building. Sounds—creaking or moaning of the building—are also signs of impending collapse. In all cases, immediately report these indicators to your superior officer; rapid evacuation is usually crucial.

Major collapses at fires are uncommon, but firefighters must be aware of the smaller, more localized collapse, which can be just as deadly. Table 7–3 details some of the collapse indicators and collapse potential based on the construction type or building component.

When a building or part of a building is in danger of collapse, **collapse zones** must be established and all firefighters must remain clear of these zones. Each collapse zone has a height and width; the height of the building, or part of the building in danger of collapse, must be transferred horizontally to the ground. The collapse zone away from the building must be at least the height of the building or part of the building in danger of collapse plus a **safety factor**. The safety factor is necessary because parts of the building may bounce outward when they hit the ground (such as bricks). Because measuring the height of the building and subsequent transfer of that dimension to the ground is an estimation, always add or estimate on the high side. Policies on establishing collapse zones may vary slightly from department to department, but the policies must always include a safety factor. The safety factor should be calculated by adding several feet, an additional story, or even as much as an additional 50% to the estimated height of the building. The collapse zone must also include the width of the building or part of the building in danger of collapse; a safety factor should also be added to this distance or dimension (fig. 7–46). Firefighters should know their department's policies and procedures for the establishment of and maintaining collapse zones.

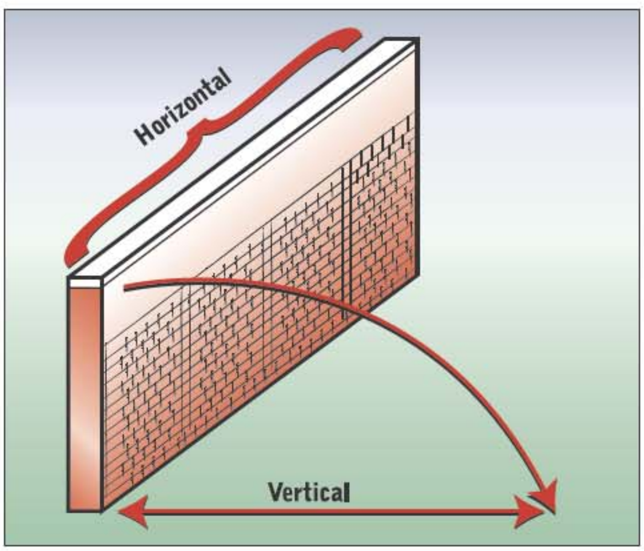

Fig. 7–46. The collapse zone must include the horizontal width of the wall and the height of the wall plus a safety factor.

There are three basic types of collapses that firefighters should understand. A **tent-type** and a **lean-to type** collapse leave void spaces in the aftermath of the collapse, where building occupants who may have survived the collapse may be located. The third type of collapse is a **pancake-type** collapse. (These types of collapses are covered in greater detail in chapter 35: Support of Technical Rescue Teams.) The pancake-type collapse leaves little if any void space for the occupant to survive the collapse.

A paramount concern to firefighters operating at any collapse incident is the potential for **secondary collapse**. Initial fire department operations at any collapse incident should be limited to the following: size-up, removing occupants from known locations that do not require technical expertise, incident stabilization, such as securing utilities from a safe location, and evacuation of adjoining structures. Firefighters operating at collapse incidents that require structural shoring or entry into collapsed areas of the structure should only operate under the direct supervision of fire officers specifically trained in collapse rescue.

RECOMMENDED STUDIES

This chapter begins your study of building construction. Each firefighter must continue to study building construction by a variety of means. Consider continuing your education by attending formal training classes on building construction, conducting walk-through drills of buildings under construction or renovation in your jurisdiction, or in other ways. During the walk-through drill you can (with the owner's or contractor's permission) take a series of digital photos, which can be made into a PowerPoint presentation. This type of presentation can be viewed during company drills and will reveal parts of the building that are no longer visible once it is completed. This serves as a refresher to some firefighters and is an invaluable tool to future generations of firefighters serving your department.

Building construction can be somewhat geographic; firefighters should constantly be aware of new trends in construction methods and materials being used in your response area. Strive to understand how these methods and materials react under fire conditions. When you experience a fire with an unusual outcome or occurrence, share this information as soon as possible with other firefighters in your department, your surrounding departments, and throughout the country. This is one benefit of the Internet! Study fire incident reports that are published regarding major fire incidents, particularly those involving building collapse and serious firefighter injuries and deaths. These reports contain valuable information regarding construction features that may have affected the incident as well as lessons learned from the incident. Each firefighter should seek to understand these lessons learned to become a safer and better firefighter. The funny thing about building construction is that the more you learn, the more you realize there is more to learn!

Table 7–3. Indicators of collapse

Construction type, building component, or feature	Collapse indicator or collapse potential
Wood-frame buildings	Sagging roofs and leaning exterior walls are indicators of collapse.
Wood-frame buildings constructed with lightweight structural components	Fire burning in the void space created by the floor or roof assemblies presents the real potential of collapse.
Freestanding masonry parapet walls	Any masonry parapet wall that is exposed to heavy fire conditions or in which the surrounding roof has burned away or any parapet wall that is out of plumb is in danger of collapse.
Ordinary-constructed building with a heavy timber truss roof	Collapse is a danger when fire is in the truss loft or where the truss has been exposed to fire. Buildings in which the truss loft is a concealed space are dangerous because the true fire conditions are concealed from the firefighters by the ceiling material.
Noncombustible-constructed buildings with a steel bar joist roof system	Steel bar joists are susceptible to collapse even after short-term exposure to fire; they have poor surface-to-mass ratio, and the heat from the fire causes the steel to reach its yield point after short exposure to fire conditions.
Ordinary-constructed flat-roof buildings with rafters of dimensional lumber	This roof system creates a redundant support system and will sustain fire conditions for a significant period of time. When the roof does fail it may do so slowly, and the initial collapse is not easily noticed by firefighters operating on the roof. Indicators of collapse for this type of roof include plumbing vent pipes that start to grow or extend up or reveal what appears to be fresh tar or roof cement around the pipe or areas along the parapet walls that appear to have fresh tar or roof cement.
Walls, floors, and roofs of all buildings	Any wall that appears to be out of plumb is in danger of collapse. Sagging floors or roofs are also indicators of collapse.
Chimneys	A chimney where the adjoining wall or roof has burned away should be considered in danger of collapse. The adjoining wall or roof provides lateral support for the chimney; and when the adjoining wall or roof burns away, the chimney is unsupported for a greater vertical distance.
Wood-frame, ordinary, and noncombustible-constructed buildings	When these buildings become well-involved in fire and the fire has taken hold of multiple floors, they are in danger of a major collapse.

QUESTIONS

1. What are examples of undesigned loads with regards to building construction?
2. Describe the main differences between live loads and dead loads.
3. A balcony that is supported at only one end is a(n) ________________.
4. Many structural columns that support roofs and floors are made of cast iron. When under a fire load, what happens to these columns?
5. In building construction, what are I-beams mostly used for?
6. Describe the factors that affect structural stability of buildings?
7. NFPA ______________ groups buildings into five classes.
8. Briefly describe each of the classes of buildings.
9. What is the main reason for center core floor plans in high-rise buildings?
10. Tilt wall construction poses safety hazards for firefighters when they are under fire conditions. Describe how the construction works and the safety hazards that exist.
11. Name the four classifications of wood-frame construction and describe them.
12. What is the significance of balloon frame construction in fire suppression strategy?