Concepts of Construction
Learning Objectives

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

- Identify the variety of forces that buildings are subjected to
- Identify the different types of loads and how they are applied to buildings
- Identify and define key different types of structural members such as columns, beams, and walls
- Identify the variety of different types of structural connections and how they behave in a fire
Introduction

Building construction has evolved over time. Although the overall rationale for a structure—to provide shelter—has remained the same, the way we build buildings has changed as new technologies and techniques emerge. From a firefighting perspective, it is important to realize that the built environment that you respond to in your community is actually an aging collection of different types of buildings, incorporating a myriad of construction methods, materials, and design concepts along with the hazards associated with each one. In essence, you must become the local “historian of building construction” in order to understand how the buildings you protect—and the people in them—will behave under fire conditions.

One thing that hasn’t changed, however, is the laws of physics. As a fire fighter, you must have a working knowledge of how the forces of nature and man cause buildings to collapse. Anticipating the reaction of a particular building to these forces is essential to your safety. It is important, therefore, that you have an understanding of the basic concepts of construction. Despite the fact that learning from fire-ground experience is critical, you can’t rely solely on this to keep you safe.

From experience, some fire officers have learned to make useful, but limited, judgments regarding the loss of structural stability in a fire. Many of the commonly taught indicators, such as sagging floors, strange noises, and the like, may be too little too late. In addition, experience with one type of building element, such as solid sawn wood joists, is not valid for trusses or wooden I-beams. Relying on experience alone is not sufficient. Fire fighters must be aware of the theories and principles involved. We will begin our study by looking at the greatest of all fire fighter enemies—gravity.

Gravity

The force of gravity is the eternal enemy of every building. Twenty-four hours a day, seven days a week, gravity exerts a force on the building. Buildings may appear to be just quietly sitting on their foundations, but, in fact, they are under great stresses. Although this may not be apparent as you look at the structure, the stresses are there nonetheless. By one means or another, in assembling a structure, the builder has defied gravity. Not all builders recognize this. A student once asked an old carpenter, “How do you defeat the laws of gravity?” He threw down his hammer and replied, “They’ve got so many #@$% laws now, you can’t get anything done.”

The gravity resistance system in a building consists of all the structural elements and the connections that supplement this resistance. Bear in mind that a building’s tendency to collapse is being increased by fire, while the fire suppression forces place additional demands on the structure. When the structure, or part of it, is no longer able to resist the loads, collapse occurs. Gravity acts instantly.

Tactical Considerations

Bear in mind that a building’s tendency to collapse is being increased by fire, while the fire suppression forces place additional demands on the structure. When the structure, or part of it, is no longer able to resist the loads, collapse occurs. Gravity acts instantly.
port and transfer the loads. Fire destroys the structural elements and/or the connections in a building, and places loads on some structural elements that cannot handle them, which can cause a collapse. Once the collapse starts, the results are unpredictable.

Some buildings are designed to be fire resistant. This means that to some degree they will resist fire-caused collapse. The vast majority of buildings are non-fire-resistant, and thus may easily collapse as a result of assault by fire on the gravity resistance system.

Definitions of Loads

A load in a building works to destroy the gravity resistance system of the structure. According to NFPA 5000, loads are defined as “forces or other actions that result from the weight of all building materials, occupants and their possessions, environmental effects, differential movement, and restrained dimensional changes.”

Specific terms are used to describe the types of different loads and the way they are placed on a building. It is important to understand and use them correctly. Dictionary definitions are not always identical to the definitions used in the construction field. The various terms, however, are not mutually exclusive. For example, a load may be a live load and an impact load at the same time.

Stress and Strain

Before we proceed any further, we must first understand the concepts of stress and strain, the result of forces applied to a structural member. People often confuse the two, so it is important that you understand the difference between them.

As we have seen, an external force that acts on a structure is called a load. The internal forces that resist the load are called stress and strain. Stress is usually measured in pounds per square inch (psi). Occasional references to pounds per square foot (psf) are also found. The unit area measurement is at the discretion of the person making the calculations. Always be careful to note the unit area when examining any calculations. KIP, a term meaning 1000 psi, is used in engineering calculations where the number of psi would be so large as to be unwieldy.

Strain, on the other hand, is the actual percent of elongation (deformation) that occurs when a material is stressed. Strain is measured in fractions of an inch of deformation per inch of original length of the material. In the common vernacular, stress and strain are considered synonyms; however, a clear understanding of the technical definitions of these terms is critical.

Compression, Tension, and Torsion Forces

Generally, three types of forces can be applied to a structural member: compression, tension, and torsion. In essence, a compressive force is one in which the force squeezes a structural member, such as a concrete column supporting a floor (Figure 2-1). Tensile forces stretch a member such as a steel cable that is supporting a suspended walkway. A torsional force is a twisting force, such as a nut on a bolt.

Dead Loads

Dead load is the weight of the building itself and any equipment permanently attached or built in. A more accurate term is self-weight. Years ago, dead load was

Fire departments should use the term building fire when dispatching. The term structure fire should be announced to all as soon as it is determined that fire is consuming or affecting (as in unprotected steel) the gravity resistance of a building. This should put all on notice to carefully and continuously observe the structure and prepare to evacuate instantly, if indicated or ordered. Instant evacuation from a building should be a drill subject for all fire fighters. This sort of thinking does not conform to the image many fire departments have of their operations. Remember that the proudest ships in the U.S. Navy drill regularly on “Abandon Ship.”
often piled on the building without regard for the consequences, or even in the mistaken belief that strength was being added to the structure by the added weight.

The modern designer more clearly understands that dead weight breeds dead weight. Efforts are made to lighten all parts of a building. Removing a pound of dead weight at the top of a building enables the builder to reduce ounces at many points in the supporting structure. Advertisements for building materials such as gypsum shaft liners emphasize weight saving over masonry enclosures. Today, buildings can be considered as being bought “by the pound.” Fire resistance is closely related to mass. All other things being equal, a heavier steel beam will take longer to fail due to heating than a lighter beam. A 4-inch by 10-inch wooden beam will support its load longer while burning than will a 2-inch by 10-inch beam. This provides a valid general principle: Any substitute structural element that is of less mass than the element previously used to carry an equivalent load is inherently less fire resistant.

**Added Dead Load**

A structure’s dead load is often increased during alteration. An example is the addition of air conditioners to the roof of a building previously without air conditioning. These loads are often added without any strengthening of the structure [Figure 2-2](#).

At a fire in a large city, fire fighters were overhauling a fire in a restaurant, seeking out hidden pockets of fire in the overhead. They attacked the fire-weakened supports of the building. Above them, added-on air-conditioning units fell, causing several fatalities.

Tactical Considerations

A residential structure will usually be designed for a floor load of about 40 pounds per square foot. This includes a factor of safety that has been found adequate for residences. If the building is converted to mercantile or office use, the load will probably be much greater than the residential load. Often, nothing is done to improve the building. The factor of safety has been compromised, possibly to the point where some slight increase in the load or loss of structural strength might cause collapse.

The fact that the structure is strengthened to cope with the added load may not be adequate in a fire. For instance, if lightweight trusses are strengthened by additional trusses, there is no improvement to resistance from fire collapse, because all the trusses will burn and lose strength at the same time.

A supermarket was converted to a Japanese restaurant with many grills. Each grill required a heavy fume hood. These hoods were hung from the roof. When the building was a supermarket, the roof did not have to support such a dead load. Now the same roof must carry the hoods—safety has been greatly reduced.
Live Loads

Live loads are any loads other than dead loads. An elevated water tank is a dead load. The water in the tank may be there for years but it is a live load. A concrete vault is a dead load. A movable safe, no matter how heavy, is a live load. These are not just picky distinctions.

- Dead loads can be accurately calculated.
- Live loads are indeterminate. The live load must be estimated based on the projected use of the building and such variables as snow, wind, or rain.

Buildings are designed with a given use in mind. The building code specifies the minimum live-floor load design for specific types of buildings. Typical building code minimum design load requirements for modern buildings are spelled out in NFPA 5000 Building Code Table A.35.6.1.2 (Table 2-1). The uniform “live load” column refers to loads distributed over the entire area (in pounds per square foot/psf) while the concentrated load is for specific large objects. An office building floor, for example, must be able to sustain a load of at least 50 psf over the entire floor but also have the ability to sustain a load of 2000 lbs at a specific location on the floor for individual or collected heavy objects like filing cabinets. Note that these are minimum design loads—if you were to find loading in areas of actual buildings that exceed these limits, it is best to contact your building department and advise them of the potentially overloaded conditions.

Table 2-1

<table>
<thead>
<tr>
<th>Occupancy or Use</th>
<th>Uniform Concentrated</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>psf (kN/m²)</td>
</tr>
<tr>
<td>------------------</td>
<td>-----------------</td>
</tr>
<tr>
<td>Apartments (see residential)</td>
<td></td>
</tr>
<tr>
<td>Access floor systems</td>
<td></td>
</tr>
<tr>
<td>Office use</td>
<td>50 (2.4)</td>
</tr>
<tr>
<td>Computer use</td>
<td>100 (4.79)</td>
</tr>
<tr>
<td>Armories and drill rooms</td>
<td>150 (7.18)</td>
</tr>
<tr>
<td>Assembly areas and theaters</td>
<td></td>
</tr>
<tr>
<td>Fixed seats (fastened to floors)</td>
<td>60 (2.87)</td>
</tr>
<tr>
<td>Lobbies</td>
<td>100 (4.79)</td>
</tr>
<tr>
<td>Movable seats</td>
<td>100 (4.79)</td>
</tr>
<tr>
<td>Platforms (assembly)</td>
<td>100 (4.79)</td>
</tr>
<tr>
<td>Stage floors</td>
<td>150 (7.18)</td>
</tr>
<tr>
<td>Corridors (see residential)</td>
<td></td>
</tr>
<tr>
<td>First floor</td>
<td>100 (4.79)</td>
</tr>
<tr>
<td>Other floors, same as occupancy served, except as indicated</td>
<td></td>
</tr>
<tr>
<td>Dance halls and ballrooms</td>
<td>100 (4.79)</td>
</tr>
<tr>
<td>Decks (patio and roof)</td>
<td></td>
</tr>
<tr>
<td>Same as area served, or for the type of occupancy accommodated</td>
<td></td>
</tr>
<tr>
<td>Dining rooms and restaurants</td>
<td>100 (4.79)</td>
</tr>
<tr>
<td>Elevator machine room grating (on area of 4 in² (2580 mm²))</td>
<td>300 (1.33)</td>
</tr>
<tr>
<td>Finish light floor plate construction (on area of 1 in² (645 mm²))</td>
<td>200 (0.89)</td>
</tr>
<tr>
<td>Fire escapes</td>
<td>100 (4.79)</td>
</tr>
<tr>
<td>On single-family dwellings only</td>
<td>40 (2.92)</td>
</tr>
<tr>
<td>Fixed Ladders</td>
<td></td>
</tr>
<tr>
<td>Garages (passenger vehicles only)</td>
<td>40 (1.92)</td>
</tr>
<tr>
<td>Trucks and buses</td>
<td>Note 2</td>
</tr>
<tr>
<td>Grandstands (see stadium and arena bleachers)</td>
<td></td>
</tr>
<tr>
<td>Gymnasiums, main floors, and balconies</td>
<td>100 (4.79)</td>
</tr>
<tr>
<td>Handrails, guardrails, and grab bars</td>
<td></td>
</tr>
<tr>
<td>See Section 4.4.</td>
<td></td>
</tr>
<tr>
<td>Hospitals</td>
<td></td>
</tr>
<tr>
<td>Operating rooms, laboratories</td>
<td>60 (2.87)</td>
</tr>
<tr>
<td>Patient rooms</td>
<td>40 (1.92)</td>
</tr>
<tr>
<td>Corridors above first floor</td>
<td>80 (3.83)</td>
</tr>
<tr>
<td>Hotels (see residential)</td>
<td></td>
</tr>
<tr>
<td>Libraries</td>
<td></td>
</tr>
<tr>
<td>Reading rooms</td>
<td>60 (2.87)</td>
</tr>
<tr>
<td>Stack rooms</td>
<td>150 (7.18)</td>
</tr>
<tr>
<td>Corridors above first floor</td>
<td>80 (3.83)</td>
</tr>
</tbody>
</table>
Table 2-1 continued

<table>
<thead>
<tr>
<th>Occupancy or Use</th>
<th>Uniform psf (kN/m²)</th>
<th>Concentrated lb (kN)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Manufacturing</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Light</td>
<td>125 (6.00)</td>
<td>2000 (8.90)</td>
</tr>
<tr>
<td>Heavy</td>
<td>250 (11.97)</td>
<td>3000 (13.40)</td>
</tr>
<tr>
<td>Marquees</td>
<td>75 (3.59)</td>
<td></td>
</tr>
<tr>
<td>Office Buildings</td>
<td></td>
<td></td>
</tr>
<tr>
<td>File and computer rooms shall be designed for heavier loads based on anticipated occupancy</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lobbies and first floor corridors</td>
<td>100 (4.79)</td>
<td>2000 (8.90)</td>
</tr>
<tr>
<td>Offices</td>
<td>50 (2.40)</td>
<td>2000 (8.90)</td>
</tr>
<tr>
<td>Corridors above first floor</td>
<td>80 (3.83)</td>
<td>2000 (8.90)</td>
</tr>
<tr>
<td>Penal institutions</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cell blocks</td>
<td>40 (1.92)</td>
<td></td>
</tr>
<tr>
<td>Corridors</td>
<td>100 (4.79)</td>
<td></td>
</tr>
<tr>
<td>Residential</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dwellings (one- and two-family)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Uninhabitable attics without storage</td>
<td>10 (0.49)</td>
<td></td>
</tr>
<tr>
<td>Uninhabitable attics with storage</td>
<td>20 (0.96)</td>
<td></td>
</tr>
<tr>
<td>Habitable attics and sleeping areas</td>
<td>30 (1.44)</td>
<td></td>
</tr>
<tr>
<td>All other areas, except stairs and balconies</td>
<td>40 (1.92)</td>
<td></td>
</tr>
<tr>
<td>Hotels and multifamily houses</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Private rooms and corridors serving them</td>
<td>40 (1.92)</td>
<td></td>
</tr>
<tr>
<td>Public rooms and corridors serving them</td>
<td>100 (4.79)</td>
<td></td>
</tr>
<tr>
<td>Reviewing stands, grandstands, and bleachers</td>
<td>100 (4.79)</td>
<td>Note 4</td>
</tr>
<tr>
<td>Roofs</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ordinary flat, pitched, and curved roofs</td>
<td>20 (0.96)</td>
<td>Note 8</td>
</tr>
<tr>
<td>Roofs used for promenade purposes</td>
<td>60 (2.87)</td>
<td>Note 8</td>
</tr>
<tr>
<td>Roofs used for roof gardens or assembly purposes</td>
<td>100 (4.79)</td>
<td></td>
</tr>
<tr>
<td>Roofs used for other special purposes</td>
<td></td>
<td>Note 9</td>
</tr>
<tr>
<td>Awnings and canopies</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fabric construction supported by a lightweight rigid skeleton structure</td>
<td>5 (0.24)</td>
<td>nonreducible</td>
</tr>
<tr>
<td>All other construction</td>
<td>20 (0.96)</td>
<td>Note 8</td>
</tr>
<tr>
<td>Store</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Retail</td>
<td></td>
<td></td>
</tr>
<tr>
<td>First floor</td>
<td>100 (4.79)</td>
<td>1000 (4.45)</td>
</tr>
<tr>
<td>Upper floors</td>
<td>75 (3.59)</td>
<td>1000 (4.45)</td>
</tr>
<tr>
<td>Wholesale floors</td>
<td>125 (6.00)</td>
<td>1000 (4.45)</td>
</tr>
<tr>
<td>Vehicle barriers</td>
<td>See Section 4.4.</td>
<td></td>
</tr>
<tr>
<td>Walkways and elevated platforms</td>
<td></td>
<td></td>
</tr>
<tr>
<td>(other than exitways)</td>
<td>60 (2.87)</td>
<td></td>
</tr>
<tr>
<td>Yards, terraces, pedestrians</td>
<td>100 (4.79)</td>
<td></td>
</tr>
</tbody>
</table>

Note 4: Primary roof members, exposed to a work floor
- Single panel point of lower chord of roof trusses or any point along primary structural members supporting roofs
- over manufacturing, storage warehouses, and repair garages
- 2000 (8.9)
- All other occupancies
- 300 (1.33)
- All roof surfaces subject to maintenance workers
- 300 (1.33)
- Schools
- Classrooms
- 40 (1.92) 1000 (4.45)
- Corridors above first floor
- 80 (3.83) 1000 (4.45)
- First floor corridors
- 100 (4.79) 1000 (4.45)
- Scuttles, skylight ribs, accessible ceilings
- 200 (0.89)
- Sidewalks, vehicular driveways, and yards subject to trucking
- 250 (11.97) 8000 (35.60)
- Note 5 Note 6
- Stadiums and arenas
- Bleachers
- 100 (4.79) Note 4
- Fixed seats (fastened to floor)
- 60 (2.87) Note 4
- Stairs and exitways
- One- and two-family residences only
- 100 (4.79) Note 7
- Storage areas above ceilings
- 20 (0.96)
- Storage warehouses (shall be designed for heavier loads if required for anticipated storage)
- Light
- 125 (6.00)
- Heavy
- 250 (11.97)
- Stores
- Retail
- First floor
- 100 (4.79) 1000 (4.45)
- Upper floors
- 75 (3.59) 1000 (4.45)
- Wholesale floors
- 125 (6.00) 1000 (4.45)
- Awnings and canopies
- Fabric construction supported by a lightweight rigid skeleton structure
- 5 (0.24) nonreducible
- All other construction
- 20 (0.96) Note 8

continued
Table 2-1 continued


Notes:
1. Floors in garages or portions of buildings used for the storage of motor vehicles shall be designed for uniformly distributed live loads of Table 4-1 (Table A.35.6.1.2) or the following concentrated load: (1) for garages restricted to passenger vehicles accommodating not more than nine passengers, 3000 lb (13.35 kN) acting on an area of 4.5 in. by 4.5 in. (114 mm by 114 mm, footprint of a jack); (2) for mechanical parking structures without slab or deck which are used for storing passenger cars only, 2250 lb (10 kN) per wheel.
2. Garages accommodating trucks and buses shall be designed in accordance with an approved method which contains provisions for truck and bus loadings.
3. The loading applies to stack room floors that support non-mobile, double-faced library bookstacks, subject to the following limitations:
   a. The nominal bookstack unit height shall not exceed 90 in. (2290 mm)
   b. The nominal shelf depth shall not exceed 12 in. (305 mm) for each face; and
c. Parallel rows of double-faced bookstacks shall be separated by aisles not less than 36 in. (914 mm) wide.
4. In addition to the vertical live loads, the design shall include horizontal swaying forces applied to each row of the seats as follows: 24 pounds per linear foot of seat applied in a direction parallel to each row of seats and 10 pounds per linear foot of seat applied in a direction perpendicular to each row of seats. The parallel and perpendicular horizontal swaying forces need not be applied simultaneously.
5. Other uniform loads in accordance with an approved method which contains provisions for truck loadings shall also be considered where appropriate.
6. The concentrated wheel load shall be applied on an area of 4.5 in. by 4.5 in. (114 mm by 114 mm, footprint of jack).
7. Minimum concentrated load on stair treads (on area of 4 in.² (2580 mm²)] is 300 lbs (1.33 kN).
8. Where uniform roof live loads are reduced to less than 20 lb/ft² (0.96 kN/m²) in accordance with Section 4.9.1 and are applied to the design of structural members arranged so as to create continuity, the reduced roof live load shall be applied to adjacent spans or to alternate spans, whichever produces the greatest unfavorable effect.
9. Roofs used for other special purposes shall be designed for appropriate loads as approved by the authority having jurisdiction.

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Added Live Loads

The water trapped in a building or on a roof can be a significant added live load. Flat-roof buildings often are built with little reserve strength. An elevated water tank is designed for a certain live load—the water in the tank. If the tank continues to overflow during freezing weather, the water will become an ice coating on the structure and could overload it to the point of collapse.

When the use of a building changes (“recycled buildings”), the design of the building should be reviewed to determine whether the structure should be structurally strengthened for its new use and whether its fire safety features should be upgraded. (This will be discussed in Chapter 4, Building and Fire Codes). Unfortunately, this is often ignored, sometimes from pressure to eliminate “bureaucratic obstructions” or to save a historic building from wreckers.

Live loads can be added to a building by firefighting operations at the scene of a fire. In one example, water thrown on a theater marquee in freezing weather turned to ice and collapsed the marquee, trapping several fire fighters. Fortunately, one fire fighter had access to a construction crane and the marquee was lifted.

Keep in mind the tremendous amounts of weight added to a building by the use of exterior heavy caliber streams. Water weighs 8.34 pounds per gallon, so a 1000-gallon-per-minute master stream will potentially add over 4 tons of weight to the building in just one minute. Be cognizant of the amount of water runoff: How much water is remaining and

Tactical Considerations

When heavy-caliber streams are used, fire fighters must be conscious of the tremendous added weight. Some of this water will be absorbed into the contents. Paper and fabrics of any type will absorb huge quantities of water. Five fire fighters died when piles of scrap from the manufacture of tissues, soaked by water from sprinklers, collapsed on them. Some fire departments have set specific drain times to permit water to drain from structures subjected to heavy master streams before personnel are permitted to enter a building.
Impact Loads

Impact loads are loads that are delivered in a short time. A load that the structure might resist, if delivered as a static load over time, may cause collapse if delivered as an impact load. The jetliner attacks on the twin towers on September 11, 2001, are examples of a tremendous impact load.

Buildings have a habit of standing up as long as they are left alone. However, fire can release different kinds of impact loads on a building. In the case of a fire, all sorts of interrelationships among building elements, which have mutually supported one another and provided strength not even calculated by the designer, are disturbed. A fire can cause innumerable undesigned changes in loading, many of which can cause collapse. An explosion; the overturning of heavy live loads, such as a big safe; the collapse of heavy, nonstructural, ornamental masonry; or even the weight of a fire fighter jumping onto a roof may be enough of an impact load to cause collapse.

The point, of course, is that there is no such thing as a “no impact” load. No matter how gingerly personnel and equipment are placed on a structure, there is a substantial increase in the stress, at least momentarily. In any event, assaults on a structure already under attack by fire are very dangerous.

Lateral Impact Loads

Lateral impact loads can produce disastrously high stresses. A lateral impact load, such as from an explosion, can be delivered from a direction that has little or no stress resistance.

Walls are designed to accept vertical compressive loads. However, even impressive masonry walls are not necessarily resistant to undesigned lateral loads. The lateral thrust of collapsing floors has brought down many brick walls.

Tactical Considerations

Water from rain, snow, or firefighting may pond on a flat roof. In the case of such ponding, the fire department may be asked to assist in water removal. Be careful—a flooded roof may be near collapse. Don’t add to the weight. Attempt to clear the debris from the drain, operating from a ladder without stepping on the roof. Merely stepping on the roof may precipitate collapse. In these litigious times, a lawsuit might ensue. Another possible solution is to build a salvage chute in a suitable location and puncture the roof from below.

Also, beware of the loading and collapse possibilities of such roofs from overspray when using master streams on a fire in an adjacent building, particularly in freezing weather. Even staying outside such a building is not always enough. A collapse of the roof could set up an air ram that could blow the windows out. Often the best tactic is to set up barriers well away from the building.

Collapses of masonry walls have killed hundreds of fire fighters. Some signs of potential for collapse can be detected by inspection before a fire.
The sudden ignition of trapped carbon monoxide or other fire-generated combustible gases has sometimes caused detonations that have destroyed substantial masonry walls (Figure 2-4).

A cooking-gas explosion caused the multi-story collapse of a 24-story concrete-panel apartment house in England. The undesigned lateral impact load blew out one bearing wall. The floor it was supporting fell and became an impact load on the floor below, and the successive collapse of the underlying floors followed. This was the so-called “Ronan Point collapse.” Gas service was replaced with electricity, and repairs were made to other units. In 1984, tenants were moved out of eight other buildings in the same group because of a fear of collapse. The repairs after the first collapse were apparently inadequate.

The safety factors built into ordinary buildings are rarely large enough to assure that there will not be progressive collapse in the wake of the first excessive impact load. Progressive collapse is a particular hazard in the construction of concrete buildings. Backdraft explosions can occur when the carbon monoxide and oxygen mixture is exactly right, and they can blow the building apart.

**Static and Repeated Loads**

Static loads are loads that are applied slowly and remain constant. A heavy safe is an example of a live, static load. It is not a dead load. Repeated loads are loads that are applied intermittently. A rolling bridge crane in an industrial plant applies repeated loads to the columns as it passes over them.

**Wind Loads**

Wind load is the force applied to a building by the wind. The designer can counter this force in a variety of ways. Small wood-frame buildings were formerly built with only a gravity connection to the foundation. Hurricane bracing in wood-frame dwellings, using strategically placed straps to hold roofs in place and bolts to hold the frame to the foundation, have found great acceptance since Hurricane Andrew devastated Florida in 1992 (Figure 2-5). Masonry, low-rise bearing wall buildings usually have enough mass in the walls that special consideration of wind load is unnecessary.

The framing of lightweight, unprotected steel buildings, however, is tied together to resist wind forces. Fire-
caused failure of one part may cause the collapse of other sections because of undesigned torsional loads transmitted through the ties. Most floors simply carry loads to the support system of columns and floors. **Diaphragm floors** are designed to stiffen the building against wind and other lateral loads such as earthquakes. One of the best examples of a need to counter wind load is found in high-rise buildings. The high-rise building must be braced against the shear force of wind. This is accomplished in one or more ways:

- **Diagonal braces**, which connect certain columns, are concealed in partition walls of such buildings. An arrangement of braces between columns that resembles the letter “K” is called **K-bracing**.
- Heavy riveting of girders to columns from top to bottom of the frame is called **portal bracing**.
- Masonry walls, needed to enclose vertical shafts, can do double duty as **shear walls**, resisting overturning. This method is satisfactory only for low- or medium-rise buildings. If used in a **megastructure**, it would require shear walls, with no other purpose than wind resistance, to be erected above the floors where some elevators terminate.
- Very tall high-rise buildings are built to take the wind load on the exterior walls rather than on the interior core. Sometimes diagonal columns are visible on the exterior.
- Externally braced buildings are known as **tube construction**, as contrasted with **core construction**.
- Unique giant **vierendeel trusses** (rectangular trusses with very rigid corner bracing), formed by exterior box columns and spandrels, provided the wind bracing of New York’s World Trade Center and allowed the buildings to carry the vertical loads around the openings created by the planes after impact.

The wind load can be particularly hazardous to fire fighters when operating in or near buildings under construction. This is because the full benefit of interconnecting all the parts of the completed building has not yet been realized. Temporary bracing may be inadequate.

In addition to its effect on structures, the wind is a force to be reckoned with in the movement of smoke in buildings. This force is often ignored by some whose solution to the high-rise fire and life safety problem rests first on “sophisticated, state of the art” smoke-control systems. Our cynical definition of **sophisticated equipment** is “you can’t get the parts when it breaks down,” and similarly, **state of the art** is “we’re trying this out on you.”

### Concentrated Loads

Concentrated loads are heavy loads located at one point in a building. A steel beam resting on a masonry wall is an example of a concentrated dead load. A safe is a concentrated live load.

In a typical concrete block wall, the building designer may insert solid block, brick, reinforced concrete, or a “wall column” to stiffen the wall and carry the weight of the concentrated load. If a wall is being breached and the structure is found to be stronger than normal, choose another location. You are probably right under a concentrated load.

Years ago, floors that were considered “fireproof” (there is no such thing as fireproof) were made of brick segmental arches. Many still exist. The wooden floor was leveled in some cases by supporting it on little **piers** (short columns). At some locations there was a gap of several inches between the floor and the arch. When such a floor burned, a live load such as a safe would fall the few inches. The impact was too much for the arch, which had carried the safety for years, and the safe wound up in the basement. To this day the testing and rating of safes involves dropping the heated safe a considerable distance.

### Tactical Considerations

If you are breaching a wall and find any evidence that the wall is strengthened at that point, stop and start elsewhere. You are likely under a concentrated load.
Throughout the United States and Canada are existing examples of almost every feature or practice of building construction. Although you may not have every feature or problem in your area, you should be aware of them, even though you concentrate on those common to your locale.

**Imposition of Loads**

Loads are also classified according to the orientation in which they are placed on the structure. They can be classified as axial or eccentric. An axial load is a force that passes through the centroid of the section under consideration. An axial load is perpendicular to the plane of the section. In simpler words, an axial load is straight and true; the load is evenly applied to the bearing structure. All other conditions being equal, a structure will sustain its greatest load when the load is axial.

Structural elements are not always loaded in the most efficient manner. Other considerations may be more important. For instance, a ladder is strongest when absolutely vertical, so that a person represents an axial load. But human nature and mechanics work against axial loading, and require slanting of the ladder.

An eccentric load is a force that is perpendicular to the plane of the section but does not pass through the center of the section, thus bending the supporting members. In simpler terms, the load is straight and true but is concentrated to one side of the center of the supporting wall or column.

For an example of such a load place a stack of books on the floor. Sit on the stack squarely. Note how evenly applied weight stabilizes the stack. Shift your weight until it bears on only part of the stack. Note the tendency of the stack to bend outward. One side of the stack is being compressed, while the other is being pulled apart. These forces are called compression and tension.
Fire Loads

Some engineers do not recognize the term fire load, or even consider the impact of a fire on a structure. Fire load represents the potential fuel available to a fire. The research work done on fire load was directed to the contents of buildings. When the building is combustible, however, the building itself is part of the fire load.

Fire load represents the total amount of potential heat in the fuel; the term heat release rate (HRR) indicates how fast the potential heat in the fuel is released. This distinction is important. All wood can generate approximately the same amount of heat per pound, but a pound of plywood will burn many times faster than a pound of heavy timber.

It used to be that fire fighters would assess the fire loading of a building solely in terms of pounds of fuel per square foot. Although this can give one a sense of the severity of a fire, it is more important to assess a fire in terms of its potential total heat release rate, Q. The basic measurement of caloric value is the Btu (British thermal unit), the amount of heat required to raise a pound of water one degree Fahrenheit. The metric equivalent is the kilojoule. One Btu is approximately equal to one kilojoule.

Each combustible material has its own caloric value. Two estimates are commonly used. Wood paper and similar materials are estimated at 8000 Btu/lb. For plastics and combustible liquids, 16,000 Btu/lb is a common estimate, though the value for some of these fuels is much higher.

The weight of the fuel is multiplied by the caloric value and divided by the floor area, to arrive at Btu/sq ft, the measure of the fire load. The metric statement is kj/m². You may find fire load expressed in pounds per square foot, a practice that dates back to when there was only one basic fuel (i.e., wood or paper), estimated at 8000 Btu per pound. Plastics were converted into “equivalent pounds” on the basis that one pound of plastics equals two pounds of wood.

A fire load of 80,000 Btu/sq ft or 10 lb of ordinary combustibles/sq ft is approximately the equivalent of a one-hour exposure to the standard fire endurance test; 160,000 Btu/sq ft is equivalent to a two-hour exposure. HRR, designated as Q, refers to the rate at which the fuel burns. A five-pound solid chunk of wood will burn more slowly than five pounds of wood chips. Five pounds of plywood will burn very rapidly. The number of Btu's or kilojoules remains the same in these fires, but the heat is released more rapidly from certain materials.

Q is usually expressed in terms of watts (W), kilowatts (KW), or megawatts (MW). For example, a typical polyurethane sofa fire has a peak HRR of approximately 3120 KW. It is this heat release rate that is a primary determinant of whether a compartment will reach flashover. Fire protection engineers also use HRR to describe a fire's size (and resultant severity). To better understand this relationship, readers are encouraged to read Chapter 5, Basic Fire Science, in NFPA 921, Guide for Fire and Explosion Investigations.

Suspended Loads

Slender tensile members can carry a load that would require a compressive member of much greater size. This...
feature currently is being used in the design of many buildings.

Designers are eliminating interior columns at selected locations by hanging the ends of beams from the overhead structure—a suspended load. A slender rod can replace a much larger column. When this is done, however, several fire problems develop. The tensile member, having less mass, has less fire resistance. In addition, the load cannot be delivered to the ground in tension; it must be converted into a compressive load. This requires one or more connections in the overhead where fire temperatures are often greater than on the floor. These connections may be hidden in the structure. In such a case, an attic fire might cause the collapse of the first floor.

In old timber buildings, overloaded beams are sometimes restored by inserting a tie rod, which goes up through the building, generally to a truss or beam extending from wall to wall in the cockloft. This may be well hidden. Look for the telltale end of the tie rod about mid-point of the beam.

### Suspended High-Rise Buildings

The concept of suspended beams has been applied in the construction of some high-rise buildings. Columns are replaced with cables suspended from beams cantilevered out from the top of the central reinforced concrete core. This provides some economy of construction, unobstructed floor space, and an open plaza at the entry level to the building. Possible fire problems of this type of structure are discussed further in Chapter 10, Fire-Resistive Construction.

### Safety Factor

The safety factor represents the ratio of the strength of the material just before failure to the safe working stress. The term safety factor is sometimes misunderstood. It is not practical to use a material in a structure so that it will be loaded to its ultimate strength, as shown in tests. The material used in a structure may not be as good as the sample tested, the workmanship may be inferior, or the material may deteriorate over the years. For these reasons the design load is only a fraction of the tested strength of the material. If the design load is only a tenth of the tested strength, the safety factor is 10; if the design load is half the tested strength, the factor of safety is 2.

Steel, which is made under controlled conditions, has...
The safety factor of steel used in excavation bracing is half what would be permitted in a structure because it is temporary. In other words, the permitted load is doubled. If a fire occurs, the steel will fail much sooner because the temperature at which heated steel fails decreases as the load increases.

Composite Materials

At times, two materials are combined to take advantage of the best characteristics of each. For instance, concrete is a relatively inexpensive material that is strong in compression but weak in tension; steel is strong in both ways but is more costly than concrete. By providing steel at the locations where tensile stresses develop, a composite material, called reinforced concrete, is developed.

All elements of a composite material must react together if there is to be no failure. If the materials separate, the composite no longer exists, and the two materials separately may be unable to carry the load successfully.

Composite Structural Elements

Two different materials may be combined in a structural element. Steel and concrete are combined in composite floors. In some cases, studs are welded to steel beams and then imbedded in the concrete of the floor. This is done to produce a diaphragm floor, which stiffens the structure. In one serious high-rise building fire, heat caused shear connectors, which joined the beams to columns, to fail. The beams did not fail because the imbedded studs kept the beams attached to the concrete.

Composite concrete-steel floors can be constructed with bar joist trusses. The top chord of the truss is set below the tops of the web, allowing triangles of steel to project upwards. These are imbedded in the concrete.

A Glitch plate girder is made by sandwiching a piece of steel between two wooden beams. The girder is much stronger than a piece of wood of the same dimensions, yet it can be installed using ordinary carpentry techniques. A sheet of plywood may also be used as the “meat” of this “sandwich.”

A brick and block-composite wall, in which cheaper concrete block substitutes for brick where it will not be seen, is another common example of composite structural elements. Do not confuse this with a brick veneered concrete block wall, in which the brick and block are not structurally united. In older construction, hollow tile is found instead of concrete block.

The term composite construction is sometimes used to describe buildings in which two different materials carry structural loads. Some concrete buildings, for instance, have a top floor or penthouse of lightweight steel.

Structural Elements

Buildings are made up of structural elements, such as beams, columns, arches, and walls that differ in how...
they carry the load and transfer it to the next element. The principles of each element are the same regardless of the material. Elements (or members) that are assembled together into a structure are often called a **structural frame**.

### Beams

The beam is probably the oldest structural member. It is not hard to imagine primitive man dropping a tree across a stream to form the first bridge. A beam transmits forces in a direction perpendicular to such forces to the reaction points (points of support). Consider a load placed on a floor beam. The beam receives the load, turns it laterally, divides it, and delivers it to the reaction points.

The definition of a beam does not consider its attitude, that is, its vertical or horizontal orientation. Although beams are ordinarily thought of as horizontal members, this is not always the case. A vertical or diagonal member that performs the functions of a beam, although it may have another name such as a rafter, is structurally a beam.

When a beam is loaded, it **deflects** or bends downward. The initial load is its own deadweight. The load placed on it is a superimposed load. Some beams are built with a slight camber or upward rise so that when the design load is superimposed, the beam will be more nearly horizontal. A carpenter selects wood floor beams accordingly.

Deflection causes the top of a beam to shorten so that the top is in compression. The bottom of the beam elongates and thus is in tension. The line along which the length of the beam does not change is the **neutral axis** or plane. It is along this line that the material in the beam is doing the least work and material can be most safely removed.

The cable is an ideal beam. Fully in tension, it makes the most economical use of the available material. Cable-supported roofs are being used for some large open area structures, but for a beam to be safe and economical is not always enough. It must deflect so little that the deflection will not be noticed. This is accomplished by using additional material, or by rearranging the shape of the material. In other words, **stiffness** or reduced deflection can be achieved by material mass or by geometry. In recent years the economics of using geometry (e.g., truss shapes) over mass has had a tremendous effect on structures.

### Carrying Capacity and Depth of Beams

The load-carrying capacity of a beam increases by the square of its depth. Consider a 2-inch by 4-inch wood beam carrying a certain load. If another 2-inch by 4-inch beam is laid alongside the first beam, the carrying capacity is increased by a factor of two. If the same amount of wood is sawn into a 2-inch by 8-inch beam, thus multiplying the depth by two, the carrying capacity is increased by the square of two, or four.

The principles governing beams are the same for all beams, regardless of the material. For examples, we will look at wooden beams. Standard carpentry manuals pro-
provide a table that details safe long-time loads, uniformly distributed, for 1800-pound structural grade lumber. For convenience in determining loads for beams of different thicknesses, the information is arranged by size from 1-inch by 4-inch to 1-inch by 16-inch, even though no beams are as thin as 1 inch. To find the strength of a 3-inch-thick beam, the figure is multiplied by three. A 1-inch by 4-inch beam spanning 6 feet can carry 533 pounds; a 1-inch by 8-inch beam spanning 6 feet can carry 2133 pounds (four times as much); and a 1-inch by 16-inch beam spanning 6 feet can carry 8533 pounds. This latter beam is four times the depth of a 1-inch by 4-inch beam.

The load-carrying capabilities of a beam increase with added dimensions. These illustrations show the different characteristics of the dimensions.

Table 2-3

<table>
<thead>
<tr>
<th>Span Distance (Feet)</th>
<th>Load Capacity (Pounds)</th>
</tr>
</thead>
<tbody>
<tr>
<td>6</td>
<td>3333</td>
</tr>
<tr>
<td>12</td>
<td>1666</td>
</tr>
<tr>
<td>18</td>
<td>1111</td>
</tr>
<tr>
<td>24</td>
<td>833</td>
</tr>
<tr>
<td>30</td>
<td>667</td>
</tr>
<tr>
<td>36</td>
<td>555</td>
</tr>
</tbody>
</table>

beam is used as an 8-inch by 4-inch beam. The 8-inch by 4-inch beam can carry only half the load.

The greater efficiency of a deeper beam must be balanced against other considerations, such as the desired thickness of the floor and the deflection of flooring between widely spaced beams. Floor boards are themselves beams. For a variety of reasons, then, the almost universal spacing for sawn wooden beams in ordinary construction is 16 inches and the depth of the beam is determined by the design load and the span.

The depth of the beam required is particularly significant in the case of trusses, because of the greater void in which combustible gases can be generated or accumulated. The length of a span, or the distance between supports, is a determinant of the safe load of a beam. As the length of the span increases, the safe load capacity decreases in direct proportion. Table 2-3 demonstrates the principle.

The figures also consider the beam’s weight, which must be deducted to get the permissible superimposed or added load. The figures assume a uniformly distributed load. If the load is concentrated at the center of a beam, the permitted load is half the distributed load. The principles involved are the same for all beams, regardless of the material used.

Types of Beams

Different terms are used for various beams.

- A simple beam is supported at two points near its ends. In simple beam construction, the load is delivered to the two reaction points and the rest of the structure renders no assistance in an overload.
- A continuous beam is supported at three or more points. Continual construction is structurally advantageous because if the span between two supports is overloaded, the rest of the beam assists in carrying the load.
- A fixed beam is supported at two points and is
rigidly held in position at both points. This rigidity may cause collapse of a wall if the beam collapses and the rigid connection does not yield properly.

- An **overhanging beam** projects beyond its support, but not far enough to be a cantilever.
- A **bracket** is a diagonal member that supports what would otherwise be a cantilever.
- A **joist** is a beam, often made of wood.
- A **steel joist** or **bar joist** is a lightweight steel truss joist.
- A **girder** is any beam, of any material (not just steel), that supports other beams.
- A **built-up girder** is made of steel plates and angles riveted together, as distinguished from a girder rolled from one piece of steel.
- A **spandrel girder** is a beam that carries the load on the exterior of a framed building between the top of one window and the bottom of the window above.
- A **lintel** is a beam that spans an opening in a masonry wall. Stone lacks tensile strength so it can only be used for quite short lintels. Many **precast** concrete lintels have the word TOP cast into the top to be sure they are erected with the reinforcing rods that provide tensile strength in the bottom. (Figure 2-14)
- A **grillage** is a series of closely spaced beams designed to carry a particularly heavy load.

- A **cantilever beam** is supported at only one end, but it is rigidly held in position at that end. It projects out over a support point. Beyond the support point, the tension is in the top and the compression is in the bottom. Cantilever structures are very likely to be unstable in a serious fire because the fire may destroy the method by which the beam is held in place. The cantilever beam resembles a playground seesaw. Many of us can recall being lifted up in the air by a playmate who then ran off and dropped us to the ground. Failure of the interior section of the cantilever can cause collapse of the projecting section. As a cantilevered structure such as a balcony collapses, it is likely to pull down a wall. This happened in New Orleans and killed three fire fighters. Cantilevers are used widely for both architectural and design economy considerations. Wooden cantilevered...
balconies are common. Temporary construction platforms, for example, on which a crane delivers material, are cantilevered out from a building. They are supported by wooden compression members delivering the load to the floor above. A fire could destroy the wood and cause the platform to fall.

- When any change is to be made in the foundation of an existing wall, the wall must be supported. Often holes are cut through the wall, and so-called needle beams are inserted and supported on both sides. They pick up the load of the walls.

- A suspended beam is a simple beam, with one or both ends suspended on a tension member such as a chain, cable, or rod. The typical theater marquee is a suspended beam. Fire may destroy the anchoring connection; the beam then becomes an undesigned cantilever. The ends of the chains were connected to the roof trusses in a Washington, D.C., theater. An attic fire destroyed the connections. Alert junior officers, who were fire science students, noticed that the front brick wall had been pulled out almost to the point of collapse. Another old theater was converted into a furniture store. In a fire the suspended marquee collapsed, killing six fire fighters. The collapsing marquee pulled down the masonry along the length of the building. One victim was about a hundred feet from the initial collapse.

- A transfer beam moves loads laterally when it is not convenient to arrange columns one above the other—the ideal arrangement. If it is necessary to change the vertical alignment, a transfer beam must be designed to receive the concentrated load of the column and deliver it laterally to supports. Improper alterations of buildings may produce undesigned transfer beams that are points of weakness. The Kansas City Hyatt Regency Hotel suffered a disastrous collapse of a walkway in 1981. Over 100 people were killed. A construction change caused a short section of the upper walkway beam to act as an undesigned transfer beam. It failed.

Beam Loading

Beam loading refers to the distribution of loads along a beam. Assume a given simple beam, which can carry eight units of distributed load. If the load is concentrated at the center, it can carry only four units. If the beam is cantilevered and the load is distributed, two units can be carried. If the load is at the unsupported end of the cantilever, only one unit can be carried.

Particularly in buildings under construction or under demolition by fire or otherwise, excessive loads may be concentrated in one area. This may have been the case recently in New Orleans when scaffolding with stacks of bricks ready for use collapsed suddenly at a building being reconstructed. Do not increase the overload by the weight of fire fighters and equipment.

Reaction and Bending

The reaction of a beam is the result of force exerted by a beam on a support. The total of the reactions of all the supports of a beam must equal the weight of the beam and its load.

The bending moment of a beam can be simply described as that load which will bend or break the beam. The amount of bending moment depends not only on the weight of the load, but also on its position. The farther a load is removed from the point of support, the greater the moment. Heavy loads should be placed directly over or very close to the point of support.

Columns

A column is a structural member that transmits a compressive force along a straight path in the direction of the member. Columns are usually thought of as being vertical, but any structural member that is compressively loaded is governed by the laws of columns, despite its attitude.

Columns by themselves are often used for monuments. Nonvertical columns are often called by other names, such as struts or rakers, which are diagonal columns with brace foundation piling (Figure 2-15).

Figure 2-15  Rakers are often used in tilt-slab construction. These diagonal shores are used by rescue teams to stabilize parts of or entire sections of a building.
Tactical Considerations

Fire moves easily through hollow columns. Fire has been transmitted from under porch space to the attic through hollow columns and vice versa. Cast-iron columns were sometimes used in part of the heating system as air ducts. Fire has extended vertically through cast-iron columns as well.

The slightest indication of column failure should cause the building to be cleared immediately. Once yield stresses are reached in column action, there is little reserve strength left and the column is on the verge of total collapse. The failure of a column is likely to be much more sudden than the failure of a beam. The failure of a column may precipitate the collapse of the entire portion of the building dependent upon that column.

A bent is a line of columns in any direction. If a line of columns is specially braced to resist wind, it is called a wind bent. A bay is the floor area between any two bents. A pillar is a free-standing masonry load-carrying column, as in a cathedral.

Decrease in Load-Carrying Capacity

Beams decrease in load-carrying capacity proportionately—a 12-foot beam can carry half the load of a similar 6-foot beam. Columns, however, lose strength by the square of the change in length. Thus, a 12-foot column can carry only one fourth the load of a 6-foot column of the same material and cross-section.

Shapes of Columns

The most efficient shape for a column is one that distributes the material equally around the axis as far as possible from the center of the cylinder. The thin wall tubing used for the legs of a child’s swing set is an example of an efficient use of steel in forming a column. In theory, column material could be paper thin, but it would be subject to local damage, as by a puncture or dent. Most codes provide for minimum wall thickness for columns to prevent local damage.

To obtain a free floor space 63 feet x 357 feet in a 48-story Tokyo high-rise the designer provided super-columns. They consist of four 39-inch square steel box columns spaced so they form a super-column 21 feet on a side. The box-column steel walls are as thick as 3 ½ inches at the base and get narrower further up the height of the column. Note that the principle of handling a compressive load—place the column material as far from the center as possible—was followed. The space inside the square is used for stairs and elevators.

It is more difficult to attach beams to round columns than to rectangular columns, so less efficient rectangular columns are often used. In cast-iron buildings, interior columns are usually circular, while wall columns (within exterior walls) are rectangular. Rectangular columns often fit better into floor plans. Structural design is often a compromise between competing needs.

When beams were discussed, we explained how a 2-inch by 8-inch joist set on the narrow edge would be a much more efficient use of wood than the same amount of wood in a 4-inch by 4-inch shape. On the other hand, the 4-inch by 4-inch shape would be the most efficient use of materials under a compressive load, because it is most nearly circular in cross-section.

Masonry walls under construction are often braced against high wind. Available scaffold planks, usually 2 inches by 8 inches or 2 inches by 10 inches, are most often used. The load on the braces is a compressive load, so the braces should be shaped like columns, but are not. One builder described the 2-inch by 8-inch planks as “snapping like matchsticks” at a construction site before the walls fell in a windstorm. If four 2-inch by 8-inch planks had been spiked together to make a hollow column and set diagonally against the wall, with 2-inch by 8-inch planks laid flat against the walls as beams, the wind load would have been much better resisted with the available material.

Wooden Columns

Most wooden columns are simply smoothed off tree trunks. Large wooden columns, almost always ornamental as well as structural, are hollow. The column consists of curved, usually tongue-and-grooved, sections glued together.

I-Beams vs. H-Columns

Whereas steel beams are I-shaped, steel columns are H-shaped, box shaped, or cylindrical. Beams are shaped like the letter “I” because the depth determines strength. Columns are shaped like the letter “H,” and of a dimension that permits a circle to be inscribed through the four points of the “H.” A builder may use an available
I-shaped steel section as a column but it is wrong to speak of I-beam columns (Figure 2-16).

**Types of Columns**

There are three types of columns, which can be differentiated by the manner in which they generally fail: Piers are short, squat columns, which fail by crushing. Long, slender columns fail by buckling. In buckling, the column assumes an S shape. Intermediate columns can fail either way.

Understanding the characteristics of long, slender columns yields information and principles applicable to columns and other structures under compressive loads, notably the top chord of trusses.

**Euler’s Law Columns**

Very long, thin columns are known as Euler’s law columns. A straight column, axially loaded, may suddenly collapse. Euler discovered that there is a critical load for a column and that the addition of even a single atom over the critical load can cause sudden buckling and collapse.

Examine the formula for Euler’s law for the understanding it will give of the three vital variables in column stability. The formula is:

\[ P_c = \frac{\pi^2EI}{L^2} \]

In which:

- \( P_c \) is the critical load, the absolute maximum load.
- \( n^2 \) is 3.1415 squared.
- \( E \) is the modulus of elasticity of the material in the column. (The modulus of elasticity is a measure of the ability of the material to yield and return to its original shape.)
- \( I \) is the moment of inertia, a mathematical value for the geometric cross-sectional shape of the column.
- \( L^2 \) is the length of the column squared.

Once the column starts to yield, there is generally very little reserve strength left and the column is on the verge of total collapse. By contrast, in beam action there is generally considerable reserve strength beyond initial yielding.

Consider a long, slender column. The load on the column tends to cause it to buckle. If the column is braced rigidly at the midpoint, the effective length of the column is cut in half. Since the square of the length is the divisor in the formula for column loading, cutting the length of the column in two increases the carrying capacity to four times what it was initially. The critical load is four times higher than it was initially. Shortening the effective length of a column by intermediate bracing pays dividends in load-carrying capacity.

The loss of bracing is a cause of column failure. Consider a high scaffold. Several long, narrow columns are securely braced at several points along its height, making several eight-foot segments. The effective length of the column, for this purpose, can be considered to be that of one of the segments. If a bracing connection fails, the effective length of that portion of the column becomes 16 feet. The decrease in load-carrying capacity is geometric. The critical load is reduced to 25 percent and (Figure 2-18).

**Temporary Bracing**

When a building is under construction, many elements are not in position or are not permanently connected. It is possible that columns might not have the full benefit of the bracing that will be provided by the completed building. Guy or temporary bracing is common. This bracing may not be adequate to resist high winds or other unexpected loads, or it may be vulnerable to fire.

**Walls**

Walls transmit to the ground the compressive forces applied along the top or received at any point on the wall. A wall resembles a wide slender column. The wall may also be required to resist flexural or bending forces, as does a beam. Wind load is an example of flexural force.

Walls are classified in two main divisions: load-bearing
walls and non-load-bearing walls. Load-bearing walls carry a load of some part of the structure in addition to the weight of the wall itself. Non-load-bearing walls support only their own weight. Veneer walls, curtain walls, panel walls, and partition walls are some examples of non-load-bearing walls.

A load-bearing wall is more stable than a non-load-bearing wall of identical construction because of the weight of the superimposed load. The load carried by any component in addition to its own deadweight provides stability. Stack up a wall of books or blocks. The wall is easily pushed over. Superimpose your weight on this wall; it is now much more difficult to push over.

The structural consequences of the collapse of a load-bearing wall may be much more serious than those following the collapse of a non-load-bearing wall, because of the collapse of building elements supported by the bearing wall. To a fire fighter caught in a collapse, however, it makes little difference whether a masonry wall is load-bearing or non-load-bearing.

Within these two broad classes of walls, other descriptors can be applied to walls. A cross wall is any wall at right angles to any other wall. The walls should brace one another. Sometimes the bond is so poor that there is no benefit from the cross wall.

A veneer wall is made of a single vertical thickness of masonry designed to improve the exterior appearance of the building. Decorative masonry such as stone, brick, or marble may be veneered over common stone masonry, concrete block, reinforced concrete, or steel. By far the greatest use of veneered walls is brick veneer on wood frame.

The veneer wall totally depends on the underlying wall for stability. It should be tied to the wall with metal ties.
embedded in the mortar. It can be catastrophically unsafe if left to itself. For example, brick veneer was applied to the visible parapetted portion of a masonry block fire wall in an apartment development near Charlotte, North Carolina, to improve its appearance. The brick was applied without ties, and was resting on the wood roof. In 1989, the brick collapsed through the roof. Fortunately no one was in the area so injuries were avoided.

A composite wall is composed of two or more masonry materials that react together under the load. In order to save costly brick used in masonry walls, brick and concrete block (in the past, terra cotta tile) are used to form a composite wall. When walls were all brick, some bricks were headers, which were turned on end to cross the wall and tie it together. This was unsatisfactory when concrete block was used in brick and block composite walls. A steel-wire masonry truss is now laid in the wall. As a result, the bricks are all laid lengthwise as stretchers. Thus, it is no longer possible to differentiate a brick veneer wall from a brick masonry wall at a glance, because both walls now can be laid as all stretchers (Figure 2-20). This is also known as a running bond.

The terms panel walls and curtain walls are often used interchangeably to describe non-load-bearing enclosing walls on framed buildings. Technically, panel walls are one story in height and curtain walls are more than one story. A party wall is a load-bearing wall common to two structures. If structural members of both buildings are located in common sockets, fire can extend through the opening (Figure 2-21).

Fire walls should be able to stop the fire with little or no assistance from firefighting forces (Figure 2-22). All penetrations of the fire wall should be equal to the fire wall in fire resistance. Openings should be protected with properly rated fire doors. Fire walls in steel-framed buildings are probably unstable if there is fire on both sides of the wall.

Partition walls are non-load-bearing walls that subdivide areas of a floor. They may be required to have some fire or smoke resistance. They also may be required to extend to the underside of the floor above or only to the ceiling line, leaving a void above.

A code term, demising walls, indicates walls bounding a tenant space. A shear wall in a framed building is designed to help resist the force of the wind. It is usually incorporated in some required enclosure such as an elevator shaft or a stair shaft. In a rubble masonry wall, the outer and inner wythes (a single vertical thickness of masonry) are laid in courses and finished. The interior consists of stones dumped in at random. Sometimes the stones are loose; in other cases mortar is dumped in around them.

Cantilever Wall

When a masonry wall is under construction, it acts as a cantilever beam with respect to wind loads received on the face of the wall. When the roof is in place, the wall, with respect to wind loads, becomes a simple beam supported at both ends. High, free-standing walls are common in the construction of large one-story-high buildings, such as shopping centers, churches, and industrial buildings.

Severe winds may topple a free-standing wall. Earlier, in the section on columns, we discussed the inadequate design of construction wall bracing. In addition, stakes so short that they move when the rain turns the ground to mud are sometimes used and fail.
Eccentric loading of the wall by hanging work platforms on one side is another cause of failure. If the wall is braced at one end by another cross wall, the unbraced end will be more vulnerable to collapse. During high winds, there are often gusts that greatly exceed an already high wind speed. In several cases, failure of what had been regarded as well-braced walls has been attributed to gusts.

Precast concrete tilt slab walls are vertical cantilevers when being erected and are braced by tormentors or temporary bracing poles (Figure 2-23). The roof of the building provides the permanent bracing. If the roof fails in a fire, the walls revert to undesigned vertical cantilevers and may collapse.

Wall Bracing

A wall can be compared to a column extended along a line. Most walls have a high height-to-thickness ratio that is comparable to a tall slender column. They are therefore similarly unstable. President Thomas Jefferson once tried to build a one-brick-thick garden wall. It failed. He reasoned that it was buckling like a column so he built a buckle into it to brace it internally. The result is the famous Thomas Jefferson-designed serpentine wall at the University of Virginia.

Walls can be braced or stiffened by several means:
- **Buttresses** are masonry structures built on the outside surface of the wall. The flying buttresses of Gothic cathedrals, which cope with the outthrust of the roof on the high slender walls, are built away from the wall. A prominent English politician once said “I am not a pillar of the church, but a buttress since I support it from without rather than from within.”
- **Pilasters** are masonry columns built on the inside surface of the wall.
- **Wall columns** are columns of steel, reinforced concrete, or solid masonry (such as brick or solid block) in a block wall. Concentrated loads such as fire walls are used to reduce the rate at which fire spreads; however, penetrations within the wall that do not meet the fire resistance requirements will allow fire to advance through the wall.

During high winds beware of all free-standing walls. Avoid both the direct collapse zone and the area that might be hit by missiles.
main girders are applied to the wall directly above the wall column.

- **Cavity or hollow walls** are built of two wythes separated by a space for rain drainage or insulation. Such a wall might be built of two rows of four-inch brick, separated by four inches of space and tied together with steel ties. It is more stable than an eight-inch solid brick wall, just as a column is more stable the farther the material is from the center. Such hollow or cavity walls were originally used to control rain. Rain penetrating the outer wythe drains down the cavity to weep holes at the bottom. Currently, the void is often filled with foamed plastic, either rigid board or foamed in place. Some of what the author has examined has not been fire inhibited. The exact fire problem with these walls is not known, but one can postulate degradation, toxic fumes, and if oxygen becomes available, possibly violent combustion.

**Wall Breaching**

If a wall is **homogeneous** (i.e., a good bond exists between bricks, blocks, and mortar), it acts as a unit. A load coming down the wall to a window or doorway does not follow a vertical path. It splits and passes on both sides of the opening. Draw a line vertically above an opening, its height at least half the width of the opening. Draw two lines connecting the top of the vertical to the ends of the opening. The masonry in this triangle is the only masonry resting on the lintel.

**Roofs**

Roofs are very important to the fire service. In some cases the roof is necessary only to keep the rain out. In other cases, such as with tilt slab concrete buildings, the roof is vital to the stability of the structure, and roof damage can cause wall collapse.

Conventional wood roofs are discussed in Chapter 6. The recent special attention to truss roofs should not cause fire fighters to ignore the hazard of the sawn joist roof. Combustible metal deck roofs are discussed in Chapter 9. Trusses are discussed in detail in the individual chapters dealing with the various types of construction. The hazard caused by tilt slab concrete buildings’ roofs is also discussed in Chapter 9.

**Arches**

The **arch** combines the function of the beam and the column (Figure 2-24). The classic appearance of the Greek temple with its closely spaced columns was dictated by the fact that the Greeks did not know of the arch. Stone beams have little tensile strength, thus spans must be short. The Romans developed the arch. The arch is under compression along its entire length. If it is properly built, connections are not important to its strength. Many Roman arches used no mortar; the stones were cut and placed perfectly.

**Tactical Considerations**

The proper way to breach a masonry wall is to open a triangular hole. If you cut the top of the hole as a line parallel to the ground, you are depending on the mortar above holding the masonry units in place, certainly an undesigned feature. If a parallel cut is made, it should be supported immediately. If wall elements fall apart easily, indicating that the wall is in poor condition, breaching should cease.

(Figure 2-24) Arches tend to push outward at the base.
Arches tend to push outward at the base and therefore must be either braced or tied. Arches usually are braced by heavy masonry buttresses. Failing buttressed arches often are tied together with steel rods. Some steel arches are tied together across the bottom of the arch, thus eliminating the need for a buttress. In some 19th-century buildings, the brick or concrete floor arch tie rods are visible across the ceiling.

Bowstring-truss roofs are sometimes described as arches or arched trusses. This is incorrect. The truss is a beam and its thrust is straight down the wall or column. The thrust of an arch is outward. When the arch is tied the thrust is downward, but it lacks the triangles that would make it a truss. This is not the only case where one construction element slides into another. Steel arches, as in heavy railroad bridges, may themselves be trusses.

The arch is not complete until all its elements are in place. The keystone is the last stone set in place in an arch, but once in place, it is no more important than other stones (voussoirs). An arch is said to spring from its point of support.

The word arch brings to mind the graceful Roman segmental arches. A segmental arch is one that describes a portion of the circumference of a circle. This is not the only arch form. Arches can have one, two, or three hinges, points at which an arch changes direction. Gothic and trefoil arches are found in churches and similar buildings. Flat arches are constructed by tapering masonry units. Hollow-tile flat floor arches are common in 19th-century and early 20th-century buildings.

The availability of laminated wood has made wood arches possible. Many are used in churches. Many exterior masonry arches over windows or doors are false. The exterior wythe is an arch. The interior wythes are carried on wood lintels. Although this author has never seen it cited, this must be the initiator of many masonry wall collapses. If the lintel is steel, elongation may displace the masonry.

Rigid Frames

The rigid frame is derived from the arch. Steel rigid frames are widely used for industrial and commercial buildings where clear space is required. Wooden rigid frames are often used for churches. Precast concrete rigid frames also have been used.

Such frames must be tied together at the bottom to resist the characteristic outward thrust of the arch. The ties often are made of steel reinforcing rods. The rods may connect the bases of the frame, or they may be “buttonhooked” into the concrete floor. In this case, the floor is structurally necessary to the building. It is possible that in the future a person cutting into such a floor may consider the tie just another rod and cut it with surprising results. In one huge hanger, the ties were cast into concrete beams to prevent this.
In one church it was observed that the ties, of a laminated wood rigid frame, apparently passed through an ordinary combustible floor-ceiling void. A fire in the basement could cause the ties to fail and perhaps collapse the frame.

**Shells and Domes**

A shell is a thin plate that is curved. Shells are built of concrete. Wide areas can be spanned with extraordinarily thin shells—shells can be less than two inches thick. The shell transmits loads along the curved surface to the supports. An eggshell provides a good example of the strength of a shell in relationship to the weight of material.

The dome is a shell. It can also be considered a three-dimensional arch. There are other forms of shells. These shapes produce roofs of varying architectural designs.

Geodesic domes are formed from a large number of triangles of equal size. They provide structures with very high volume-to-weight ratios. The sheath may be any desired material.

**Transmission of Loads**

It is important to understand how loads are transmitted from the point of application to the ground. Consider an ordinary brick and wood-joisted building with interior columns. A load is placed on a wood floor. The floor boards are beams and deliver the load to the joists. The joists deliver the load to a masonry wall at one end, and to a girder at the other. One end of the girder rests on a masonry wall. The other end rests on a column.

When a load is placed on the floorboards, they transmit the load to the joists on either side of the load point. The amount of the load transmitted to each joist depends upon the distance of the load point from each of the joists. The nearer joists, of course, receive the greater load.

The load transmitted by the floorboards to the joists is transmitted by the joists to the wall on one end and to the girder on the other. The proportion of load delivered to each support point again depends on the relative distances from the point at which the load is applied to the ends. The load received by the wall is delivered to the foundation, and thus to the ground. The load delivered to the girder is divided among both walls and the column, again in proportion to the distance. The structural engineer must calculate the distribution of the loads. The building does it automatically, according to the laws of physics.

This example makes use of a simple masonry and wood-joisted building. Regardless of the size of the building or the construction materials, the principles are the same. Any weight on the roof of a giant high-rise building is transmitted to the ground by the structure of the building.

All loads must be transmitted continuously to the ground from the point at which they are applied. Any failure of continuity will lead to partial or total collapse. Having accurate knowledge of the ground on which a structure is built is vital to its stability.

There is a tendency among those who are concerned about building stability to make light of partial collapse and consider it unimportant. A partial collapse is very important to at least two groups—those under it and those on top of it. If you are caught in a collapse, it is of little importance whether the building collapsed entirely or partially. The fatal collapse of the walkways in the Kansas City Hyatt Regency Hotel, which claimed more than a hundred lives, was only a partial collapse.

**Foundations**

Ultimately, all loads are delivered to the ground through the foundation. The nature of the ground and the weight of the structure determine the foundation. Foundations can range from simple footings to grade beams or a foundation under the entire wall to foundations that literally float the building on poor soil. In some cases, wood or concrete piles are driven either to bedrock or until the accumulated friction stops the pile. Almost all foundations today are of concrete. In some locations, decay-treated wood is used for small houses.

**Connections**

Except for the very simplest structures, connections, which transfer the load from one structural element to another, are a vital part of a structure's gravity resistance system. The connection system must be absolutely complete. It is only as strong as its weakest link. A single failure can be disastrous.

Proponents of building materials trumpet the virtues of their products. They may have interesting information about their materials, but it is important to know about the connections of these materials. For example, heavy wood beams are slow to ignite, but what is also significant is the connections of wooden girders to cast iron columns, or laminated beams supported on unprotected steel columns.

**Tactical Considerations**

When you preplan a building, take a hard look at the connections so that you will not be in the collapse path if they fail.
There are two general types of connections:

- A building is said to be **pinned** when the elements are connected by simple connectors such as bolts, rivets, or welded joints. These are usually not strong enough to reroute forces if a member is removed.
- In a **rigid-framed** building, the connections are strong enough to reroute forces if a member is removed.

A **monolithic concrete** structure is one in which the successive poured castings are joined together so that the completed building is like one piece of stone. A monolithic concrete building is rigid-framed. If a column is removed, it is quite possible for the building to redistribute the load to the remaining members. If no member is thereby overloaded, the building will not collapse.

Precast concrete buildings may be pinned or may be made monolithic by the use of **wet joints** in which cast-in-place concrete unites rods that project from precast sections. Some concrete buildings may have both types of connections. In an ordinary riveted steel-framed building, the collapse of a column will cause the collapse of all elements supported by that column. Some steel buildings have connections that redirect overloads to other sections of the building. This is called **plastic design** (\*\*Figure 2-26\*\*).

**Failure of Connections**

The great majority of buildings stand up. Up to a point a building can cope with undesigned loads, either vertical or lateral. Occasionally, a building not under construction or demolition collapses. A building on fire can be considered a building under demolition. Often structural failure is due to a failure of the connections. There are numerous ways in which connections can fail:

- Masonry walls shift outward, dropping joists.
- Temporary field bolting of steel gives way in a high wind.
- Steel connectors rust.
- Concrete disintegrates.

In many buildings, particularly older buildings, the connections may be adequate as long as the building is axially loaded. However, an eccentric or lateral load, or shifting wall, floor, or column alignment, may cause collapse even after the building has been standing for many years (\*\*Figure 2-27\*\*).

Be especially wary of buildings in areas where there was, or is, no building code supervision, such as rural areas that suddenly become urbanized. A Los Angeles City fire fighter died in a roof collapse over what once had been a vacant lot between two brick buildings. To provide a roof over the vacant area, mortar had been removed from between bricks. Pieces of shingle were hammered into the gaps. A **ledger board** nailed to the shingle pieces supported a wood joist roof. The makeshift assembly survived for a number of years until a fire destroyed it.

Connections are concealed in finished areas of buildings. Do not pass up the opportunity to examine basements and attics. What you see there is probably typical of the building. Buildings of the same age were probably built by the same methods. Additional problems associated with connections are discussed in other chapters. However, here are examples of some important connection defects.
Sand-lime mortar was used exclusively in masonry work until about 1880. Sand-lime mortar is water soluble. A fire fighter, operating with his unit in the basement of a building, noticed that a hose stream had washed the mortar out from the bricks. He alerted the officer. The building was evacuated and shortly thereafter collapsed.

Gravity connections in buildings simply depend on the weight of the building element to hold them in place. This is especially true for cast-iron columns. A gravity-fit, cast-iron column was one of the causes of the collapse of the Vendome Hotel in Boston in which nine fire fighters died.

Houses formerly simply sat on their foundations. Since the 1940s many codes have required that a structure be anchored to the foundation. The need for such anchoring is often disregarded by builders who know nothing of the reason for the requirement. Connections enter into the construction of almost every building. Lightweight wood trusses are held together with steel gusset plates or gang nails. Destruction of the fibers holding the gusset plate releases the plate and the truss fails.

Steel is often intermixed with other combustible construction elements. If the building is not required to be fire resistive, the steel is unprotected. Steel heated to 1000°F elongates 9 inches per 100 feet of length. If the girder is restrained and cannot elongate, it will overturn and drop its load of wood joists; at higher temperatures, the steel fails.

Unprotected steel connections can often be found in precast reinforced concrete buildings. Unprotected steel rods and cables (which fail at 800°F) are often used to tie failing buildings together, or to provide some additional resistance to earthquake movement.

It was noted earlier that a load can be suspended on a thin rod as contrasted with the bulky column required to support it in compression. This advantage has not been lost on designers. The load cannot stay in tension, however. It must be changed to a compressive load and delivered to the ground. This requires a series of connections. The vulnerable point is the connection most susceptible to fire. This may be floors away from the suspended structure. The steel tension rod connection to a wooden beam may be hidden in the cockloft or the space between the top-floor ceiling and roof. The burning of the beam will cause the connection to fail, dropping the rod and its load. Thus, a cockloft fire might cause an interior collapse.

Many codes require that wood joists in masonry walls be fire-cut. The end of the joist is cut off at an angle to permit the joist to fall out of the wall without damaging the wall. The removal of wood lessens the inherent resistance of the joist to fire and can precipitate floor collapse.

Heavy timber buildings are often built with self-releasing floors. Floor girders are set on brackets attached to columns. A wood cleat or steel dog-iron similar to a big staple is used to provide minimal stability. Such a floor can be expected to release sooner than if it were tightly connected. Some designers, recognizing this, require tight connections.

Tactical Considerations

A building with fire-cut or self-releasing floors is designed to collapse. It is the duty of a fire officer to see to it that fire fighters are not under the structure when the designed collapse occurs.
Overhanging and Drop-in Beams

Structural design is often intended to be as economical as possible. The economy may be in material or in the work of erection. Consider a space three bays wide. There are two masonry walls and two lines of columns supporting girders. Sometimes it is more economical to let the two outermost beams overhang the girders by two or three feet. The gap is then closed by a beam dropped in and nailed to the overhanging ends of the outer beams. As a result, the drop-in beams are connected only by the nailing. They have no support underneath.

Spliced Beams

Long wooden beams are not always available for building needs. Shorter lengths are often spliced together with metal connectors to produce the desired length. The resultant beam will carry its design load, but the connectors may fall out when heated sufficiently, causing collapse. In some buildings these connectors may have been made to look decorative. Take a second look!

Some years ago the sports arena in Daytona Beach, Florida, was destroyed by fire. The roof was supported on laminated wood arches. The owners of the building sued the supplier of the foam plastic insulation on the roof, alleging that the flammable plastic had destroyed their sturdy heavy timber building. Pictures of the fire clearly showed that the arches had fallen apart at the connections. When the plaintiffs learned that the defendants had these convincing pictures, they withdrew their suit.

These examples are but a few of the many connection failures which can occur, possibly catastrophically in a fire.
Chapter Summary

• All buildings are subject to one enemy: gravity.
• A load in a building works to destroy the gravity resistance system of the structure.
• Specific terms are used to describe the types of different loads and the way they are placed on a building. It is important to understand and use them correctly. Remember that dictionary definitions are not always identical to the definitions used in the construction field.
• At times, two materials are combined to take advantage of the best characteristics of each, making a composite material. In addition, two different materials may be combined in a structural element.
• Buildings are made up of structural elements, such as beams, columns, arches, and walls that differ in how they carry the load and transfer it to the next element.
• Connections, which transfer the load from one structural element to another, are a vital part of a structure’s gravity resistance system. The connection system must be absolutely complete. It is only as strong as its weakest link.

Key Terms

Arch: Combines the function of a beam and a column.

Axial load: A load that passes through the centroid of a section under construction and is perpendicular to the plane of the section.

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

Bar-joist truss: Used to construct composite concrete steel floors. The top chord of the truss is set below the tops of the web, allowing triangles of steel to project upwards.

Beam: A structural member transversely supporting a load. A structural member carrying building loads from one support to another. Sometimes referred to as a girder.

Bracket: Diagonal member that supports what would otherwise be a cantilever.

Brick and block-composite wall: Consists of an exterior wythe of brick directly mortared or parged to an inner wythe of concrete masonry unit (CMU).

Btu: British thermal unit. The quantity of heat required to raise the temperature of 1 pound of water 1°F at the pressure of 1 atmosphere and temperature of 60°F.

Built-up girder: Made of steel plates and angles riveted together, as distinguished from one rolled from one piece of steel.

Buttress: Mass of masonry built against a wall to strengthen it. Necessary when a vault or an arch places a heavy load or thrust on one part of a wall.

Caloric value: Measured in British thermal units (Btus); the amount of heat required to raise 1 pound of water 1 degree Fahrenheit.

Cantilever beam: Slanting beam fixed at the base, often used to support the free end, as in a common bracket.

Cantilevered: An overhang where one floor extends beyond and over a foundation wall.

Cavity or hollow wall: Built of two wythes (a single vertical thickness of masonry) separated by a space for rain drainage or insulation.

Centroid: The center point at which a body would be stable, or balance, under the influence of gravity.

Chord: An outside member of a truss, as opposed to the inner "webbed members".

Column: A vertical structural compression member with support loads.

Composite: Built up of different parts, pieces or materials.

Composite wall: Masonry wall made up of wythes of two or more different types of masonry units.

Compression: Direct pushing force, in line with the axis member; the opposite of tension.

Concentrated load: A load acting on a very small area of the structure's surface; the exact opposite of a distributed load.

Continuous beam: A beam supported at three or more points. Structurally advantageous because if the span between two supports is overloaded, the rest of the beam assists in carrying the load.

Core construction: No external braces involved; bracing is done within the core of the structure.

Cross wall: Any wall at right angles to any other wall; the walls should brace one another.

Dead load: The weight of a building; the dead load consists of the weight of all materials of construction incorporated into a building, including but not limited to walls, floor, roofs, ceilings, stairways, built-in partitions, finishes, cladding, and other similarly incorporated architectural and structural items, as well as fixed service equipment, including the weight of cranes.
Deflects: The deformation or displacement of a structural member as a result of loads acting on it.
Demising wall: Wall bounding a tenant space.
Diagonal brace: A tie used for supporting and strengthening the various parts of a building, such as between studs or joists.
Diaphragm floor: Designed to stiffen a building against wind and other lateral loads such as earthquakes.
Eccentric load: Load that is applied parallel to, but not having a common axis with, the primary axis.
Fire load: Weight of combustibles in a fire area or on a floor in buildings and structures, including either contents or building parts or both.
Fire resistance: Applies to materials that are not combustible in the temperatures of ordinary fires and will withstand such fires for a minimum of one hour.
Fire wall: Wall with a fire-resistive rating and structural stability that separates buildings or subdivides a building to prevent the spread of fire.
Fire-cut: The end of a joist is cut at an angle to permit the joist to fall out of a wall without damaging the load-bearing wall.
Fixed beam: Beam supported at two points and rigidly held in position at both points. This rigidity may cause collapse of a wall if the beam collapses and the rigid connection does not yield properly.
Foundation: Supporting portion of a structure below the first floor construction, or below grade, including the footings.
Gang nail: Connecting plate made of wood or lightweight metal used in trusses.
Girder: A large or principal beam of wood or steel used to support concentrated loads at isolated points along its length.
Glitch plate girder: Made by sandwiching a piece of steel between two wooden beams.
Gravity connection: Depends on the weight of the building to hold it in place.
Gravity resistance system: Consists of all the structural elements and the connections that support and transfer the loads.
Grillage: A series of closely spaced beams designed to carry a particularly heavy load.
Gusset plate: A connecting plate made of wood or lightweight metal used in trusses.
Header: A masonry unit that overlaps two or more adjoining wythes of masonry to tie them together.

Heat release rate (HRR): Indicates how fast the potential heat in a fuel is released.
Homogeneous: A product that is made up of only one material.
Impact load: The effect of a moving load upon a stationary structure.
Joist: Wooden 2 x 8s, 10s, or 12s that run parallel to one another and support a floor or ceiling, and are supported in turn by larger beams, girders, or bearing walls.
K-bracing: An arrangement of braces between columns that resembles the letter "K."
Kilojoule: Metric equation approximately equivalent to one British thermal unit (Btu).
Kilowatts (KW): Derived and qualified unit for power distribution equal to 1000 watts.
KIP: 1000 pounds per square inch (psi).
Lateral impact load: A force that acts on a structure from a horizontal direction, such as wind or seismic forces.
Ledger board: A wood strip nailed to the lower side of a girder to provide a bearing surface for joists.
Lightweight truss: A collection of lightweight structural components joined in a triangular conflagration that can be used to support either floors or roofs.
Lintel: The horizontal beam that forms the upper structural member of an opening for a window or door and supports part of the structure above it.
Live load: The weight of the building contents.
Load-bearing wall: Includes all exterior walls and any interior wall that is aligned above a support beam or girder. Normally, any wall that has a double horizontal top plate.
Load: Force or other action that result from the weight of all building materials, occupants and their possessions, environmental effects, differential movement, and restrained dimensional changes.
Megastructure: High-rise structure.
Megawatts (MW): Derived and qualified unit for power distribution equal to 1 million watts.
Monolithic concrete: All successive poured concrete castings are joined together so that a structure seems to be like one piece of stone.
Needle beam: When any change is to be made in the foundation of an existing wall, the wall must be supported. Often holes are cut through the wall, and so-called needle beams are inserted and supported on both sides. They pick up the load of the walls.
Neutral axis: The line along which the length of the beam does not change.

Non-load-bearing wall: A wall supporting no load other than its own weight.

Overhanging beam: Projects beyond its support, but not far enough to be a cantilever.

Panel wall (curtain wall): Non-load-bearing enclosing wall on framed buildings.

Partition wall: A non-load-bearing wall that subdivides spaces within any story of a building or room.

Party wall: A load-bearing wall that is common to two structures.

Pier: A short column of masonry, usually rectangular in horizontal cross-section, used to support other structural members.

Pilaster: A masonry column built on the inside surface of the wall.

Pinned: Structural elements are connected by simple connectors such as bolts, rivets, or welded joints.

Plastic design: Connections that redirect overloads to other sections of the building.

Portal bracing: Heavy riveting of girders to columns from the top to the bottom of the frame.

Precast: A concrete member that is cast and cured in a place other than its final position in the structure.

Precast concrete tilt slab wall: This is a vertical cantilever when being erected and is braced by tormentors or temporary bracing poles.

Q: A designation of the heat release rate (HRR); refers to the rate at which a fuel will burn.

Raker: Braced sheeting used in soil walls to protect against collapse.

Reaction: The response in structures to the imposed loads, which are generally developed at the supports.

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

Repeated load: A load that is applied intermittently.

Rigid-framed: Structural frame in which all columns and beams are rigidly connected. There are no hinged joints, and the angular relationship between beam and column members is maintained under load.

Rubble masonry wall: Rough stones of irregular shapes and sizes; can be coursed or uncoursed.

Safety factor: Represents the ratio of the strength of the material just before failure to the safe working stress.

Sand-lime mortar: Water-soluble mixture; when water is applied the mortar can be washed away from the wall.

Self-releasing floor: Floor girders are set on brackets attached to columns. A wood cleat or steel dog-iron similar to a big staple is used to provide minimal stability. Often used in heavy-timber construction.

Self-weight: Another term for dead load.

Serpentine wall: Garden wall.

Shear wall: A wall that resists shear forces in its own plane due to wind or earthquake forces.

Simple beam: Supported at two points near its ends. In simple beam construction, the load is delivered to the two reaction points and the rest of the structure renders no assistance in an overload.

Spandrel girder: A beam that carries the load on the exterior of a framed building between the top of one window and the bottom of the window above.

Steel joist: An open web design used for the support of floors and roofs.

Stiffness: The capacity of a member or framework to resist imposed loads without excessive deflection.

Strain: The deformation caused by stress.

Stress: The total internal forces per unit of area, or the stress divided by the area.

Stretcher: A masonry unit laid horizontally with its length in the direction of the face of the wall.

Structural elements: Include beams, columns, arches, and walls.

Structural frame: Consists of all members in a structure that are tied together to carry the imposed loads to the substructure, and hence to the ground.

Strut: A bracing member, or any piece of a frame that resists thrusts in the direction of its own length.

Suspended beam: A simple beam, with one or both ends suspended on a tension member such as a chain, cable, or rod.

Suspended load: Interior columns are placed at selected locations by hanging the ends of the beams from the overhead structure.

Tension: A pulling or stretching force in line with the axis of the body; the opposite of compression, which is pushing, crushing stress.

Tie rod: A rod in tension; used to hold parts of a structure together.
Wrap-Up

**Torsion**: The force tending to twist an architectural member.

**Transfer beam**: Moves loads laterally when it is not convenient to arrange columns one above the other—the ideal arrangement.

**Transmitted**: Shows how a load is spread from the point of application to the ground.

**Tube construction**: Externally braced structure.

**Ultimate strength**: The highest load that a member or structure can sustain before failure occurs.

**Uniformly distributed load**: Receives the load, which is identical in weight along the entire length of a member.

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

**Vierendeel truss**: A rectangular truss with very rigid corner bracing.

**Voussoir**: A wedge-shaped block whose converging sides radiate from a center forming an element of an arch or vaulted ceiling.

**Wall column**: A column of steel, reinforced concrete, or solid masonry (such as brick or solid block) in a block wall. Concentrated loads such as main girders are applied to the wall directly above the wall column.

**Wall**: Transmits to the ground the compressive forces applied along the top or received at any point on the wall.

**Watts (W)**: The unit of power, or rate of work. It is equal to one joule per second, or the rate of work represented by a current of one ampere under the potential of one volt.

**Web**: The cross wall connecting the face shells of a hollow concrete unit.

**Wet joint**: Cast-in-place concrete unites rods that project from precast sections.

**Wind load**: The positive or negative force of the wind acting on a structure.

**Wythe**: A single continuous vertical wall of bricks, one masonry unit in thickness.
While conducting a prefire plan at a furniture and appliance store of heavy timber construction, you notice that heavy appliances are stored on the second floor of the structure. You also notice that the roof of the building is being renovated. Answer the following questions about the hazards that might be faced within this building.

1. What type of load is being applied to the floor section of the second floor?
   A. Dead load
   B. Eccentric load
   C. Lateral load
   D. Live load

2. The building being constructed of heavy timber material has a floor assembly that has wood cleats to provide the stability of the floor. What type of floor construction does this signify?
   A. Tie rod
   B. Self-releasing
   C. Rigid framed
   D. Grillage

3. They are adding steel components to the roof supports of the structure. We know from the chapter that steel elongates when heated. At what temperature will steel elongate 9 inches per 100 feet of length?
   A. 500 degrees
   B. 1000 degrees
   C. 1500 degrees
   D. 2000 degrees

4. True or False: The steel trusses in this structure will hold more loads than the wooden heavy timber.