1.1 INTRODUCTION

The variety of materials that may be used in building construction is broad and constantly evolving. This chapter provides an introduction to selected building materials commonly used in construction. The materials are classified as either **structural** or **nonstructural** in function. The structural materials addressed in this chapter include **steel**, **concrete**, **masonry**, and wood. The nonstructural materials addressed include common types of insulation, roof covering, and wall cladding materials. Building construction also utilizes a wide range of other materials such as **fenestration** products (windows and doors), sealants, air and water barriers, and interior finishes.[1] A discussion of these other materials is beyond the scope of this chapter.

1.2 STRUCTURAL MATERIALS

In construction terminology, the word structural typically defines an element that is relied upon to support more than simply its own self-weight. **Structural materials** are often also referred to as load-bearing materials. A structural **column**, for example, would be designed to adequately resist any loads transferred to it from the floor or roof above the column. In contrast, a nonstructural column might serve an aesthetic purpose, but would not be counted upon to resist any building loads.

Materials used for structural purposes in construction must therefore possess sufficient strength, either alone or when used in combination with other reinforcing materials, to adequately resist required loads in an economically viable manner. The following sections provide a brief description of selected structural building materials, their advantages and disadvantages relative to other structural materials, and how structural material requirements are addressed in commonly used building codes and standards.

1.2.1 Steel

1.2.1.1 Description

Steel is an alloy of iron that contains carbon. It is both the most widely used and most recycled metal on earth. The carbon content of typical steels ranges from approximately 0.04 percent to 1.5 percent by weight. Steels with relatively low carbon amounts, referred to as mild carbon steels, have good workability—that is, they are relatively easy to form, weld, and cut. The introduction of additional carbon, such as in medium and high carbon steels, increases its strength and hardness, but decreases its workability. Other elements, such as manganese, phosphorus, sulfur, silicon, and others are also often added to create steel alloys with different properties for a wide range of applications.

1.2.1.2 Advantages and Disadvantages

Steel has a significantly higher strength-to-weight ratio when compared to other structural materials, such as **concrete** and masonry. Structural members may be

1. For information on interior finish materials, see Chapter 10 of this book.

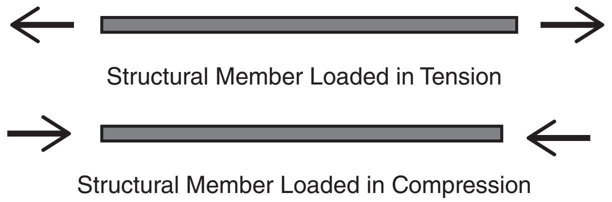

FIGURE 1.1 *Structural Member Loaded in Tension or Compression*
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loaded in tension (i.e., pulled apart) or in compression (i.e., pushed together), as illustrated in Figure 1.1.

Tensile (i.e., loaded in tension) tests are often performed on steel specimens to define the **stress** versus **strain** curve for a given steel alloy. These tests measure the strength of the steel in tension. They also provide information about the ability of the steel to permanently deform under **tensile loads**, which provides advance warning of overload and impending failure, and allows for the dissipation of energy under extreme loads such as heavy impacts and earthquakes. Envision a steel structural member, having a cross-sectional area (A), being pulled in tension by a force (P) and elongating from its original length (L) by an amount (Δ), as shown in Figure 1.2.

The stress, or pressure, is defined as the load (P) divided by the cross-sectional area (A) being tested. The **strain** is the elongation of the specimen (Δ) divided by its original length (L). The applied stress and measured strain can be plotted to show the relationship between stress and strain from the start of the test to the point where the steel specimen is pulled apart in tension. A typical stress versus strain curve for a steel member loaded in tension is shown in Figure 1.3.

As shown in Figure 1.3, the slope of the stress versus strain curve is generally constant until the steel reaches its **yield stress**. This slope, referred to as the "elastic modulus," is a measure of the stiffness of the steel. Until the steel reaches its yield stress, it undergoes **"elastic" deformation**, meaning that, if the test is terminated and the specimen is unloaded, it will return undeformed to its original length and cross-sectional area. Typical structural steels will have yield stresses of 36,000 to 75,000 pounds per square inch (**PSI**), although higher strength steels are available.

The maximum stress value withstood by the test specimen is referred to as the **ultimate stress**. As the applied strain increases further, the specimen becomes less and less able to resist the load until it fractures or fails. At stresses above the yield stress, the steel behaves inelastically, or plastically, meaning when the test is terminated

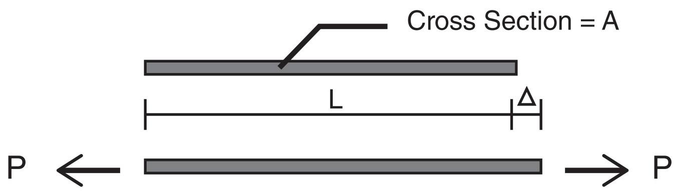

FIGURE 1.2 *Elongation of Member during Tensile Test*
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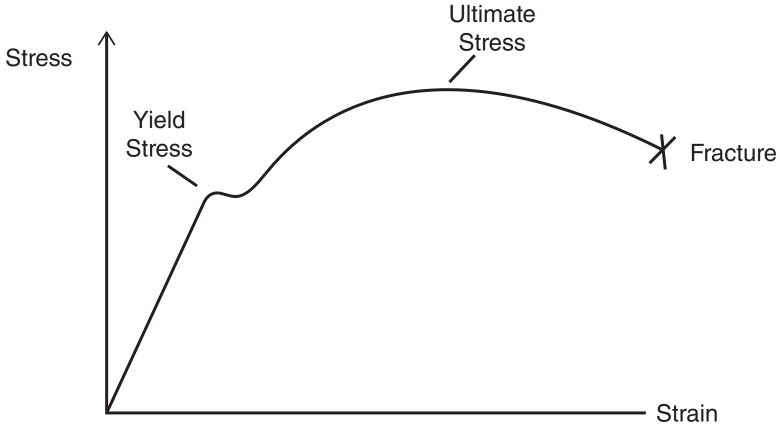

FIGURE 1.3 *Typical Stress versus Strain Curve for Steel Member in Tension*
Reproduced with permission from CTL Group.

and the specimen is unloaded, it will exhibit an elongation and narrowing of cross-sectional area (i.e., necking), as shown in Figure 1.4.

This ability to elongate through inelastic behavior is referred to as **ductility**. The high ductility of some steels is beneficial for several reasons. First, the large inelastic deformations that some steels exhibit provide a warning that they are loaded past their yield stress and approaching the point of failure. Moreover, the ductility of steel is also beneficial in resisting extreme loads such as impacts and earthquakes, because they allow for energy to dissipate. In contrast to a ductile steel material, concrete and masonry are brittle (non-ductile) materials in tension. Steel also has much greater tensile strength than concrete or masonry.

Mild carbon steels typically have lower yield stresses but increased ductility. Increasing the carbon content of steel tends to increase its yield stress but often reduces its ductility.

Structural steel may be formed into a variety of shapes to make the most efficient use of the material. When a steel **beam** is formed, the material farthest from the central, or neutral, axis is more effective in resisting loads in bending. For this reason, a member with a wide flange (or I) cross section is significantly more effective as a beam than a member with a rectangular cross section. Figure 1.5 compares a rectangular

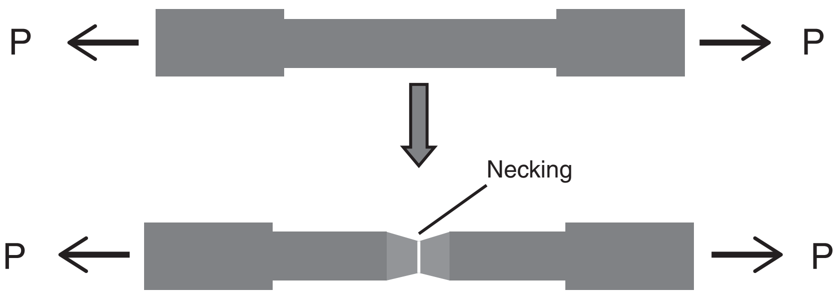

FIGURE 1.4 *Plastic Deformation (Necking) of Tensile Test Specimen*
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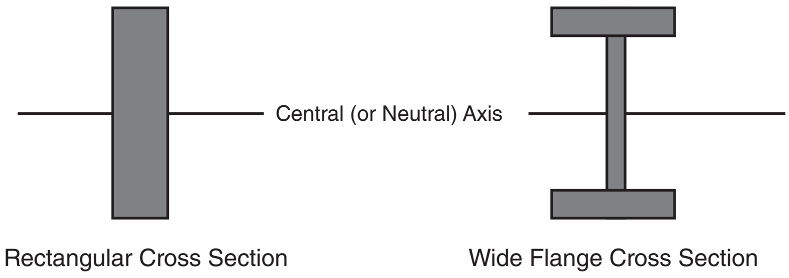

FIGURE 1.5 *Rectangular Cross Section and Wide Flange Cross Section of Beams of Equal Area*
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steel cross section and a wide flange cross section of approximately equal steel areas. Note how the wide flange section has considerably more material at a further distance from the central axis. The wide flange cross section results in a significantly stiffer and stronger steel beam than a rectangular cross section of the same steel area.

Heavier steel shapes are typically formed through a hot rolling process, whereas thinner shapes may be cold formed by rolling, pressing, or brake forming. Hot rolling is a process in which a steel cross section is formed by rolling at very high temperatures (typically over 1,700 degrees Fahrenheit). Cold forming is done at much lower temperatures, and the cross section is formed by deforming or bending the steel through rolling or brake pressing. Steel members may be fabricated into curved shapes for applications such as bridge girders. Structural steel members are typically joined either by welding or bolting. These connections are often made in the fabrication shop, allowing an assembly to be shipped to a job site for subsequent erection, but they can also be made in the field.

Figure 1.6 shows some of the steel shapes most commonly used in construction.

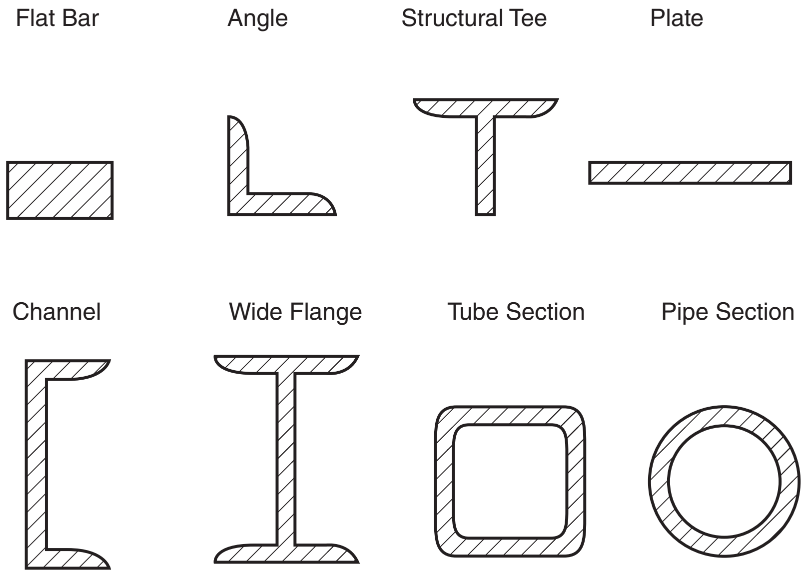

FIGURE 1.6 *Common Steel Shapes Utilized in Construction*
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One disadvantage of using steel as a structural material is that it is subject to corrosion in the presence of oxygen and moisture. Corrosion is an electrochemical process through which the iron in the steel is oxidized, producing rust. Rust occupies approximately six times the volume of the original material. If the steel is confined (e.g., embedded in concrete), the corrosion will induce expansive forces that will stress and potentially damage the confining material. Moreover, even in the absence of confinement, corrosion itself degrades the steel, reducing its strength and creating discoloration that may be aesthetically objectionable.

Several means have been developed to address the problem of corrosion. **Stainless steel** alloys, which resist corrosion, may be used in construction applications, but they are relatively expensive. Stainless steel alloys are made by adding chromium to low carbon steel. In the presence of oxygen, a thin layer of chromium oxide forms at the steel surface and protects it from corrosion. The chromium oxide layer repairs itself if the stainless steel material is scratched or cut, restoring its corrosion protection. Additional elements, such as nickel, molybdenum, and titanium, may also be added to enhance corrosion resistance. However, given the relatively high cost of stainless steels, they are seldom used for large structural members. Stainless steels are more commonly used in construction for items such as cladding panels, flashings, and fasteners.

Galvanization is a more cost-effective means of providing corrosion protection to steel. Galvanization is a process in which a zinc coating is applied to the surface of steel. The zinc acts as a sacrificial anode in the electrochemical process, protecting the adjacent steel from corroding. The degree of galvanization is usually described as the weight of zinc per surface area. For example, a steel sheet with a G60 coating would have a total zinc coating weight of 0.60 ounces per square foot, or 0.30 ounces of zinc per square foot on each surface.

Structural steel may be "hot dip galvanized" by being deposited into a molten zinc bath. Steel may also be galvanized through an electroplating process, where zinc ions in a solution are deposited onto the steel using an electric current. Electroplating is preferable for situations in which a thinner, more controlled, coating layer is required, such as for small fasteners.

Advances in technology have made a wide variety of other coatings for steel, including metal alloys and nonmetallic materials, commercially available for corrosion protection purposes.

Another disadvantage of using steel as a structural material is that, although it is **noncombustible**, it rapidly loses strength as temperature increases. At 500 degrees Celsius (approximately 930 degrees Fahrenheit), mild steel will lose almost half its strength. For this reason, protective coatings are often applied to structural steel when a specified level of fire resistance is required.

1.2.1.3 Applicable Building Codes and Standards

The International Building Code[2] (IBC) is a model building code very commonly used in the United States. The current version of the IBC (2015 edition) requires that steel design, construction, and materials comply with various standards promulgated by the following industry organizations:

- American Institute of Steel Construction (AISC)
- American Iron and Steel Institute (AISI)
- American Society of Civil Engineers (ASCE)

2. International Building Code, ©2015 by International Code Council, Inc., www.iccsafe.org.

- American Welding Society (AWS)
- Steel Deck Institute (SDI)
- Steel Joist Institute (SJI)

In addition, the IBC references numerous steel standards and specifications promulgated by the American Society for Testing and Materials (ASTM) International. The ASTM standards and specifications are consensus documents developed by ASTM committees and are commonly used in the United States, and increasingly used in other parts of the world. A typical example is ASTM C36 Standard Specification for Carbon Structural Steel, which contains chemical requirements for the steel material as well as specified minimum values for properties such as yield stress, ultimate stress, and elongation.

1.2.2 Concrete

1.2.2.1 Description

Concrete has been used in various forms for construction for thousands of years. Concrete is often used for building foundations, basements, floor slabs, frames, bridges, dams, and pavements. It is the most commonly used man-made material on earth. In modern construction, concrete is often used in combination with reinforcing steel, which utilizes the **compressive** strength of concrete with the **tensile strength** of the steel reinforcing bars.

Concrete is made from a mixture of **cementitious materials** (including portland cement, slag, or fly ash serving as binders), coarse aggregate (gravel), fine aggregate (sand), and water. The cementitious materials undergo a chemical reaction, or **hydration**, when mixed with water, which results in the eventual hardening of the concrete. Concrete mix designs will typically specify the **water cement ratio**, or ratio by weight of water to cement, to be used for a given mix. Excess amounts of water added to the concrete mix improve the flow and workability of the concrete but reduce its strength.

Chemical additives, or **admixtures**, may be added to the concrete mix. For example, an air-entraining admixture may be added to capture air in the form of tiny bubbles within the concrete, which improves its performance under freeze–thaw conditions. Other commonly used admixtures include accelerators or retarders of the hydration process, resulting in more rapid or slower hardening, or plasticizers, which increase the workability of the fresh concrete without adding more water.

The **slump** of the concrete is a measure of its consistency. Slump values are given in inches, and are measured using a simplified test that may be readily performed at the construction site. Higher slump values are indicative of a concrete material that has more of a tendency to flow when placed in a form.

Concrete that is transported to the construction site in an unhardened state and cast into forms is referred to as **cast-in-place concrete**. Cast-in-place concrete may be mixed either remotely, at a batch plant, or at the site. The concrete is placed into forms using a variety of methods including by hand using a shovel, by pumping it, or by allowing it to free fall. Concrete may be placed underwater by **tremie**, a system where the concrete is placed by gravity feed from a hopper through a vertical pipe to below the water level.

Freshly placed concrete is often agitated using mechanical vibrators to consolidate it and ensure that it uniformly and completely fills the form. When cast-in-place concrete is used for configurations such as elevated slabs, temporary supports called **shores** are used to support its weight until the concrete has gained sufficient strength to support itself.

As previously discussed, the hardening of concrete results from a hydration process that requires water. Moisture or curing compounds are often applied to the surface of concrete as it cures to attain full hydration and prevent rapid drying, which may lead to shrinkage and cracking. A variety of finishing techniques may be used to give exposed concrete surfaces varying textures, patterns, and colors.

Unlike cast-in-place concrete, **precast concrete** is mixed, placed, cured, and finished to its final form in a plant. Precast concrete is often used for items such as concrete wall panels and girders. Precasting concrete allows for some cost efficiencies, because items such as concrete forms may be repeatedly reused. It also allows work to be done in an environmentally controlled plant, potentially allowing for greater process control and eliminating weather uncertainties. Precast concrete has increased shipping costs, because the relatively heavy precast members must be transported to the construction site.

1.2.2.2 Advantages and Disadvantages

Concrete has relatively high **compressive strength** but little **tensile strength**. In ancient times, designers compensated for the lack of tensile strength in concrete by utilizing it in structures such as arches and domes, where the geometric configuration allowed the concrete to resist loads primarily in compression. Modern construction frequently uses reinforcing steel in concrete when it is subject to tensile **stress** to compensate for its inherent tensile weakness. In reinforced concrete structures, the structural design typically assumes that the concrete will resist the loads under compression, while the reinforcing steel will resist the **tensile loads**.

In addition to steel reinforcement, modern construction also uses **prestressed concrete** to compensate for the inherent tensile weakness of the material. In the prestressing process, pre-stressing tendons provide a compressive, or clamping, force to the concrete member. Any external tensile forces applied to the prestressed concrete must first overcome this internal compressive prestressing force before the concrete is subjected to tension. Prestressing may be accomplished by either pretensioning or post-tensioning the concrete member. In pretensioning, concrete is cast around steel tendons that are loaded in tension. Once the concrete has cured and bonded to the tendon, the tension force is released, and a resulting compressive force is transferred to the concrete through friction. In post-tensioning, the concrete is cast around small ducts containing the tendons. Once the concrete has cured, a tensile force is generated by jacking the tendons against the concrete member, generating a compressive force in the concrete.

As previously discussed, concrete hardens and gains strength through a hydration process. Typically, concrete gains strength over time as illustrated by the strength gain curve shown in Figure 1.7.

The compressive strength of concrete at 28 days is typically the strength value considered for structural design purposes. The curve shows the relative concrete compressive strength as a function of age in days. The 28-day compressive strength for structural concrete may range from 3,000 to 10,000 pounds per square inch (**PSI**) or more, depending on the mix design. As shown in the curve in Figure 1.7, the compressive strength of a typical concrete mix at three days and seven days may be approximately 37 percent and 60 percent, respectively, of the 28-day strength. The rate of strength gain will vary depending on the specific mix design, and is an important consideration for determining when shores and forms may be removed.

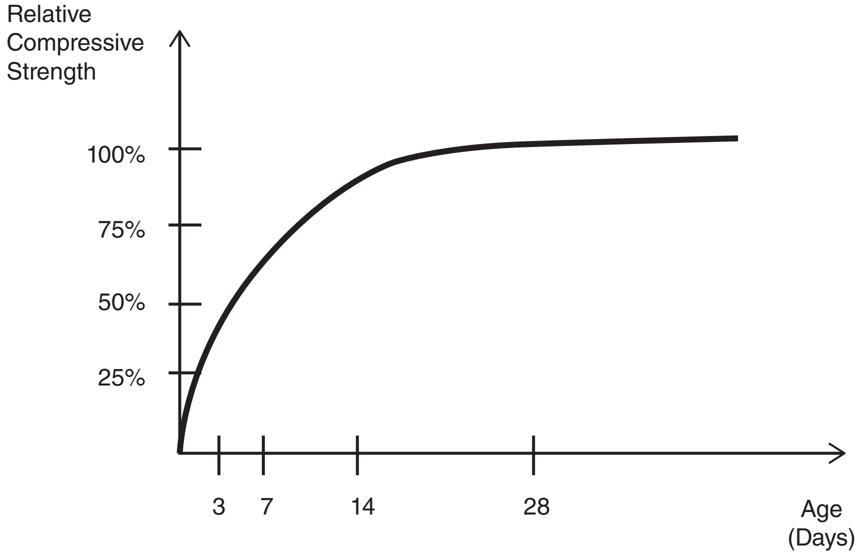

FIGURE 1.7 *Typical Compressive Strength Gain of Concrete*
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Although concrete is much cheaper than steel on a weight basis, a reinforced concrete structure will typically be heavier than a comparable steel structure, due to the larger quantity of material required.

Concrete has good fire resistance performance because it is noncombustible. It has significantly lower heat conductivity than steel, and will therefore remain cooler under similar fire conditions. For this reason, concrete and other **cementitious materials** are often used as fire protection for steel members.

The hydration process of **cement** is **exothermic**, meaning it liberates heat as it gains strength. The amount of heat liberated by the curing process is particularly significant in mass concrete pours, such as for large foundations and dams, and in mix designs incorporating larger amounts of portland cement. A large heat build-up may result in cracking of the concrete. The concrete mix design, concrete placement quantities and sequence, and formwork design may all be evaluated to reduce the amount of heat generated and potential for cracking. Cooling tubes may also be incorporated within the cast concrete to avoid excessive heat build-up.

1.2.2.3 Applicable Building Codes and Standards

The current version of the IBC (2015 edition) requires that **concrete** design, construction, and materials comply with various standards promulgated by the following industry organizations:

- American Concrete Institute (ACI)
- Precast Prestressed Concrete Institute (PCI)
- Post-Tensioning Institute (PTI)

In addition, the IBC references numerous ASTM concrete standards and specifications. A typical example is ASTM C31 Standard Specification for Concrete Aggregates, which specifies requirements for aggregates to be used in concrete.

1.2.3 Masonry

1.2.3.1 Description

Masonry construction consists of individual units (called **masonry units**) bonded together with **mortar**. The masonry units are typically made of clay or shale brick, **concrete** block, or stone. These units come in a variety of shapes, sizes, colors, and surface textures. As in concrete construction, masonry construction may incorporate steel reinforcement to compensate for the inherent weakness of masonry in tension.

The mortar used in masonry construction typically contains a mixture of portland cement, lime, sand, and water. The following are standard types of mortar used in construction:

- Type M mortar is often used for foundations. It is typically made with one part portland cement, six parts sand, and one-quarter part lime. It has an average 28-day compressive strength of 2,500 PSI.
- Type S mortar is a general purpose, high-strength mortar often used for reinforced masonry walls. It is typically made with one part portland cement, four and one-half parts sand, and one-half part lime. It has an average 28-day compressive strength of 1,800 PSI.
- Type N mortar is a moderate strength mortar with good workability due to higher lime content. It is typically made with one part portland cement, six parts sand, and one part lime. It has an average 28-day compressive strength of 750 PSI.

In brick masonry, each horizontal row of bricks is known as a **course**, and each continuous vertical section, one unit thick, is known as a **wythe**. The wythes are bound together with **headers**, which are bricks running transverse to the wall.

Courses, wythes, and headers are illustrated in Figure 1.8.

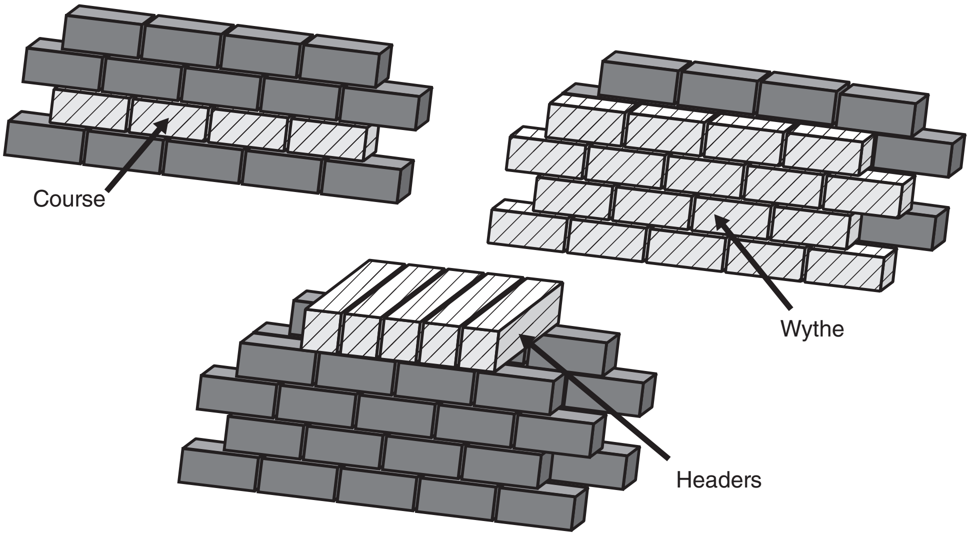

FIGURE 1.8 *Masonry Course, Wythe, and Header*
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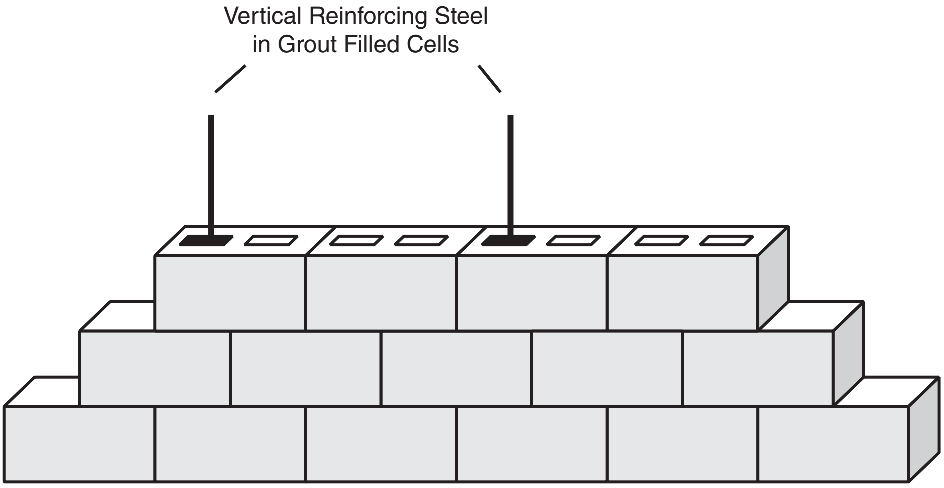

FIGURE 1.9 *Concrete Masonry Wall with Grouted and Reinforced Cells*
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Brick and concrete block are often supplied with hollow interior cores, sometimes called cells. The hollow cells tend to reduce the weight of the individual units, and may subsequently be filled with grout, or a combination of vertical steel reinforcement and grout, for added strength. **Grouts** are similar to mortars, except that they are mixed to be applied by pouring, rather than by trowel. Grouts therefore tend to have high flow characteristics, allowing them to be poured to fill the cores or cells.

A figure of a concrete masonry wall containing reinforced and grouted cells is shown in Figure 1.9.

1.2.3.2 Advantages and Disadvantages

The advantages and disadvantages of masonry are similar to those of concrete in many respects. Like concrete, masonry has a relatively high **compressive strength** but little **tensile strength**. The use of unreinforced masonry for structural purposes is therefore limited. Both horizontal and vertical steel reinforcement is often used to carry **tensile loads** in masonry construction.

Masonry units are available in a variety of shapes, sizes, colors, and textures, and may be assembled in a variety of patterns. Masonry construction therefore offers a wide range of aesthetic options in terms of finished appearance.

Like concrete, a masonry structure will typically be considerably heavier than a comparable steel structure due to the greater quantity of material involved. Masonry construction is also relatively labor intensive due to the placement and mortaring of the individual masonry units.

Masonry is noncombustible and, depending on the type of masonry units employed, typically has relatively low heat conductivity. It therefore tends to have good fire resistance performance.

1.2.3.3 Applicable Building Codes and Standards

The current version of the IBC (2015 edition) requires that masonry design, construction, and materials comply with various standards promulgated by the following industry organizations:

- American Concrete Institute (ACI)
- American National Standards Institute (ANSI)
- American Society of Civil Engineers (ASCE)
- National Concrete Masonry Association (NCMA)
- The Masonry Society (TMS)

In addition, the IBC references numerous ASTM masonry standards and specifications. A typical example is ASTM C90 Standard Specification for Loadbearing Concrete Masonry Units, which specifies requirements for concrete masonry units that are used in load-bearing (structural) applications.

1.2.4 Wood

1.2.4.1 Description

Wood was likely one of the first materials used by humans to build shelters due to its widespread availability. The structural properties of wood, such as its strength and stiffness, vary according to the wood species and grade. These properties may be degraded by natural imperfections, such as knots and splits. Wood properties are also affected by direction relative to the wood grain. The grain of wood in trees is oriented vertically, and wood has its greatest strength and stiffness in the direction parallel to the grain. Wood properties may be further degraded when exposed to moisture, which causes it to stain and rot.

The wood used in construction today may include solid-sawn members, or a variety of built-up sections composed of solid-sawn members, veneers, or reconstituted elements (e.g., wood flakes, strands, or fibers) that are laminated to optimize the cross-sectional shape and grain direction.

1.2.4.1.1 Solid-Sawn Lumber

Solid-sawn lumber are wood members that have been formed from solid material that was sawn and planed from softwood logs to standard dimensions (e.g., 2 × 4s), as opposed to lumber that has been formed from processed wood material. Solid-sawn lumber is used for structural framing, such as **wall studs** and **rafters**, as well as for cladding members, such as shingles and siding. The nomenclature applied to wood framing corresponds to nominal size designations, not actual cross-sectional measurements. Thus, a 2 × 4 stud has an actual cross section of 1½ inches by 3½ inches.

Framing members, such as 2 × 4s, 2 × 6s, and so on, are typically used in a repetitive manner and spaced 16 inches or 24 inches apart when used as studs or rafters. **Post and beam construction** is a type of wood construction employing heavier timbers, requiring fewer support members, and allowing for longer spans than conventional wood framing.

Solid-sawn members are also often used in wood **trusses**. A wood truss is a combination of wood members, connected by metal plates, that form a rigid frame for supporting loads over a span, for example, a roof. A typical wood truss is shown in Figure 1.10.

1.2.4.1.2 I-joists

A wood I-joist is a horizontal framing member whose **flanges** (the top and bottom members) are typically made of solid sawn lumber or laminated veneers, and whose **web** (the middle member that joins the flanges) is typically made of **plywood** or

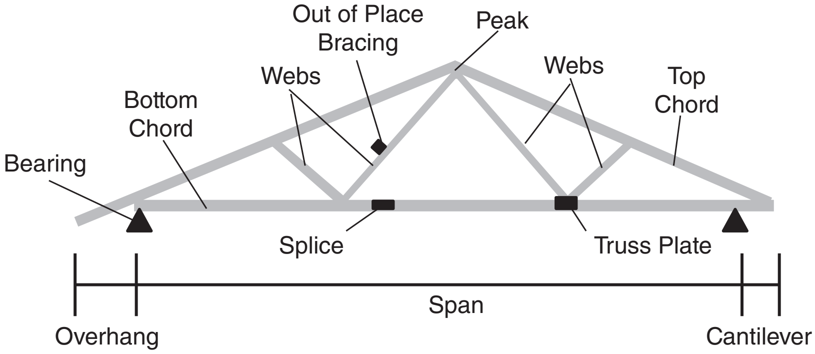

FIGURE 1.10 *Typical Wood Truss*
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oriented strand board (**OSB**). **Joists** are used as horizontal framing members to support a floor or flat roof. A typical wood I-joist is shown in Figure 1.11.

1.2.4.1.3 Structural Wood Panels

Structural wood panels, which are used for sheathing walls, floors, and roofs, are generally made from either **plywood** or **OSB**. Plywood panels are composed of laminated veneers, which are thin sheets of wood adhesively bonded to one another. The veneers are positioned so that the grain direction of each veneer is rotated 90 degrees from the adjacent ply to optimize the panel strength. An OSB panel is made from reconstituted oriented wood strands bonded with adhesive. The grain direction of these strands is mechanically oriented to optimize the panel strength.

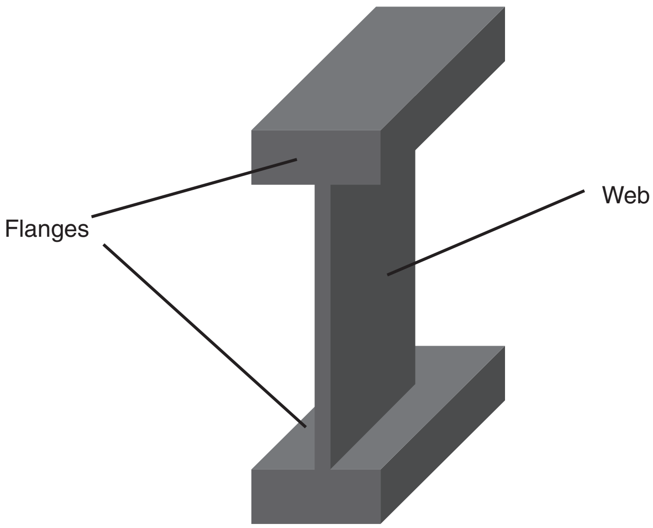

FIGURE 1.11 *Typical Wood I-Joist*
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1.2.4.1.4 Glue–Laminated Lumber

Glue–Laminated Lumber (**or Glulam**) refers to layers of solid-sawn dimensional lumber bonded together, typically to form a larger beam or column. The lumber grades and adhesives used in Glulam are specifically selected to provide higher strengths than typical solid-sawn lumber. The ability to form a Glulam member from multiple layers or strips also allows for the fabrication of longer and wider structural members than are normally available from solid-sawn lumber.

1.2.4.2 Advantages and Disadvantages

Wood is significantly easier to cut and fasten than other structural building materials. It can readily be cut using hand or small power tools, and fastened using nails, fasteners, or bolts.

Wood has a very high strength-to-weight ratio, that is, its strength values are very high relative to its light weight, although the strength values of woods vary by species and are also impacted by defects, such as knots, checks, or splits. Moreover, as previously discussed, the strength of wood is very direction dependent, with the highest strength values obtained in the direction parallel to the grain. For this reason, the ability to orient the grain in laminated veneer or reconstituted wood products allows for strength optimization. Typical ultimate strength values in the direction parallel to grain range from approximately 4,250 to 7,500 PSI in tension and 2,000 to 4,000 PSI in compression.

Unlike steel, concrete, or masonry, however, wood is inherently combustible, which limits its use in construction as further discussed later. It has relatively low heat conductivity, so it provides reasonably good fire resistance until it reaches the point of combustion. Various fire retardants may be used either as surface coatings or incorporated integrally into the wood under pressure to improve its fire performance.

Wood has less dimensional stability when exposed to moisture changes than steel, concrete, or masonry and hence is more prone to shrinking or swelling. It will also decay when subject to prolonged exposure to moisture, and may be damaged by insects such as termites. Preservatives serving as fungicides and insecticides may be used to improve wood performance when exposed to moisture and insects. Prior to 2004, arsenic and chromium (chromated copper arsenic, or CCA) was widely used in the United States as a preservative treatment for residential lumber. Since 2004, a variety of alternative treatments have replaced CCA, several of which contain higher levels of copper and can be more corrosive when in contact with steel. For this reason, steel fasteners with higher levels of galvanization, or **stainless steel** fasteners, are often specified for use with preservative-treated wood.

1.2.4.3 Applicable Building Codes and Standards

As previously noted, the strength of wood is limited by naturally occurring defects such as knots, checks, or splits; hence the IBC requires that all solid-sawn and veneer lumber be visually inspected and graded.

The IBC identifies five general types of construction and limits the use of structural wood members to certain construction types.[3]

3. International Building Code, 2015 ed., sec. 602, International Code Council, Inc.

The current version of the IBC (2015 edition) requires that wood design, construction, and materials comply with various standards promulgated by the following industry organizations:

- APA—Engineered Wood Association (APA)
- American Wood Protection Association (AWPA)
- Truss Plate Institute (TPI)
- West Coast Lumber Inspection Bureau (WCLIB)

In addition, the IBC references numerous ASTM wood standards and specifications. A typical example is ASTM D5055 Standard Specification for Establishing and Monitoring Structural Capacities of Prefabricated Wood I-Joists, which specifies requirements for wood I-joists used in structural applications.

1.3 NONSTRUCTURAL MATERIALS

As previously discussed, the term structural refers to an element that is relied upon to support more than its own self-weight. **Nonstructural materials**, such as insulation, roof coverings, and wall claddings, while not relied upon to contribute to the overall strength of the building, are used to control heat and moisture movement through the building envelope and may also serve an aesthetic function. Materials exposed to the exterior, such as roof coverings and wall claddings, must be sufficiently strong and suitably attached to resist the forces that may be exerted upon them. Roof coverings, for example, may be subjected to considerable wind forces.

1.3.1 Insulation Materials

Insulation materials are used to reduce heat transfer through the exterior building enclosure. Heat transfer may occur in one of three ways:

- **Conductive Heat Transfer,** which is the transfer of heat through solid members such as studs, sheathing, and solid insulation products. The thermal resistance, or R-value, of an insulation material is a measure of its resistance to conductive heat transfer. Insulation materials with higher R-values are therefore more effective insulation materials.
- **Convective Heat Transfer,** which is the transfer of heat through viscous materials, such as fluids or gases. Insulation materials with high R-values will be rendered less effective if air is allowed to leak through or around them, transferring heat by convection.
- **Radiant Heat Transfer,** which is the transfer of heat through energy waves. Insulation products such as foil-faced sheathings may be used to reduce this type of heat transfer.

Insulation materials in construction are often used in combination with air or vapor barriers, or retarders. An **air barrier** inhibits air leakage through the exterior building enclosure and the resulting heat transfer through convection. A **vapor barrier** or **retarder** inhibits the movement of moisture vapor through the exterior building enclosure, preventing it from coming in contact with cold surfaces where it may condense.

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