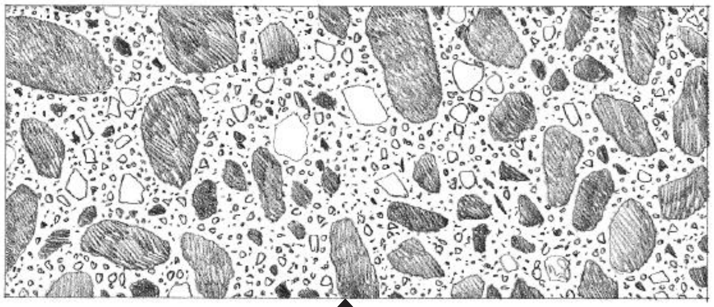


Concrete is made by mixing cement and various mineral aggregates with sufficient water to cause the cement to set and bind the entire mass. While concrete is inherently strong in compression, steel reinforcement is required to handle tensile and shear stresses. It is capable of being formed into almost any shape with a variety of surface finishes and textures. In addition, concrete structures are relatively low in cost and inherently fire-resistant. Concrete's liabilities include its weight—150 pcf (2400 kg/$m^3$) for normal reinforced concrete—and the forming or molding process that is required before it can be placed to set and cure.

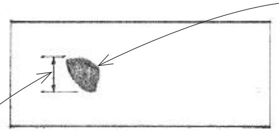
### Cement

- Portland cement is a hydraulic cement made by burning a mixture of clay and limestone in a rotary kiln and pulverizing the resulting clinker into a very fine powder.

- Type I normal portland cement is used for general construction, having none of the distinguishing qualities of the other types.
- Type II moderate portland cement is used in general construction where resistance to moderate sulfate action is required or where heat buildup can be damaging, as in the construction of large piers and heavy retaining walls.
- Type III high-early-strength portland cement cures faster and gains strength earlier than normal portland cement; it is used when the early removal of formwork is desired, or in cold-weather construction to reduce the time required for protection from low temperatures.
- Type IV low-heat portland cement generates less heat of hydration than normal portland cement; it is used in the construction of massive concrete structures, as in gravity dams, where a large buildup in heat can be damaging.
- Type V sulfate-resisting portland cement is used where resistance to severe sulfate action is required.
- Air-entraining portland cement is a Type I, Type II, or Type III portland cement to which a small quantity of an air-entraining agent has been interground during manufacture; it is designated by the suffix A.

### Water

- The water used in a concrete mix must be free of organic material, clay, and salts; a general criterion is that the water should be fit for drinking.
- Cement paste is a mixture of cement and water for coating, setting, and binding the aggregate particles together in a concrete mix.



- 1/3 the depth of a slab, 1/5 the thickness of a wall, or 3/4 of the clear space between reinforcing bars or between the bars and the formwork

### Lightweight Concrete

- Structural lightweight concrete, made with expanded shale or slate aggregate, has a unit weight from 85 to 115 pcf (1362 to 1840 kg/$m^3$) and compressive strength comparable to that of normal concrete.
- Insulating concrete, made with perlite aggregate or a foaming agent, has a unit weight of less than 60 pcf (960 kg/ $m^3$) and low thermal conductivity.

### Aggregate

- Aggregate refers to any of various inert mineral materials, as sand and gravel, added to a cement paste to make concrete. Because aggregate represents from 60% to 80% of the concrete volume, its properties are important to the strength, weight, and fire-resistance of the hardened concrete. Aggregate should be hard, dimensionally stable, and free of clay, silt, and organic matter that can prevent the cement matrix from binding the particles together.
- Fine aggregate consists of sand having a particle size smaller than 1/4" (6).
- Coarse aggregate consists of crushed stone, gravel, or blast-furnace slag having a particle size larger than 1/4" (6).
- The maximum size of coarse aggregate in reinforced concrete is limited by the size of the section and the spacing of the reinforcing bars.

### Admixtures

Admixtures may be added to a concrete mix to alter its properties or those of the hardened product.

- Air-entraining agents disperse microscopic, spherical air bubbles in a concrete mix to increase workability, improve resistance of the cured product to the cracking induced by free-thaw cycles or the scaling caused by deicing chemicals, and in larger amounts, to produce lightweight, insulating concrete.
- Accelerators hasten the setting and strength development of a concrete mix, while retarders slow the setting of a concrete mix in order to allow more time for placing and working the mix.
- Surface-active agents, or surfactants, reduce the surface tension of the mixing water in a concrete mix, thereby facilitating the wetting and penetrating action of the water or aiding in the emulsifying and dispersion of other additives in the mix.
- Water-reducing agents, or superplasticizers, reduce the amount of mixing water required for the desired workability of a concrete or mortar mix. Lowering the water-cement ratio in this manner generally results in increased strength.
- Coloring agents are pigments or dyes added to a concrete mix to alter or control its color.

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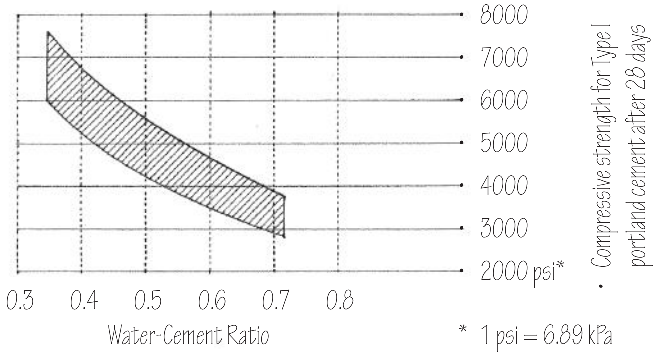
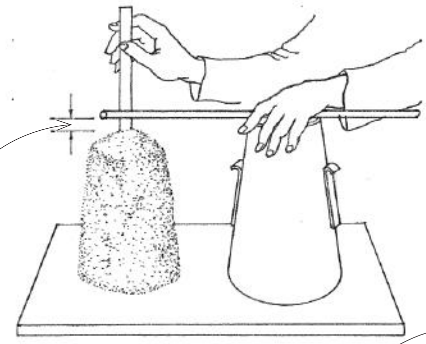
### Water-Cement Ratio

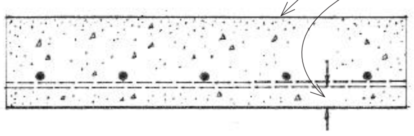
Water-cement ratio is the ratio of mixing water to cement in a unit volume of a concrete mix, expressed by weight as a decimal fraction or as gallons of water per sack of cement. The water-cement ratio controls the strength, durability, and watertightness of hardened concrete. According to Abrams' law, formulated by D. A. Abrams in 1919 from experiments at the Lewis Institute in Chicago, the compressive strength of concrete is inversely proportional to the ratio of water to cement. If too much water is used, the concrete mix will be weak and porous after curing. If too little water is used, the mix will be dense but difficult to place and work. For most applications, the water-cement ratio should range from 0.45 to 0.60.




Concrete is normally specified according to the compressive strength it will develop within 28 days after placement (7 days for high-early-strength concrete).

- Slump test is a method for determining the consistency and workability of freshly mixed concrete by measuring the slump of a test specimen, expressed as the vertical settling, in inches, of a specimen after it has been placed in a slump cone, tamped in a prescribed manner, and the cone is lifted.
- Compression test for determining the compressive strength of a concrete batch uses a hydraulic press to measure the maximum load a test cylinder 6" (150) ø and 12" (305) high can support in axial compression before fracturing.





- Reinforced concrete slab
- 3/4" (19) minimum for #5 bars and smaller; 1-1/2" (38) minimum when exposed to weather; 2" (51) minimum for #6 bars and larger
- For minimum coverage of steel reinforcement in other concrete members, see 3.08 for spread footings, 4.04 for concrete beams, 5.04 for concrete columns, and 5.06 for concrete walls.

- Reinforcing steel must be protected by the surrounding concrete against corrosion and fire. Minimum requirements for cover and spacing are specified by the American Concrete Institute (ACI) *Building Code Requirements for Reinforced Concrete* according to the concrete's exposure, and the size of the coarse aggregate and steel used.

### Steel Reinforcement

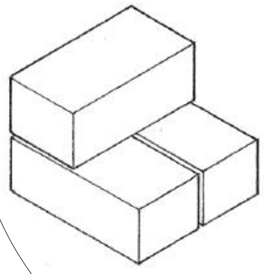
Because concrete is relatively weak in tension, reinforcement consisting of steel bars, strands, or wires is required to absorb tensile, shearing, and sometimes the compressive stresses in a concrete member or structure. Steel reinforcement is also required to tie vertical and horizontal elements, reinforce the edges around openings, minimize shrinkage cracking, and control thermal expansion and contraction. All reinforcement should be designed by a qualified structural engineer.

- Reinforcing bars are steel sections hot-rolled with ribs or other deformations for better mechanical bonding to concrete. The bar number refers to its diameter in eighths of an inch—for example, a #5 bar is 5/8" (16) in diameter.
- Welded wire fabric consists of a grid of steel wires or bars welded together at all points of intersection. The fabric is typically used to provide temperature reinforcement for slabs but the heavier gauges can also be used to reinforce concrete walls. The fabric is designated by the size of the grid in inches followed by a number indicating the wire gauge or cross-sectional area; see 3.18 for typical sizes.


**ASTM Standard Reinforcing Bars**

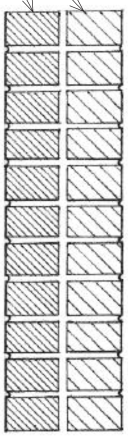
| Bar Size | Nominal Dimensions | | |
|---|---|---|---|
| | Diameter inches (mm) | Cross-Sectional Area sq. in. (mm$^2$) | Weight plf (N/m) |
| #3 | 0.375 (10) | 0.11 (71) | 0.38 (5.5) |
| #4 | 0.50 (13) | 0.20 (129) | 0.67 (9.7) |
| #5 | 0.625 (16) | 0.31 (200) | 1.04 (15.2) |
| #6 | 0.75 (19) | 0.44 (284) | 1.50 (21.9) |
| #7 | 0.875 (22) | 0.60 (387) | 2.04 (29.8) |
| #8 | 1.00 (25) | 0.79 (510) | 2.67 (39.0) |
| #9 | 1.125 (29) | 1.00 (645) | 3.40 (49.6) |
| #10 | 1.25 (32) | 1.27 (819) | 4.30 (62.8) |

- Common brick, also called building brick, is made for general building purposes and not specially treated for color and texture.
- Face brick is made of special clays for facing a wall, often treated to produce the desired color and surface texture.

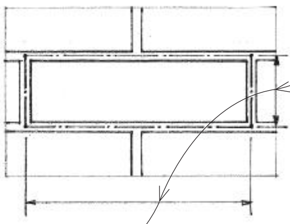


### Brick Types

- Brick type designates the permissible variation in size, color, chippage, and distortion allowed in a face brick unit.
- FBX is face brick suitable for use where a minimum variation in size, narrow color range, and high degree of mechanical perfection are required.
- FBS is face brick suitable for use where a wider color range and greater variation in size are permitted than for type FBX.
- FBA is face brick suitable for use where particular effects are desired resulting from nonuniformity in size, color, and texture of the individual units.



- Efflorescence is a white, powdery deposit that forms on an exposed masonry or concrete surface, caused by the leaching and crystallization of soluble salts from within the material. Reducing moisture absorption is the best assurance against efflorescence.



| Brick Unit | Nominal Dimensions thickness x height x length | | Modular Coursing | |
|---|---|---|---|---|
| | inches | mm | inches | mm |
| Modular | 4 x 2-2/3 x 8 | 100 x 68 x 205 | 3C = 8 | 205 |
| Norman | 4 x 2-2/3 x 12 | 100 x 68 x 305 | 3C = 8 | 205 |
| Engineer | 4 x 3-1/5 x 8 | 100 x 81 x 205 | 5C = 16 | 405 |
| Norwegian | 4 x 3-1/5 x 12 | 100 x 81 x 305 | 5C = 16 | 405 |
| Roman | 4 x 2 x 12 | 100 x 51 x 305 | 2C = 4 | 100 |
| Utility | 4 x 4 x 12 | 100 x 100 x 305 | 1C = 4 | 100 |

- See 5.26 for modular brick coursing and 5.27 for masonry bonding patterns.

Masonry refers to building with units of various natural or manufactured products, such as brick, stone, or concrete block, usually with the use of mortar as a bonding agent. The modular aspect (i.e., uniform sizes and proportional relationships) of unit masonry distinguishes it from most of the other building materials discussed in this chapter. Because unit masonry is structurally most effective in compression, the masonry units should be laid up in such a way that the entire masonry mass acts as an entity.

### Brick

Brick is a masonry unit of clay, formed into a rectangular prism while plastic and hardened by firing in a kiln or drying in the sun.

- Soft-mud process refers to forming brick by molding relatively wet clay having a moisture content of 20% to 30%.
- Sandstruck brick is formed in the soft-mud process with a mold lined with sand to prevent sticking, producing a matte-textured surface.
- Waterstruck brick is formed in the soft-mud process with a mold lubricated with water to prevent sticking, producing a smooth, dense surface.
- Stiff-mud process refers to forming brick and structural tile by extruding stiff but plastic clay having a moisture content of 12% to 15% through a die and cutting the extrusion to length with wires before firing.
- Dry-press process refers to forming brick by molding relatively dry clay having a moisture content of 5% to 7% under high pressure, resulting in sharp-edged, smooth-surfaced bricks.

- The actual dimensions of brick units vary due to shrinkage during the manufacturing process. The nominal dimensions given in the table include the thickness of the mortar joints, which vary from 1/4" to 1/2" (6 to 13).

### Brick Grades

- Brick grade designates the durability of a brick unit when exposed to weathering. The United States is divided into three weathering regions—severe, moderate, and negligible—according to annual winter rainfall and the annual number of freezing-cycle days. Brick is graded for use in each region according to compressive strength, maximum water absorption, and maximum saturation coefficient.
- SW is brick suitable for exposure to severe weathering, as when in contact with the ground or used on surfaces likely to be permeated with water in subfreezing temperatures; minimum compressive strength of 2500 psi (17,235 kPa).
- MW is brick suitable for exposure to moderate weathering, as when used above grade on surfaces unlikely to be permeated with water in subfreezing temperatures; minimum compressive strength of 2200 psi (15,167 kPa).
- NW is brick suitable for exposure to negligible weathering, as when used as a backup or in interior masonry; minimum compressive strength of 1250 psi (8,618 kPa).
- The allowable compressive stresses in masonry walls are much less than the values given here because the quality of the masonry units, mortar, and workmanship may vary. See table on 5.15 for these values.

## Concrete Masonry

Concrete masonry units (CMU) are precast of portland cement, fine aggregate, and water, molded into various shapes to satisfy various construction conditions. The availability of these types varies with locality and manufacturer.

- Concrete block, often incorrectly referred to as cement block, is a hollow concrete masonry unit having a compressive strength from 600 to 1500 psi (4137 to 10,342 kPa).
- Normal-weight block is made from concrete weighing more than 125 pcf (2000 kg/$m^3$).
- Medium-weight block is made from concrete weighing from 105 to 125 pcf (1680 to 2000 kg/$m^3$).
- Lightweight block is made from concrete weighing 105 pcf (1680 kg/$m^3$) or less.

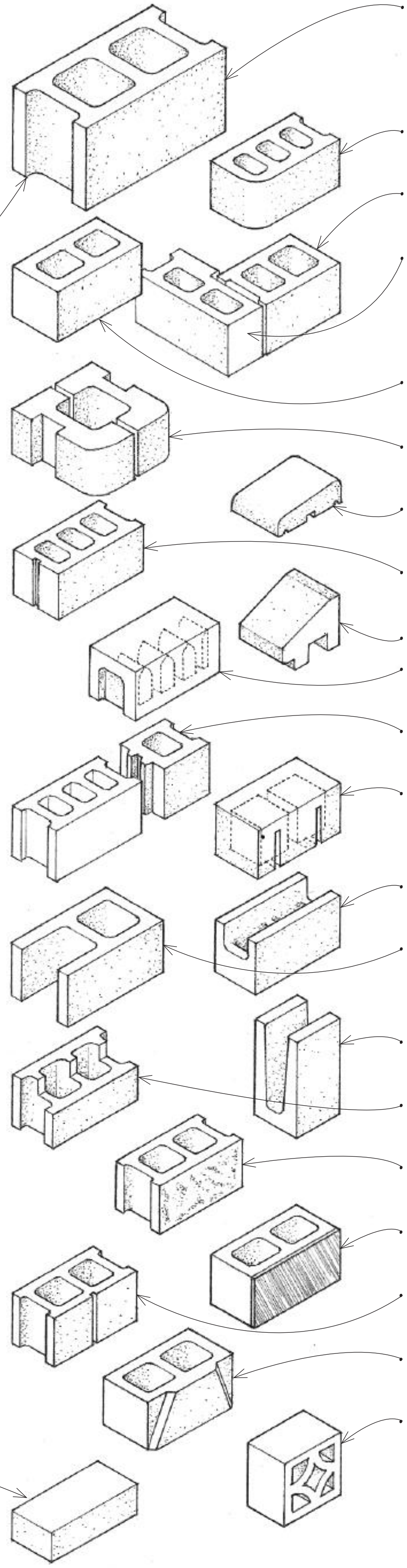
## CMU Grades

- Grade N is a loadbearing concrete masonry unit suitable for use both above and below grade in walls exposed to moisture or weather; grade N units have a compressive strength from 800 to 1500 psi (5516 to 10,342 kPa).
- Grade S is a loadbearing concrete masonry unit limited to use above grade, in exterior walls with weather-protective coatings, or in walls not exposed to moisture or weather; grade S units have a compressive strength from 600 to 1000 psi (4137 to 6895 kPa).

## CMU Types

- Type I is a concrete masonry unit manufactured to a specified limit of moisture content in order to minimize the drying shrinkage that can cause cracking.
- Type II is a concrete masonry unit not manufactured to a specified limit moisture content.

- Concrete brick is a solid rectangular concrete masonry unit usually identical in size to a modular clay brick but also available in 12" (305) lengths; concrete brick units have a compressive strength from 2000 to 3000 psi (13,790 to 20,685 kPa).



- Stretcher blocks have two or three cores and nominal dimensions of 8" x 8" x 16" (205 x 205 x 405); 4", 6", 10" and 12" (100, 150, 255 and 305) wide units are also available.
- Bullnose blocks have one or more rounded exterior corners.
- Corner blocks have a solid end face for use in constructing the end or corner of a wall.
- Corner-return blocks are used at the corners of 6", 10", and 12" (150, 255, and 305) walls to maintain horizontal coursing with the appearance of full- and half-length units.
- Double-corner blocks have solid faces at both ends and are used in constructing a masonry pier.
- Pilaster blocks are used in constructing a plain or reinforced masonry pilaster.
- Coping blocks are used in constructing the top or finishing course of a masonry wall.
- Sash or jamb blocks have an end slot or rabbet to receive the jamb of a door or window frame.
- Sill blocks have a wash to shed rainwater from a sill.
- Cap blocks have a solid top for use as a bearing surface in the finishing course of a foundation wall.
- Control-joint blocks are used in constructing a vertical control joint.
- Sound-absorbing masonry units have a solid top and a slotted face shell, and sometimes a fibrous filler, for increased sound absorption.
- Bond-beam blocks have a depressed section in which reinforcing steel can be placed for embedment in grout.
- Open-end blocks have one end open in which vertical steel reinforcement can be placed for embedment in grout.
- Lintel blocks have a U-shaped section in which reinforcing steel can be placed for embedment in grout.
- Header blocks have a portion of one face shell removed to receive headers in a bonded masonry wall.
- Split-face blocks are split lengthwise by a machine after curing to produce a rough, fractured face texture.
- Faced blocks have a special ceramic, glazed, or polished face.
- Scored blocks have one or more vertical grooves that simulate raked joints.
- Shadow blocks have a face shell with a pattern of beveled recesses.
- Screen blocks, used especially in tropical architecture, have a decorative pattern of transverse openings for admitting air and excluding sunlight.

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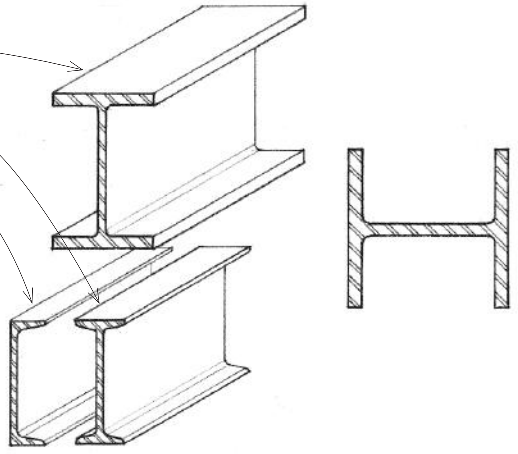
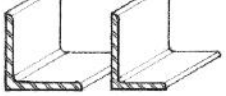
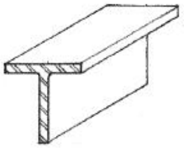
- W shape (wide flange)
- S shape (American standard)
- C shape (American standard channel)

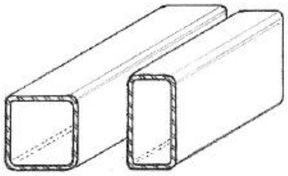




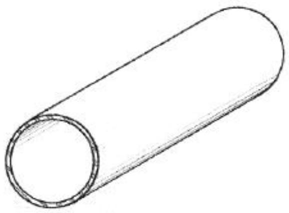
- L shapes (equal and unequal leg angles)



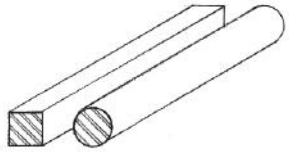
- WT shape (structural tee cut from W shape)



- Structural tubing (square or rectangular)



- Structural tubing (circular pipe)



- Bars (square, round, and flat)

### Steel Shapes

- Refer to the American Institute of Steel Construction (AISC) *Manual of Steel Construction* for complete listing of sizes and weights.

Steel refers to any of various iron-based alloys having a carbon content less than that of cast iron and more than that of wrought iron, and having qualities of strength, hardness, and elasticity varying according to composition and heat treatment. Steel is used for light and heavy structural framing, as well as a wide range of building products such as windows, doors, hardware, and fastenings. As a structural material, steel combines high strength and stiffness with elasticity. Measured in terms of weight to volume, it is probably the strongest low-cost material available. Although classified as an incombustible material, steel becomes ductile and loses its strength when subject to temperatures over 1000°F (538°C). When used in buildings requiring fire-resistive construction, structural steel must be coated, covered, or enclosed with fire-resistant materials; see A.12. Because it is normally subject to corrosion, steel must be painted, galvanized, or chemically treated for protection against oxidation.

- Carbon steel is unalloyed steel in which the residual elements, such as carbon, manganese, phosphorus, sulfur, and silicon, are controlled. Any increase in carbon content increases the strength and hardness of the steel but reduces its ductility and weldability.
  - Mild or soft steel is a low-carbon steel containing from 0.15% to 0.25% carbon.
  - Medium steel is a carbon steel containing from 0.25% to 0.45% carbon; most structural steel is medium-carbon steel; ASTM A36 is the most common strength grade with a yield point of 36,000 psi (248,220 kPa).
  - Hard steel is a high-carbon steel containing from 0.45% to 0.85% carbon.
  - Spring steel is a high-carbon steel containing 0.85% to 1.8% carbon.

- Alloy steel refers to a carbon steel to which various elements, such as chromium, cobalt, copper, manganese, molybdenum, nickel, tungsten, or vanadium, have been added in a sufficient amount to obtain particular physical or chemical properties.
  - Stainless steel contains a minimum of 12% chromium, sometimes with nickel, manganese, or molybdenum as additional alloying elements, so as to be highly resistant to corrosion.
  - High-strength low-alloy steel is a low-carbon steel containing less than 2% alloys in a chemical composition specifically developed for increased strength, ductility, and resistance to corrosion; ASTM A572 is the most common strength grade with a yield point of 50,000 psi (344,750 kPa).
  - Weathering steel is a high-strength, low-alloy steel that forms an oxide coating when exposed to rain or moisture in the atmosphere; this coating adheres firmly to the base metal and protects it from further corrosion. Structures using weathering steel should be detailed to prevent the small amounts of oxide carried off by rainwater from staining adjoining materials.
  - Tungsten steel is an alloy steel containing 10% to 20% tungsten for increased hardness and heat retention at high temperatures.

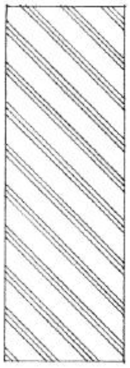
Other ferrous metals used in building construction include:

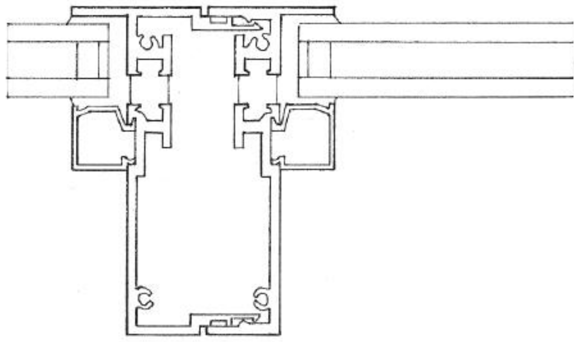
- Cast iron, a hard, brittle, nonmalleable iron-based alloy containing 2.0% to 4.5% carbon and 0.5% to 3% silicon, cast in a sand mold and machined to make many building products, such as piping, grating, and ornamental work
- Malleable cast iron, which has been annealed by transforming the carbon content into graphite or removing it completely
- Wrought iron, a tough, malleable, relatively soft iron that is readily forged and welded, having a fibrous structure containing approximately 0.2% carbon and a small amount of uniformly distributed slag
- Galvanized iron, which is coated with zinc to prevent rust

CSI MasterFormat 05 12 00: Structural Steel Framing

Nonferrous metals contain no iron. Aluminum, copper, and lead are nonferrous metals commonly used in building construction.

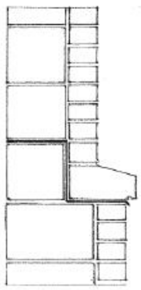
Aluminum is a ductile, malleable, silver-white metallic element that is used in forming many hard, light alloys. Its natural resistance to corrosion is due to the transparent film of oxide that forms on its surface; this oxide coating can be thickened to increase corrosion resistance by an electrical and chemical process known as anodizing. During the anodizing process, the naturally light, reflective surface of aluminum can be dyed a number of warm, bright colors. Care must be taken to insulate aluminum from contact with other metals to prevent galvanic action. It should also be isolated from alkaline materials such as wet concrete, mortar, and plaster.



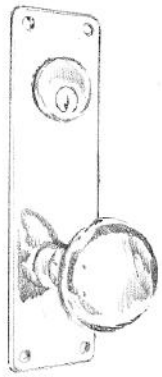


Aluminum is widely used in extruded and sheet forms for secondary building elements such as windows, doors, roofing, flashing, trim, and hardware. For use in structural framing, high-strength aluminum alloys are available in shapes similar to those of structural steel. Aluminum sections may be welded, bonded with adhesives, or mechanically fastened.

Copper is a ductile, malleable metallic element that is widely used for electrical wiring, water piping, and in the manufacture of alloys, as bronze and brass. Its color and resistance to corrosion also make it an excellent roofing and flashing material. However, copper will corrode aluminum, steel, stainless steel, and zinc. It should be fastened, attached, or supported only with copper or carefully selected brass fittings. Contact with red cedar in the presence of moisture will cause premature deterioration of the copper.



Brass refers to any of various alloys consisting essentially of copper and zinc, used for windows, railings, trim, and finish hardware. Alloys that are brass by definition may have names that include the word bronze, as architectural bronze.



Lead is a heavy, soft, malleable, bluish-gray metallic element used for flashing, sound isolation, and radiation shielding. Although lead is the heaviest of the common metals, its pliability makes it desirable for application over uneven surfaces. Lead dust and vapors are toxic.

### Galvanic Action

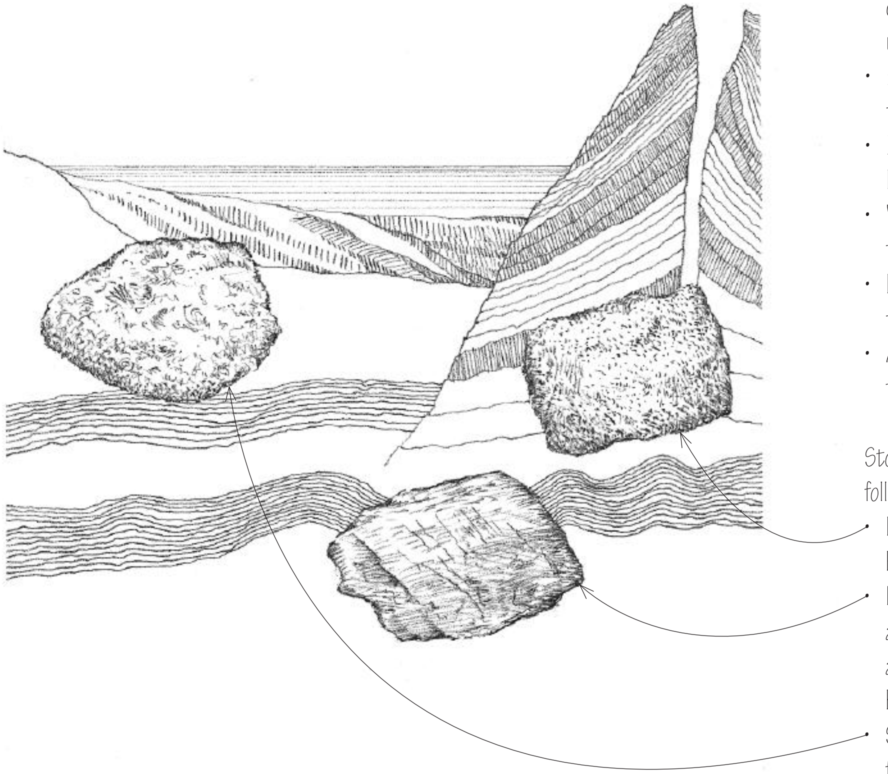
Galvanic action can occur between two dissimilar metals when enough moisture is present for electric current to flow. This electric current will tend to corrode one metal while plating the other. The severity of the galvanic action depends on how far apart the two metals are on the galvanic series table.

| | | |
|---|---|---|
| • Gold, platinum | Most noble | |
| • Titanium | Cathode | (+) |
| • Silver | | |
| • Stainless steel | | |
| • Bronze | | |
| • Copper | | |
| • Brass | | |
| • Nickel | | |
| • Tin | | |
| • Lead | | |
| • Cast iron | | |
| • Mild steel | | |
| • Aluminum, 2024 T4 | | |
| • Cadmium | | |
| • Aluminum, 1100 | | |
| • Zinc | Anode | (−) |
| • Magnesium | Least noble | |

• Current flows from positive to negative.

### Galvanic Series

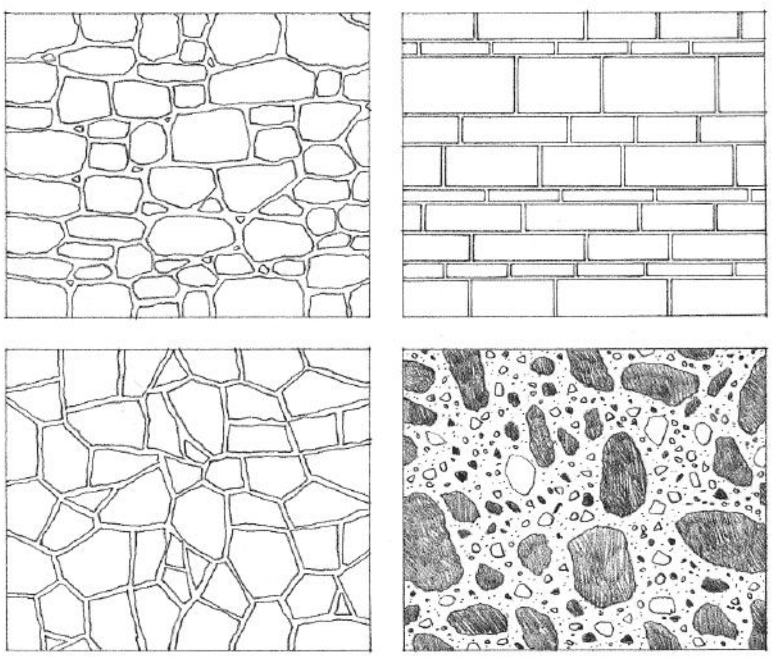
- The galvanic series lists metals in order from most noble to least noble.
- Noble metals, such as gold and silver, resist oxidation when heated in air and solution by inorganic acids.
- The metal that is lower in the list is sacrificial and corrodes when enough moisture is present for electric current to flow.
- The farther apart two metals are on the list, the more susceptible the least noble one is to corrosive deterioration.



Stone is an aggregate or combination of minerals, each of which is composed of inorganic chemical substances. To qualify as a construction material, stone should have the following qualities:

- Strength: Most types of stone have more than adequate compressive strength. The shear strength of stone, however, is usually about 1/10 of its compressive strength.
- Hardness: Hardness is important when stone is used for flooring, paving, and stair treads.
- Durability: Resistance to the weathering effects of rain, wind, heat, and frost action is necessary for exterior stonework.
- Workability: A stone's hardness and grain texture must allow it to be quarried, cut, and shaped.
- Density: A stone's porosity affects its ability to withstand frost action and staining.
- Appearance: Appearance factors include color, grain, and texture.

Stone may be classified according to geological origin into the following types:
- Igneous rock, such as granite, obsidian, and malachite, is formed by the crystallization of molten magma.
- Metamorphic rock, such as marble and slate, has undergone a change in structure, texture, or composition due to natural agencies, such as heat and pressure, especially when the rock becomes harder and more crystalline.
- Sedimentary rock, such as limestone, sandstone, and shale, is formed by the deposition of sediment by glacial action.

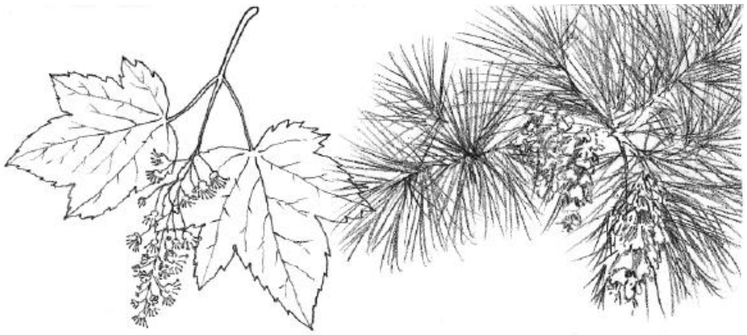


As a loadbearing wall material, stone is similar to modular unit masonry. Although stone masonry is not necessarily uniform in size, it is laid up with mortar and used in compression. Almost all stone is adversely affected by sudden changes in temperature and should not be used where a high degree of fire resistance is required.

Stone is used in construction in the following forms:
- Rubble consists of rough fragments of broken stone that have at least one good face for exposure in a wall.
- Dimension stone is quarried and squared stone 2' (610) or more in length and width and of specified thickness, used commonly for wall panels, cornices, copings, lintels, and flooring.
- Flagstone refers to flat stone slabs used for flooring and horizontal surfacing.
- Crushed stone is used as aggregate in concrete products.

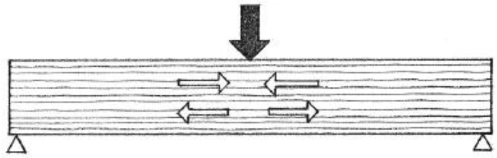
- See 5.33 for types of stone masonry.

As a construction material, wood is strong, durable, light in weight, and easy to work. In addition, it offers natural beauty and warmth to sight and touch. Although it has become necessary to employ conservation measures to ensure a continued supply, wood is still used on construction in many and varied forms.

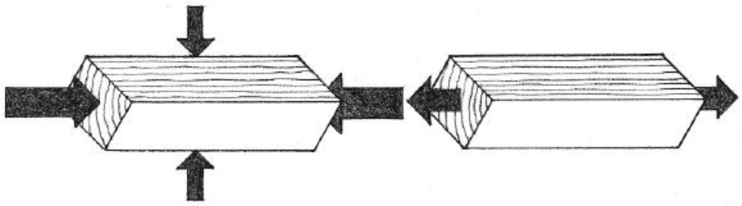


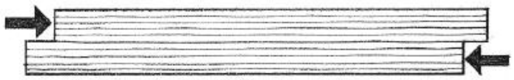
There are two major classes of wood—softwood and hardwood. These terms are not descriptive of the actual hardness, softness, or strength of a wood. Softwood is the wood from any of various predominantly evergreen, cone-bearing trees, such as pine, fir, hemlock, and spruce, used for general construction. Hardwood is the wood from a broad-leaved flowering tree, such as cherry, maple, or oak, typically used for flooring, paneling, furniture, and interior trim.

The manner in which a tree grows affects its strength, its susceptibility to expansion and contraction, and its effectiveness as an insulator. Tree growth also affects how pieces of sawn wood may be joined to form the structure and enclosure of a building.



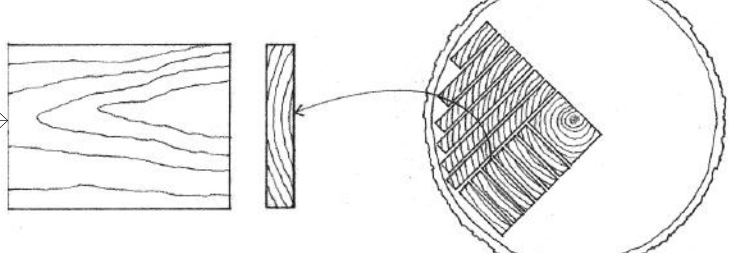
Grain direction is the major determining factor in the use of wood as a structural material. Tensile and compressive forces are best handled by wood in a direction parallel to the grain. Typically, a given piece of wood will withstand $^1/_3$ more force in compression than in tension parallel to its grain. The allowable compressive force perpendicular to its grain is only about $^1/_5$ to $^1/_2$ of the allowable compressive force parallel to the grain. Tensile forces perpendicular to the grain will cause the wood to split. The shear strength of wood is greater across its grain than parallel to the grain. It is therefore more susceptible to horizontal shear than to vertical shear.





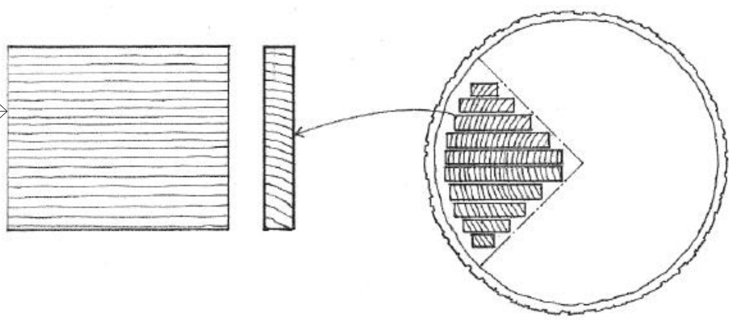
The manner in which lumber is cut from a log affects its strength as well as its appearance. Plainsawing a squared log into boards with evenly spaced parallel cuts results in flat grain lumber that:

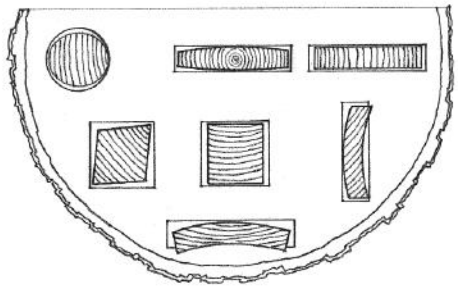
- May have a variety of noticeable grain patterns;
- Tends to twist and cup, and wears unevenly;
- Tends to have raised grain;
- Shrinks and swells less in thickness, more in width.

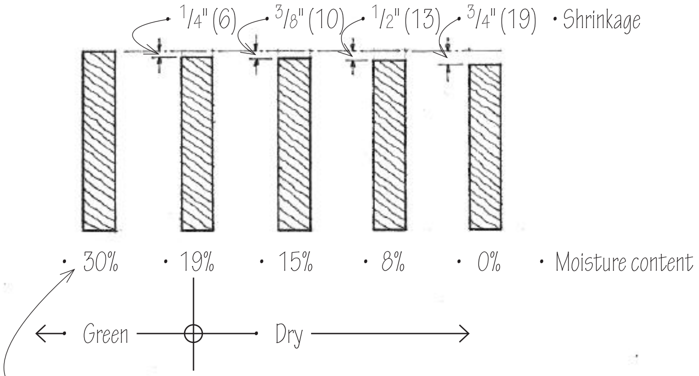


Quartersawing logs approximately at right angles to the annual rings results in edge or vertical grain lumber that:

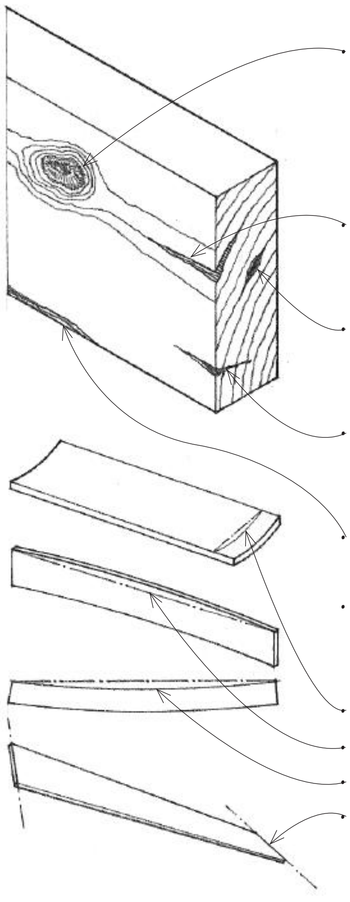
- Has more even grain patterns;
- Wears more evenly with less raised grain and warping;
- Shrinks and swells less in width, more in thickness;
- Is less affected by surface checks;
- Results in more waste in cutting and is more expensive.








• Fiber saturation point is the stage at which the cell walls are fully saturated but the cell cavities are void of water, ranging from a moisture content of 25% to 32% for commonly used species. Further drying results in shrinkage and generally greater strength, stiffness, and density of the wood.



- Knots are hard nodes of wood that occur where branches join the trunk of a tree, appearing as circular, cross-grained masses in a piece of sawn lumber. In the structural grading of a wood piece, knots are restricted by size and location.
- Shakes are separations along the grain of a wood piece, usually between the annual rings, caused by stresses on a tree while standing or during felling.
- Pitch pockets are well-defined openings between the annual rings of a softwood, containing or having once contained solid or liquid pitch.
- Checks are lengthwise separations of wood across the annual rings, caused by uneven or rapid shrinkage during the seasoning process.
- Wane is the presence of bark or absence of wood at a corner or along an edge of a piece.
- Warping is usually caused by uneven drying during the seasoning process or by a change in moisture content.
- Cup is a curvature across the face of a wood piece.
- Bow is a curvature along the length of a wood piece.
- Crook is a curvature along the edge of a wood piece.
- Twist results from the turning of the edges of a wood piece in opposite directions.

To increase its strength, stability, and resistance to fungi, decay, and insects, wood is seasoned—dried to reduce its moisture content—by air-drying or kiln-drying under controlled conditions of heat, air circulation, and humidity. It is impossible to completely seal a piece of wood to prevent changes in its moisture content. Below a moisture content of about 30%, wood expands as it absorbs moisture and shrinks as it loses moisture. This possibility of shrinkage and swelling must always be taken into account when detailing and constructing wood joints, both in small- and large-scale work.

Shrinkage tangential to the wood grain is usually twice as much as radial shrinkage. Vertical grain lumber shrinks uniformly while plainsawn cuts near a log's perimeter will cup away from the center. Because the thermal expansion of wood is generally much less than volume changes due to changes in moisture content, moisture content is therefore the controlling factor.

Wood is decay-resistant when its moisture content is under 20%. If installed and maintained below this moisture content level, wood will usually not rot. Species that are naturally resistant to decay-causing fungi include redwood, cedar, bald cypress, black locust, and black walnut. Insect-resistant species include redwood, eastern red cedar, and bald cypress.

Preservative treatments are available to further protect wood from decay and insect attack. Of these, pressure treatment is the most effective, especially when the wood is in contact with the ground. There are three types of preservatives.

- Water-borne preservatives leave the wood clean, odorless, and readily paintable; preservatives do not leach out when exposed to weather.
  - AWPB (American Wood Preservers Bureau)
  - LP-2 (LP-22 for ground contact)
- Oil-borne preservatives may color the wood, but treated wood is paintable; pentachlorophenol is highly toxic.
  - AWPB LP-3 (LP-33 for ground contact)
- Creosote treatment leaves wood with colored, oily surfaces; odor remains for a long period; used especially in marine and saltwater installations.
  - AWPB LP-5 (LP-55 for ground contact)

Defects affect the grading, appearance, and use of wood members. They may also affect a wood's strength, depending on their number, size, and location. Defects include the natural characteristics of wood, such as knots, shakes, and pitch pockets, as well as the effects of manufacturing, such as checks and warping.

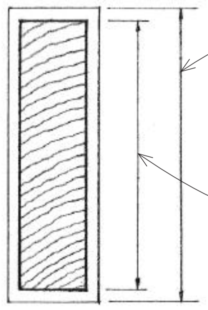
Because of the diversity of its applications and its use for remanufacturing purposes, hardwood is graded according to the amount of clear, usable lumber in a piece that may be cut into smaller pieces of a certain grade and size. Softwood is classified in the following manner.

- Yard lumber: softwood lumber intended for general building purposes, including boards, dimension lumber, and timbers
  - Boards: less than 2" (51) thick and 2" (51) or more wide, graded for appearance rather than strength and used as siding, subflooring, and interior trim
  - Dimension lumber: from 2" to 4" (51 to 100) thick and 2" (51) or more wide, graded for strength rather than appearance, and used for general construction
    - Joists and planks: from 2" to 4" (51 to 100) thick and more than 4" (100) wide, graded primarily with respect to bending strength when loaded either on the narrow face as a joist or on the wide face as a plank
    - Light framing: 2" to 4" (51 to 100) thick and 2" to 4" (51 to 100) wide, intended for use where high strength values are not required
    - Decking: 2" to 4" (51 to 100) thick and 4" (100) or more wide, graded primarily with respect to bending strength when loaded on the wide face
  - Timbers: 5" (125) or more in the least dimension, graded for strength and serviceability, and often stocked in green, undressed condition
- Factory and shop lumber: sawn or selected primarily for further manufacture into doors, windows, and millwork, and graded according to the amount of usable wood that will produce cuttings of a specified size and quality
- Structural lumber: dimension lumber and timbers graded either by visual inspection or mechanically on the basis of strength and intended use
  - Beams and stringers: at least 5" (125) thick and a width more than 2" (51) greater than the thickness, graded primarily with respect to bending strength when loaded on the narrow face
  - Posts and timbers: 5" x 5" (125 x 125) or larger and a width not more than 2" (51) greater than the thickness, graded primarily for use as columns carrying an axial load

Lumber is specified by species and grade. Each piece of lumber is graded for structural strength and appearance. Structural lumber may be graded visually by trained inspectors according to quality-reducing characteristics that affect strength, appearance, or utility, or by a machine that flexes a test specimen, measures its resistance to bending, calculates its modulus of elasticity, and electronically computes the appropriate stress grade, taking into account such factors as the effects of knots, slope of grain, density, and moisture content.

- Each piece of lumber has a grademark indicating the assigned stress grade, mill of origin, moisture content at time of manufacture, species or species group, and the grading authority.
- Stress grade is a grade of structural lumber for which a set of base values and corresponding modulus of elasticity is established for a species or group of species by a grading agency.


- Design value: any of the allowable unit stresses for a species and grade of structural lumber obtained by modifying the base value by factors related to size and conditions of use
- = Base value: any of the allowable unit stresses for bending, compression perpendicular and parallel to grain, tension parallel to grain, horizontal shear, and corresponding modulus of elasticity, established by a grading agency for various species and grades of structural lumber
- x Base values must be adjusted first for size and then for conditions of use. Size-adjusted values are increased for repetitive members and members subject to short-term loading, and decreased for members exceeding a moisture content of 19% in use.



- Lumber is measured in board feet; 1 board foot is equal to the volume of a piece whose nominal dimensions are 12" (305) square and 1" (25) thick.
- Nominal dimensions are the dimensions of a piece of lumber before drying and surfacing, used for convenience in defining size and computing quantity. Nominal dimensions are always written without inch marks (").
- Dressed sizes are the actual dimensions of a piece of lumber after seasoning and surfacing, from 3/8" to 3/4" (10 to 19) less than the nominal dimensions.
- For dressed sizes:
  - Subtract 1/4" (6) from nominal dimensions up to 2" (51);
  - Subtract 1/2" (13) from nominal dimensions of 2" to 6" (51 to 150);
  - Subtract 3/4" (19) from nominal dimensions greater than 6" (150).
- Lumber is generally available in lengths from 6' to 24' (1830 to 7315), in multiples of 2' (610).