SECTION ELEVEN

WALL, FLOOR, AND CEILING SYSTEMS

Frederick S. Merritt*
Consulting Engineer,
West Palm Beach, Florida

This section discusses design and construction of systems generally used for enclosing buildings and the spaces within them. (Some such systems, such as roofs and foundations, however, are treated in other sections, because of their special functions in addition to enclosure of spaces.) The systems covered in this section, as described in Art. 1.7, include exterior walls; interior walls, or partitions; floors; and ceilings.

Each of these systems usually consists of one or more facing subsystems and a structural subsystem that supports them. The facing subsystems may be the surfaces of the structural subsystem or separate entities that enclose that subsystem. They serve esthetic purposes, provide privacy, and bar, or at least restrict, passage of people or other moving objects, water, air, sound, heat and also often light.

Wood structural subsystems are discussed in Sec. 10, and concrete is discussed in Sec. 9. Basic principles of waterproofing building exteriors are presented in Art. 3.4.2. This section describes techniques applicable to unit masonry and curtain walls.

Floors provide not only a horizontal separation of interior building spaces but also a surface on which human activities can take place and on which materials and equipment can be stored. The structural subsystem usually consists of a slab or deck and also often of beams that support it. These are described in Secs. 7 through 10. This section discusses constructions used for the upper facing, or floor coverings, which serve esthetic purposes and act as a wearing surface. The bottom facing, or ceiling, may be the bottom surface of the slab or deck or a separate entity, such as a gypsum-plaster membrane, which is also discussed in this section, or acoustical tile.

*Deceased.

MASONRY WALLS

Masonry comprises assemblages of nonmetallic, incombustible materials, such as stone, brick, structural clay tile, concrete block, glass block, gypsum block, or adobe brick. Unit masonry consists of pieces of such materials, usually between 4 and 24 in in length and height and between 4 and 12 in in thickness. The units are bonded together with mortar or other cementitious materials.

Walls and partitions are classified as load-bearing and non-load-bearing. Different design criteria are applied to the two types.

Minimum requirements for both types of masonry walls are given in ANSI Standard Building Code Requirements for Masonry, A41.1 and ANSI Standard Building Code Requirements for Reinforced Masonry, A41.2, American National Standards Institute; Building Code Requirements for Engineered Brick Masonry, Brick Institute of America, and ACI Standard Building Code Requirements for Concrete Masonry Structures, ACI 531, American Concrete Institute.

Like other structural materials, masonry may be designed by application of engineering principles. In the absence of such design, the empirical rules given in this section and adopted by building codes may be used.

11.1 MASONRY DEFINITIONS

Following are some of the terms most commonly encountered in masonry construction:

Architectural Terra Cotta. (See Ceramic Veneer.)

Ashlar Masonry. Masonry composed of rectangular units usually larger in size than brick and properly bonded, having sawed, dressed, or squared beds. It is laid in mortar.

Bearing Walls. (See Load-Bearing Wall.)

Bonder. (See Header.)

Brick. A rectangular masonry building unit, not less than 75% solid, made from burned clay, shale, or a mixture of these materials.

Buttress. A bonded masonry column built as an integral part of a wall and decreasing in thickness from base to top, though never thinner than the wall. It is used to provide lateral stability to the wall.

Ceramic Veneer. Hard-burned, non-load-bearing, clay building units, glazed or unglazed, plain or ornamental.

Chase. A continuous recess in a wall to receive pipes, ducts, conduits.

Column. A compression member with width not exceeding 4 times the thickness, and with height more than 3 times the least lateral dimension.

Concrete Block. A machine-formed masonry building unit composed of portland cement, aggregates, and water.

Coping. A cap or finish on top of a wall, pier, chimney, or pilaster to prevent penetration of water to masonry below.

Corbel. Successive course of masonry projecting from the face of a wall to increase its thickness or to form a shelf or ledge (Fig. 11.3*f*).

Course. A continuous horizontal layer of masonry units bonded together (Fig. 11.3).

Cross-Sectional Area. Net cross-sectional area of a masonry unit is the gross cross-sectional area minus the area of cores or cellular spaces. Gross cross-sectional area of scored units is determined to the outside of the scoring, but the cross-sectional area of the grooves is not deducted to obtain the net area.

Eccentricity. The normal distance between the centroidal axis of a member and the component of resultant load parallel to that axis.

Effective Height. The height of a member to be assumed for calculating the slenderness ratio.

Effective Thickness. The thickness of a member to be assumed for calculating the slenderness ratio.

Grout. A mixture of cementitious material, fine aggregate, and sufficient water to produce pouring consistency without segregation of the constituents.

Grouted Masonry. Masonry in which the interior joints are filled by pouring grout into them as the work progresses.

Header (Bonder). A brick or other masonry unit laid flat across a wall with end surface exposed, to bond two wythes (Fig. 11.1*b*).

Height of Wall. Vertical distance from top of wall to foundation wall or other intermediate support.

Hollow Masonry Unit. Masonry with net cross-sectional area in any plane parallel to the bearing surface less than 75% of its gross cross-sectional area measured in the same plane.

Lateral Support. Members such as cross walls, columns, pilasters, buttresses, floors, roofs, or spandrel beams that have sufficient strength and stability to resist horizontal forces transmitted to them may be considered lateral supports.

Load-Bearing Wall. A wall that supports any vertical load in addition to its own weight.

Masonry. A built-up construction or combination of masonry units bonded together with mortar or other cementitious material.

Mortar. A plastic mixture of cementitious materials, fine aggregates, and water.

Partition. An interior non-bearing wall one story or less in height.

Pier. An isolated column of masonry. A bearing wall not bonded at the sides into associated masonry is considered a pier when its horizontal dimension measured at right angles to the thickness does not exceed 4 times its thickness.

Pilaster. A bonded or keyed column of masonry built as part of a wall, but thicker than the wall, and of uniform thickness throughout its height. It serves as a vertical beam, column, or both.

Prism. An assemblage of brick and mortar for the purpose of laboratory testing for design strength, quality control of materials, and workmanship. Minimum height for prisms is 12 in, and the slenderness ratio should lie between 2 and 5.

Rubble:

Coursed Rubble. Masonry composed of roughly shaped stones fitting approximately on level beds, well bonded, and brought at vertical intervals to continuous level beds or courses.

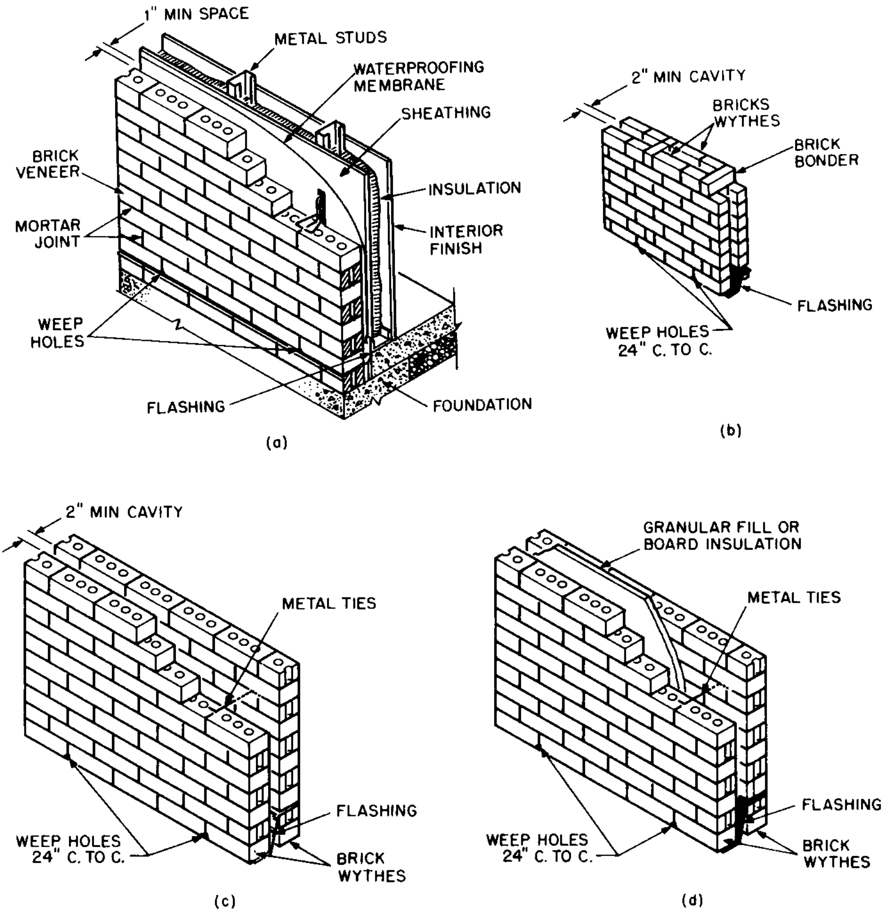


FIGURE 11.1 Brick exterior walls: (*a*) brick veneer with metal-stud framing; (*b*) masonry-bonded hollow walls; (*c*) hollow wall with metal ties between wythes; (*d*) insulated cavity wall.

Random Rubble. Masonry composed of roughly shaped stones, well bonded and brought at irregular vertical intervals to discontinuous but approximately level beds or courses.

Rough or Ordinary Rubble. Masonry composed of nonshaped field stones laid without regularity of coursing, but well bonded.

Slenderness Ratio. Ratio of the effective height of a member to its effective thickness.

Solid Masonry Unit. A masonry unit with net cross-sectional area in every plane parallel to the bearing surface 75% or more of its gross cross-sectional area measured in the same plane.

Solid Masonry Wall. A wall built of solid masonry units laid contiguously, with joints between units filled with mortar or grout.

Stretcher. A masonry unit laid with length horizontal and parallel with the wall face (Fig. 12.3).

Veneer. A wythe securely attached to a wall but not considered as sharing load or adding strength to it (Fig. 11.1*a*).

Virtual Eccentricity. The eccentricity of resultant axial loads required to produce axial and bending stresses equivalent to those produced by applied axial and transverse loads.

Wall. Vertical or near-vertical construction, with length exceeding three times the thickness, for enclosing space or retaining earth or stored materials.

Bearing Wall. A wall that supports any vertical load in addition to its own weight.

Cavity Wall. (See *Hollow Wall* below.)

Curtain Wall. A non-load-bearing exterior wall.

Faced Wall. A wall in which the masonry facing and the backing are of different materials and are so bonded as to exert a common reaction under load.

Hollow Wall. A wall of masonry so arranged as to provide an air space within the wall between the inner and outer wythes (Fig. 11.1*b*, *c*, and *d*). A cavity wall is built of masonry units or plain concrete, or of a combination of these materials, so arranged as to provide an airspace within the wall, which may be filled with insulation, and in which inner and outer wythes are tied together with metal ties (Fig. 11.1*d*).

Nonbearing Wall. A wall that supports no vertical load other than its own weight.

Party Wall. A wall on an interior lot line used or adapted for joint service between two buildings.

Shear Wall. A wall that resists horizontal forces applied in the plane of the wall.

Spandrel Wall. An exterior curtain wall at the level of the outside floor beams in multistory buildings. It may extend from the head of the window below the floor to the sill of the window above.

Veneered Wall. A wall having a facing of masonry or other material securely attached to a backing, but not so bonded as to exert a common reaction under load (Fig. 11.1*a*).

Wythe. Each continuous vertical section of a wall one masonry unit in thickness (Fig. 11.1).

11.2 QUALITY OF MATERIALS FOR MASONRY

Materials used in masonry construction should be capable of meeting the requirements of the applicable standard of ASTM.

Second-hand materials should be used only with extreme caution. Much salvaged brick, for example, comes from demolition of old buildings constructed of solid brick in which hard-burned units were used on the exterior and salmon units as backup. Because the color differences that guided the original masons in sorting and selecting bricks become obscured with exposure and contact with mortar, there is a definite danger that the salmon bricks may be used for exterior exposure and may disintegrate rapidly. Masonry units salvaged from chimneys are not recommended because they may be impregnated with oils or tarry material.

Design of load-bearing brick structures may be based on rational engineering analysis instead of the empirical requirements for minimum wall thickness and maximum wall height contained in building codes and given in Art. 11.8. Those requirements usually make bearing-wall construction for buildings higher than three to five stories uneconomical, and encourage use of other methods of support (steel or concrete skeleton frame). Since 1965, engineered brick buildings 10 or more stories high, with design based on rational structural analysis, have been built in the United States. This construction was stimulated by the many load-bearing brick buildings exceeding 10 stories in height constructed during the preceding two decades in Europe.

Design requirements for engineered brick structures given in this section are taken from ''Building Code Requirements for Engineered Brick Masonry,'' promulgated by the Brick Institute of America, 11490 Commerce Park Drive, Reston, VA 22091.

11.2.1 General Requirements of Design Standard

''Building Code Requirements for Engineered Brick Masonry'' provides minimum requirements predicated on a general analysis of the structure and based on generally accepted engineering analysis procedures. The standard contains a requirement for architectural or engineering inspection of the workmanship to ascertain, in general, if the construction and workmanship are in accordance with the contract drawings and specifications. Frequency of inspections should be such that an inspector can inspect the various stages of construction and see that the work is being properly performed. The standard requires reduced allowable stresses and capacities for loads when such architectural or engineering inspection is not provided.

Engineered brick bearing-wall structures do not require new techniques of analysis and design, but merely application of engineering principles used in the analysis and design of other structural systems. The method of analysis depends on the complexity of the building with respect to height, shape, wall location, and openings in the wall. A few conservative assumptions, however, accompanied by proper details to support them, can result in a simplified and satisfactory solution for most bearing-wall structures up to 12 stories high. More rigorous analysis for bearing-wall structures beyond this height may be required to maintain the economics of this type of construction.

11.2.2 Materials for Masonry Construction

Strength (compressive, shearing, and transverse) of brick structures is affected by the properties of the brick and the mortar in which they are laid. In compression, strength of brick has the greater effect. Although mortar is also a factor in compressive strength, its greater effect is on the transverse and shearing strengths of masonry. For these reasons, there are specific design requirements for and limitations on materials used in engineered brick structures.

Brick. These units must conform to the requirements for grade MW or SW, ASTM ''Standard Specifications for Building Brick,'' C62. In addition, brick used in load-bearing or shear walls must comply with the dimension and distortion tolerances specified for type FBS of ASTM ''Standard Specifications for Facing

Brick,'' C216. Bricks that do not comply with these tolerance requirements may be used if the ultimate compressive strength of the masonry is determined by prism tests.

Mortar. Most of the test data on which allowable stresses for engineered brick masonry are based were obtained for specimens built with portland cement-hydrated lime mortars. Three mortar types are provided for: M, S, and N, as described in ASTM C270 (see Art. 4.16), except that the mortar must consist of mixtures of portland cement (type I, II, or III), hydrated lime (type S, non-air-entrained), and aggregate when the allowable stresses specified in ''Building Code Requirements for Engineered Brick Masonry'' are used. This standard provides, however, that ''Other mortars . . . may be used when approved by the Building Official, provided strengths for such masonry construction are established by tests . . ''.

For ordinary unit masonry, mortar should meet the requirements of ASTM C270 and C476. These define the types of mortar described in Art. 4.16. Each type is used for a specific purpose, as indicated in Table 11.1, based on compressive strength. However, it should not be assumed that higher-strength mortars are preferable to lower-strength mortars where lower strength is permitted for particular uses. The primary purpose of mortar is to bond masonry units together.

Mortars containing lime are generally preferred because of greater workability. Commonly used:

TABLE 11.1 Mortar Requirements of Masonry

Kind of masonry	Types of mortar
Masonry in contact with earth:	
Footings	M or S
Walls of solid units	M, S, or N
Walls of hollow units	M or S
Hollow walls	M or S
Masonry above grade or interior:	
Piers of solid masonry	M, S, or N
Piers of hollow units	M or S
Walls of solid masonry	M, S, N, or O
Grouted masonry	PL or PM
Walls of hollow units; load-bearing or exterior, and hollow walls 12 in or more in thickness	M, S, or N
Hollow walls less than 12 in in thickness where assumed design wind pressure:	
a. Exceeds 20 psf	M or S
b. Does not exceed 20 psf	M, S, or N
Glass-block masonry	M, S, or N
Nonbearing partitions of fireproofing composed of structural clay tile or concrete masonry units	M, S, N, O, or gypsum
Gypsum partition tile or block	Gypsum
Firebrick	Refractory air-setting mortar
Linings of existing masonry	M or S
Masonry other than above	M, S, or N

For concrete block, 1 part cement, 1 part lime putty, 5 to 6 parts sand

For rubble, 1 part cement, 1 to 2 parts lime hydrate or putty, 5 to 7 parts sand

For brick, 1 part cement, 1 part lime, 6 parts sand

For setting tile, 1 part cement, ½ part lime, 3 parts sand

11.3 CONSTRUCTION OF MASONRY

Compressive strength of masonry depends to a great extent on workmanship and the completeness with which units are bedded. Tensile strength is a function of the adhesion of mortar to a unit and of the area of bonding (degree of completeness with which joints are filled). Hence, in specifying masonry work, it is important to call for a full bed of mortar, with each course well hammered down, and all joints completely filled with mortar. To minimize the entrance of water through a masonry wall, follow the practices recommended in Art. 3.4.2.

In particular, in filling head joints, a heavy buttering of mortar should be applied on one end of the masonry, and the unit should be pushed down into the bed joint into place so that the mortar squeezes out from the top and sides of the head joint. Mortar should correspondingly cover the entire side of a unit before it is placed as a header. An attempt to fill head joints by slushing or dashing will not succeed in producing watertight joints. Partial filling of joints by ''buttering'' or ''spotting'' the vertical edge of the unit with mortar cut from the extruded bed joint is likewise ineffective and should be prohibited. Where closures are required, the opening should be filled with mortar so that insertion of the closure will extrude mortar both laterally and vertically.

Mortar joints usually range from ¼ to ¾ in in thickness.

Tooling of joints, if done properly can help to resist penetration of water; but it is not a substitute for complete filling, or a remedy for incomplete filling of joints. A concave joint (Fig. 11.2) is recommended. Use of raked or other joints that provide horizontal water tables should be avoided. Mortar should not be too stiff at time of tooling, or compaction will not take place, nor should it be too fluid, or the units may move—and units should never be moved after initial contact with mortar. If a unit is out of line, it should be removed, mortar scraped off and fresh mortar applied before the unit is relaid.

The back face of exterior wythes should be back plastered, or parged, before backup units are laid. If the backup is laid first, the front of the backup should be parged. The mortar should be the same as that used for laying the masonry and should be applied from ¼ to ⅜ in thick.

The rate of absorption of water by unit masonry at the time of laying is important in determining the strength and resistance to penetration of water of a mortared joint. This rate can be reduced by wetting the unit before laying. Medium absorptive

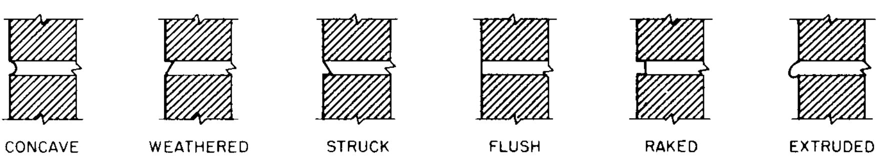


FIGURE 11.2 Types of joints between masonry units.

units may need to be thoroughly soaked with water. Highly absorptive units may require total immersion in water for some time before unit ''suction'' is reduced to the low limits needed.

The test for the rate of absorption of brick is described in ASTM Standard C67. For water-resistant masonry, the suction (rate of absorption) of the brick should not exceed 0.35, 0.5, and 0.7 oz, respectively, for properly constructed all-brick walls or facings of normal 4-, 8-, and 12-in thickness.

The amount of wetting that bricks will require to control rate of absorption properly when laid should be known or determined by measurements made before the bricks are used in the wall. Some medium absorptive bricks may require only frequent wetting in the pile; others may need to be totally immersed for an hour or more. While the immersion method is more costly than hosing in the pile, it ensures that all bricks are more or less saturated when removed from immersion. A short time interval may be needed before the bricks are laid; but the bricks are likely to remain on the scaffold, in a suitable condition to lay, for some time. Bricks on the scaffold should be inspected and moisture condition checked several times a day.

In general, method of manufacture and surface texture of masonry do not greatly affect the permeability of walls. However, water-resistant joints may be difficult to obtain if the units are deeply scored, particularly if the mortar is of a dry consistency. Loose sand should be brushed away or otherwise removed from units that are heavily sanded.

Mortar to be used in above-grade, water-resistant brick-faced and all-brick walls should be of as wet a consistency as can be handled by the mason and meet requirements of ASTM Standard C270, Type N. Water retention of the mortar should not be less than 75%, and preferably 80% or more. For laying absorptive brick that contain a considerable amount of absorbed water, the mortars having a water retention of 80% or more may be used without excessive ''bleeding'' at the joints and ''floating'' of the brick. The mortar may contain a masonry cement meeting the requirements of ASTM C91, except that water retention should not be less than 75 or 80%. Excellent mortar may also be made with portland cement and hydrated lime, mixed in the proportion of 1:1:6 parts by volume of cement, lime, and loose damp sand. The hydrated lime should be highly plastic. Type S lime conforming with the requirements of ASTM C207 is highly plastic, and mortar containing it, in equal parts by volume with cement, will probably have a water retention of 80% or more.

Since capillary penetration of moisture through concrete and mortar is of minor importance, particularly in above-grade walls, the mortar need not contain an integral water repellent. However, if desired, water-repellent mortar may be advantageously used in a few courses at the grade line to reduce capillary rise of moisture from the ground into the masonry. The mortar should be of a type that does not stiffen rapidly on the board, except through loss of moisture by evaporation.

Mortar should be retempered frequently if necessary to maintain as wet a consistency as is practically possible for the mason to use. At air temperatures below 80°F, mortar should be used or discarded within 3½ hr after mixing; for air temperatures of 80°F or higher, unused mortar should be discarded after 2½ hr.

11.3.1 Cold-Weather Construction of Masonry Walls

Masonry should be protected against damage by freezing. The following special precautions should be taken:

Materials to be used should be kept dry. Tops of all walls not enclosed or sheltered should be covered whenever work stops. The protection should extend downward at least 2 ft.

Frozen materials must be thawed before use. Masonry units should be heated to at least 40°F. Mortar temperature should be between 40 and 120°F, and mortar should not be placed on a frozen surface. If necessary, the wall should be protected with heat and windbreaks for at least 48 hr. Use of mortars made with high-early-strength cement may be advantageous for cold-weather masonry construction.

11.3.2 Bond between Wythes in Masonry Walls

When headers are used for bonding the facing and backing in solid masonry walls and faced walls, as shown in Fig. 11.3, not less than 4% of the wall surface of each face should be composed of headers, which should extend at least 4 in into the backing. These headers should not be more than 24 in apart vertically or hor-

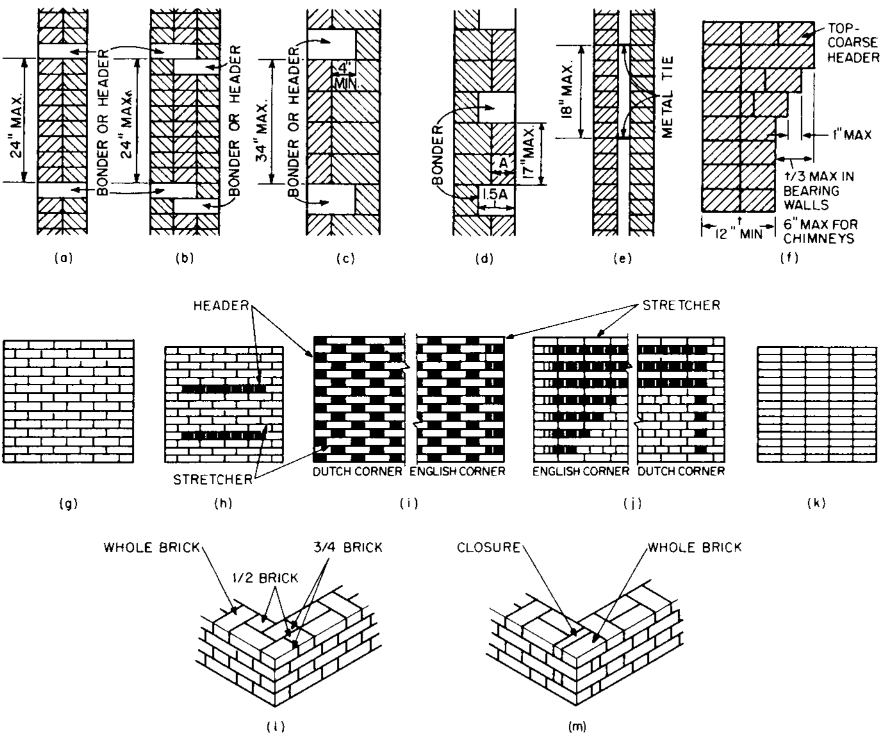


FIGURE 11.3 Types of unit-masonry construction. Cross sections through walls show: (*a*) two-wythe solid wall with bonders; (*b*) three-wythe solid wall with bonders; (*c*) and (*d*) hollow-unit walls; (*e*) hollow or cavity wall; (*f*) corbeled wall. Elevations of walls show types of masonry courses: (*g*) running bond; (*h*) common, or header, bond with bonders every sixth course; (*i*) Flemish bond with bonders in every course; (*j*) English bond; (*k*) stack bond. Types of corner bond: (*l*) Dutch; (*m*) English.

izontally (Fig. 11.3*a* and *b*). In walls in which a single bonder does not extend through the wall, headers from opposite sides should overlap at 4 in or should be covered with another bonder course overlapping headers below at least 4 in.

If metal ties (Figs. 11.3*e* and 11.4) are used for bonding, they should be corrosion-resistant. For bonding facing and backing of solid masonry walls and faced walls, there should be at least one metal tie for each 4½ ft^2 of wall area. Ties in alternate courses should be staggered, the maximum vertical distance between ties should not exceed 18 in, and the maximum horizontal distance should not be more than 36 in.

In walls composed of two or more thicknesses of hollow units, stretcher courses should be bonded by one of the following methods: At vertical intervals up to 34 in, there should be a course lapping units below at least 4 in (Fig. 11.3*c*). Or at vertical intervals up to 17 in, lapping should be accomplished with units at least 50% thicker than the units below (Fig. 11.3*d*). Or at least one metal tie should be incorporated for each 4½ ft^2 of wall area. Ties in alternate courses should be staggered; the maximum vertical distance between ties should be 18 in and maximum horizontal distance, 36 in. Full mortar coverage should be provided in both horizontal and vertical joints at ends and edges of face shells of the hollow units.

In ashlar masonry, bond stones should be uniformly distributed throughout the wall and form at least 10% of the area of exposed faces.

In rubble stone masonry up to 24 in thick, bond stones should have a maximum spacing of 3 ft vertically and horizontally. In thicker walls, there should be at least one bond stone for each 6 ft^2 of wall surface on both sides.

For bonding ashlar facing, the percentage of bond stones should be computed from the exposed face area of the wall. At least 10% of this area should be composed of uniformly distributed bond stones extending 4 in or more into the backup. Every bond stone and, when alternate courses are not full bond courses, every stone should be securely anchored to the backup with corrosion-resistant metal anchors. These should have a minimum cross section of $\frac{3}{16} \times 1$ in. There should be at least one anchor to a stone and at least two anchors for stones more than 2 ft long or with a face area of more than 3 ft^2. Larger facing stones should have at least one anchor per 4 ft^2 of face area of the stone, but not less than two anchors.

Cavity-wall wythes should be bonded with $\frac{3}{16}$-in-diameter steel rods or metal ties of equivalent stiffness embedded in horizontal joints. There should be at least one metal tie for each 4½ ft^2 of wall area. Ties in alternate courses should be staggered, the maximum vertical distance between ties should not exceed 18 in (Fig 11.3*e*), and the maximum horizontal distance, 36 in. Rods bent to rectangular shape should be used with hollow masonry units laid with cells vertical. In other walls,

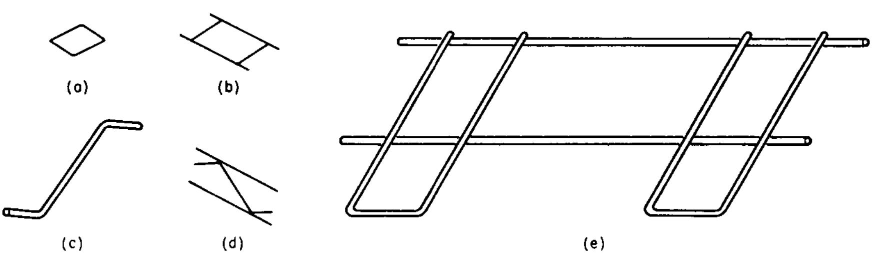


FIGURE 11.4 Types of metal ties for masonry walls: (*a*) rectangular; (*b*) ladder; (*c*) Z; (*d*) truss; (*e*) U.

the ends of ties should be bent to 90° angles to provide hooks at least 2 in long. Additional bonding ties should be provided at all openings. These ties should be spaced not more than 3 ft apart around the perimeter and within 12 in of the opening.

When two bearing walls intersect and the courses are built up together, the intersections should be bonded by laying in true bond at least 50% of the units at the intersection. When the courses are carried up separately, the intersecting walls should be regularly toothed or blocked with 8-in maximum offsets. The joints should be provided with metal anchors having a minimum section of ¼ × 1½ in with ends bent up at least 2 in or with cross pins to form an anchorage. Such anchors should be at least 2 ft long and spaced not more than 4 ft apart.

11.3.3 Grouted Masonry

Construction of walls requiring two or more wythes of brick or solid concrete block, similar to the wall shown in Fig. 11.3*a*, may be speeded by pouring grout between the two outer wythes, to fill the interior joints. Building codes usually require that, for the wythes, the mortar be type M or S, consisting of portland cement, lime, and aggregate (Art. 4.16). Also, they may require that, when laid, burned-clay brick and sand-lime units should have a rate of absorption of not more than 0.025 oz/in^2 over a 1-mm period in the standard absorption test (ASTM C67). All units in the two outer wythes should be laid with full head and bed joints.

Low-Lift Grouting. The vertical spaces between wythes that are to be grouted should be at least ¾ in wide. Masonry headers should not project into the gap. One of the outer wythes may be carried up 18 in before grout is poured. The other outer wythe is restricted to a height up to 6 times the grouting space, but not more than 8 in, before grout is poured. Thus, in this type of construction, grout is poured in lifts not exceeding 8 in. The grout should be puddled with a grout stick immediately after it has been poured. If work has to be stopped for an hour or more, horizontal construction joints should be formed by raising all wythes to the same level and leaving the grout 1 in below the top. A suitable grout for this type of construction consists of 1 part portland cement, 0.1 part hydrated lime or lime putty, and 2¼ to 3 parts sand.

High-Lift Grouting. This type of construction is often used where steel reinforcement is to be inserted in the vertical spaces between wythes; for example, in the cavity of the wall shown in Fig. 11.3*e*. Grout is poured continuously in lifts up to 6 ft high and up to 30 ft long in the vertical spaces. (Vertical barriers, or dams, of solid masonry may be built in the grout space to control the horizontal flow of grout.) Building codes may require each lift to be completed within one day. The grout should be consolidated by puddling or mechanical vibrating as it is placed and reconsolidated after excess moisture has been absorbed but before plasticity has been lost. A suitable grout for gaps 2 or more inches wide consists of 1 part portland cement, 0.1 part hydrated lime or lime putty, 2 to 3 parts sand, and not more than 2 parts gravel, by volume.

In construction of the wall, the wythes should be kept at about the same level. No wythe should lay behind the others more than 16 in in height. The masonry should be allowed to cure for at least 3 days, to gain strength, before grout is poured. The grout space should be at least 2 in wide. If, however, horizontal reinforcement is to be placed in the gap, it should be wide enough to provide ¼ in clearance around the steel, but not less than 3 in wide.

Cleanouts should be provided for every pour. This may be done by omitting every other unit in the bottom course of the wall section being poured. Before grout is placed, excess mortar, mortar fins, and other foreign matter should be removed from the grout space. A high-pressure water jet may be used for the purpose. After inspection but before placement of grout, the cleanout holes should be plugged with masonry units, which should then be braced to resist the grout pressure.

Wire ties should be inserted in the mortar joints between masonry courses and span across each grout space, to bond the wythes (Fig. 11.5). The ties should be formed into rectangles, 4 in wide and with a length 2 in less than the distance between outer faces of the wythes being bonded. The wire size should not be less than No.9. Spacing of ties should not exceed 24 in horizontally. For running-bond masonry (Fig. 11.3*f*), vertical tie spacing should not exceed 16 in, and for stack-bond masonry (Fig. 11.3*j*), 12 in.

11.3.4 Support Conditions for Walls

Provision should be made to distribute concentrated loads safely on masonry walls and piers. Heavily loaded members should have steel bearing plates under the ends

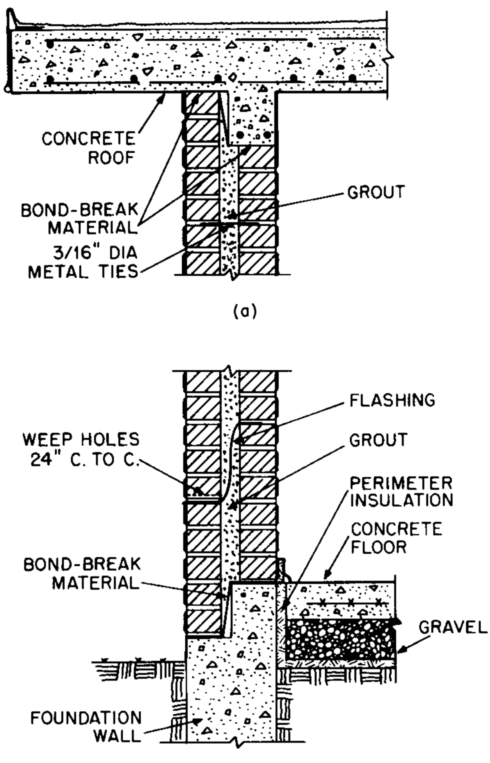


FIGURE 11.5 Grouted masonry wall: (*a*) cross section at the roof; (*b*) cross section at the base of the wall.

to distribute the load to the masonry within allowable bearing stresses. Length of bearing should be at least 3 in. Lightly loaded members may be supported directly on the masonry if the bearing stresses in the masonry are within permissible limits and if length of bearing is 3 in or more.

Masonry should not be supported on wood construction.

11.3.5 Corbeling

Where a solid masonry wall 12 in or more thick must be increased in thickness above a specific level, the increase should be achieved gradually by corbeling. In this method, successive courses are projected from the face of the wall, as indicated in Fig. 11.3*f*.

The maximum corbeled horizontal projection beyond the face of a wall should not exceed one-third the wall thickness for walls supporting structural members. In any case, projection of any course of masonry should not exceed 1 in.

Chimneys generally may not be corbeled more than 6 in from the face of the wall. In the second story of two-story dwellings, however, corbeling of chimneys on the exterior of enclosing walls may equal the wall thickness.

11.3.6 Openings, Chases, and Recesses in Masonry Walls

Masonry above openings should be supported by arches or lintels of metal or reinforced masonry, which should bear on the wall at each end at least 4 in. Stone or other nonreinforced masonry lintels should not be used unless supplemented on the inside of the wall with structural steel lintels, suitable masonry arches, or reinforced-masonry lintels carrying the masonry backing. Lintels should be stiff enough to carry the superimposed load with a deflection of less than $1/720$ of the clear span.

In plain concrete walls, reinforcement arranged symmetrically in the thickness of the wall should be placed not less than 1 in above and 2 in below openings. It should extend at least 24 in on each side of the opening or be equivalently developed with hooks. Minimum reinforcement that should be used is one No.5 bar for each 6 in of wall thickness.

In structures other than low residences, masonry walls should not have chases and recesses deeper than one-third the wall thickness, or longer than 4 ft horizontally or in horizontal projection. There should be at least 8 in of masonry in back of chases and recesses, and between adjacent chases or recesses and the jambs of openings.

Chases and recesses should not be cut in walls of hollow masonry units or in hollow walls but may be built in. They should not be allowed within the required area of a pier.

The aggregate area of recesses and chases in any wall should not exceed one-fourth of the whole area of the face of the wall in any story.

In dwellings not more than two stories high, vertical chases may be built in 8-in walls if the chases are not more than 4 in deep and occupy less than 4 ft^2 of wall area. However, recesses below windows may extend from floor to sill and may be the width of the opening above. Masonry above chases or recesses wider than 12 in should be supported on lintels.

Recesses may be left in walls for stairways and elevators, but the walls should not be reduced in thickness to less than 12 in unless reinforced in some approved manner. Recesses for alcoves and similar purposes should have at least 8 in of masonry at the back. They should be less than 8 ft wide and should be arched over or spanned with lintels.

If the strength of a wall will not be impaired, pipe or conduit may be passed horizontally or vertically through the masonry in a sleeve. Sleeves, however, should not be placed closer than three diameters center to center.

11.3.7 Flashing in Masonry Walls

Flashing should be used to divert to the exterior of a building water that may penetrate or condense on the interior face of masonry walls. Accordingly, flashing should be installed in exterior walls at horizontal surfaces, such as roofs, parapets, and floors, depending on type of construction; at shelf angles; at openings, such as doors and windows (Fig. 11.6*a* and *b*); and at the bases of walls just above grade (Fig. 11.6*c* and *e*). The flashing should extend through a mortar joint to the outside face of the wall, where it should turn down to form a drip.

Flashing in tooled mortar joints, however, would trap water unless some means is provided to drain it to the outside. Consequently, flashing should be used in conjunction with weep holes, which should be formed in head joints immediately above the flashing (Fig. 11.6*d*). When the weep holes are left open, spacing should not exceed 24 in c to c. If wicks of glass-fiber or nylon rope, cotton sash cord, or similar materials are left in the holes, spacing should not exceed 16 in c to c.

Materials used for flashing include sheet copper, bituminous fabrics, plastics, or a combination of these. Copper may be selected for its durability, but cost may be greater than for other materials. Combinations of materials, such as cold-formed steel and plastic or bituminous coating, may yield a durable flashing at lower cost.

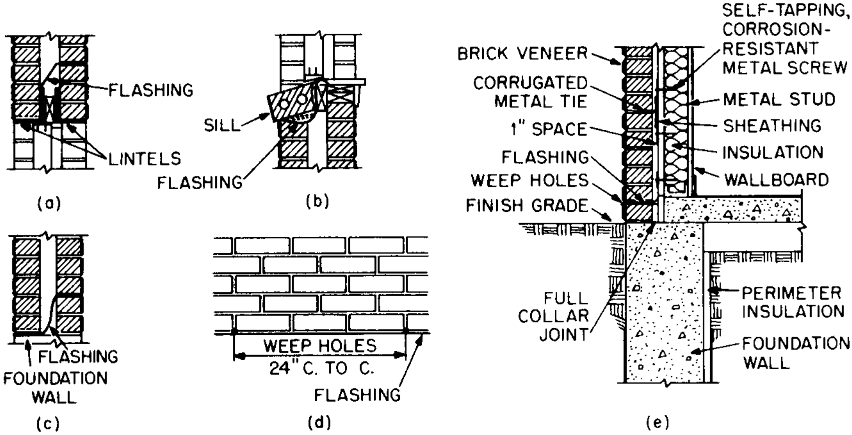


FIGURE 11.6 Flashing in masonry walls: (*a*) over an opening for a window or door; (*b*) under a window sill; (*c*) at the base of a wall; (*d*) and (*e*) below weep holes.

11.4 LATERAL SUPPORT FOR MASONRY WALLS

For unreinforced solid or grouted masonry bearing walls, the ratio of unsupported height to nominal thickness, or the ratio of unsupported length to nominal thickness, should not exceed 20. For hollow walls or walls of hollow masonry units, the ratio should be 18 or less. For cavity or stone walls, the ratio should not exceed 14. See "ANSI Standard Building Code Requirements for Masonry," 41.1, American National Standards Institute.

In calculating the ratio of unsupported length to thickness for cavity walls, you can take the thickness as the sum of the nominal thickness of the inner and outer wythes. For walls composed of different kinds or classes of units or mortars, the ratio should not exceed that allowed for the weakest of the combinations. Veneers should not be considered part of the wall in computing thickness for strength or stability.

For nonbearing, unreinforced exterior walls, the thickness ratio should not exceed 20. For unreinforced partitions, the ratio should be 36 or less.

Cantilever walls and masonry walls in locations exposed to high winds should not be built higher than 10 times their thickness unless adequately braced or designed in accordance with engineering principles. Backfill should not be placed against foundation walls until they have been braced to withstand horizontal pressure.

In determining the unsupported length of walls, existing cross walls, piers, or buttresses may be considered as lateral supports, if these members are well bonded or anchored to the walls and capable of transmitting forces perpendicular to the plane of the wall to connected structural members or to the ground.

In determining the unsupported height of walls, the floors and roofs may be considered as lateral supports, if they can resist a lateral force of at least 200 lb/lin ft and provision is made to transmit the lateral forces to the ground. Ends of floor joists or beams bearing on masonry walls should be securely fastened to the walls (Fig. 11.7). (See also Arts. 11.6 and 11.11.) Interior ends of anchored joists should be lapped and spiked, or the equivalent, so as to form continuous ties across the building. When lateral support is to be provided by joists parallel to walls, anchors should be spaced no more than 6 ft apart and engage at least three joists which should be bridged solidly at the anchors.

Unsupported height of piers should not exceed 10 times the least dimension. However, when structural clay tile or hollow concrete units are used for isolated piers to support beams or girders, unsupported height should not exceed 4 times the least dimension unless the cellular spaces are filled solidly with concrete or either Type M or S mortar (Art. 4.16).

Anchors for Masonry Facings. Support perpendicular to its plane may be provided an exterior masonry wythe, whether it is a veneer (non-load-bearing) or the outer wythe of a hollow wall, by anchoring it to construction capable of furnishing the required lateral support. Accordingly, a masonry veneer may be tied with masonry bonders or metal ties to a backup masonry wall that is given lateral support or the veneer may be anchored directly to structural framing. Methods of bonding wythes together are described in Art. 11.3.2. The following applies to anchorage of masonry walls to structural framing.

Several types of anchors are illustrated in Fig. 11.8. They should be corrosion resistant. Also, they should be able to resist tension and compression applied by

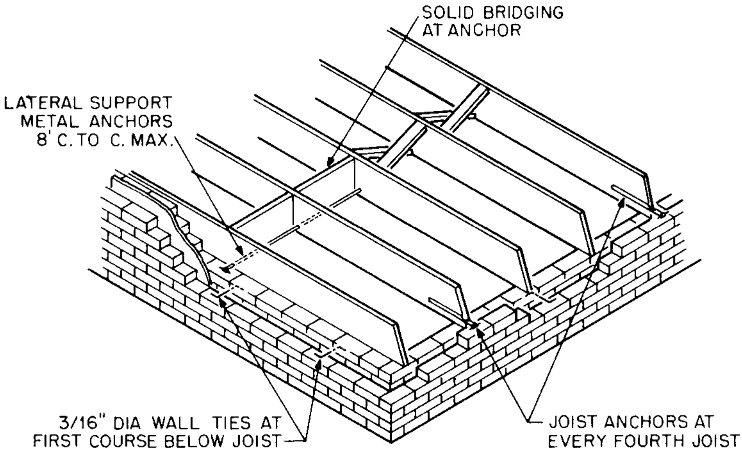


FIGURE 11.7 Anchorage of joists to bearing walls.

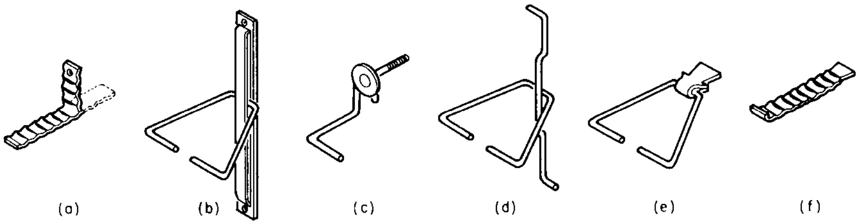


FIGURE 11.8 Anchors for use between masonry walls and structural framing: (*a*) corrugated metal for tie to wood studs; (*b*) and (*c*) wire ties for attachment to metal studs; (*d*) wire tie for anchorage to structural steel; (*e*) dovetail anchor for use with concrete; (*f*) corrugated metal for tie to cast-in-place concrete.

forces acting perpendicular to the wall. Yet, the anchors should be flexible enough to permit, between walls and framing, small differential horizontal and vertical movements parallel to the plane of the wall. The anchors should be embedded at one end in the mortar of bed joints and extend almost to the face of the wall. The other end should be securely attached to framing providing lateral support. The type of anchor to use depends on the construction to which the wall is to be anchored.

Figure 11.8*a* shows a corrugated metal tie for attachment of masonry walls to wood studs. Such ties should be fastened to studs with corrosion-resistant nails that are driven through sheathing to penetrate at least 1½ in into the studs. The ties should have a thickness of at least 22 ga, width of ⅞ in, and length of 6 in.

Anchors shown in Fig. 11.8*b* and *c* may be used to attach masonry walls to metal studs. The wires of these anchors should be at least 9 ga. The anchor shown in Fig. 11.8*d* is suitable for tying masonry walls to structural steel framing, as illustrated in Fig. 11.9*b*.

Dovetail anchors for anchorage of masonry walls into dovetail slots in concrete framing are illustrated in Fig. 11.8*e* and *f*. Applications of the type shown in Fig.

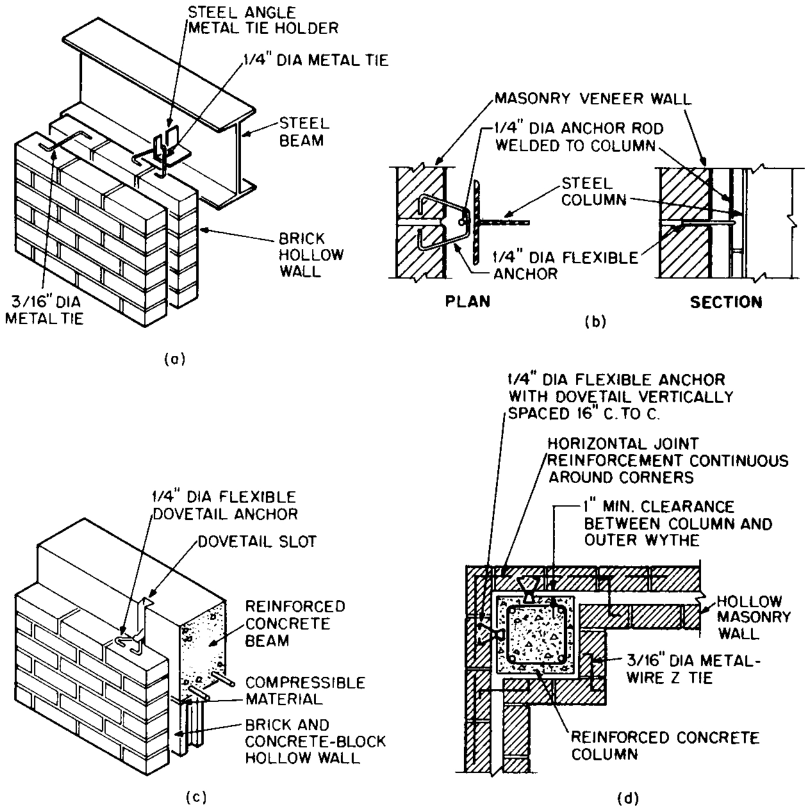


FIGURE 11.9 Anchorage of walls to structural framing: (*a*) hollow-wall ties to a structural steel beam; (*b*) masonry veneer wall anchored to a structural steel column; (*c*) masonry veneer wall anchored to a reinforced concrete beam; (*d*) hollow wall anchored to a concrete corner column.

11.8*e* are shown in Fig. 11.9*c* and *d*. Wires in these anchors should be at least 6 ga and should be spread to a width of at least 4 in for embedment at least 2 in into bed joints in the wall. The flat-bar type (Fig. 11.8*f*) should have a minimum thickness of 16 ga and width of ⅞ in. The end to be embedded in a bed joint should be turned upward at least ¼ in.

11.5 CHIMNEYS AND FIREPLACES

Minimum requirements for chimneys may be obtained from local building codes or any model building code. In brief, chimneys should extend at least 3 ft above the highest point where they pass through the roof of a building and at least 2 ft higher than any ridge within 10 ft. (For chimneys for industrial-type appliances with discharge temperatures between 1400 and 2000°F, minimum height above the roof opening or any part of the building within 25 ft should be 10 ft. For discharge temperatures over 2000°F, minimum height above any part of the building should be 20 ft.) Masonry chimneys should be constructed of solid masonry units or reinforced concrete and lined with firebrick or fire-clay tile. In dwellings, thickness of chimney walls may be 4 in. In other buildings, the thickness of chimneys for heating appliances should be at least 8 in for most masonry. Rubble stone thickness should be a minimum of 12 in. Cleanout openings equipped with steel doors should be provided at the base of every chimney.

When a chimney incorporates two or more flues, they should be separated by masonry at least 4 in thick.

In seismic zones where damage may occur, chimneys should be of reinforced masonry construction. They should be anchored to floors and ceilings more than 6 ft above grade and to roofs.

Fireplaces should have backs and sides of solid masonry or reinforced concrete, not less than 8 in thick. A lining of firebrick at least 2 in thick or other approved material should be provided unless the thickness is 12 in.

Fireplaces should have hearths of brick, stone, tile, or other noncombustible material supported on a fireproof slab or on brick trimmer arches. Such hearths should extend at least 20 in outside the chimney breast and not less than 12 in beyond each side of the fireplace opening along the chimney breast. Combined thickness of hearth and supporting construction should not be less than 6 in. Spaces between chimney and joists, beams, or girders and any combustible materials should be fire-stopped by filling with noncombustible material.

The throat of the fireplace should be not less than 4 in and preferably 8 in above the top of the fireplace opening. A metal damper (12 ga or thicker) extending the full width of the fireplace opening should be placed in the throat. The flue should have an effective area equal to one-twelfth to one-tenth the area of the fireplace opening.

11.6 PROVISIONS FOR DIMENSIONAL CHANGES

In design and construction of masonry walls, allowance should be made for relative movements of the masonry and contiguous construction. If this is not done, unsightly or troublesome cracking or even structural failure may result. In the past, such damage has occurred in masonry walls because of:

1. Restraint offered by contiguous construction to dimensional changes in the masonry. Such changes may be produced by temperature changes or by absorption of water by the masonry after construction.
2. Restraint offered by the masonry to movements of or dimensional changes in contiguous or bonded construction, such as concrete frames or backup walls. Such changes may be produced by drying shrinkage, elastic deformations under load, or creep of the concrete after construction.

To avoid such restraints, it is necessary to install in walls expansion joints with proper gaps, at appropriate intervals, and to break bond between the walls and construction that would restrain relative movements (Fig. 11.10).

Vertical expansion joints should be installed in masonry walls to permit horizontal movements of the masonry, and horizontal expansion joints, to permit vertical movements. In the absence of specific information on thermal and water-

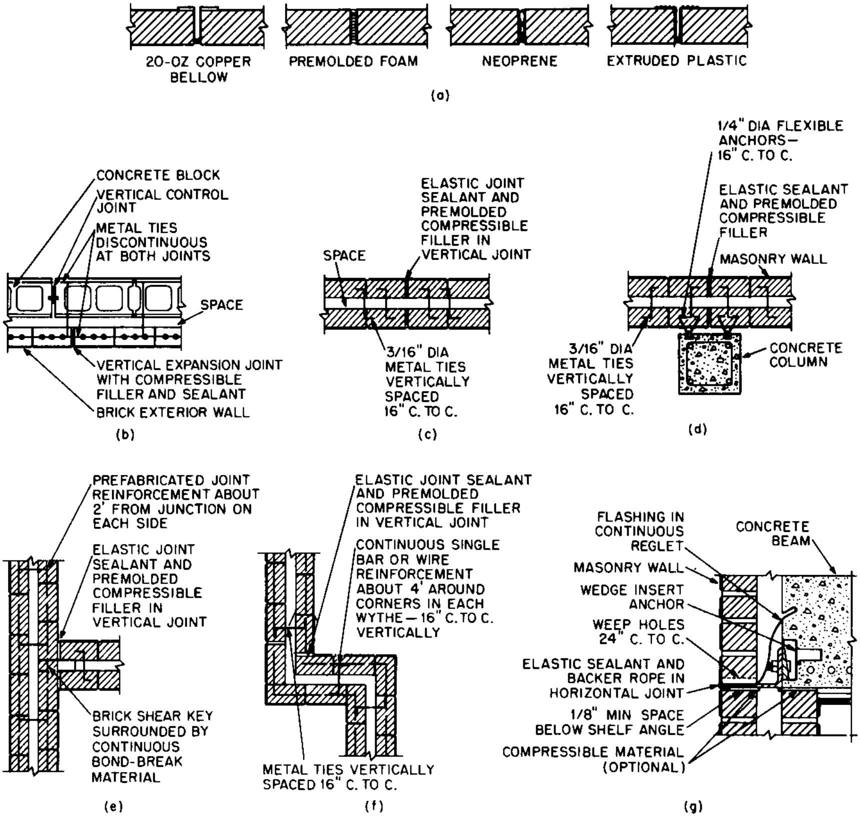


FIGURE 11.10 Cross sections show expansion joints in masonry walls: (*a*) types of fillers used; (*b*) expansion joint in brick veneer with a control joint in a concrete-block backup; (*c*) joint in a hollow wall; (*d*) joint at the anchorage of a wall to a column; (*e*) joint at a T intersection of a masonry wall; (*f*) joints at an offset in a hollow wall; (*g*) joint below a shelf angle.

absorption properties, the unit strain may be assumed to be 0.0007 in/in in a brick wall when movement is restricted, for example, by bond to a concrete foundation. Thus, for 60-ft spacing of expansion joints in a straight brick wall, a joint width of $2 \times 60 \times 12 \times 0.0007$, or about 1 in, would be required. In general, spacing of vertical expansion joints should range between 50 and 100 ft, and a joint should be placed not more than 30 ft from wall intersections.

The width required for an expansion joint also depends on the maximum allowable strain of the sealant used to seal the gap. If the size of a joint is controlled by the elastic properties of the sealant, joint spacing should be adjusted to limit the joint size to accommodate the elasticity of the sealant. The sealant should be placed at the exterior wall face and inserted in the joint to a depth of at least ⅛ in but not deeper than one-half the joint width. This depth may be controlled by a backup material that is inserted in the joint before the sealant is applied and that will not adhere to the sealant.

In brick facades, horizontal expansion joints should be inserted directly under horizontal lintels that are supported on concrete frames (Fig. 11.10*g*). The joints should be sized for probable expansion of the masonry below the lintels plus probable shortening of the concrete frame produced by drying shrinkage, compressive loading, and creep. In the absence of specific information on the properties of the materials to be used, a relative vertical movement of 0.0014 in/in may be assumed. Thus, where a brick facade is supported on steel shelf angles, for example, spaced 15 ft apart vertically, a gap of $15 \times 12 \times 0.0014$, or about ¼ in, would be required. As for vertical joints, a sealant and backup material should seal the horizontal expansion joint.

Slip joints should be provided where abrupt changes in wall dimensions occur; for example, at panels bounding or included between openings in a masonry wall, such as those for windows and doors. Bond should be prevented by insertion of sheet metal, building paper, or other material that would permit sliding when thermal movements occur.

Similarly, to permit relative horizontal movements, slip planes should be provided between cast-in-place concrete floors or roofs and masonry bearing walls that support them (Fig. 11.5*a*). Flexible anchors that permit sliding may be installed between the slabs and walls to prevent uplift. Such anchors, however, should not be installed within a distance from a slab corner of one-tenth the slab length. The reason for this is that such corners tend to curl upward when shrinkage occurs, in which case the anchorages would apply tension to and crack the walls.

Particular care should be taken to provide for relative movements when dissimilar materials are combined in a wall. Preferably, they should be separated at least ½ in and joined with flexible ties (Fig. 11.10*b* and *d*). In particular, because of different thermal movements of the materials, bond should be prevented between brick walls and contiguous concrete foundation walls below that are exposed to the weather (Fig. 11.5*b*). Flexible anchors should be provided between the walls and foundations, to permit horizontal sliding yet prevent uplift. Also, foundations should be made sufficiently stiff to prevent deflections that would crack the walls above. In addition, for the same purpose, the walls may be designed as deep beams or Vierendeel masonry trusses. (A Vierendeel truss does not consist solely of triangular configurations of members as do conventional trusses, and thus the members are subjected to a combination of axial forces and bending moments. Such a truss would be formed by a wall with openings for doors and windows.)

When bearing-wall construction is used for a building, differential movements of adjacent supports of horizontal structural members should be kept very small. For this reason, bearing walls of dissimilar materials should not be used in the same structure, inasmuch as they are likely to have physical properties that cause unequal deformations. For example, either load-bearing brick walls or concrete walls, but not both, should be used in a structure.

11.7 REPAIR OF LEAKY JOINTS

Leakage of wind-driven rain through the joints in permeable brick masonry walls can be stopped by either repointing or grouting the joints. It is usually advisable to treat all the joints, both vertical and horizontal, in the wall face. Some "tuck-pointing" operations in which only a few, obviously defective joints are treated may be inadequate and do not necessarily ensure that the untreated joints will not leak.

Repointing consists of cutting away and replacing the mortar from all joints to a depth of about ⅝ in. After the old mortar has been removed, the dust and dirt should be washed from the wall and the brick thoroughly wetted with water to near saturation. While the masonry is still very damp but with no water showing, the joints should be repointed with a suitable mortar. This mortar may have a somewhat stiff consistency to enable it to be tightly packed into place, and it may be ‘‘pre-hydrated’’ by standing for 1 or 2 hr before retempering and using. Pre-hydration is said to stabilize the plasticity and workability of the mortar and to reduce the shrinkage of the mortar after its application to the joints.

After repointing, the masonry should be kept in a damp condition for 2 or 3 days. If the brick are highly absorptive, they may contain a sufficient amount of water to aid materially in curing.

Weathering and permeability tests described in C. C. Fishburn, ‘‘Effect of Outdoor Exposure on the Water Permeability of Masonry Walls,’’ *National Bureau of Standards BMS Report 76* indicate that repointing of the face joints in permeable brick masonry walls was the most effective and durable of all the remedial treatments against leakage that did not change the appearance of the masonry.

Joints are **grouted** by scrubbing a thin coating of a grout over the joints in the masonry. The grout may consist of equal parts by volume of portland cement and fine sand, the sand passing a No.30 sieve.

The masonry should be thoroughly wetted and in a damp condition when the grout is applied. The grout should be of the consistency of a heavy cream and should be scrubbed into the joints with a stiff bristle brush, particularly into the juncture between brick and mortar. The apparent width of the joint is slightly increased by some staining of the brick with grout at the joint line. Excess grout may be removed from smooth-textured brick with a damp sponge, before the grout hardens. Care should be taken not to remove grout from between the edges of the brick and the mortar joints. If the bricks are rough-textured, staining may be controlled by the use of a template or by masking the bricks with paper masking tape.

Bond of the grout to the joints is better for ‘‘cut’’ or flush joints than for tooled joints. If the joints have been tooled, they should preferably not be grouted until after sufficient weathering has occurred to remove the film of cementing materials from the joint surface, exposing the sand aggregate.

Grouting of the joints has been tried in the field and found to be effective on leaky brick walls. The treatment is not so durable and water-resistant as a repointing job but is much less expensive than repointing. Some tests of the water resistance of grouted joints in brick masonry test walls are described in *National Bureau of Standards BMS Report 76.*

The cost of either repointing or grouting the joints in brick masonry walls probably greatly exceeds the cost of the additional labor and supervision needed to make the walls water-resistant when built.

11.8 MASONRY-THICKNESS REQUIREMENTS

Walls should not vary in thickness between lateral supports. When it is necessary to change thickness between floor levels to meet minimum-thickness requirements, the greater thickness should be carried up to the next floor level.

Where walls of masonry hollow units or bonded hollow walls are decreased in thickness, a course of solid masonry should be interposed between the wall below and the thinner wall above, or else special units or construction should be used to transmit the loads between the walls of different thickness.

The following limits on dimensions of masonry walls should be observed unless the walls are designed for reinforcement, by application of engineering principles:

Bearing Walls. These should be at least 12 in thick for the uppermost 35 ft of their height. Thickness should be increased 4 in for each successive 35 ft or fraction of this distance measured downward from the top of the wall. Rough or random or coursed rubble stone walls should be 4 in thicker than this, but in no case less than 16 in thick. However, for other than rubble stone walls, the following exceptions apply to masonry bearing walls:

Stiffened Walls. Where solid masonry bearing walls are stiffened at distances not greater than 12 ft by masonry cross walls or by reinforced-concrete floors, they may be made 12 in thick for the uppermost 70 ft but should be increased 4 in in thickness for each successive 70 ft or fraction of that distance.

Top-Story Walls. The top-story bearing wall of a building not over 35 ft high may be made 8 in thick. But this wall should be no more than 12 ft high and should not be subjected to lateral thrust from the roof construction.

Residential Walls. In dwellings up to three stories high, walls may be 8 in thick (if not more than 35 ft high), if not subjected to lateral thrust from the roof construction. Such walls in one-story houses and one-story private garages may be 6 in thick, if the height is 9 ft or less or if the height to the peak of a gable does not exceed 15 ft.

Penthouses and Roof Structures. Masonry walls up to 12 ft high above roof level, enclosing stairways, machinery rooms, shafts, or penthouses, may be made 8 in thick. They need not be included in determining the height for meeting thickness requirements for the wall below.

Plain Concrete and Grouted Brick Walls. Such walls may be 2 in less in thickness than the minimum basic requirements, but in general not less than 8 in—and not less than 6 in in one-story dwellings and garages.

Hollow Walls. Cavity or masonry bonded hollow walls should not be more than 35 ft high. In particular, 10-in cavity walls should be limited to 25 ft in height, above supports. The facing and backing of cavity walls should be at least 4 in thick, and the cavity should not be less than 2 in or more than 3 in wide.

Faced Walls. Neither the height of faced (composite) walls nor the distance between lateral supports should exceed that prescribed for masonry of either of the types forming the facing and the backing. Actual (not nominal) thickness of material used for facings should not be less than 2 in and in no case less than one-eighth the height of the unit.

Nonbearing Walls. In general, parapet walls should be at least 8 in thick and the height should not exceed 3 times the thickness. The thickness may be less than 8 in, however, if the parapet is reinforced to withstand safely earthquake and wind forces to which it may be subjected.

Nonbearing exterior masonry walls may be 4 in less in thickness than the minimum for bearing walls. However, the thickness should not be less than 8 in except that where 6-in bearing walls are permitted, 6-in nonbearing walls can be used also.

Nonbearing masonry partitions should be supported laterally at distances of not more than 36 times the actual thickness of the partition, including plaster. If lateral support depends on a ceiling, floor, or roof, the top of the partition should have adequate anchorage to transmit the forces. This anchorage may be accomplished with metal anchors or by keying the top of the partition to overhead work. Suspended ceilings may be considered as lateral support if ceilings and anchorages are capable of resisting a horizontal force of 200 lb/lin ft of wall.

11.9 DETERMINATION OF MASONRY COMPRESSIVE STRENGTH

Allowable stresses are based, for the most part, on the ultimate compressive strength f'_m psi, of masonry used. This strength may be determined by prism testing, or may be based on the compressive strength of the bricks and the type of mortar used. Compressive strength tests of brick should be conducted in accordance with ASTM "Standard Methods of Sampling and Testing Brick," C67.

Prism Tests. When the compressive strength of the masonry is to be established by preliminary tests, the tests should be made in advance of construction with prisms built of similar materials, assembled under the same conditions and bonding arrangements as for the structure. In building the prisms, the moisture content of the units at the time of laying, consistency of the mortar, thickness of mortar joints, and workmanship should be the same as will be used in the structure.

Prisms. Prisms should be stored in an air temperature of not less than 65°F and aged, before testing, for 28 days in accordance with the provisions of ASTM "Standard Method of Test for Compressive Strength of Masonry Assemblages," E447. Seven-day test results may be used if the relationship between 7- and 28-day strengths of the masonry has been established by tests. In the absence of such data, the 7-day compressive strength of the masonry may be assumed to be 90% of the 28-day compressive strength.

The value of f'_m used in the standard, "Building Code Requirements for Engineered Brick Masonry," is based on a height-thickness ratio h/t of 5. If the h/t of prisms tested is less than 5, which will cause higher test results, the compressive strength of the specimens obtained in the tests should be multiplied by the appropriate correction factor given in Table 11.2. Interpolation may be used to obtain intermediate values.

Brick Tests. When the compressive strength of masonry is not determined by prism tests, but the brick, mortar, and workmanship conform to all applicable requirements of the standard, allowable stresses may be based on an assumed value of the 28-day compressive strength f'_m computed from Eq. (11.1) or interpolated from the values in Table 11.3.

$$f'_m = A(400 + Bf'_b) \tag{11.1}$$

TABLE 11.2 Strength Correction Factors for Short Prisms

Ratio of height to thickness h/t	2.0	2.5	3.0	3.5	4.0	4.5	5.0
Correction factor	0.82	0.85	0.88	0.91	0.94	0.97	1.00

TABLE 11.3 Assumed Compressive Strength of Brick Masonry, psi

Compressive strength of brick, psi	Without inspection			With inspection		
	Type N mortar	Type S mortar	Type M mortar	Type N mortar	Type S mortar	Type M mortar
14,000 plus	2,140	2,600	3,070	3,200	3,900	4,600
12,000	1,870	2,270	2,670	2,800	3,400	4,000
10,000	1,600	1,930	2,270	2,400	2,900	3,400
8,000	1,340	1,600	1,870	2,000	2,400	2,800
6,000	1,070	1,270	1,470	1,600	1,900	2,200
4,000	800	930	1,070	1,200	1,400	1,600
2,000	530	600	670	800	900	1,000

where A = coefficient (⅔ without inspection and 1.0 with inspection)
B = coefficient (0.2 for type N mortar, 0.25 for type S mortar, and 0.3 for type M mortar)
f'_b = average compressive strength of brick, psi $\leq$ 14,000 psi

When there is no engineering or architectural inspection to ensure compliance with the workmanship requirements of the standard, the values in Table 11.3 under "Without inspection" should be used.

11.10 ALLOWABLE STRESSES IN MASONRY

In determining stresses in masonry, effects of loads should be computed on actual dimensions, not nominal. Except for engineered masonry, the stresses should not exceed the allowable stresses given in ANSI Standard Building Code Requirements for Masonry (A41.1), which are summarized for convenience in Table 11.4.

This standard recommends also that, in composite walls or other structural members composed of different kinds or grades of units or mortars the maximum stress should not exceed the allowable stress for the weakest of the combination of units and mortars of which the member is composed.

11.10.1 Allowable Stresses for Brick Construction

Allowable stresses—compressive f_n tensile f_t and shearing f_v—for brick construction should not exceed the values shown in Tables 11.5 and 11.6. For allowable loads on walls and columns, see Art. 11.10.2.

For wind, blast, or earthquake loads combined with dead and live loads, the allowable stresses in brick construction may be increased by one-third, if the resultant section will not be less than that required for dead loads plus reduced live loads alone. Where the actual stresses exceed the allowable, the designer should specify a larger section or reinforced brick masonry.

TABLE 11.4 Allowable Stresses in Unit Masonry*

Construction and grade of unit	Allowable compressive stress on gross cross section, psi†				
	Type M mortar	Type S mortar	Type N mortar	Type O mortar	Type PL or PM mortar
Solid masonry of brick or other solid units:					
8000+ psi	400	350	300	200	
4500 to 8000 psi	250	225	200	150	
2500 to 4500 psi	175	160	140	100	
1200 to 2500 psi	125	115	100	75	
Grouted solid masonry of brick or other solid units:					
8000+ psi				500	
4500 to 8000 psi				350	
2500 to 4500 psi				275	
1200 to 2500 psi				225	
Solid masonry of through-the-wall solid units:					
8000+ psi	500	400	300		
4500 to 8000 psi	350	275	200		
2500 to 4500 psi	275	200	150		
1200 to 2500 psi	225	175	125		
Masonry of hollow units:					
1000+ psi	100	90	85		
700 to 1000 psi	85	75	70		
Piers of hollow units, cellular spaces filled	105	95	90		
Hollow walls (cavity or masonry bonded):‡					
Solid units:					
4500+ psi	180	170	140		
2500 to 4500 psi	140	130	110		
1200 to 2500 psi	100	90	80		
Hollow units:					
1000+ psi	80	70	65		
700 to 1000 psi	70	60	55		
Stone ashlar masonry:					
Granite	800	720	640	500	
Limestone or marble	500	450	400	325	
Sandstone or cast stone	400	360	320	250	
Rubble, coursed, rough or random	140	120	100	80	

*See also Tables 11.5 and 11.6.

†Allowable bearing stress directly under concentrated loads may be taken 50% larger than the tabulated values.

‡On gross cross section of wall minus area of cavity between wythes. The allowable compressive stresses for cavity walls are based on the assumption that floor loads bear on only one of the two wythes. Increase stresses 25% for hollow walls loaded concentrically.

TABLE 11.5 Allowable Stresses for Nonreinforced Brick Masonry, psi

Description		Without inspection	With inspection
Axial compression			
Walls	f_m	$0.20\ f'_m$	$0.20\ f'_m$
Columns	f_m	$0.16\ f'_m$	$0.16\ f'_m$
Flexural compression			
Walls	f_m	$0.32\ f'_m$	$0.32\ f'_m$
Columns	f_m	$0.26\ f'_m$	$0.26\ f'_m$
Flexural tension			
Normal to bed joints			
M or S mortar	f_t	24	36
N mortar	f_t	19	28
Parallel to bed joints			
M or S mortar	f_t	48	72
N mortar	f_t	37	56
Shear			
M or S mortar	v_m	$0.3\sqrt{f'_m} \leq 40$	$0.5\sqrt{f'_m} \leq 80$
N mortar	v_m	$0.3\sqrt{f'_m} \leq 28$	$0.5\sqrt{f'_m} \leq 56$
Bearing			
On full area	f_m	$0.25\ f'_m$	$0.25\ f'_m$
On one-third area or less	f_m	$0.375\ f'_m$	$0.375\ f'_m$
Modulus of elasticity	E_m	$1000\ f'_m \leq 2{,}000{,}000$ psi	$1000\ f'_m \leq 3{,}000{,}000$ psi
Modulus of rigidity	E_v	$400\ f'_m \leq 800{,}000$ psi	$400\ f'_m \leq 1{,}200\ 000$ psi

11.10.2 Allowable Loads on Brick Walls and Columns

Two stress-reduction factors are used in calculating allowable loads on walls and columns: slenderness coefficient C_s and eccentricity coefficient C_e. The eccentricity coefficient is used to reduce the allowable axial load in lieu of performing a separate bending analysis. The slenderness coefficient is used to reduce the allowable axial load to prevent buckling.

Allowable Axial Loads. Allowable loads, lb, on brick walls and columns can be computed from

$$P = C_e C_s f_m A_g \tag{11.2}$$

where C_e = eccentricity coefficient
C_s = slenderness coefficient
f_m = allowable axial compressive stress, psi (Table 11.5 or 11.6)
A_g = gross cross-sectional area, in^2

To determine C_e and C_s, three constants are needed: end eccentricity ratio e_1/e_2, ratio of maximum virtual eccentricity to wall thickness e/t, and slenderness ratio h/t.

Eccentricity Ratio. At the top and bottom of any wall or column, a virtual eccentricity (Art. 11.1) of some magnitude (including zero) occurs. e_1/e_2 is the ratio of the smaller virtual eccentricity to the larger virtual eccentricity of the loads acting

TABLE 11.6 Allowable Stresses for Reinforced Brick Construction, psi

Description		Without inspection	With inspection
Axial compression			
Walls	f_m	$0.25\ f'_m$	$0.25\ f'_m$
Columns	f_m	$0.20\ f'_m$	$0.20\ f'_m$
Flexural compression			
Walls and beams	f_m	$0.40\ f'_m$	$0.40\ f'_m$
Columns	f_m	$0.32\ f'_m$	$0.32\ f'_m$
Shear			
No shear reinforcement			
Flexural members	v_m	$0.43\sqrt{f'_m} \leq 25$	$0.7\sqrt{f'_m} \leq 50$
Shear walls	v_m	$0.3\sqrt{f'_m} \leq 50$	$0.5\sqrt{f'_m} \leq 100$
With shear reinforcement taking entire shear			
Flexural members	v	$1.2\sqrt{f'_m} \leq 60$	$2.0\sqrt{f'_m} \leq 120$
Shear walls	v	$0.9\sqrt{f'_m} \leq 75$	$1.5\sqrt{f'_m}$ 150
Bond			
Plain bars	u	53	80
Deformed bars	u	107	160
Bearing			
On full area	f_m	$0.25\ f'_m$	$0.25\ f'_m$
On one-third area or less	f_m	$0.375\ f'_m$	$0.375\ f'_m$
Modulus of elasticity	E_m	$1000\ f'_m \leq 2{,}000{,}000$ psi	$1000\ f'_m \leq 3{,}000\ 000$ psi
Modulus of rigidity	E_v	$400\ f'_m \leq 800{,}000$ psi	$400\ f'_m \leq 1{,}200{,}000$ psi

on a member. By this definition, the absolute value of the ratio is always less than or equal to 1.0. Where e_1 or e_2, or both, are equal to zero, e_1/e_2 is assumed to be zero. When the member is bent in single curvature (top and bottom virtual eccentricities occurring on the same side of the centroidal axis of a wall or column), e_1/e_2 is positive. When the member is bent in double curvature (top and bottom virtual eccentricities occurring on opposite sides of a wall or column centroidal axis), e_1/e_2 is negative (Fig. 11.11).

Eccentricity-Thickness Ratio. The ratio of maximum virtual eccentricity to wall thickness e/t is used in selecting the eccentricity coefficient C_e. Design of a nonreinforced member requires that e/t be less than or equal to ⅓. If e/t is greater than ⅓, the designer should specify a larger section, different bearing details for load transfer to the masonry, or reinforced brick construction.

Slenderness Ratio. This is the ratio of the unsupported height h to the wall thickness t. It is used in selecting the slenderness coefficient C_s.

The unsupported height h is the actual distance between lateral supports. Not always the floor-to-floor height, h may be taken as the distance from the top of the lower floor to the bearing of the upper floor where these floors provide lateral support.

The effective thickness t for nonreinforced solid masonry is the actual wall thickness, except for metal-tied cavity walls. In cavity walls, each wythe is consid-

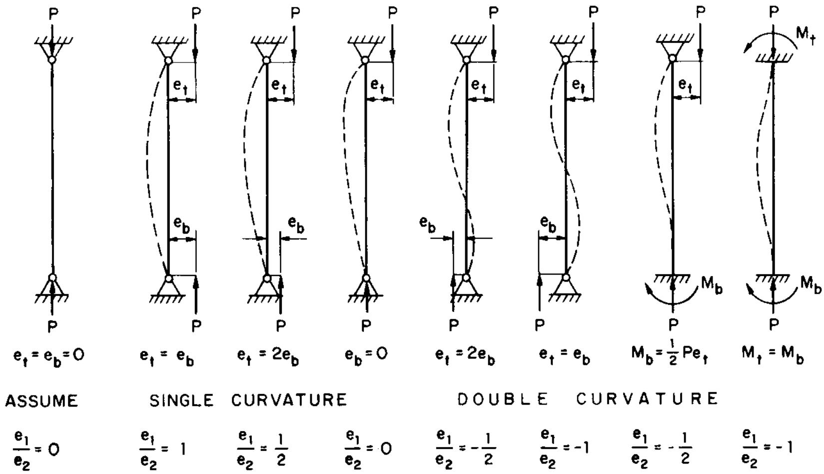


FIGURE 11.11 Axis of a compression member with positive eccentricity ratio e_1/e_2 has a single curvature and with negative eccentricity ratio, double curvature.

ered to act independently, thus producing two different walls. When the cavity is filled with grout, the effective thickness becomes the total wall thickness.

Eccentricity Coefficients. C_e may be selected from Table 11.7, or calculated from Eqs. (11.3) to (11.5). Linear interpolation is permitted within the table.

$$C_e = 1.0 \quad 0 < \frac{e}{t} \leqq 0.05 \tag{11.3}$$

$$C_e = \frac{1.3}{1 + 6e/t} + \frac{1}{2}\left(\frac{e}{t} - \frac{1}{20}\right)\left(1 - \frac{e_1}{e_2}\right) \quad 0.05 < \frac{e}{t} \leqq 0.167 \tag{11.4}$$

$$C_e = 1.95\left(\frac{1}{2} - \frac{e}{t}\right) + \frac{1}{2}\left(\frac{e}{t} - \frac{1}{20}\right)\left(1 - \frac{e_1}{e_2}\right) \quad 0.167 < \frac{e}{t} \leqq 0.333 \tag{11.5}$$

TABLE 11.7 Eccentricity Coefficients C_e

	e_1/e_2								
e/t	−1	−¾	−½	−¼	0	¼	½	¾	1
0–0.05	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
0.10	0.86	0.86	0.85	0.84	0.84	0.83	0.83	0.82	0.81
0.15	0.78	0.77	0.76	0.75	0.73	0.72	0.71	0.70	0.68
0.167	0.77	0.75	0.74	0.72	0.71	0.69	0.68	0.66	0.65
0.20	0.74	0.72	0.71	0.68	0.66	0.64	0.62	0.60	0.59
0.25	0.69	0.66	0.64	0.61	0.59	0.56	0.54	0.51	0.49
0.30	0.64	0.61	0.58	0.55	0.52	0.48	0.45	0.42	0.39
0.333	0.61	0.57	0.54	0.50	0.47	0.43	0.40	0.36	0.32

Slenderness Coefficient. C_s may be selected from Table 11.8, or calculated from Eq. (11.6). Linear interpolation is permitted within the table.

$$C_s = 1.20 - \frac{h/t}{300}\left[5.75 + \left(1.5 + \frac{e_1}{e_2}\right)^2\right] \leq 1.0 \tag{11.6}$$

11.10.3 Eccentrically Loaded Shear Walls

"Building Code Requirements for Engineered Brick Masonry" also provides a basis for design of eccentrically loaded shear walls. The standard requires that, in a nonreinforced shear wall, the virtual eccentricity e_L about the principal axis normal to the length L of the wall not exceed an amount that will produce tension. In a nonreinforced shear wall subject to bending about both principal axes, $e_tL + e_Lt$ should not exceed $tL/3$, where e_t = virtual eccentricity about the principal axis normal to the thickness t of the shear wall. Where the virtual eccentricity exceeds the preceding limits, shear walls should be designed as reinforced or partly reinforced walls.

Consequently, for a planar wall the virtual eccentricity e_L, which is found by dividing the overturning moment about an axis normal to the plane of the wall by the axial load, should not exceed $L/6$. In theory, any virtual eccentricity exceeding $L/6$ for planar shear wall will result in development of tensile stresses. If, however, intersecting walls form resisting flanges, the classic approach may be used where the bending stress Mc/I is combined with the axial stress P/A. If the bending stress exceeds the axial stress, then tensile stresses are present. (Note that some building codes require a safety factor against overturning. It is usually 1.5 for nonreinforced walls. But the codes state that, if the walls are vertically reinforced to resist tension, the safety factor does not apply.)

TABLE 11.8 Slenderness Coefficients C_s

	e_1/e_2								
h/t	−1	−¾	−½	−¼	0	¼	½	¾	1
5.0	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
7.5	1.00	1.00	1.00	1.00	1.00	0.98	0.96	0.93	0.90
10.0	1.00	0.99	0.98	0.96	0.93	0.91	0.88	0.84	0.80
12.5	0.95	0.94	0.92	0.90	0.87	0.83	0.79	0.75	0.70
15.0	0.90	0.88	0.86	0.83	0.80	0.76	0.71	0.66	0.60
17.5	0.85	0.83	0.81	0.77	0.73	0.69	0.63	0.57	0.50
20.0	0.80	0.78	0.75	0.71	0.67	0.61	0.55	0.48	0.40
22.5	0.75	0.73	0.69	0.65	0.60	0.54	0.47	0.39	
25.0	0.70	0.67	0.64	0.59	0.53	0.47	0.39		
27.5	0.65	0.62	0.58	0.53	0.47	0.39			
30.0	0.60	0.57	0.52	0.47	0.40				
32.5	0.55	0.52	0.47	0.41					
35.0	0.50	0.46	0.41						
37.5	0.45	0.41							
40.0	0.40								

For investigation of biaxial bending, the eccentricity limitation may, for convenience, be placed in the form:

$$\frac{e}{t} = \frac{e_i}{t} + \frac{e_L}{L} \leq \frac{1}{3} \tag{11.7}$$

Allowable vertical loads on shear walls may be computed from Eq. (11.2). The effective height h for computing C_s should be taken as the minimum vertical or horizontal distance between lateral supports.

Allowable shearing stresses for shear walls should be taken as the sum of the allowable shear stress given in Table 11.5 or 11.6 and one-fifth the average compressive stress produced by dead load at the level being analyzed, but not more than the maximum values listed in these tables.

In computation of shear resistance of a shear wall with intersecting walls treated as flanges, only the parts serving as webs should be considered effective in resisting the shear.

When non-load-bearing shear walls are required to resist overturning moment only by their own weight, the design can become critical. Consequently, positive ties should be provided between shear walls and bearing walls, to take advantage of the bearing-wall loads in resisting overturning. The shear stress at the connection of the shear wall to the bearing wall should be checked. The designer should exercise judgment in assumption of the distribution of the axial loads into the non-load-bearing shear walls.

11.10.4 Bearing Walls

Walls whose function is to carry only vertical loads should be proportioned primarily for compressive stress. Allowable vertical loads are given by Eq. (11.2). Effects of all loads and conditions of loading should be investigated. For application of Eq. (11.2), each loading should be converted to a vertical load and a virtual eccentricity.

In the lower stories of a building, the compressive stress is usually sufficient to suppress development of tensile stress. But in the upper stories of tall buildings, where the exterior walls are subject to high lateral wind loads and small axial loads, the allowable tensile stress may be exceeded occasionally and make reinforcement necessary.

When lateral forces act parallel to the plane of bearing walls that act as load-bearing shear walls, the walls must meet the requirements for both shear walls and biaxial bending (Art. 11.10.3). Such walls must be checked, to preclude development of tensile stress or excessive compressive or shearing stresses. If analysis indicates that tension requirements are not satisfied, the size, shape, or number of shear walls must be revised or the wall must be designed as reinforced masonry.

11.11 FLOOR-WALL CONNECTIONS

Bending moments caused in a wall by floor loading depend on such factors as type of floor system, detail of floor-wall connections, and sequence of construction.

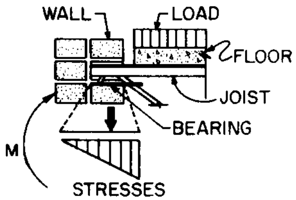


FIGURE 11.12 Stress distribution in a wall supporting a joist.

Because information available on their effects is limited, engineers must make certain design assumptions when providing for such moments. Conservative assumptions that may be used in design are discussed in the following.

For a floor system that acts hinged at the floor-wall connection, such as steel joists and stems from precast-concrete joists, a triangular stress distribution can be assumed under the bearing (Fig. 11.12). The moment in the wall produced by dead and live loads is then equal to the reaction times the eccentricity resulting from this stress distribution.

For precast-concrete-plank floor systems, which deflect and rotate at the time of placing, a triangular stress distribution similarly can be assumed to result from the dead load of the plank, which also induces a moment in the wall. When the topping is placed as each level is constructed, a triangular stress distribution can still be assumed. The moment resulting from the dead load of the floor system, including the topping, then is that due to the eccentric loading. If, however, the topping is placed after the wall above has been built and the wall clamps the plank end in place, creating a restrained end condition, the moment in the wall will then be the sum of the moment due to the eccentric load of the plank itself and the fixed-end moment resulting from the superimposed loads of topping weight and live load (Fig. 11.13).

The degree of fixity and the resulting magnitude of the restrained end moments usually must be assumed. Full fixity of floors due to the clamping action of a wall under large axial loads in the lower stories of high-and medium-rise buildings appears a logical assumption. The same large axial loads that provide the clamping action in the lower stories also act to suppress development of tensile stresses in the wall at the floor-wall connection. Because axial loads are smaller in upper stories, however, the degree of fixity may be assumed reduced, with occurrence of slight rotation and elevation of the extreme end of the slab. Based on this assumption, slight, local stress-relieving in connections in upper stories could take place. Regardless of the assumption, the maximum moment transferred to the wall can never be greater than the negative-moment capacity of the floor system.

When full fixity is assumed, the magnitude of the moment in the wall will be approximately the distribution factor times the initial fixed-end moment of the slab

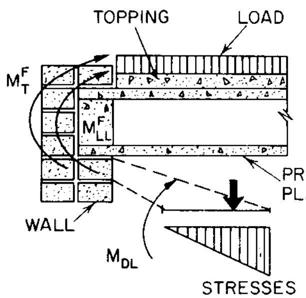


FIGURE 11.13 Stress distribution in a wall supporting a precast-concrete plank.

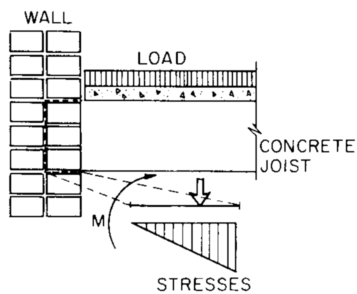


FIGURE 11.14 Stress distribution in a wall with only a joist stem embedded in it.

at the face of the wall. As an approximation for precast-concrete plank with uniform load w and span L, $wL^2/36$ may be conservatively assumed as the wall moment. [Preliminary test results have indicated about 80% moment transfer from the slab into the wall sections (40% to the upper and 40% to the lower wall section) with flat, precast plank penetrating the full wall thickness.]

For a cast-in-place concrete slab, a fixed-end moment may be assumed for both dead and live loads, because usually the wall above the slab will be built before removal of shoring.

Because restrained end moments in a wall can become large, reduction of the eccentricity of the floor reaction is advantageous in limiting the moment in the wall. This may be accomplished by projecting only the stems of cast-in-place or precast-concrete systems into the wall (Fig. 11.14). In such cases, a bearing pad should be placed immediately under each stem.

11.12 GLASS BLOCK

For control of light that enters a building and for better insulation than obtained with ordinary glass panes, masonry walls of glass block are frequently used (Fig. 11.15). These units are hollow, 3⅞ in thick by 6 in square, 8 in square, or 12 in square (actual length and height ¼ in less, for modular coordination, to allow for mortar joints). Faces of the units may be cut into prisms to throw light upward or the block may be treated to diffuse light.

Glass blocks may be used as nonbearing walls and to fill openings in walls. The glass block so used should have a minimum thickness of 3 in at the mortar joint. Also, surfaces of the block should be satisfactorily treated for mortar bonding.

For exterior walls, glass-block panels should not have an unsupported area of more than 144 ft^2. They should be no more than 15 ft long or high between supports.

For interior walls, glass-block panels should not have an unsupported area of more than 250 ft^2. Neither length nor height should exceed 25 ft.

Exterior panels should be held in place in the wall opening to resist both internal and external wind pressures. The panels should be set in recesses at the jambs so as to provide a bearing surface at least 1 in wide along the edges. Panels more than 10 ft long should also be recessed at the head. Some building codes, however, permit anchoring small panels in low buildings with noncorrodible perforated metal strips.

Steel reinforcement should be placed in the horizontal mortar joints of glass-block panels at vertical intervals of 2 ft or less. It should extend the full length of the joints but not across expansion joints. When splices are necessary, the reinforcement should be lapped at least 6 in. In addition, reinforcement should be placed in the joint immediately below and above any openings in a panel.

The reinforcement should consist of two parallel longitudinal galvanized-steel wires, No.9 ga or larger, spaced 2 in apart, and having welded to them No.14 or heavier-gage cross wires at intervals up to 8 in.

Glass block should be laid in Type S mortar. Mortar joints should be from ¼ to ⅜ in thick. They should be completely filled with mortar.

Exterior glass-block panels should be provided with ½-in expansion joints at sides and top. These joints should be kept free of mortar and should be filled with resilient material (Fig. 11.15). An opening may be filled one block at a time, as in Fig. 11.15, or with a preassembled panel.

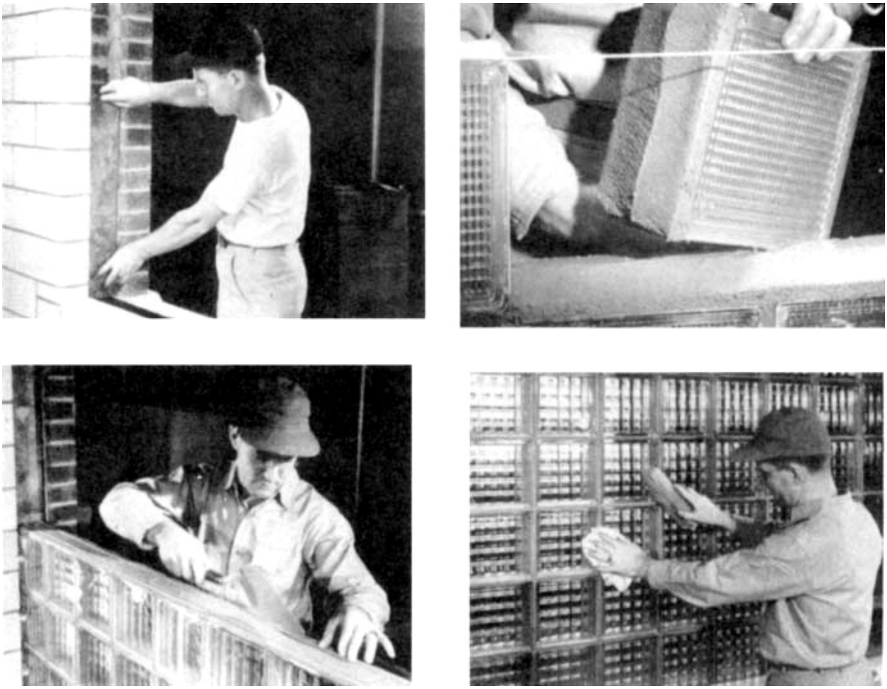


FIGURE 11.15 (*Top left*) First step in installation of a glass-block panel is to coat the sill with an asphalt emulsion to allow for movement due to temperature changes. Continuous expansion strips are installed at side and head jambs. (*Top right*) Blocks are set with full mortar joints. (*Bottom left*) Welded-wire ties are embedded in the mortar to reinforce the panel. (*Bottom right*) After all the blocks are placed, joints tooled to a smooth, concave finish, and the edges of the panel calked, the blocks are cleaned.

11.13 MASONRY BIBLIOGRAPHY

The following publications are available from the Brick Institute of America, McLean, Va.:

J. G. Gross, R. D. Dikkers, and J. C. Grogan, "Recommended Practice for Engineered Brick Masonry

H. C. Plummer, "Brick and Tile Engineering."

"Building Code Requirements for Engineered Brick Masonry."

"Technical Notes on Brick and Tile Construction"—a series.

See also the following standards of the American Concrete Institute, P.O. Box 19150, Redford Station, Detroit, MI 48219:

"Building Code Requirements for Concrete Masonry Structures" and "Commentary. . . ," ACI 531.

"Specification for Concrete Masonry Construction," ACI 531.1.

STUD WALLS

Load-bearing walls in buildings up to three stories high and story-high partitions often are constructed of framing composed of thin pieces of wood or metal. When the main structural members of such walls are installed vertically at close spacing, the members are called **studs** and the walls are referred to as stud walls. Any of a wide variety of materials may be applied to the studs as facings for the walls.

Stud walls permit placement of insulation between studs, so that no increase in thickness is required to accommodate insulation. Also, pipe and conduit may be inexpensively hidden in the walls. Cost of stud construction is usually less than for all-masonry walls.

11.14 STUD-WALL CONSTRUCTION

Load-bearing and non-load-bearing stud walls may be built of wood, aluminum, or cold-formed steel. Basic framing consists of vertical structural members, or **studs,** seated on a bottom, horizontal, bearing member, called a **sole plate,** and capped with a horizontal tie, called a **top plate** (Fig. 11.16). In addition, diagonal and horizontal bracing may be applied to the framing to prevent racking due to horizontal forces acting in the plane of the wall.

The studs usually are spaced 16 or 24 in on centers. Traditional surfacing materials are manufactured to accommodate these spacings; for example, panels to be attached to the framing usually come 48 in wide. (Inasmuch as the panels are fastened to each stud, panel thickness required, and hence cost, is determined by the stud spacing and generally is larger for 24-in spacing than for 16-in. Overall wall cost, however, may not be larger for the wider spacing, because it requires fewer studs.)

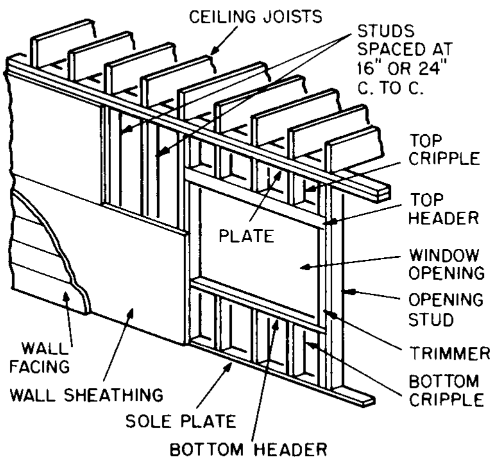


FIGURE 11.16 Stud-wall construction incorporating a window opening.

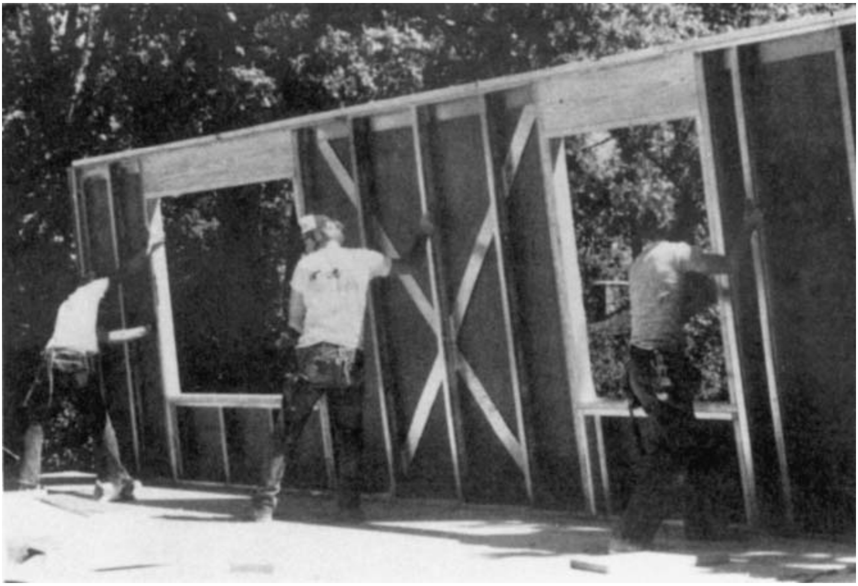


FIGURE 11.17 Erection of a preassembled stud wall. (*U.S. Gypsum Company.*)

Wood stud walls are normally built of nominal 2 × 4-in lumber. This type of construction, usually used for residential buildings, is described in Art. 10.25. Advantages of wood construction include light weight and ease of fabrication and assembly, especially in the field.

Aluminum and cold-formed steel construction offer the advantages over wood of incombustibility and freedom from warping, shrinking, swelling, and attack by insects. Studs may be provided with punched openings, which not only reduce weight but also permit passage of pipe and conduit without the necessity of drilling holes in the field. Stud spacing usually is 24 in, rather than 16 in, to reduce the number of studs required.

Metal framing is not so easy to cut and fit in the field as wood. Hence, prefabrication of metal walls in convenient lengths is desirable.

Metal members are manufactured with a variety of widths, leg dimensions, lengths, and thicknesses. Steel studs, for example, are available as C shapes, channels and nailable sections; that is, attachments can be nailed to the flanges. Widths range from ½ to 6 in, and lengths, from 6 to 40 ft.

For partitions, a nonstructural interior finish, such as gypsum plaster, gypsumboard, fiberboard, or wood paneling, may be applied to both faces of stud-wall framing. For exterior walls, the interior face may be the same as for partitions, whereas the outer side must be enclosed with durable, weather-excluding materials, such as water-resistant sheating and siding or masonry veneer.

For quick assembly, stud walls may be prefabricated. Figure 11.17 illustrates erection of a cold-formed steel stud wall that has been preassembled with sheathing already attached.

11.15 SHEATHING

To deter passage of air and water through exterior stud walls, sheathing may be attached to the exterior faces of the studs. When sheathing in the form of rigid panels, such as plywood, is fastened to the studs so as to resist racking of the walls, it may be permissible to eliminate diagonal wall bracing, which contributes significantly to wall construction costs. Panels, however, may be constructed of weak materials, especially when the sheathing is also required to serve as thermal insulation, inasmuch as the sheathing is usually protected on the weather side by a facade of siding, masonry veneer, or stucco.

Materials commonly used for sheathing include plywood (see Art. 10.12), fiberboard, gypsum, urethanes, isocyanates, and polystyrene foams. Sheathing usually is available in 4-ft wide panels, with lengths of 8 ft or more. Available thicknesses range from ½ to 2½ in. Some panels require a protective facing of waterproofing paper or of aluminum foil, which also serves as reflective insulation.

CURTAIN WALLS

With skeleton-frame construction, exterior walls need carry no load other than their own weight, and therefore their principal function is to keep wind and weather out of the building—hence the name curtain wall. Nonbearing walls may be supported on the structural frame of a building, on supplementary framing (girts or studs, for example) in turn supported on the structural frame of a building, or on the floors.

11.16 FUNCTIONAL REQUIREMENTS OF CURTAIN WALLS

Curtain walls do not have to be any thicker than required to serve their principal function. Many industrial buildings are enclosed only with light-gage metal. However, for structures with certain types of occupancies and for buildings close to others, attractive appearance and fire resistance are important characteristics. Fire-resistance requirements in local building codes often govern in determining the thickness and type of material used for curtain walls.

In many types of buildings, it is desirable to have an exterior wall with good insulating properties. Sometimes a dead-air space is used for this purpose. Sometimes insulating material is incorporated in the wall or erected as a backup.

The exterior surface of a curtain wall should be made of a durable material, capable of lasting as long as the building. Maintenance should be a minimum; initial cost of the wall is not so important as the life-cycle cost (initial cost plus maintenance and repair costs).

To meet requirements of the owner and the local building code, curtain walls may vary in construction from a simple siding to a multilayer-sandwich wall. They may be job-assembled or be delivered to the job completely prefabricated.

Walls with masonry components should meet the requirements of Arts. 11.2 to 11.12.

11.17 WOOD FACADES

Wood is often applied on low buildings as an exterior finish in the form of siding, shingles, half timbers, or plywood sheets.

Siding may be drop, or novelty; lap, or clapboard; vertical boarding or horizontal flush boarding.

Drop siding can combine sheathing and siding in one piece. This type of siding consists of tongued-and-grooved individual pieces that are driven tightly up against each other when they are nailed horizontally in place to make the wall weathertight (Fig. 11.18*a* and *b*). It is not considered a good finish for permanent structures.

Lap siding or clapboard are beveled boards, thinner along one edge than the opposite edge, which are nailed horizontally over sheathing and building paper (Fig. 11.18*c*). Usually boards up to 6 in wide lap each other about 1 in; wider boards, more than 2 in. At the eaves, the top siding boards slip under the lower edge of a frieze board to make a weathertight joint.

When vertical or horizontal boards are used for the exterior finish, precautions should be taken to make the joints watertight. Joints should be coated with white lead in linseed oil just before the boards are nailed in place, and the boards should be driven tight against each other. Battens (narrow boards) should be applied over the joints if the boards are squared-edged.

In half-timber construction, timber may be used to form a structural frame of heavy horizontal, vertical, and diagonal members, the spaces between being filled with brick. This type of construction is sometimes imitated by nailing boards in a similar pattern to an ordinary sheathed frame and filling the space between boards with stucco.

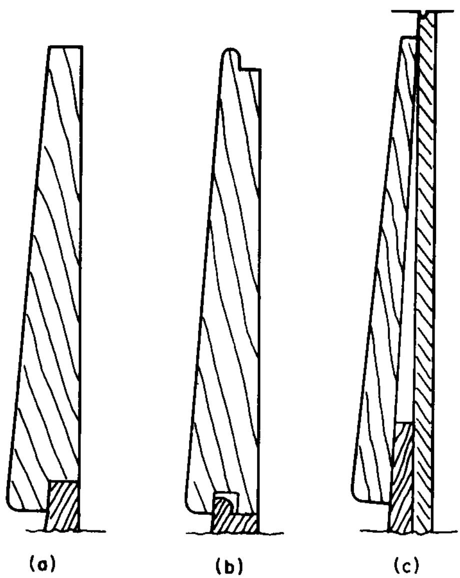


FIGURE 11.18 Types of wood siding: (*a*) and (*b*) drop siding; (*c*) lap siding.

Plywood for exterior use should be an exterior grade, with plies bonded with permanent waterproof glue (see Art. 10.12). The curtain wall may consist of a single sheet of plywood or of a sandwich of which plywood is a component. Also, plywood may be laminated to another material, such as a light-gage metal, to give it stiffness.

11.18 WALL SHINGLES AND SIDING

Wood, asphalt, and mineral fiber are frequently used for shingles over a sheathed frame. Shingles are made in a variety of forms and shapes and are applied in different ways. The various manufacturers make available instructions for application of their products.

Either in flat sheets or corrugated form, cold-formed metal, plastics or mineral-fiber panels may be used to form a lightweight enclosure. Corrugated sheets are stiffer than the flat. If the sheets are very thin, they should be fastened to sheathing or closely spaced supports.

When corrugated siding is used, details should be planned so that the siding will shed water. Horizontal splices should be placed at supporting members and the sheets should lap about 4 in. Vertical splices should lap at least 1½ corrugations. Sheets should be held firmly together at splices and intersections to prevent water from leaking through. Consideration should be given to sealing strips at openings where corrugated sheets terminate against plane surfaces. The bottommost girt supporting the siding should be placed at least 1 ft above the foundation because of the difficulty of attaching the corrugated materials to masonry. The siding should not be sealed in a slot in the foundation because the metal may corrode or a brittle siding may crack.

When flat sheets are used, precautions should be taken to prevent water from penetrating splices and intersections. The sheets may be installed in sash like window glass, or the splices may be covered with battens. Edges of metal sheets may be flanged to interlock and exclude wind and rain.

Pressed-metal panels, mostly with troughed or boxed cross sections, are also used to form lightweight walls.

Provision should be made in all cases for expansion and contraction with temperature changes. Allowance for movement should be made at connections. Methods of attachment vary with the type of sheet and generally should be carried out in accordance with the manufacturer's recommendations.

11.19 STUCCO

Applied like plaster, stucco is a mixture of sand, portland cement, lime, and water. Two coats are applied to masonry, three coats on metal lath. The finish coat may be tinted by adding coloring matter to the mix or the outside surface may be painted with a suitable material.

The metal lath should be heavily galvanized. It should weigh at least 2.5 lb/yd^2, even though furring strips are closely spaced. When supports are 16 in c to c, it should weigh 3.4 lb/yd^2. (See Table 11.9 in Art. 11.25.6). The lath sheets should be applied with long dimensions horizontal and should be tied with 16-ga wire. Edges should be lapped at least 1 in, ends 2 in.

The first, or scratch, coat should be forced through the interstices in the lath so as to embed the metal completely. In three-coat applications, the coat should be at least ½ in thick. Its surface should be scored to aid bond with the second, or brown, coat. That coat should be applied as soon as the scratch coat has gained sufficient strength to carry the weight of both coats, usually after about 4 or 5 hr from completion of the scratch coat. The second coat should be at least ⅜ in thick. It should be moist cured for at least 48 hr with fine sprays of water and then allowed to dry for at least 1 week. The finish coat should be at least ⅜ in thick. (When only two coats are used, for example, on a masonry base, the base coat should be a minimum of ⅜ in thick and the finish coat, ¼ in. Before application of the base coat, a bond coat, consisting of one part portland cement and one to two parts sand, should be dashed on the masonry with a stiff brush and allowed to set.)

For both the scratch and brown coats, the mix, by volume, may be 1 part portland cement to 3 to 5 parts sand, plus hydrated lime in amount equal to 25% of the volume of cement. Masonry cement may be used instead of portland cement, but without addition of lime, inasmuch as masonry cement contains lime. The finish coat may be a factory-prepared stucco-finish mix or a job mix of 1 part white portland cement, not more than ¼ part of hydrated lime, 2 to 3 parts of a light-colored sand, and mineral oxide pigment, if desired.

Ingredients should be thoroughly mixed dry. Then, water should be added and the materials mixed for at least 5 mm in a power mixer. The first two coats usually are applied with a trowel. The finish coat may be sprayed or manually applied.

(''Plasterer's Manual,'' EBO49M, Portland Cement Association.)

11.20 PRECAST-CONCRETE OR METAL AND GLASS FACINGS

In contrast to siding in which a single material forms the complete wall, precast concrete or metal and glass are sometimes used as the facing, which is backed up with insulation, fire-resistant material, and an interior finish. The glass usually is tinted and is held in a light frame in the same manner as window glass. Metal panels may be fastened similarly in a light frame, attached to mullions or other secondary framing members, anchored to brackets at each floor level, or connected to the structural frame of the building. The panels may be small and light enough for one man to carry or one or two stories high, prefabricated with windows.

Provision for expansion and contraction should be made in the frames, when they are used, and at connections with building members. Metal panels should be shaped so that changes in surface appearance will not be noticeable as the metal expands and contracts. Frequently, light-gage metal panels are given decorative patterns, which also hide movements due to temperature variations (''canning'') and stiffen the sheets. Flat sheets may be given a slight initial curvature and stiffened on the rear side with ribs, so that temperature variations will only change the curvature a little and not reverse it. Or flat sheets may be laminated to one or more flat stiffening sheets, like mineral-fiber panels or mineral-fiber panels and a second light-gage metal sheet, to prevent ''canning.''

It may be desirable in many cases to treat the metal to prevent passage of sound. Usual practice is to apply a sound-absorbing coating on the inside surface of the panel. Some of these coatings have the additional beneficial effect of preventing moisture from condensing on this face.

Metal panels generally are flanged and interlocked to prevent penetration of water. A good joint will be self-flashing and will not require calking. Care must be taken that water will not be blown through weep holes from the outside into the building. Flashing and other details should be arranged so that any water that may penetrate the facing will be drained to the outside. (See also Art. 11.21.)

11.21 SANDWICH PANELS

Walls may be built of prefabricated panels that are considerably larger in size than unit masonry and capable of meeting requirements of appearance, strength, durability, insulation, acoustics, and permeability. Such panels generally consist of an insulation core sandwiched between a thin lightweight facing and backing.

When the edges of the panels are sealed, small holes should be left in the seal. Otherwise, heat of the sun could set up sizable vapor pressure, which could cause trouble.

The panels could be fastened in place in a light frame, attached to secondary framing members (Fig. 11.19*b*), anchored to brackets at each floor level, or connected to the structural frame of the building. Because of the large size of the panels, special precautions should be taken to allow for expansion and contraction due to temperature changes. Usually such movements are provided for at points of support.

With metal curtain walls, special consideration also must be given to prevention of leakage, since metal and glass are totally nonabsorptive. It is difficult to make the outer face completely invulnerable to water penetration under all conditions; so a secondary defense in the form of an internal drainage system must be provided. Any water entering the wall must be drained to the exterior. Bear in mind that water can penetrate a joint through capillary action, reinforced by wind pressure. Running down a vertical surface, water can turn a corner to flow along a horizontal surface, defying gravity, into a joint.

When light frames are not used to support the units, adjoining panels generally interlock, and the joints are calked and sealed with rubber or rubberlike material to prevent rain from penetrating. Flashing and other details should be arranged so that any water that comes through will be drained to the outside. For typical details, see J. H. Callender, ‘‘Time-Saver Standards for Architectural Design Data,’’ 6th ed., McGraw-Hill, Inc., New York; and ‘‘Tilt-up Concrete Walls,’’ PA079.01B, Portland Cement Association.

Metal curtain walls may be custom, commercial, or industrial type. Custom-type walls are those designed for a specific project, generally multistory buildings. Commercial-type walls are those built up of parts standardized by manufacturers. Industrial-type walls are comprised of ribbed, fluted, or otherwise preformed metal sheets in stock sizes, standard metal sash, and insulation.

Metal curtain walls may be classified according to the methods used for field installation:

Stick Systems. Walls installed piece by piece. Each principal framing member, with windows and panels, is assembled in place separately (Fig. 11.19*a*). This type of system involves more parts and field joints than other types and is not so widely used.

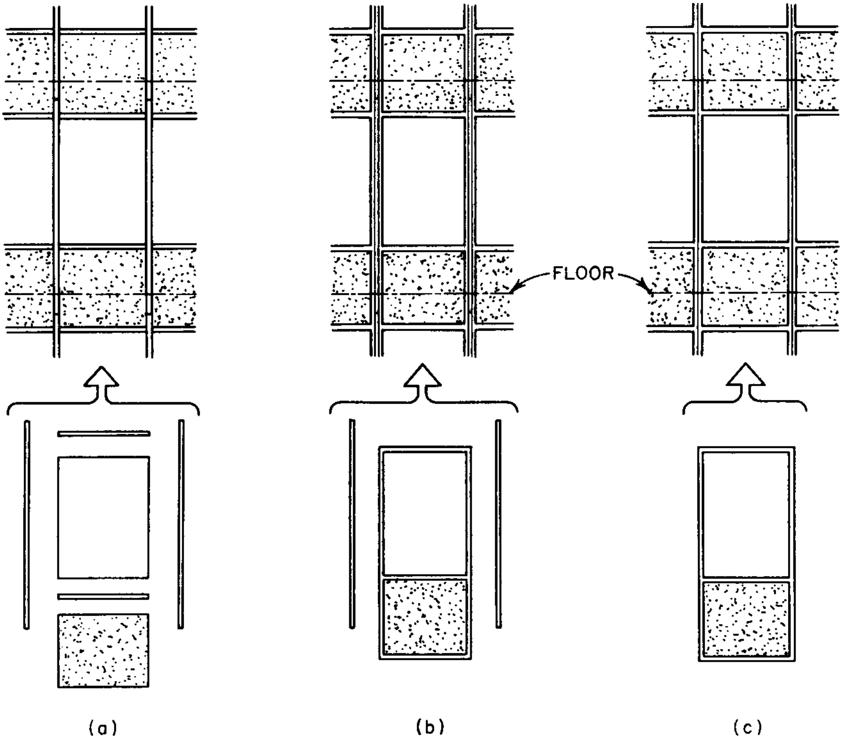


FIGURE 11.19 Methods for field installation of metal curtain walls: (*a*) stick; (*b*) mullion and panel; (*c*) panel system.

Mullion-and-Panel Systems. Walls in which vertical supporting members (mullions) are erected first, and then wall units, usually incorporating windows (generally unglazed), are placed between them (Fig. 11.19*b*). Often, a cover strip is added to cap the vertical joint between units.

Panel Systems. Walls composed of factory-assembled units (generally unglazed) and installed by connecting to anchors on the building frame and to each other (Fig. 11.19*c*). Units may be one or two stories high. This system requires fewer pieces and fewer field joints than the other systems.

Ample provision for movement is one of the most important considerations in designing metal curtain walls. Movement continually occurs because of thermal expansion and contraction, wind loads, gravity, and other causes. Joints and connections must be designed to accommodate it.

When mullions are used, it is customary to provide for horizontal movement at each mullion location, and in multistory buildings, to accommodate vertical movement at each floor, or at alternate floors when two-story-high components are used. Common ways of providing for horizontal movements include use of split mullions, bellows mullions, batten mullions, and elastic structural gaskets. Split mullions comprise two channel-shaped components permitted to move relative to each other in the plane of the wall. Bellow mullions have side walls flexible enough to absorb wall movements. Batten mullions consist of inner and outer cap sections that clamp the edges of adjacent panels, but not so tightly as to restrict movement in the plane of the wall. Structural gaskets provide a flexible link between mullions and panels. To accommodate vertical movement, mullions are spliced with a telescoping slip joint.

When mullions are not used and wall panels are connected to each other along their vertical edges, the connection is generally made through deep flanges. With the bolts several inches from the face of the wall, movement is permitted by the flexibility of the flanges.

Slotted holes are unreliable as a means of accommodating wall movement, though they are useful in providing dimensional tolerance in installing wall panels. Bolts drawn up too tightly or corrosion may prevent slotted holes from functioning as intended. If slotted holes are used, the connections should be made with shoulder bolts or sleeves and Bellville or nylon washers, to provide light but positive pressure and prevent rattling.

Since metals are good transmitters of heat, it is particularly important with metal curtain walls to avoid thermal short circuits and metallic contacts between inner and outer wall faces. When, for example, mullions project through the wall, the inner face should be insulated, or each mullion should comprise two sections separated by insulation.

For more details on curtain walls, see W. F. Koppes, ‘‘Metal Curtain Wall Specifications Manual,’’ National Association of Architectural Metal Manufacturers, 600 S. Federal St., Chicago, IL 60605; ‘‘Curtain Wall Handbook,’’ U.S. Gypsum Co., Chicago, IL 60606.

PARTITIONS

Partitions are dividing walls one story or less in height used to subdivide the interior space in buildings. They may be bearing or nonbearing walls. (See also Art. 1.7.)

11.22 TYPES OF PARTITIONS

Bearing partitions may be built of masonry or concrete or of wood or light-gage metal studs. These materials may be faced with plaster, wallboard, plywood, wood boards, plastic, or other materials that meet functional and architectural requirements. Masonry partitions should satisfy the requirements of Arts. 11.2 to 11.12. See also Art. 11.14.

Nonbearing partitions may be permanently fixed in place, temporary (or movable) so that the walls may be easily shifted when desired, or folding. Since the principal function of these walls is to separate space, the type of construction and materials used may vary widely. They may be opaque or transparent; they may be louvered or hollow or solid; they may extend from floor to ceiling or only partway; and they may serve additionally as cabinets or closets or as a concealment for piping and electrical conduit.

Fire resistance sometimes dictates the type of construction. If a high fire rating is desired or required by local building codes, the local building official should be consulted for information on approved types of construction or the fire ratings given in the following should be used: ‘‘Fire Resistance Design Manual,’’ Gypsum Association, 810 First Street, NE, #510, Washington, D.C. 20002; ‘‘Approval Guide,’’ Factory Mutual System, 1151 Boston-Providence Turnpike, Norwood, MA 02062; ‘‘Fire Resistance Directory,’’ Underwriters Laboratories, 333 Pfingsten Road, Northbrook, IL 60062.

When movable partitions may be installed, the structural framing should be designed to support their weight wherever they may be placed.

Acoustics also sometimes affects the type of construction of partitions. Thin construction that can vibrate like a sounding board should be avoided. Depending on functional requirements, acoustic treatment may range from acoustic finishes on partition surfaces to use of double walls separated completely by an airspace or an insulating material.

Light-transmission requirements may also govern the selection of materials and type of construction. Where transparency or translucence is desired, the partition may be constructed of glass, or of glass block or plastic, or it may contain glass windows.

For installation of facings of ceramic wall tiles, see Arts. 11.28 and 11.29. For plaster or gypsumboard partitions, see Arts. 11.24 to 11.27.

Consideration should also be given to the necessity for concealing pipes, conduits, and ducts in partitions.

11.23 STRUCTURAL REQUIREMENTS OF PARTITIONS

Bearing partitions should be capable of supporting their own weight and superimposed loads in accordance with recommended engineering practice and should rest in turn on adequate supports that will not deflect excessively. Masonry partitions should meet the requirements of Arts. 11.2 to 11.12.

Nonbearing partitions should be stable laterally between lateral supports or additional lateral supports should be added. Since they are not designed for vertical loads other than their own weight, such partitions should not be allowed to take loads from overhead beams that may deflect and press down on them. Also, the beams under the partition should not deflect to the extent that there is a visible separation between bottom of partition and the floor or that the partition cracks.

Folding partitions, in a sense, are large doors. Depending on size and weight, they may be electrically or manually operated. They may be made of wood, lightgage metal, or synthetic fabric on a light collapsible frame. Provision should be made for framing and supporting them in a manner similar to that for large folding doors (Art. 11.57).

PLASTER AND GYPSUMBOARD

For walls or ceilings, an interior finish made of gypsum products may consist of materials partly or completely prepared in the field, or of prefabricated sheets (drytype construction). Factors such as initial cost, cost of maintenance and repair, fire resistance, sound control, decorative effects, and speed of construction must be considered in choosing between them.

When field-prepared materials are used, the plaster finish generally consists of a base and one or more coats of plaster. When dry-type construction is used, one or more plies of prefabricated sheet may be combined to achieve desired results. For fire-resistance and sound-transmission ratings of plaster construction, see ‘‘Fire Resistance Design Manual,’’ Gypsum Association, 810 First Street, NE, #510, Washington, D.C., 20002.

11.24 PLASTER AND GYPSUMBOARD CONSTRUCTION TERMS

Absorption. The rate of absorption of water into gypsumboard, as determined by the test described in ASTM C473.

Accelerator. Any material added to gypsum plaster that speeds the set.

Acoustical Plaster. A finishing plaster that corrects sound reverberations or reduces noise intensity.

Adhesive Spreader. A notched trowel or special tool that aids in application of laminating adhesives.

Adhesive Wall Clips. Special clips or nails with large, perforated bases for mastic application to a firm surface.

Adhesives:

Contact. An adhesive that forms a strong, instantaneous bond between two plies of gypsumboard when the two surfaces are brought together.

Laminating. An adhesive that forms a slowly developing bond between two plies of gypsumboard or between masonry or concrete and gypsumboard.

Stud. An adhesive suitable for attaching gypsumboard to framing.

Admixture. Any substance added to a plaster component or plaster mortar to alter its properties. (See also Dope.)

Arris. A sharp edge forming an external corner at the junction of two surfaces.

Back Blocking. Support provided for gypsumboard butt joints that fall between framing members.

Back Clip. A clip attached to the back of gypsumboard and designed to fit into slots in framing to hold the board in place. Used for demountable partitions.

Back Plastering. Application of plaster to one face of a lath system after application and hardening of plaster applied to the opposite face (used for solid plaster partitions and curtain walls).

Backing (Backer) Board. A type of gypsumboard intended to serve as a base layer in a multilayer gypsumboard system or for application with adhesive of acoustical tile or panels.

Band. A flat molding.

Banjo Taper. A mechanical device that dispenses tape and taping compound simultaneously.

Base (Baseboard). A plastic, wood, or metal trim or molding applied to a wall at the floor line to protect the wall from damage.

Base Coat. The plaster coat or combination of coats applied before the finish coat.

Batten. A predecorated strip or joint covering used to conceal the junction between two boards. It is often used with demountable systems.

Bead. A strip of sheet metal usually with a projecting nosing, to establish plaster grounds, and two perforated or expanded flanges, for attachment to the plaster base, for use at the perimeter of a plaster membrane as a stop or at projecting angles to define and reinforce the edge.

Beaded Molding. A cast plaster string of beads set in a molding or cornice.

Beading. (See Ridging.)

Bed, or Bedding, Coat. The first coat of joint compound over tape, bead, or fastener heads.

Bed Mold or Bed. A flat area in a cornice in which ornamentation is placed.

Bench, Hangers'. A low scaffold used by workers to reach the ceiling.

Binder. A chemical added during formulation of the gypsumboard core, often starch, to improve bond between the core and paper facings.

Bleeding. A discoloration, usually at a joint, on a finished wall or ceiling of gypsumboard.

Blister. Protuberance on the finish coat of plaster caused by application over too damp a base coat, or troweling too soon, or a loose, raised spot on the face of a gypsumboard, usually due to an airspace or void in the core. Also denotes a bulge under joint reinforcing tape, usually caused by insufficient compound under the tape.

Blow. Separation of a large area of paper facing from the core during the manufacturing process and usually appearing as a large, puffy blister or a full loose sheet of paper.

Board Knife. A hand tool that holds a replaceable blade for scoring or trimming gypsumboards

Board Saw. A short handsaw with very coarse teeth used to cut gypsumboards for framed openings for windows and doors.

Bond Plaster. A plaster formulated to serve as a first coat applied to monolithic concrete.

Boss. A Gothic ornament set at the intersection of moldings.

Broad Knife. A wide, flexible finishing knife for applying joint-finishing compound.

Brown Coat. Coat of plaster directly beneath the finish coat. In two-coat work, brown coat refers to the base-coat plaster applied over the lath. In three-coat work, the brown coat refers to the second coat applied over a scratch coat.

Bubble. A large void in the core of gypsumboard caused by entrapment of air while the core is in a fluid state during manufacture.

Buckles. Raised or ruptured spots in plaster that eventually crack, exposing the lath. Most common cause for buckling is application of plaster over dry, broken, or incorrectly applied wood lath.

Bull Nose. This term describes an external angle that is rounded to eliminate a sharp corner and is used largely at window returns and door frames.

Butterflies. Color imperfections on a lime-putty finish wall, caused by lime lumps not put through a screen, or insufficient mixing of the gaging.

Caging. Framing, usually of metal, used to enclose pipes, columns, beams, or other components to be concealed by gypsumboard.

Capital or Cap. The ornamental head of a column or pilaster.

Case Mold. Plaster shell used to hold various parts of a plaster mold in correct position. Also used with gelatin and wax molds to prevent distortions during pouring operation.

Casing Bead. A bead set at the perimeter of a plaster membrane or around openings to provide a stop or separation from adjacent materials.

Casts. (See Staff.)

Catface. Flaw in the finish coat of plaster comparable to a pock mark.

Ceilings:

Coffered. Ornamental ceilings composed of recessed panels between ribs.

Contact. Ceilings attached in direct contact with the construction above, without use of runner channels or furring.

Cross Furred. Ceilings applied to furring members attached at right angles to the underside of main runners or other structural supports.

Furred. Ceilings applied to furring members attached directly to the structural members of the building.

Suspended. Ceilings applied to furring members suspended below the structural members of the building.

Chamfer. A beveled corner or edge.

Chase. A groove in a masonry wall to provide for pipes, ducts, or conduits.

Check Cracks. Cracks in plaster caused by shrinkage, but the plaster remains bonded to its base.

Chip Cracks. Similar to check cracks, except the bond is partly destroyed. Also referred to as fire cracks, map cracks, crazing, fire checks, and hair cracks.

Circle Cutter. An adjustable scribe for cutting circular openings in gypsumboard for lighting fixtures and other devices.

Cockle. A crease-like wrinkle or small depression in gypsumboard paper facing, usually extending in the long direction.

Compounds:

All-Purpose. A joint treatment material that can be used for bedding tape, finishing, laminating adhesive, and texturing.

Joint. A cementitious material for covering joints, corners, and fasteners in finishing of gypsumboard installations, to produce a smooth surface.

Setting-Type. A joint compound that hardens by chemical reactions before drying and that is used for shortening the time required for patching and completing joint finishing.

Taping. A joint compound specially formulated for embedment of joint tape.

Topping. A joint compound specially formulated to serve as the final finishing coat for a joint, but not intended for embedment of tape.

Core. The gypsum structure between face and back papers of gypsumboard.

Coreboard. A gypsumboard, usually 24 in wide and up to 1 in thick, with square, rounded or tongue-and-groove edges, and homogeneous or laminated.

Corner Bead. A strip of sheet metal with flanges and a nosing at the junction of the flanges; used to protect arrises.

Corner Cracks. Cracks in joint of intersecting walls or walls and ceilings.

Corner Floating. (See Floating Angles.)

Cornerite. Reinforcement for plaster at a reentrant corner.

Cornice. A molding, with or without reinforcement.

Cove. A curved concave, or vaulted, surface.

Crown. A buildup of joint compound over a joint to conceal the tape over the joint.

Cure. Treatment, usually of a portland-cement plaster, to ensure hydration after application.

Dado. The lower part of a wall usually separated from the upper by a molding or other device.

Darby. A flat wood tool with handles about 4 in wide and 42 in long; used to smooth or float the brown coat; also used on finish coat to give a preliminary true and even surface.

Dentils. Small rectangular blocks set in a row in the bed mold of a cornice.

Dimple. The depression in the surface of gypsumboard caused by a hammer in setting a nail head slightly below the surface, to permit concealment of the nail with joint compound.

Dope. Additives put in any type of mortar to accelerate or retard set.

Double-up. Applications of plaster in successive operations without a setting and drying interval between coats.

Double Nailing. A method of applying gypsumboard to framing with pairs of nails at intervals of about 12 in along the framing, to ensure firm contact. (The nails in each pair are usually set about 2 in apart.)

Dry out. Soft chalky plaster caused by water evaporating before setting.

Drywall Construction. Application of gypsumboard. (This is basically a dry process rather than a wet process, such as lath and plaster.)

Edges:

Beveled. The factory-formed edge of gypsumboard that has been sloped so that, where two boards abut, a V-groove joint is created.

Chisel. A slanted factory edge on gypsumboard.

Feathered. A thin edge formed by tapering joint compound at a joint to blend with adjoining gypsumboard surfaces; also denotes the skived edge of joint tape.

Featured. A configuration of the paper-bound edges of gypsumboard that provides special design or performance characteristics.

Floating. An edge that does not lie directly over framing and that will be unsupported after installation of gypsumboard or plaster.

Hard. A special core formulation used along the paper-bound edges of gypsumboard to improve resistance to damage during handling and application of the board.

Skive. The outside edges of joint tape that have been sanded or chamfered to improve adhesion and reduce waviness.

Tapered. A factory edge on gypsumboard that is progressively reduced in thickness to allow for concealment of joint tape below the plane of the gypsumboard surface.

Efflorescence. White fleecy deposit on the face of plastered walls, caused by salts in the sand or backing; also referred to as ''whiskering'' or ''saltpetering.''

Egg and Dart. Ornamentation used in cornices consisting of an oval and a dart alternately.

Eggshelling. Plaster chip-cracked concave to the surface, the bond being partly destroyed.

Enrichments. Any cast ornament that cannot be executed by a running mold.

Expanded Metals. Sheets of metal that are slit and drawn out to form diamond-shaped openings.

Fat. Material accumulated on a trowel during the finishing operation of plaster and used to fill in small imperfections. Also denotes a mortar that is not too stiff, too watery, or oversanded.

Feather Edge. A beveled-edge wood tool used to straighten reentrant angles in the finish plaster coat.

Fines. Aggregate capable of passing through a No. 200 sieve.

Finish Coat. Last and final coat of plaster; also denotes a thin coat of joint treatment to reduce variations in surface texture and suction.

Finisher. A tradesman with skill in finishing of gypsumboard joints.

Fire Taping. Taping of gypsumboard joints without subsequent finishing coats, usually used where esthetics is not important.

Fisheyes. Spots in plaster finish coat about ¼ in in diameter, caused by lumpy lime because of age or insufficient blending of material.

Float. A tool shaped like a trowel, with a handle braced at both ends and wood base for blade, used to straighten, level, and texture finish plaster coats.

Floating Angles (Corner Floating). Unrestrained surfaces intersecting at about 90°, usually with fasteners omitted near the intersection (Fig. 11.28).

Foil Back. A gypsumboard with a reflective aluminum-foil composite laminated to its back surface.

Furring. Strips that are nailed over studs, joists, rafters, or masonry to support lath or gypsumboard. This construction permits free circulation of air behind the plaster or gypsumboard.

Gaging. Mixing of gaging plaster with lime putty to acquire the proper setting time and initial strength. Also denotes type of plaster used for mixing with the putty.

Green Board. A gypsumboard with a tinted face paper, usually light green or blue, to distinguish special types of board; also denotes gypsumboard that is damp.

Green Plaster. Wet or damp plaster.

Grounds. A piece of wood, metal, or plaster attached to the framing to indicate the thickness of plaster to be applied.

Gypsum. Fully hydrated calcium sulfate (calcium sulfate dihydrate).

Gypsum Base. Gypsum lath used as a base for veneer plasters.

Gypsumboard. A noncombustible board with gypsum core enclosed in tough, smooth paper.

Type X. A gypsumboard specially formulated with high fire resistance for use in fire-rated assemblies.

Hardwall. Gypsum neat base-coat plaster.

Joint Treatment. Concealing of gypsumboard joints, usually with tape and joint compound.

Joints:

Butt. Joints in which gypsumboard ends with core exposed (usually in the direction of the board width) are placed together.

Crown (High or Hump). Protrusion of joint compound from gypsumboard surface at a joint.

Floating. (See Edges, Floating.)

Keene's Cement. A dead-burned gypsum product that yields a hard, high-strength plaster.

Lamination:

Sheet. A ply of gypsumboard attached to another ply with adhesive over the entire surface to be bonded.

Strip. A ply of gypsumboard attached to another ply by parallel strips of adhesive, usually 16 or 24 in apart.

Lath. A base to receive plaster.

Lime. Oxide of calcium produced by burning limestone. Heat drives out the carbon dioxide leaving calcium oxide, commonly termed "quicklime." Addition of water to quicklime yields hydrated or slaked lime.

Lime Plaster. Base-coat plaster consisting essentially of lime and aggregate.

Lime Putty. Thick paste of water and slaked quicklime or hydrated lime.

Marezzo. An imitation marble formed with Keene's cement to which colors have been added.

Mud. (See Compounds.)

Nail Popping. Protrusion above the face of gypsumboard of a nail used to attach the board to framing; usually caused by shrinkage due to drying of inadequately cured wood framing.

Nail Spotter. A small, box-type applicator used to cover with joint compound the heads of nails in gypsumboard.

Neat Plaster. A base-coat plaster to which sand is added at the job.

Niche. A small recess in a wall.

Ogee. A curved section of a molding, partly convex and partly concave.

Papers:

Calendered. Papers with a high glossy finish.

Cream (*Ivory or Manila*). Highly sized and calendered papers used as the face papers on gypsumboard.

Gray. Unsized, uncalendered papers used on the back side of regular gypsumboard and as the face and back papers of backing boards.

Sized. Paper treated with a sealant to equalize suction for paint and prevent rise of nap.

Perimeter Relief. A construction arrangement that permits building movements; also denotes gaskets that relieve stresses at intersections of walls and ceilings.

Pinhole. A small hole that appears in a plaster cast because of excess water in preparation of the plaster; also denotes a small perforation in gypsumboard paper or paper joint tape.

Plasterboard. (See Gypsumboard.)

Prefill. An application method used in preparation of joints of tapered- or beveled-edge gypsumboard to receive tape and joint treatment with the objective of reducing the possibility of ridging or beading.

Primer. A base coat of paint used to improve the bond and appearance of the finish coat of paint; usually referred to as an undercoat when tinted. (See also Sealer and Sizing.)

Punch out. A hole made in gypsumboard to fit closely around pipe that passes through the board.

Putty Coat. A smooth, troweled-finish coat containing lime putty and a gaging material.

Quicklime. (See Lime.)

Relief. Ornamental figures above a plane surface.

Retarder. Any material added to gypsum plaster that slows its set.

Return. The terminal of a cornice or molding that takes the form of an external miter and stops at the wall line.

Reveal. The vertical face of a door or window opening between the face of the interior wall and the window or door frame.

Ridging. A linear surface protrusion along treated joints.

Ripper. A narrow strip of gypsumboard used for soffits, window reveals, and finished openings.

Runner. A metal or wood track or strip placed at floor and ceiling to receive framing members for partitions.

Sanding. Smoothing a joint treatment for gypsumboard with sandpaper. In wet sanding, the joint is smoothed with a coarse wet sponge, so that less dust is produced than in dry sanding.

Scagliola. An imitation marble, usually precast, made with Keene's cement.

Score. A groove cut in the surface of a board with a sharp blade to expedite manual breaking of the board.

Scratch Coat. First coat of plaster in three-coat work.

Screeds. Long, narrow strips that serve as guides for plastering; also denotes tools, such as straightedges, used to shape an unhardened surface.

Sealer. A base coat of paint used to seal a surface and equalize differences in surface suction, to improve the bond and appearance of the finish coat. (See also Primer and Sizing.)

Seam. A treated gypsumboard joint.

Sheathing, Gypsum. A gypsumboard formulated for use as an enclosure for an exterior wall and a base for siding or other exterior facings, but not intended for long-time direct exposure to the weather.

Ship Lap. An offset lamination of two layers of gypsumboard.

Shoulder. The area between the tapered edge and the face of a gypsumboard.

Sizing. A surface sealant used to equalize suction of paint when applied to gypsumboard paper and prevent rising of the nap.

Skim Coat. (See Finish Coat.)

Skip Trowel. A method of texturing a surface that results in a rough *Spanish Stucco* effect.

Slaking. Adding water to hydrate quicklime into a putty.

Soffit. The underside of an arch, cornice, bead, or other construction.

Soffit Board. A gypsumboard formulated for use on the underside of exterior overhangs, carport ceilings, and other areas protected from the weather.

Splay Angle. An angle of more than 90°.

Spray Texture. A mechanically applied material, which may contain aggregates to produce various effects, used to form decorative finishes.

Staff (Casts). Plaster casts made in molds and reinforced with fiber; usually wired or nailed into place.

Stucco. Plaster applied to the exterior of a building.

Substrate. A surface capable of receiving additional finish or decoration; also denotes the base or concealed layer of gypsumboard in a composite assembly.

Suspension System. Construction, usually incorporating heavy-gage hanging wire, for supporting a ceiling set below structural floor framing, roof, subfloor, or floor deck.

Sweat out. A soft, damp wall area of plaster caused by poor drying conditions.

Swirl Texturing. A method of applying texturing material in a decorative circular pattern.

Tape:

Dry. A tape applied over gypsumboard joints with adhesive other than conventional joint compound.

Joint. A paper tape or fiber mesh for reinforcing joint compound to conceal and reinforce the joints of gypsumboard.

Tape Creaser. A hand-held tool for folding joint tape for use in reentrant corners.

Temper. Mixing of plaster to a workable consistency.

Template. A gage, pattern, or mold used as a guide to produce arches, curves, and various other shapes.

Veneer Plasters. Gypsum plasters meeting requirements of ASTM C587, and that may be applied in one or more coats to a maximum thickness of ¼ in.

Wadding. The act of hanging staff by fastening wads made of plaster of paris and excelsior or fiber to the casts and winding them around the framing.

Wainscot. The lower 3 or 4 ft of an interior wall when it is finished differently from the remainder of the wall.

Wallboard:

Gypsum. A gypsumboard used primarily as an interior surface.

Laminated. Two or more layers of gypsumboard held together with an adhesive.

Predecorated. A gypsumboard with a finished surface, such as paint, texturing material, vinyl film, or printed paper coverings, applied before the board is delivered to the building site.

White Coat. A gaged lime-putty troweled-finish coat.

11.25 PLASTER FINISHES

Prepared on the building site, plaster finishes are classified as wet-type construction. They take longer to complete than dry-type construction, because they are field mixed with water and require curing before decorative materials, such as paint or wallpaper, can be applied. Plaster finishes are selected nevertheless because they are hard, abrasion resistant, rigid, incombustible, and provide a monolithic (unseamed) surface, even at corners. They are relatively brittle, however, and must be properly applied to avoid cracking when movements due to drying shrinkage or thermal changes are restrained.

11.25.1 Components of Plaster

A plaster finish consists of a supporting base, such as masonry or lath, and one or more coats of plaster or mix of plaster and other ingredients with water that is troweled or machine sprayed over the base.

The principal ingredient of plaster usually is gypsum but may be portland cement. (Portland-cement plaster, or stucco, is discussed in Art. 11.19.) Gypsum plasters generally are formulated to meet the requirements of ‘‘Standard Specification for Gypsum Plasters,’’ ASTM C28, or ‘‘Standard Specification for Gypsum Veneer Plaster,’’ ASTM C587.

C28 gypsum plasters include ready-mixed, neat, wood-fiber and gaging plasters. They may be applied over a masonry or lath base, generally in two or more coats, with a total thickness exceeding ½ in. They are required to contain 66% or more by weight of $CaSO_4 \cdot \frac{1}{2}H_2O$.

Veneer plasters must be applied over a special gypsum base, meeting the requirements of ASTM C588, and are limited in thickness to a maximum of ¼ in. They are usually selected because of low cost, rapid installation (permitting application of decorative materials 24 hr after plastering), and high resistance to cracking, nail popping, and impact and abrasion failure. The finishes are, however, not so rigid as conventional lath and plaster. Also, veneer plasters are more susceptible than gypsum plasters to ridging and cracking at joints when dried too rapidly because of low humidity, high temperature, or exposure to drafts.

Application of gypsum and veneer plasters should meet the requirements of the following ASTM specifications:

C841. Installation of Interior Lathing and Furring

C842. Application of Interior Gypsum Plaster

C843. Application of Gypsum Veneer Plaster

C844. Application of Gypsum Base to Receive Gypsum Veneer Plaster

See also Art. 11.27.

11.25.2 Plaster Mixes

Plaster coats other than veneer plasters are generally composed of gypsum plaster, lime, an aggregate (sand, vermiculite, perlite), and water.

Sisal or synthetic fibers, such as nylon, may be added to some scratch-coat plasters for application to metal lath, to limit to what is needed for good bond the amount of plaster that passes through the lath meshes. Fibering, however, adds no strength.

Sand should comply with ASTM C35. It should be clean, free of organic material, more than about 5% clay, silt, or other impurities, and should not contain salt or alkali. The proportion of sand in the plaster has an important bearing on the characteristics of the product. Oversanding results in considerable reduction in strength and hardness. A mix as lean as 4:1 by weight should never be used.

The Gypsum Association suggests that a 1-ft^3 measuring box be used for preparing mixes. Some plasterers use a No.2 shovel, which holds about 16 lb of moist sand, for maintaining proper proportions. Thus, with each 100-lb bag of plaster, a 1:2 mix requires 12 shovels of sand and a 1:3 mix 18 shovels (“Manual of Gypsum Lathing and Plastering”).

Water should be clean and free of substances that might affect the rate of set of the plaster. It is not advisable to use water in which plasterers’ tools have been washed because it might change the set. Excessive water is undesirable in the mix, because when the water evaporates, it leaves numerous large voids, which decrease the strength of the plaster. Hence, manufacturers’ recommendations should be observed closely in determining water requirements.

Perlite and vermiculite are manufactured lightweight aggregates that are used to produce a lightweight plaster with relatively high fire resistance for a given thickness. Both aggregates should conform with ASTM C35, and the mix should be prepared strictly in accordance with manufacturers’ recommendations.

11.25.3 Mixing Plaster

A mechanical mixer disperses the ingredients of a mix more evenly and therefore is to be preferred over box mixing. Recommended practice is as follows: (1) Place the anticipated water requirements in the mixer; (2) add about half the required sand (or all required perlite or vermiculite); (3) add all the plaster; (4) add the rest of the sand; (5) mix at least 2 mm, but not more than 5 mm, adding water, if necessary, to obtain proper workability; and (6) dump the entire batch at once.

The mixer should be thoroughly cleaned when it is not in use. If partly set material is left in it, the set of the plaster might be accelerated. For this reason also, tools should be kept clean.

For hand mixing, first sand and plaster should be mixed dry to a uniform color in a mixing box, water added, and the plaster hoed into the water immediately and thoroughly mixed. Undermixed plaster is difficult to apply and will produce soft and hard spots in the plastered surface.

Plaster should not be mixed more than 1 hr in advance. Nor should a new mix, or gaging, be mixed in with a previously prepared one. And once plaster has started to set, it should not be remixed or retempered.

11.25.4 Plaster Drying

A minimum temperature of 55°F should be maintained in the building where walls are to be plastered when outdoor temperatures are less than 55°F, and held for at least 1 week before plaster is applied and 1 week after the plaster is dry.

In hot, dry weather, precautions should be taken to prevent water from evaporating before the plaster has set. Plastered surfaces should not be exposed to drafts, and openings to the outside should be closed off temporarily. After the plaster sets, the excess moisture it contains evaporates. Hence, the room should be adequately ventilated to allow this moisture to escape.

("Architect Data Book—Construction Products and Systems," Gold Bond Building Products, a National Gypsum Division, 2001 Rexford Road, Charlotte, NC 28211; "Gypsum Products Design Data," Gypsum Association, 810 First Street, NE, #510, Washington, D.C., 20002; "Gypsum Construction Handbook," United States Gypsum, 125 South Franklin Street, Chicago, IL 60606.)

11.25.5 Gypsum Bases for Plaster

One commonly used base for plaster is gypsum lath. This is a noncombustible sheet generally 16 × 48 in by ⅜ or ½ in thick, or 16 × 96 in by ⅜ in thick. It is composed principally of calcined gypsum that has been mixed with water, hardened, dried, and then sandwiched between two paper sheets (ASTM C37). Insulating gypsum lath is made by cementing shiny aluminum foil to the back of plain lath. It is used for vapor control, and for insulation against heat loss or gain. Also available is gypsum lath with a core specially formulated with minerals for high resistance to fire.

Gypsum lath has the advantage over metal lath that less plaster is required, because the first, or scratch, coat is applied only over the lath surface. Also, when used for suspended ceilings or hollow partitions, plaster on gypsum lath is less susceptible to cracking than on metal lath.

Installation of gypsum lath should meet the requirements of ASTM C841, "Installation of Interior Lathing and Furring." The lath should be applied to studs with long dimension horizontal, and vertical joints should be staggered (Fig. 11.20). In ceilings, the long sides should span supports. Ends should rest on or be nailed to framing, headers, or nailing blocks. Each lath should be in contact with adjoining sheets, but if spaces more than ½ in wide are necessary, the plaster should be reinforced with self-furring metal lath that is stapled or tied with wire to the gypsum lath.

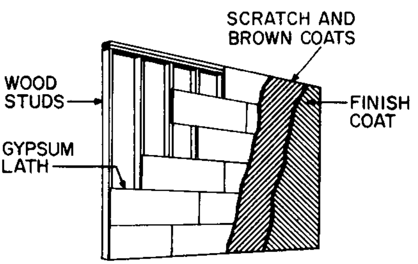


FIGURE 11.20 Two coats of plaster applied to perforated gypsum lath attached to wood studs.

When nailed to wood members, ⅜-in-thick gypsum lath should be attached with four nails, and ½-in lath with five nails, to each framing member covered. Nails should be blued gypsum lath nails, made of 13-ga wire, 1⅛ in long, with a 19⁄64-in-diam flat head. They should be driven until the head is just below the paper surface without breaking the paper. Lath also may be attached to wood framing with four or five 16-ga staples, 7⁄16 in wide, with ⅜-in divergent legs. With metal framing, screws should be used, as recommended by the lath manufacturer. Clips, however, are a suitable alternative for use with wood or metal framing. Fasteners should be driven at least ⅜ in away from ends and edges. Clips must secure the lath to framing at each intersection with the framing.

Studs or ceiling members supporting lath may be spaced up to 16 in c to c with ⅜-in gypsum lath, and up to 24 in c to c with ½-in lath.

Except at intersections that are to be unrestrained, reentrant corners should be reinforced with cornerite stapled or tied with wire to the gypsum lath. Exterior-angle corners should be finished with corner beads set to true grounds and nailed or tied with wire to the structural frame or to furring. Casing beads should be used around wall openings and at intersections of plaster with other finishes and of lath and lathless construction.

Gypsum Base for Veneer Plasters. Special gypsum lath meeting requirements of ASTM C588 is required as a base for veneer plasters. It is formulated to provide the strength and absorption necessary for proper application and performance of these thin coatings. The lath comes in thicknesses of ⅜ (for two-coat systems), ½, and ⅝ in, the last permitting 24-in spacing of wood framing. Installation should meet the requirements of ASTM C844. In general, gypsum base should be applied first to the ceiling, then to the walls. Maximum spacing of nails is 7 in on ceilings and 8 in on walls. Screw spacing should not exceed 12 in for wood framing 24 in c to c or for steel framing or for wood ceiling framing, or 16 in for wood studs spaced 16 in c to c.

11.25.6 Metal Lath

A metal base often is used in plaster construction because it imparts strength and resists cracking. Plaster holds to metal lath by mechanical bond between the initial coat of plaster and the metal. So it is important that the plaster completely surrounds and embeds the metal.

Basic types commonly used are expanded-metal, punched sheet-metal, and paper-backed welded-wire lath. Woven-wire lath may be used as a supplemental reinforcement over solid plaster bases, but not as the primary base for gypsum plaster. Wire lath should be made of galvanized, copper-bearing steel. The other types should be made of galvanized steel or copper-bearing steel with a protective coat of paint.

Expanded-metal lath is fabricated by slitting sheet steel and expanding it to form a mesh. Several types are available:

Diamond-mesh lath, with more than 11,000 meshes/yd^2, is an all-purpose lath, suitable as a base for flat or curved plaster surfaces (Fig. 11.21). The small meshes are helpful in reducing droppings of plaster during plastering. A self-furring type also is available. When it is attached to a backing, it is separated from the backing by at least ¼ in. Thus, self-furring lath is convenient for use as exterior stucco bases and bases for column fireproofing and replastering over old surfaces.

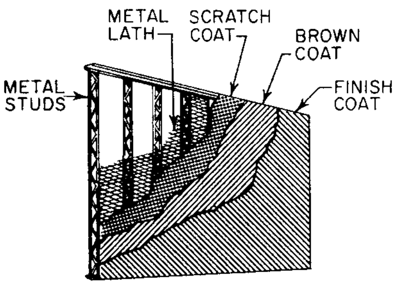


FIGURE 11.21 Three coats of plaster applied to metal lath attached to steel studs.

Flat-rib expanded-metal lath comes with smaller openings than diamond mesh, and it has ribs parallel to the length of the sheet that make it more rigid. Flat-rib lath is generally preferred for nailing to wood framing and tying to framing for flat ceilings, but it is not suitable for contour lathing.

High-rib expanded-metal lath is used when greater rigidity is desired, for example, for spacing supports up to 24 in c to c and for solid, studless plaster partitions. The lath has a herringbone mesh pattern and V-shaped ribs running the length of each sheet. For ⅜-in rib lath, ⅜-in-deep ribs are spaced 4½ in c to c, alternating with inverted 3⁄16-in ribs. For ¾-in rib lath, ¾-in-deep ribs are spaced 6 in c to c. This type of high-rib lath may be used as a form and reinforcement for concrete slabs, but its thickness makes it generally unsuitable for plaster construction. The ⅜-in rib lath may also be used as a concrete form, but its rigidity makes it unsuitable for contour lathing.

Welded-wire lath should be made of wire 16 ga or thicker, forming 2 × 2-in or smaller meshes, stiffened continuously parallel to the long dimension of the sheet at intervals not exceeding 6 in. The paper backing should comply with Federal Specifications UU-B-790, "Building Paper, Vegetable Fiber (Kraft, Waterproofed, Water Repellant, and Fire Resistant)." Acting as a base to which plaster can adhere while hardening about the wire, the backing should permit full embedment in at least ⅛ in of plaster of more than half the total length and weight of the wires.

Table 11.9 lists limiting spans for various types and weights of metal lath for ceilings and walls.

Tying and Nailing. Installation of metal lath should meet the requirements of ASTM C841. Attachments of metal lath to supports should not be spaced farther apart than 6 in along the supports.

When metal framing or furring is used, metal lath should be tied to it with 18-ga, or heavier, galvanized soft-annealed wire. Rib lath, however, should be attached to open-web steel joists with single loops of 16-ga, or heavier, wire, or double

TABLE 11.9 Limiting Spans for Metal Lath, in

		Vertical supports			Horizontal supports	
			Metal			
Type of lath	Min wt., lb/yd²	Wood	Solid partitions*	Other	Wood or concrete	Metal
Diamond mesh (flat	2.5	16	16	12	12	12
expanded) metal lath	3.4	16	16	16	16	13½
Flat- (⅛-in) rib expanded	2.75	16	16	16	16	16
metal lath	3.4	19	24	19	19	19
⅜-in rib expanded metal lath†	3.4	24	24†	24	24	24
	4.0	24	24§	24	24	24
¾-in rib expanded metal lath	5.4		†	24	36‡	36‡
Sheet-metal lath†	4.5	24	†	24	24	24
Welded-wire lath	1.16§	16	16	16	16	16
	1.95¶	24	24	24	24	24

* For paper-backed lath, only absorbent, perforated, or slotted paper separator should be used.
† Permitted for studless solid partitions.
‡ Permitted only for contact or furred ceilings.
§ Welded 16-ga wire, paper-backed lath.
¶ Paper-backed lath with welded wire, face wires 16 ga, every third back wire parallel to line dimension of lath 11 ga.
Source: Based on "Uniform Building Code," International Conference of Building Officials, Inc.

loops of 18-ga wire, with the ends of each loop twisted together. Also, rib lath should be tied to concrete joists with loops of 14-ga, or heavier, wire or with wire hangers not less than 10 ga.

With wood supports, diamond-mesh, flat-rib, and welded-wire lath should be attached to horizontal framing with 1½-in, 11 ga, 7⁄16-in-head, barbed, galvanized, or blued roofing nails, driven full length. For vertical wood supports the following may be used: 4d common nails; 1-in, 14-ga wire staples driven full length; and 1-in roofing nails driven at least ¾ in into the supports. Common nails should be bent over to engage a rib or at least three strands of lath. Alternatives of equal strength also may be used.

Metal lath should be applied with long sides of sheets spanning supports. Each sheet should underlap or overlap adjoining sheets on both sides and ends. Expanded-metal and sheet-metal lath should be lapped ½ in along the sides, or have edge ribs nested, and 1 in along the ends. Welded-wire lath should be lapped one mesh at sides and ends. All side laps of metal lath should be fastened to supports and tied between supports at intervals not exceeding 9 in.

Wherever possible, end laps should be staggered, and the ends should be placed at and fastened to framing. If end laps fall between supports, the adjoining ends should be laced or securely tied with 18-gage, galvanized, annealed steel wire.

Normally, metal lath should be applied first to ceilings. Flexible sheets may be carried down 6 in on walls and partitions. As an alternative, preferable for more rigid sheets, sides and ends of the lath may be butted into horizontal reentrant angles and the corner reinforced with cornerite. But for large ceilings (length exceeding 60 ft in any direction, or more than 2400 ft^2 in area) and other cases in which restraint should be avoided, and for portland-cement plaster ceilings, cornerite should not be used. Instead, the abutting sides and ends should terminate at a casing bead, control joint, or similar device that will isolate the ceiling lath and plaster from the walls and partitions.

Similar considerations govern installation of metal lath at vertical reentrant corners. Between partitions, flexible sheets may be bent around vertical corners and attached at least one support away from them; more rigid sheets may be butted and the corner reinforced with cornerite. But where restraint is undesirable at reentrant corners, for example, where partitions meet structural walls or columns, or where load-bearing walls intersect, cornerite should not be used. Instead, the walls, partitions, and structural members should be isolated from each other, as described for ceiling-wall corners.

11.25.7 Masonry Bases for Plaster

Gypsum partition tile has scored faces to provide a mechanical bond as well as the natural bond of gypsum to gypsum plaster. The 12 × 30-in faces of the tile present an unwarped plastering surface because the tile is dried without burning. This is done so that a mechanic can lay a straighter wall than with other types of units. The Gypsum Association's ''Manual of Gypsum Lathing and Plastering'' recommends that only gypsum plaster be applied to gypsum partition tile, since lime and portland cement do not bond adequately. Also, only gypsum mortar should be used for laying tile.

Brick and clay tile can be used as a plaster base if they are not smooth-surfaced or of a nonporous type. If the surface does not provide sufficient suction, it should offer a means for developing a mechanical bond, such as does scored tile.

Plaster should not be applied directly to exterior masonry walls because dampness may damage the plaster. It is advisable to fur the plaster at least 1 in in from the masonry.

Properly aged concrete block may serve in walls as a plaster base, but for block ceilings, a bonding agent or a special bonding plaster should be applied first.

For precast or cast-in-place concrete with smooth dense surfaces, a bonding agent or a special bonding plaster should be used first. But if a plaster thickness of more than $\frac{3}{8}$ in is required for concrete ceilings, or $\frac{5}{8}$ in for concrete walls, metal lath should be secured to the concrete before plastering, in which case sanded plaster can be used.

11.25.8 Plaster Base Coats

The base coat is the portion of the plaster finish that is applied to masonry or lath bases and supports the finish coat (Fig. 11.22).

Except for veneer plasters, plaster applications may be three-coat (Fig. 11.21) or two-coat (Fig. 11.20). The former consists of (1) a scratch coat, which is applied directly to the plaster base, cross-raked after it has "taken up," and allowed to set and partly dry; (2) a brown coat, which is surfaced out to the proper grounds, darbied (float-finished), and allowed to set and partly dry; and (3) the finish coat. Three-coat plaster is required over metal lath, $\frac{1}{2}$-in gypsum lath spanning horizontal supports more than 16 in c to c, all gypsum lath attached by clips providing only edge support, and $\frac{3}{8}$-in perforated gypsum lath on ceilings.

The two-coat application is similar, except that cross-raking of the scratch coat is omitted and the brown coat is applied within a few minutes to the unset scratch coat. Three coats are generally preferred, because the base coat thus produced is stronger and harder.

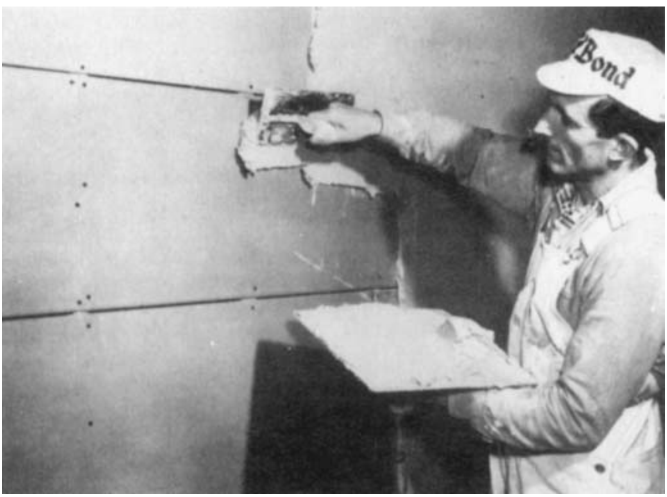


FIGURE 11.22 Application of a base coat of plaster to gypsum lath. (*Gold Bond Building Products, a National Gypsum Division.*)

Veneer plaster applications, 1⁄16 in thick, may be one-coat or two-coat, both applied to special gypsum base (Arts. 11.25.1 and 11.25.5). The single coat is composed of a scratch coat without cross-raking and a double-up coat immediately applied, then worked to a smooth or textured finish.

See also Art. 11.25.9 and "Manual of Gypsum Lathing and Plastering," Gypsum Association.

Plaster Grounds. Except for veneer plasters, thickness of base-coat plaster should be controlled with grounds—wood or metal strips applied at the perimeter of all openings and at baseboards or continuous strips of plaster applied at intervals along a wall or ceiling, to serve as screeds. Plaster screeds should be used on all plaster surfaces of large area.

Minimum Thicknesses. Grounds should be set to provide a minimum plaster thickness of ½ in over gypsum lath and gypsum partition tile; ⅝ in over brick, clay tile, or other masonry; and ⅝ in from the face of metal lath. A thickness of 1⁄16 in is included for the finish coat.

Gypsum Base-Coat Plasters. Three types of gypsum base-coat plasters are in general use: gypsum heat plaster, gypsum ready-mixed plaster, and veneer plasters, which may be used in thin one-coat or two-coat systems. In two-coat veneer-plaster systems, the base-coat veneer plaster should be applied to a thickness of 1⁄16 to 3⁄32 in, and left with a rough surface to receive the finish coat. Veneer plasters should meet the requirements of ASTM C587 and application should be in accordance with ASTM C843.

Gypsum neat plaster, sometimes called hardwall or gypsum-cement plaster, is sold in powder form and mixed with an aggregate and water at the construction site. Mixed with no more than 3 parts sand by weight, it makes a strong base coat at low cost. Scratch coats generally consist of 1 part plaster powder to 2 parts sand by weight, fibered or unfibered; the base coat in two-coat work usually is a 1:2½ mix; brown coats are 1:3 mixes. With perlite or vermiculite instead of sand, a 1:2 mix may be used.

Gypsum ready-mixed plaster requires the addition only of water at the site, since it is sold in bags containing the proper proportions of aggregate and plaster. It is specified when good plastering sand is high cost or not available, or to avoid the possibility of oversanding. It costs a little more than neat plaster because of the extra cost of transporting the sand.

The water ratio for base coat neat and ready-mixed plasters should be such that slump does not exceed 4 in when tested with a 2 × 4 × 6-in cone at the mixer, for mixes with sand proportions not exceeding those given for gypsum neat plaster.

Application of gypsum plaster should meet the requirements of ASTM C842. The scratch coat (Figs. 11.20 and 11.21) applied to lath should be laid on with enough pressure to form a strong clinch or key. The coat should cover the lath to a thickness of ¼ in. For two-coat systems, the double-up brown coat is applied immediately. For three-coat systems, after the surface has been trued, the scratch coat should be scratched horizontally and vertically with a toothed tool to form a good bonding surface, then left to dry partly. When the surface is so hard that the edges of the scoring do not yield easily under the pressure of a thumbnail, the brown coat may be applied. Hardening may take at least 1 day, and sometimes as long as 1 week, depending on drying conditions.

The brown coat not only forms the base for the finish coat, but is also the straightening coat. The plaster should be laid on with a steel float, trued with rod or darby, and left rough in preparation for the finish coat.

11.25.9 Finish Plaster Coats

Several types of plasters are available for the finish coat (Figs. 11.20 and 11.21). Usually, lime is an important ingredient, because it gives plasticity and bulk to the coat.

Gaging plasters are coarsely ground gypsum plasters, which are available in quicksetting and slow-setting mixtures; so it is not necessary to add an accelerator or a retarder at the site. Gaging plasters also are supplied as white gaging plaster and a slightly darker local gaging plaster. Finish coats made with these plasters are amply hard for ordinary usages and are the lowest-cost plaster finishes. However, they are not intended for ornamental cornice work or run moldings, which should be made of a finer-ground plaster. Gypsum gaging plasters should conform with ASTM C28. Application should conform with ASTM C842.

Typical mixes consist of 3 parts lime putty to 1 part gaging plaster, by volume. If a harder surface is desired, the gaging content may be increased up to 1 part gaging to 2 parts lime putty.

The lime is prepared first, being slaked to a smooth putty, then formed on the plasterer's board into a ring with water in the center. Next, gaging plaster is gradually sifted into the water. Then, aggregates, if required, are added. Finally, all ingredients are thoroughly mixed and kneaded. Alternatively, materials, including Type S hydrated lime, may be blended in a mechanical mixer.

The lime-gaging plaster should be applied in at least two coats, when the brown coat is nearly dry. The first coat should be laid on very thin, with sufficient pressure to be forced into the roughened surface of the base coat. After the first coat has been allowed to draw a few minutes, a second or leveling coat, also thin, should be applied.

The base coat draws the water from the finish coats; so the finished surface should be moistened with a wet brush as it is being troweled. Pressure should be exerted on the trowel to densify the surface and produce a smooth hard finish. Finally, the surface should be dampened with the brush and clean water. It should be allowed to stand at least 30 days before oil paints are applied.

Prepared gypsum trowel finishes also are available that require only addition of water at the site. The resulting surface may be decorated as soon as dry. The plaster is applied in the same manner as lime-gaging plaster, but the base coat should be dry and, because the prepared plaster has a moderately fast set, it should be troweled before it sets. For best results, three very thin coats should be applied and water should be used sparingly.

Sand float finishes are similar to gypsum trowel finishes, except that these float finishes contain a fine aggregate to yield a fine-textured surface and the final surface is finished with a float. The base coat should be firm and uniformly damp when the finish coat is applied. These finishes have high resistance to cracking.

Molding plaster, intended for ornamental work, is made with a finer grind than other gaging plasters. It produces a smooth surface, free from streaks or indentations as might be obtained with coarser-ground materials. Equal parts of lime putty and molding plaster are recommended by the Gypsum Association for cornice moldings.

Veneer plasters, applied to a thickness of only $\frac{1}{16}$ to $\frac{3}{32}$ in, develop hard abrasion-resistant surfaces that can be decorated the day after application. Factory prepared, these plasters are easy to work, have high plasticity, and provide good coverage. The finish may be applied in one-coat systems over special gypsum base (Art. 11.25.5), or in two-coat systems over a veneer-plaster or sanded gypsum base coat. They require only addition of water on the job. Veneer plasters should meet the requirements of ASTM C587 and application should conform with ASTM C843.

11.26 GYPSUMBOARD FINISHES

To avoid construction delays due to the necessity of mixing plaster ingredients with water on the building site and, after application, waiting for the plaster to cure, dry-type construction with gypsum products may be used. (For discussion of other dry-type interior finishes, see Arts. 11.30 to 11.31.) For the purpose, gypsumboard is factory fabricated and delivered to the site ready for application.

Gypsumboard is the generic name for a variety of panels, each consisting of a non-combustible core, made primarily of gypsum, and a bonded tough paper surfacing over the face, back, and long edges. Different types of paper are used for specific purposes. Gypsumboard with a factory-applied, decorative face or with an aluminum-foil back for insulation purposes also is available.

The panels may be attached directly to framing, such as studs or joists. While gypsumboard also may be attached directly to unit masonry or concrete, use of furring strips between the panels and backing is desirable because of the possibilities of interference from surface irregularities in the backing or of moisture penetration through exterior walls. Successive panels are applied with edges or ends abutting each other. Depending on esthetic requirements, the joints may be left exposed, covered with battens, or treated to present an unseamed, or monolithic, appearance. Gypsumboard also can be used to construct self-supporting partitions spanning between floor and ceiling.

See also Art. 4.26.

11.26.1 General Application Procedures for Gypsumboard

Gypsumboards may be used in single-ply construction (Fig. 11.23) or combined in multiply systems (Fig. 11.27). The latter are preferred for greater sound control and fire resistance. Application and finishing should conform with ASTM C840.

Precautions. When outdoor temperatures are less than 55°F, the temperature of the building interior should be maintained at a minimum of 55°F for at least 24 hr before installation of gypsumboards. Heating should be continued until a permanent heating system is in operation, or outdoor temperatures stay continuously above 55°F. In warm or cold weather, gypsumboards should be protected from the weather.

Green lumber should not be used for framing or furring gypsumboard systems. Moisture content of the lumber should not exceed 19%, to avoid defects caused by shrinkage as the wood dries. For the same reason, dry lumber should be kept dry during storage and erection and afterward.

To prevent damage from structural movements or dimensional changes, control and expansion joints should be provided and floating-angle construction used, as described in Art. 11.27.

Many building components may be affected by the decision to use gypsumboard construction. For example, window and door frames should have the appropriate depth for the wall thickness resulting from use of wallboard. Therefore, walls and partitions and related installations, including mechanical and electrical equipment, should be carefully planned and coordinated.

Application. Wallboard preferably should be applied to studs with long dimension horizontal (Fig. 11.23), and vertical joints should be staggered. In ceilings, the long sides should span supports (often referred to as horizontal, or across, application). Board ends and edges parallel to framing or furring should be supported on those members, except for face layers of two-ply systems. Otherwise, back blocking should be used to reinforce the joints.

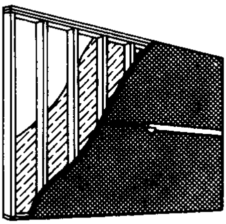


FIGURE 11.23 Single-ply application of gypsumboard to studs with long dimension horizontal.

Ceiling panels should be installed first, then the walls. Adjoining boards should be placed in contact, but not forced against each other. Tapered edges should be placed next to tapered edges, square ends in contact with square ends. (Joints formed by placing square ends next to tapered edges are difficult to conceal.)

TABLE 11.10 Maximum Spacing, in, of Framing for Single-Ply Gypsumboard

Board thickness, in	Orientation	Spacing c to c, in
	a. Applications in ceilings	
⅜*†	Across	16
½*	Across	24
½*	Parallel	16
⅝	Across	24
⅝	Parallel	16
	b. Applications in walls	
⅜	Across or parallel	16
½	Across or parallel	24
⅝	Across or parallel	24

* Gypsumboard for ceilings to receive a water-base-spray texture finish should be applied only across (perpendicular to) framing. For 16-in spacing of framing, hoard thickness should be increased from ⅜ to ½ in. For 24-in spacing of framing, board thickness should be increased from ½ to ⅝ in.

† Should not support thermal insulation.

Furring. Supplementary framing, or furring, should be used when framing spacing exceeds the maximum spacing recommended by the gypsumboard manufacturer for the thickness of board to be used (Table 11.10), or when the surface of framing or base layer is too far out of alignment.

At gypsumboard joints, wood furring should be at least 1½ in wide, and metal furring 1¼ in wide, to provide adequate bearing surface and space for attachment of the gypsumboard. The furring should be aligned to receive the board, and securely fastened to framing or masonry or concrete backing. For rigidity, lumber used for furring should be at least 2 × 2 in when nails are used and 1 × 3 in when screws are used for attachment of gypsumboard. Furring on masonry or concrete may be as small as ⅝ x 1½ in.

Fastening. Gypsumboards may be held in place with various types of fasteners or adhesives, or both. Special nails, staples, and screws are required for attachment of gypsumboards, because ordinary fasteners may not hold the boards tightly in place or countersink neatly, to be easily concealed. Clips and staples may be used only to attach the base layer in multi-ply construction.

To avoid damaging edges or ends, fasteners should be placed no closer to them than ⅜ in (Figs. 11.25 and 11.26). With a board held firmly in position, fastening should start at the middle of the board and proceed outward toward the edges or ends. Nails should be driven with a crown-headed hammer until a uniform depression, or dimple, not more than 1⁄32 in deep is formed around the nail head. Care should be taken in driving not to tear the paper or crush the gypsum core.

Nails. For use in attachment of gypsumboard, nails should conform with ASTM C514. (Some fire-rated systems, however, may require special nails recommended by the gypsumboard manufacturer.) For easy concealment, nail heads should be flat or slightly concave and thin at the rim. Diameter of nail heads should be ¼ or 5⁄16 in. Length of smooth-shank nails should be sufficient for penetration into wood framing of at least ⅞ in, and length of annular-grooved nails for ¾-in penetration.

Screws. Three types of screws, all with cupped Phillips heads are used for attachment of gypsumboard. Type W, used with wood framing, should penetrate at least ⅝ in into the wood. Type S, used for sheet metal, should extend at least ⅜ in beyond the inner gypsumboard surface. Type G, used for solid gypsum construction, should penetrate at least ⅜ in into supporting gypsumboard. These screws, however, should not be used to attach wallboard to ⅜-in backing board, because sufficient holding power cannot be developed. Nails or longer screws should be driven through both plies.

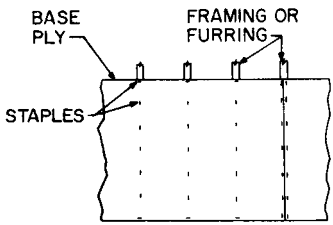


FIGURE 11.24 Gypsumboard base ply attached to wood supports with staples.

Staples. Used for attaching base ply to wood framing in multi-ply systems (Fig. 11.24) staples should be made of flattened, galvanized, 16-ga wire. The crown should be at least 7⁄16 in wide. Legs should be long enough to permit penetration into supports of at least ⅝ in, and should have spreading points.

When the face ply is to be laminated with adhesive to the base ply, the staples should be spaced 7 in c to c. When the face ply is to be nailed, the staples should be placed 16 in c to c.

Adhesives. These may be used to attach gypsumboard to framing or furring, or to existing flat surfaces. Nails or screws may also be used to provide supplemental support.

Adhesives used for bonding wallboard may be classified as stud, laminating, or contact or modified contact.

Stud adhesives are used to attach wallboard to wood or steel framing or furring. They should conform with ASTM C557. They should be applied to supporting members in continuous, or nearly so, beads.

Laminating adhesives are used to bond gypsumboards to each other, or to suitable masonry or concrete surfaces. They are generally supplied in powder form, and water is added on the site. Only as much adhesive should be mixed at one time as can be applied within the period specified by the manufacturer. The adhesive may be spread over the entire area to be bonded, or in parallel beads or a pattern of large spots, as recommended by the manufacturer. Supplemental fasteners or temporary support should be provided the face boards until sufficient bond has been developed.

Contact adhesives are used to laminate gypsumboards to each other, or to attach wallboard to metal framing or furring. A thin, uniform coat of adhesive should be applied to both surfaces to be joined. After a short drying time, the face board should be applied to the base layer and tapped with a rubber mallet, to ensure overall adhesion. Once contact has been made, it may not be feasible to move or adjust the boards being bonded.

Modified contact adhesives, however, permit adjustments, often for periods of up to ½ hr after contact. Also, they generally are formulated with greater bridging ability than contact adhesives. Modified adhesives may be used for bonding wallboard to all kinds of supporting construction.

See also Arts. 11.26.2 to 11.26.4 and 11.27.

11.26.2 Single-Ply Gypsumboard Construction

A single-ply system consists of one layer of wallboard attached to framing, furring, masonry, or concrete (Fig. 11.23). This type of system is usually used for residential construction and where fire-rating and sound-control requirements are not stringent. Maximum spacing of supports should not exceed the limits specified in Table 11.10.

Nail Attachment. Spacing of nails generally is determined by requirements for fire resistance and for firmness of contact between wallboard and framing necessary to avoid surface defects. Spacing normally used depends on whether single nailing or double nailing is selected. Double nailing provides tighter contact, but requires more nails. In either method, one row of nails is driven along each support crossed by a board or on which a board end or edge rests. The spacing applies to the center-to-center distance between nails in each row.

In the single-nailing method, nails should be spaced not more than 7 in apart for ceilings and 8 in apart for walls (Fig. 11.25).

In the double-nailing method, pairs of nails are driven 12 in c to c, except at edges or ends, in a special sequence (Fig. 11.26). First, one nail of each pair is placed, starting at the middle of the board and then proceeding toward edges and ends. Next, the second nail is driven 2 in from the first. Finally, the first set of nails placed should be given an extra hammer blow to reseat them firmly. Single-nailing spacing should be used for edges or ends at supports.

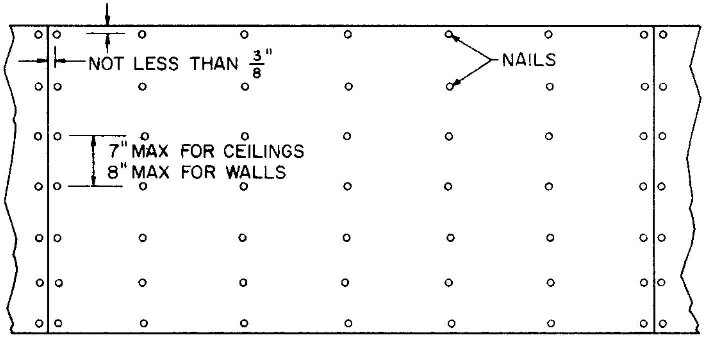


FIGURE 11.25 Wallboard attached to wood framing with single nailing.

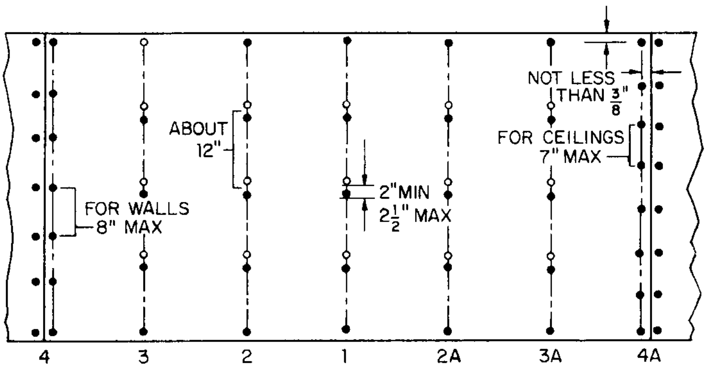


FIGURE 11.26 Wallboard attached to wood framing with double nailing. Starting at the middle of the board, one person nails rows 1 to 4, and a second person. rows 2A to 4A (solid dots). Then, again starting at the middle of the board, they drive the second set of nails (open dots). Finally, they reset the first set of nails with a blow on each nail.

Screw Attachment. Fewer screws than nails are needed for attachment of wallboard. With wood framing, Type W screws should be spaced 12 in c to c for ceilings. Spacing should not exceed 16 in for studs 16 in c to c, or 12 in for studs 24 in c to c. With metal framing, spacing of Type S screws should not exceed 12 in for walls or ceilings.

Adhesive Nail-on Attachment. With this method, at least 50% fewer nails are required in the middle of the wallboard than with conventional nailing. Also, a stiffer assembly results.

The first step is to apply stud adhesive to framing or furring in beads about ¼ in in diameter. Each bead should contain enough adhesive so that it will spread to an average width of 1 in and thickness of 1⁄16 in when wallboard is pressed against it, but there should not be so much adhesive that it will squeeze out at joints. If joints are to be treated, an undulating or zigzag bead should be applied to supports under joints. If joints are to be untreated, as is likely to be the case for predecorated wallboards, two parallel beads should be applied near each edge of the framing. Along other supports a single, continuous, straight bead is adequate. Adhesive, however, should not be applied to members, such as diagonal bracing, blocking, and plates, not required for wallboard support.

The number and spacing of supplemental fasteners needed with adhesives depend on adhesive properties. Stud adhesives generally require only perimeter fasteners for walls. One fastener should be driven wherever each edge or end crosses a stud. For edges or ends bearing on studs, fasteners should be spaced 16 in c to c. The same perimeter fastening should be used for ceilings, but in addition, fasteners should be spaced 24 in c to c along all framing crossed by the wallboard.

Where perimeter fasteners cannot be used, for example, with predecorated wallboard for which joint treatment is unnecessary or undesirable, prebowing or temporary bracing should be used to keep the wallboard pressed against the framing until the adhesive develops full strength. Bracing should be left in place for at least 24 hr. Prebowing bends in wallboard so that the finish side faces the center of curvature. The arc is employed to keep the board in tight contact with the adhesive as the board is pressed into place starting at one end.

11.26.3 Multi-Ply Gypsumboard Construction

A multi-ply system consists of two or more layers of gypsumboard attached to framing, furring, masonry, or concrete. This type of system has better fire resistance and sound control than can be achieved with single-ply systems, principally because of greater thickness, but also because better insulation can be used for the base layer.

Face layers usually are laminated (glued), but may be nailed or screwed, to a base layer of wallboard, backing board, or sound-deadening board. Backing board, however, often is used for economy. When adhesives are used for attaching the face ply, some fasteners generally are also used to ensure bond.

Maximum support spacing depends principally on the thickness of the base ply and its orientation relative to the framing, as indicated in Table 11.11, and is the same for wood or metal framing or furring.

Nails, screws, or staples may be used to attach base ply to supports. For wood framing, when the face ply is to be laminated to the base ply, staples should be spaced 7 in c to c (Fig. 11.24), and nails and screws should be single-nailed as recommended for single-ply construction (Art. 11.26.2). If the face ply is to be nailed, nails and staples for the base ply should be driven 16 in c to c, and screws 24 in c to c. For metal framing and furring, Type S screws for the base ply should be spaced 12 in c to c if the face ply is to laminated, and 16 in c to c if the face ply is to be attached with screws.

For attachment of the face ply with adhesive, sheet, strip, or spot lamination may be used. In sheet lamination, the entire back of the face ply is covered with adhesive, usually applied with a notched spreader. In strip lamination, adhesive is applied by a special spreader in grouped parallel beads, with groups spaced 16 to 24 in c to c. In spot lamination, adhesive is brushed or daubed on the back of the face ply at close intervals. Partitions with strip or spot lamination provide better sound control than those with sheet lamination.

Supplemental fasteners or temporary bracing is required to ensure complete bond between face and base plies. If a fire rating is not required, temporary fasteners may be placed at 24-in intervals. For fire-rated assemblies, permanent fasteners generally are required, and spacing depends on that used in the assembly tested

TABLE 11.11 Maximum Spacing of Framing for Two-Ply Gypsumboard

Base thickness, in	Face thickness, in	Orientation: Base	Orientation: Face	Spacing, c to c, in: Fasteners only	Spacing, c to c, in: Adhesive between plies
		a. Application in ceilings			
3/8	3/8*	Across	Across	16	16
3/8	3/8*	Across	Parallel	†	16
1/2	3/8*	Parallel	Across	16	16
1/2	1/2	Parallel	Across	16	16
1/2	1/2*	Across	Across	24	16
5/8	1/2*	Across	Across	24	24
5/8	1/2*	Parallel	Across or parallel	†	24
5/8	5/8	Across	Across	24	24
5/8	5/8	Parallel	Across or parallel		24
		b. Application in walls			
3/8, 1/2, 5/8	3/8	Across or parallel		16	24
3/8, 1/2, 5/8	1/2, 5/8	Across or parallel		24	24

*Gypsumboard for ceilings to receive a water-base-spray texture finish should be applied only across (perpendicular to) framing. For 16-in spacing of framing, board thickness should be increased from 3/8 to 1/2 in. For 24-in spacing of framing, board thickness should be increased from 1/2 to 5/8 in.

†Not recommended.

and rated. Nails should penetrate at least 1 1/8 in into supports. With sound-deadening base plies, fastener spacing should be as recommended by the base manufacturer.

In placing face ply on base ply, joints in the two layers should be offset at least 10 in. Face ply may be applied horizontally or vertically. Horizontal application (long sides of sheet perpendicular to supports) usually provides fewer joints, but vertical application may be preferred for predecorated wallboard that is to have joints trimmed with battens.

11.26.4 Finishing Procedures for Gypsumboard

The finish surface of wallboard may come predecorated or may require decoration. Predecorated wallboard may require no further treatment other than at corners, or may need treatment of joints and concealment of fasteners. Corner and edge trim are applied for appearance and protection, and battens often are used for decorative concealment of flush joints. Other types of wallboard require preparation before decoration can be applied.

While trim can be applied to undecorated wallboard, as for predecorated panels, usually, instead, joints are made inconspicuous.

Joint-Treatment Products. Materials used for treatment of wallboard joints to make them inconspicuous should meet the requirements of ASTM C475. Application of joint treatments should conform with ASTM C840. These materials include:

Joint tape, a strip of strong paper reinforcement with feathered edges, for embedment in joint compound. Sometimes supplied with small perforations, the tape usually is about 2 in wide and $\frac{1}{16}$ in thick.

Joint compound, and adhesive, with or without fillers, for bonding and embedding the tape. Two types may be used. One, usually referred to as joint, or taping, compound, is applied as an initial coat for filling depressions at joints and fasteners and for adhering joint tape. The second, called topping, or finishing, compound, is used to conceal the tape and for final smoothing and leveling at joints and fasteners. As an alternative, an all-purpose compound that combines the features of taping and topping compounds may be used for all coats. Compounds may be supplied premixed, or may require addition of water on the job.

Flush Joints and Fasteners. For concealing fastener heads and where wallboards in the same plane meet, at least three coats of joint compound should be used. The first coat, of taping compound, should be used for adhering tape at edges and ends of the boards and to fill all depressions over fastener heads and at tapered edges. Joint tape should be centered over each joint for the length or width of the wall or panel and pressed into the compound, without wrinkling, with a tape applicator, a broad knife. Excess compound should be redistributed as a skim coat over the tape. A skim coat of joint compound applied immediately after tape embedment reduces the possibility of edge wrinkling or curling, which may result in edge cracking.

A second, or bedding, coat should be applied with topping compound at fastener heads and joints after the taping compound has dried. The waiting period may be 24 hr if regular taping compound is used, and about 3 hr if a quick-setting compound is used. This bedding coat should be thin. At joints, it should completely cover the tape and should be feathered out 1 to 2 in beyond each edge of the tape at tapered edges, and over a width of 10 to 12 in at square edges.

When the coat has dried, a second, thin coat of the topping compound should be applied for finish at fasteners and joints. At joints, it should completely cover the preceding coat and should be feathered out 1 to 2 in beyond its edges at tapered edges, and over a width of 18 in at square edges. Irregularities may be removed by light sanding after each coat has hardened. But if joint treatment is done skillfully, such sanding should not be necessary.

Reentrant Corners. Treatment of interior corners differs only slightly from that of flush joints. Joint compound should first be applied to both sides of each joint. Joint tape should be creased along its center, then embedded in the compound to form a sharp angle. After the compound has dried, finishing compound should be applied, as for flush joints.

Trim. Exposed corners and edges should be protected with a hard material. Wood or metal casings may be used for protection and to conceal the joints at door and window frames. Baseboard may be attached to protect wallboard edges at floors. Corner beads may be applied at exterior corners when inconspicuous protection is desired. Casing beads may be similarly used in other places.

At least three-coat finishing with joint compound is required to conceal fasteners and obtain a smooth surface with trim shapes.

Decoration. Before wallboard is decorated, imperfections should be repaired. This may require filling with joint compound and sanding. Joint compound should be thoroughly dry before decoration starts.

The first step should be to seal or prime the wallboard surface. (Glue size, shellac, and varnish are not suitable sealers or primers.) An emulsion sealer blocks the pores and reduces suction and temperature differences between paper and joint compound. If wallpaper is used over such a sealer, the paper can be removed later without damaging the wallboard surface and will leave a base suitable for redecorating. A good primer provides a base for paint and conceals color and surface variations. Some paints, such as high-quality latex paints, often have good sealing and priming properties.

11.27 ISOLATION AND CONTROL JOINTS IN GYPSUMBOARD CONSTRUCTION

Plaster and gypsumboard construction have low resistance to stresses induced by structural movements. They also are subject to dimensional changes because of changes in temperature and humidity. If proper provision is not made in the application of plaster and gypsumboard systems for these conditions, cracking or chipping may occur or fasteners may pop out.

Generally, such defects may be prevented by applying these systems so that movement is not restrained. Thus, gypsumboard or lath and plaster surfaces should be isolated by expansion or control joints, floating angles, or other means where a partition or ceiling abuts any structural element, except the floor, or meets a dissimilar wall or partition assembly, or other vertical penetration. Isolation also is advisable where the construction changes in the plane of the partition or ceiling. In addition, expansion or control joints should be inserted where expansion or

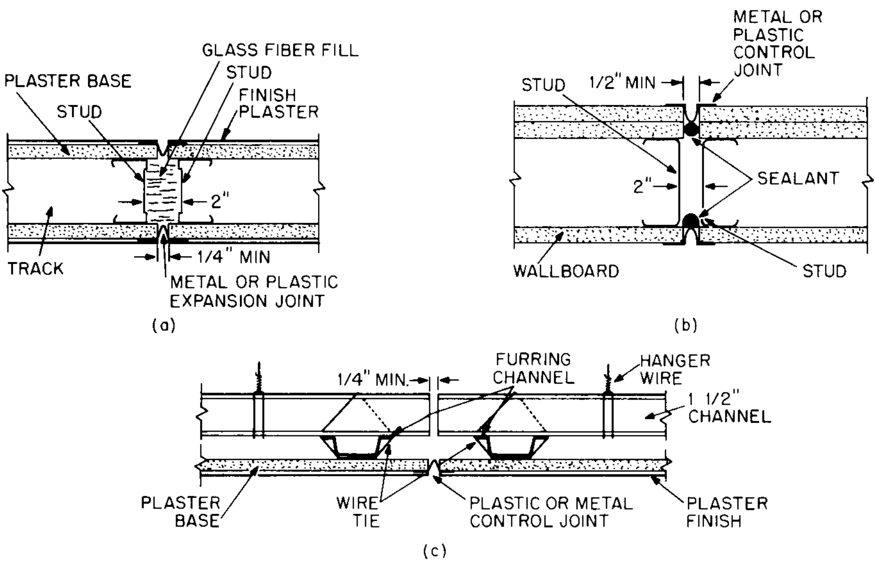


FIGURE 11.27 Control joints: (*a*) expansion joint in a plastered, metal-stud partition: (*b*) control joint in a wallboard, metal-stud wall; (*c*) control joint in a plastered, suspended ceiling.

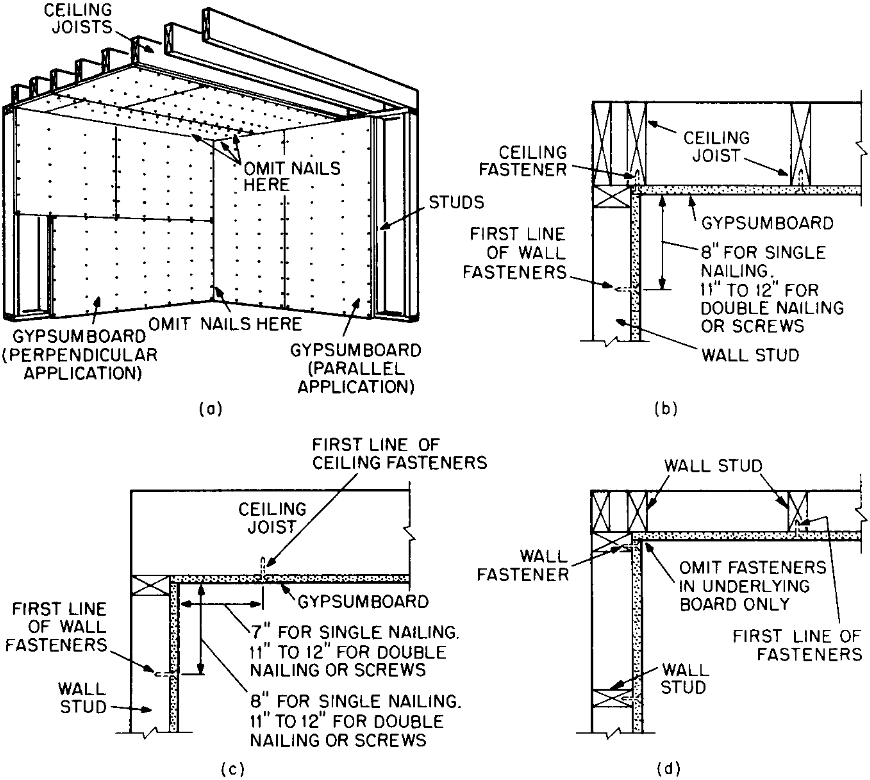


FIGURE 11.28 Floating interior angles with gypsumboard construction (gypsum lath similar): (*a*) omission of nails at intersections; (*b*) wall-ceiling intersection with ceiling boards applied parallel to joists; (*c*) wall-ceiling intersection with ceiling boards applied perpendicular to joists; (*d*) reentrant corner at walls.

control joints, respectively, occur in structural components of the building and along the intersection of wings of L-, U-, and T-shaped ceilings.

In long walls or partitions, control joints should be inserted not more than 30 ft apart. In large ceiling areas, control joints should not be spaced more than 30 ft apart for plaster and 50 ft apart for gypsumboard. Control joints may be conveniently located along lighting fixtures, heating vents, or air-conditioning diffusers, where continuity would ordinarily be broken. Door frames extending from floor to ceiling may serve as control joints. With shorter frames, however, control joints should be inserted from the top corners of the frames to the ceiling.

Installation of Joints. Where a control joint is to be provided, the continuity of gypsumboard or lath in plaster installations should be interrupted (Fig. 11.27). The gap for gypsumboard should be at least ½ in and for lath at least ¼ in. A framing member should be inserted on each side of the gap to support the edges of the boards or lath. (Steel studs, however, should be fastened on only one side of the joint.)

The joint should be covered at the surface with a flexible material to prevent entrance of dirt into the wall. For the purpose, plastic or noncorrodible-metal, bellows-type stops, called expansion joints or control joints, may be used (Fig. 11.27). For plaster, the flanges of the control joint should be stapled or wire tied to the lath, and the surface of the gap should be protected with tape. Then, plaster should be applied over the lath, flush to grounds. After the finished surface has been completed, the protective tape should be removed. For gypsumboard, similarly, the control-joint flanges should be stapled to the board and the gap protected with tape. Next, the joint should be treated with joint compound or veneer plaster. Then, the protective tape should be removed. Where sound control or fire ratings are important, a sealant should be installed behind the control joints.

Floating Interior Angles. A floating angle is desirable at reentrant intersections of ceilings and walls or partitions (Fig. 11.28*a*). It is constructed by installing gypsum lath or gypsumboard first in the ceiling. The first line of ceiling fasteners should be spaced as shown in Fig. 11.28*b* and *c*. Normal fastener spacing should be used in the rest of the ceiling away from the wall. Gypsum lath or gypsumboard should then be applied to the wall with firm contact at the ceiling line to support the edges of the ceiling panels. The first line of fasteners for the wall panels also should be spaced as shown in Fig. 11.28*b* and *c*. At wall intersections, fasteners should be omitted or inserted as indicated in Fig. 11.28*d*.

(''Architect Data Book—Construction Products and Systems,'' Gold Bond Building Products, a National Gypsum Division, 2001 Rexford Road, Charlotte, NC 28211; ''Gypsum Products Design Data,'' Gypsum Association, 810 First Street, NE, #510, Washington, D.C., 20002; ''Gypsum Construction Handbook,'' United States Gypsum, 125 South Franklin Street, Chicago, IL 60606.)

CERAMIC-TILE CONSTRUCTION

When a hard, incombustible, abrasion-resistant, easily cleaned finish is required for walls, ceilings, or floors, ceramic tile often is selected, although construction cost usually is higher than for other commonly used finishes. Ceramic tile is especially suitable where an attractive, water-resistant surface is desired, for instance, for shower enclosures or swimming pools.

11.28 TYPES OF CERAMIC TILE

Ceramic tile is a surfacing unit, relatively thin with respect to surface area, with a body of clay or a mixture of clay and other ceramic materials that has been fired above red heat. The tile should meet the requirements of the Recommended Standard Specification for Ceramic Tile, TCA 137.1, of the Tile Council of America, Inc., Princeton, NJ 08540.

Ceramic tile is referred to as **glazed** if it is given a surface finish composed of ceramic materials that have been fused into the body of the tile and that may be impervious, vitreous, semivitreous, or non vitreous. [Glazed tiles tend to be slippery, especially when wet. If this characteristic is undesirable (for example, for floors), then unglazed tile, which has a homogenous composition, or tile incorporating a dispersed abrasive should be used.] **Impervious tile** is required to have water absorption of less than 0.5% when tested as described in ASTM C373. **Vitreous tile** is required to have water absorption between 0.5 and 3%.

Ceramic tile is classified as wall, ceramic mosaic, quarry, or paver tile. Mosaic, paver, and quarry tile are generally used as floor coverings.

Wall tile is glazed and usually nonvitreous (water absorption greater than 3% but less than 18%). It has a body that is suitable for interior applications, although it is not expected to withstand impact. Flat wall tile is nominally 5⁄16 in thick. Rectangular in shape, it generally comes in nominal sizes of 4¼ × 4¼, 6 × 4¼, and 6 × 6 in. Also, trim units are available with various shapes necessary for completing an installation. These units include bases, coves, caps, curbs, angles, and moldings.

Ceramic mosaic tile is made of porcelain or natural clay. It may be glazed or unglazed, and if glazed, may be either plain or contain a dispersed abrasive. Nominal thickness is ¼ in. Surface area is less than 6 in^2. Available in rectangular, hexagonal, and other shapes, flat mosaic tiles come in nominal sizes 1 × 1, 2 × 1, and 2 × 2 in. The tiles usually are mounted on sheets 1 ft by 2 ft, to facilitate tile setting.

Quarry tile is made by extrusion from natural clay or shale and is unglazed. It usually is ½ to ¾ in thick. Surface area generally exceeds 6 in^2.

Paver tile is similar to ceramic mosaic tile but is thicker, larger, and unglazed. Thickness usually is ⅜ or ½ in. Nominal sizes generally are 4 × 4, 6 × 6, and 8 × 4 in.

11.29 TILE INSTALLATION METHODS

Installation of ceramic tile should be in accordance with the appropriate specification in the A108 series of the American National Standards Institute, depending on the type of setting compound used. Specifications for materials commonly used for setting and grouting the tile are given in the series A118. These materials include portland-cement mortar, dry-set or latex portland-cement mortar, organic adhesive, and chemical-resistant, water-cleanable, tile-setting and grouting epoxy.

Tiles may be set into plastic mortar or adhesive or may be bonded to hardened mortar. (To ensure good alignment, the tile may be preassembled in groups, lightly adhered to sheets.) When the bond is sufficiently strong to prevent the tile from moving, the joints between tiles should be grouted. (Mounted tiles also are available pregrouted, usually with an elastomeric material.) The tiles may be face mounted, back mounted, or edge bonded. Face-mounted tiles are stuck face down on paper or other suitable material with a water-soluble adhesive so that the sheet can be removed easily after tile setting, before the joints are grouted. For back-mounted tiles, the back side, and for edge-bonded tiles, the edges, are adhered to perforated paper, fiber mesh, resin, or other suitable material, which remains in place after tile setting.

Quality and cost of tile installations are affected by the stability, permanence, and precision of installation of the backing or base material on which the tiles are set. The backing should be sound, clean, and dimensionally stable. Deflection of the supporting members under total load should not exceed 1⁄360 of the span.

While the tile may not deteriorate when exposed to moisture, the backing may. For installations exposed to wetting, therefore, the backing should be concrete, masonry, or portland-cement mortar, or else a cleavage, or water-resistant, membrane should be inserted to protect the backing.

11.29.1 Backing for Tiles

When portland-cement mortar is to be applied, for tile setting, to a gypsum-product backing, a membrane and metal lath should be applied first to cover the backing. In contrast, sound concrete or masonry may have tile directly applied, after the surface has been prepared by sandblasting, chipping, or scarifying to expose an uncontaminated surface. (Without such preparation, use of metal lath is desirable.) For installations with organic adhesive or dry-set or latex portland-cement mortar, which are applied as a thin coating, it is especially desirable that the backing used be dimensionally stable and have negligible variation from a plane.

In all types of installation, control joints or other effective means of preventing cracking should be placed at appropriate intervals.

Exterior walls should be constructed to prevent moisture from collecting behind the tile. For the purpose, flashing, coping, and vapor barriers should be installed, and weep holes draining to the outside should be provided at the base of the exterior walls (see Art. 11.3.7).

Crack-free concrete floors with a screed finish may have portland-cement mortar directly bonded to them as a backing for tile. Concrete floors with a steel-troweled finish, including precast concrete, should be covered with a cleavage membrane before placement of the mortar, and steel reinforcement should be incorporated in the mortar bed. When mortar or adhesive is the type that is applied as a thin coating, the backing should have negligible variations from a plane, or else, a portland-cement mortar bed at least 1¼ in thick should be placed atop the concrete slab.

Metal Lath. Installation of metal lath for reinforcing a mortar bed for tile should be in accordance with the Standard Specification for Installation of Interior Lathing and Furring. ASTM C841. The lath should be galvanized for protection against corrosion. It should be the flat-expanded type and weigh at least 2.5 lb/yd^2.

For application of metal lath to wood or steel studs or to wood furring, a cleavage membrane—15-lb roofing felt or 4-mil polyethylene film—should be attached first, with joints lapped at least 2 in. Then, the lath should be fastened in place on the side to be mortared (Fig. 11.29*i*). (See also Art. 11.25.6.) Where sheets of lath are joined, the lath should be lapped at least 2 in at sides and ends. (If wire fabric is used, it should be lapped at least one full mesh.)

11.29.2 Scratch and Leveling Coats

Over rough-surfaced backings, a level surface to receive tile may be built up with portland-cement mortar. For walls and ceilings, the mortar mix for the scratch and leveling coats for application to metal lath, concrete, or masonry should be 1 part portland cement and 3 parts dry sand or 4 parts damp sand, by volume. The ingredients should be mixed dry. Then, sufficient water should be added to make a stiff mix. The scratch coat should be cured for at least 24 hr.

A leveling coat is desirable when the surface of the scratch coat varies more than ¼ in in 8 ft from the required plane or when the required mortar-bed thickness exceeds ¾ in. As for the scratch coat, the leveling coat should be scratched and cured before the next bond coat is applied.

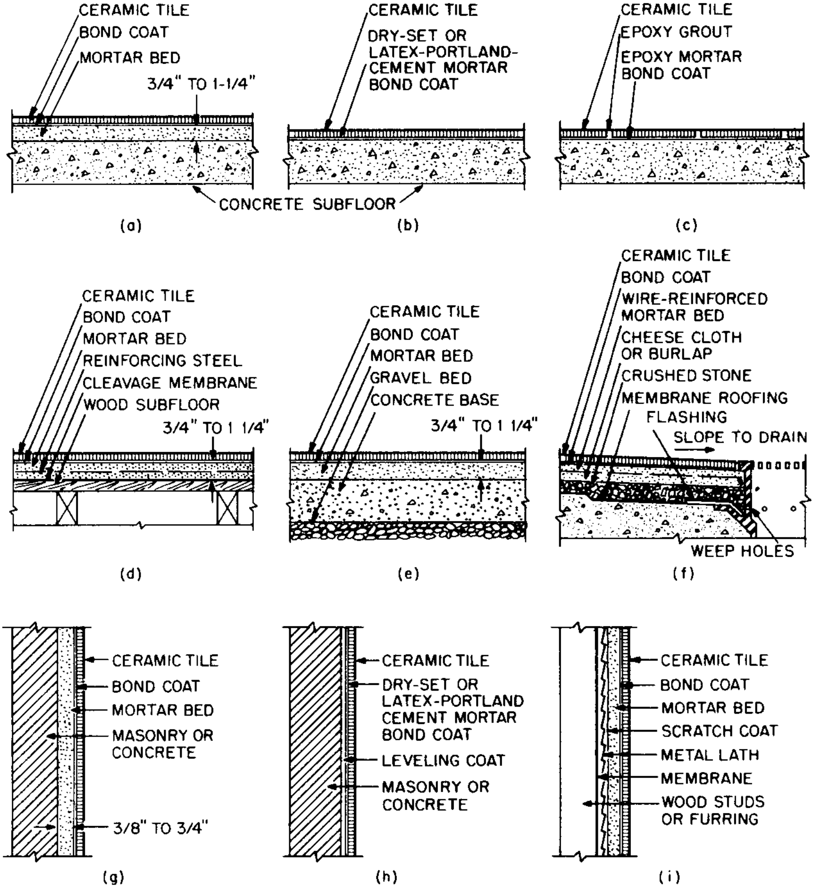


FIGURE 11.29 Ceramic tile construction. For interior floors: (*a*) portland-cement mortar bed on a concrete subfloor; (*b*) bond coat of dry set or latex portland-cement mortar on a concrete subfloor; (*c*) epoxy bond coat on a concrete subfloor; (*d*) reinforced mortar bed on a wood subfloor. For an outdoor walkway: (*e*) portland-cement mortar bed on a concrete base. For roofs: (*f*) reinforced mortar bed on crushed stone. For interior walls: (*g*) cement mortar on masonry or concrete; (*h*) dry set or latex portland-cement mortar on masonry or concrete: (*i*) cement mortar on metal lath attached to studs or furring.

11.29.3 Mortars and Adhesives

For setting ceramic tile, portland-cement mortar is the only type recommended by the Tile Council of America for a thick bed. Other mortars and adhesives should be used only for thin beds. Setting materials such as epoxies and furans that do not contain portland cement offer special properties but are more expensive than cement-based mortars.

Portland-Cement Mortar. This is suitable for most surfaces and ordinary installations. For floors, the mix may be 1 part portland cement and about 6 parts sand. For walls, about ½ part of hydrated lime may be added to the floor mix. The bed may be ¾ to 1¼ in thick. Tiles may be set into the bed while the mortar is still plastic (ANSI A108.1). Or, after the mortar has cured, the tiles may be bonded to the mortar bed with a 1⁄16-in-thick coat of dry-set or latex portland-cement mortar or with neat cement. If a neat-cement bond coat is used and the tile is absorptive, it should be soaked before being set. (See Fig. 11.29*a, d, e, f, g,* and *i*.)

Dry-Set Mortar. This is a mix of portland cement and sand, with additives that impart water retentivity. The mortar should meet the requirements of ANSI A118.1 or A118.2. Applied as a coat as thin as 3⁄32 in, the mortar is suitable for use on stable backings with true surfaces (Fig. 11.29*b* and *h*). Tile installation should be in accordance with ANSI A108.5 or A108.7.

Latex Portland-Cement Mortar. This is a mix containing portland cement, sand, and a latex additive, prepared to meet requirements of ANSI A118.4. Tile applications and installation method with this mortar are similar to those for dry-set mortar and should be in accordance with ANSI A108.5. (See Fig. 11.29*b* and *h*.) Early exposure of latex mortar to water inhibits development of full strength and increases sensitivity to water. Hence, for applications such as swimming pools and showers, the mortar should be cured at least 14 days and allowed to dry thoroughly before exposure to water.

Organic Adhesive. This is an organic material that cures or sets by evaporation. It should meet the requirements of ANSI A136.1. Applied in a thin layer with a notched trowel, organic adhesive is suitable for use on stable backings with true surfaces, but not for swimming pools or exterior applications. Tile installation should be in accordance with ANSI A108.4.

Epoxy Mortar. Suitable for use where chemical resistance, high bond strength, or high impact resistance is needed, this mortar contains epoxy resin and hardener and meets requirements of ANSI A118.3. It should be applied as a thin coat in accordance with ANSI A108.6 (Fig. 11.29*c*).

Furan Mortar. Suitable for use where chemical resistance is important, this mortar consists of furan resin and hardener. It should be used in accordance with the manufacturer's recommendations.

Grouting Materials for Tile. After tile has been set, the joints should be grouted. Most grouts have a portland-cement base but are modified to provide specific qualities, such as whiteness, uniformity, hardness, flexibility, or water retentivity. Damp curing of such grouts for about 72 hr is required.

A grout mix may be prepared in the field with portland cement and a fine graded sand, with up to ⅕ part lime, if desired. The ratio of portland cement to sand, by volume, may be as follows: 1:1 for joints up to ⅛ in wide; 1:2 for joints up to ½ in wide, and 1:3 for joints wider than ½ in. Prepared cement-based mixes include commercial portland-cement grout and dry-set grout. A latex portland-cement grout may be prepared by adding latex to any of the preceding mixes and offers the advantages of lower permeability and no curing, but it is less rigid than regular cement grout.

Grouts also are available with mastic, furan, epoxy, or silicone rubber, to provide such properties as flexibility, stain resistance, high impact resistance, and capacity to withstand below-freezing temperatures and hot, humid conditions. Such grouts, however, are more expensive than the cement-based ones.

11.29.4 Expansion Joints

These generally are required where tiles abut restraints, such as walls, curbs, columns, or pipes, and where joints occur in structural backings, such as concrete floors and walls. For interior tile floors covering large areas, expansion joints generally should be inserted every 24 to 36 ft if the mortars are cement based. For roofs and outdoor floors, joint spacing may range from 12 to 16 ft. For interior walls, expansion joints are generally required directly over masonry control joints, where there are changes in materials, or every 24 to 36 ft.

Joint width should be at least 4 times any expected movement. The width should be at least ⅜ in for exterior joints that are 12 ft apart and ½ in for those 16 ft apart. These widths should be increased 1⁄16 in for each 15° that the actual temperature range may exceed 100°F between summer high and winter low temperature. For interior joints, width should be at least ¼ in. In any case, if there is a structural joint in the backing, the tile expansion joint should be at least as wide as the structural joint.

The joint sealant should be a nonsagging type in vertical joints and a self-leveling type in horizontal joints. It should be inserted to a depth of not less than ⅛ in or more than one-half the joint width. The depth should be controlled by insertion of a backup strip, which should be flexible and compressible, with a rounded surface where it contacts the sealant. Closed-cell foamed polyethylene or butyl rubber is a suitable material for the backup.

(''Handbook for Ceramic Tile,'' Tile Council of America, Inc., 100 Clemson Research Blvd., Anderson, SC 29625.)

PANEL FINISHES

For speedy installation of interior finishes on walls or ceilings, rigid or semirigid boards, some of which require no additional decorative treatment, may be nailed directly to studs or masonry or to furring. For acoustic materials, see Arts. 11.79 to 11.82. Gypsumboard is discussed in Art. 11.26.

Joints between panels may be concealed or accentuated according to the architectural treatment desired. The boards may interlock with each other, or battens, moldings, or beads may be applied at joints.

When the boards are thinner than conventional lath and plaster, framing members may have to be furred out to conventional thicknesses unless stock doors and windows intended for use with panels can be used.

11.30 PLYWOOD FINISHES

Available with a large variety of surface veneers, including plastics, plywood is nailed directly to framing members or furring. Small finish nails, such as 4d, should be used, with a spacing not exceeding 6 in. All edges should be nailed down, intermediate blocking being inserted if necessary. The plywood should also be nailed to intermediate members. When joints are not to be covered, the nailheads should be driven below the surface (set). Under wood battens, ordinary flat-headed nails can be used. Water-resistant adhesive may be applied between plywood and framing members for additional rigidity. (See also, Art. 10.12.)

11.31 OTHER TYPES OF PANEL FINISHES

Like other types of panels, mineral-fiber panels can be nailed directly to framing members or furring. Thin sheets usually are backed with plywood or insulation boards to increase resistance to impact. Joints generally are covered with moldings or beads.

Fabricated with a wide variety of surface effects, fiber and pulp boards also are available with high acoustic and thermal insulation values. Application is similar to that for plywood. Generally, adjoining boards should be placed in moderate contact with each other, not forced.

FLOOR SYSTEMS

For proper selection of floor systems, designers should take into account many factors, including use of lightweight-concrete slabs, subfloors in direct contact with the ground, radiant heating, air conditioning, possible necessity for decontamination, dustlessness, traffic loads, and maintenance costs-all of which have an important bearing on floor selection. Consideration should be given to current standards of styling, comfort, color, and quietness.

The primary consideration of the designer of a flooring system is to select a floor covering that can meet the maximum standards at reasonable cost. To avoid the dissatisfaction that would arise from failure to select the proper flooring, designers must consider all the factors relevant to flooring selection.

This section contains information that can provide a guide toward this end. It summarizes the characteristics of the major types of floor coverings and describes briefly methods for the proper installation of these materials. (For ceramic-tile installations, see Arts. 11.28 and 11.29.)

11.32 ASPHALT TILES

These tiles are intended for use on rigid subfloors, such as smooth-finished or screeded concrete, structurally sound plywood, or hardboard floors not subject to excessive dimensional changes or flexing. The tiles can be satisfactorily installed on below-grade concrete subject to slight moisture from the ground.

Low cost and large selection of colors and designs make asphalt tile an economically desirable flooring.

Asphalt tile is composed of mineral fibers, mineral coloring pigments, and inert fillers bound together. For dark colors the binder is Gilsonite asphalt; for intermediate and light colors, the binder may consist of resins of the cumarone indene type or of those produced from petroleum. Tiles most commonly used are 9×9 in and $\frac{1}{8}$ in thick.

Colors are classified into groups A, B, C, and D, graded from black and dark red (A) to cream, white, yellow, blue, and bright red (D). Cost is generally lower for the darker colors.

To avoid permanent indentations in asphalt tiles, contact surfaces of furniture or equipment should be smooth and flat to distribute the weight. This is particularly necessary for installations over radiant-heated floors and on areas near windows exposed to sun.

Never use on asphalt tiles waxes containing benzene, turpentine, or naphthatype solvents and free fats or oils. Avoid strong detergents or cleaning compounds containing abrasives or preparations not readily soluble in water. These may soften the tiles and cause colors to bleed. Grease, oils, fats, vinegar, and fruit juices allowed to remain in contact with asphalt tiles will stain and soften them. Because of these restrictions, asphalt tiles are not recommended for use in kitchens or bathrooms.

See also Art. 11.36.

11.33 CORK TILES

Cork flooring is intended for use on rigid subfloors, such as smooth-finished or screeded concrete supported above grade and free of moisture, or on structurally sound plywood or hardboard. Cork tile is not recommended for application below grade. When it is installed at grade, moisture-free conditions must be ensured.

Cork tile is manufactured by baking cork granules with phenolic or other resin binders under pressure. Four types of finishes are produced: natural, factory-prefinished wax, resin-reinforced wax, and vinyl cork tile (Art. 14.8). The tiles are generally 6 × 6, 6 × 12, 9 × 9, 12 × 12, 12 × 24, or 36 × 36 in and ⅛, 3⁄16, 5⁄16, or ½ in thick.

Natural cork tile must be sanded (to level), sealed, and waxed immediately after installation.

Unless the exposed surface of cork floors is maintained with sealers and protective coatings, permanent stains from spillage and excessive soiling by heavy traffic will result.

Cork tiles are particularly suitable for areas where quiet and comfort are of paramount importance.

See also Art. 11.36.

11.34 VINYL FLOORING

Flooring of this type is unbacked. For a discussion of backed vinyl, see below. It is intended for use on rigid subfloors, such as smooth-finished or screeded concrete supported above grade, or structurally sound plywood or hardboard floors. Vinyl floors are not recommended for use below grade. They must be applied with an alkaline, moisture-resistant adhesive when used at grade.

Vinyl mats or runners may be laid without adhesive over relatively smooth surfaces. Large mats generally are installed in a recess in the concrete floor at building entrances. The mats are ribbed or perforated for drainage.

Vinyl flooring consists predominantly of polyvinyl chloride resin as a binder, plasticizers, stabilizers, extenders, inert fillers, and coloring pigments. Because of its unlimited color possibilities and opaqueness to transparent effects, it is widely used. Common thicknesses are 0.080, 3⁄32, and ⅛ in.

Since vinyl resins are tough synthetic polymers, vinyl flooring can withstand heavy loads without indentation, and yet is resilient and comfortable under foot. It is practically unaffected by grease, fat, oils, household cleaners, or solvents. But unless given a protective finish, it is easily scratched and scuffed.

See also Art. 11.36.

Backed Vinyl. The family of backed-vinyl flooring comprises vinyl wearing surfaces from 0.02 to 0.050 in thick, laminated to many different backing materials. In some products, the vinyl surfaces are unfilled transparent films placed over a design on paper, cork, or degraded vinyl. Filled vinyl surfaces with a 34% vinyl resin binder are placed over plastic composition backing or asphalt-saturated or resin-impregnated felt. The asphalt-felt type may be used in moist areas. Foamed rubber or plastic is incorporated in some of these materials to increase comfort and decrease impact noise.

Asphalt-felt-backed vinyl materials may be applied with a moisture-resistant adhesive on concrete at or below grade.

See also Art. 11.36.

11.35 RUBBER FLOORING

Rubber flooring is intended for use on rigid subfloors, such as smooth-finished or screeded concrete supported above grade, or on structurally sound plywood or hardwood subfloors. Rubber is not recommended for use below grade. When used at grade, it must be applied with an alkaline, moisture-resistant adhesive.

Rubber mats or runners may be laid without adhesive over relatively smooth surfaces. Large mats generally are installed in a recess in the concrete floor at building entrances. The mats are ribbed or perforated for drainage.

Most rubber flooring is produced from styrene-butadiene rubber. Reclaimed rubber is added to some floorings. The flooring also contains mineral pigments and mineral fillers, such as zinc oxide, magnesium oxide, and various clays. Another synthetic-rubber flooring, chlorosulfonated polyethylene (Hypalon), also is available.

Rubber floorings can be obtained in thicknesses of $\frac{3}{32}$, $\frac{1}{8}$, or $\frac{3}{16}$ in. They have excellent resistance to permanent deformation under load. Yet they are resilient and quiet under foot.

See also Art. 11.36.

11.36 INSTALLATION OF THIN COVERINGS

Most manufacturers and trade associations make available instructions and specifications for installation and maintenance of their floorings.

The most important requirement for a satisfactory installation of a thin floor covering is a dry, even, rigid, and clean subfloor.

Protection from moisture is a prime consideration in applying a flooring over concrete. Moisture within a concrete slab must be brought to a low level before installation begins. Moisture barriers, such as 6-mil polyethylene, 55-lb asphalt-saturated and coated roofing felt, or $\frac{1}{32}$-in butyl rubber, should be placed under concrete slabs at or below grade, and a minimum of 30 days' (90 in some cases) drying time should be allowed after placement of concrete before installation of the flooring.

Particular care should be taken with installations on lightweight concrete. It always has a higher gross water requirement than ordinary concrete and therefore takes longer to dry. So a longer drying period should be allowed before installation of flooring. Flooring manufacturers provide advice and sometimes also equipment to test for moisture.

As indication of dryness at any given time is no assurance that a concrete slab at or below grade will always remain dry. Therefore, protection from moisture from external sources must be given considerable attention. (See also Art. 3.4.)

Some concrete curing agents containing oils and waxes may cause trouble with adhesive-applied flooring. Commercial curing agents that have been shown to be satisfactory include styrene-butadiene copolymer or petroleum-hydrocarbon resin dissolved in a hydrocarbon solvent. These products dry to a hard film in 24 hr. Parting agents, used as slab separators in lift-slab and tiltup construction, may cause bond failure of adhesive-applied flooring if they contain nonvolatile oils or waxes. Concrete surfaces that have been treated with or have come in contact with oils, kerosene, or waxes must be cleaned as recommended by the adhesive manufacturer.

All concrete surfaces to receive adhesive-applied, thin flooring must be smooth. Also, they should be free from serious irregularities that would ‘‘telegraph’’ through the covering and be detrimental to appearance and serviceability. For rough or uneven concrete floors, a troweled-on underlayment of rubber latex composition or asphalt mastic is recommended. It can be applied from a thickness of ¼ in to a featheredge. Small holes, cracks, and crevices may be filled with a reliable cement crack filler.

TABLE 11.12 Adhesives Used to Install Flooring*

Flooring	Concrete below grade	Concrete on grade	Concrete above grade	Plywood or hardboard
Asphalt and vinyl-asbestos tiles	Asphalt, cutback Asphalt, emulsion	Asphalt, cutback Asphalt, emulsion	Asphalt, cutback Asphalt, emulsion	Asphalt, cutback Asphalt, emulsion
Rubber and vinyl	Chemical set Latex	Latex	Latex	Latex
Linoleum, cork, and vinyl backed with felt or cork	Do not install	Do not install	Linoleum paste	Linoleum paste
Vinyl backed with asbestos felt	Latex	Latex	Latex Linoleum paste	Linoleum paste
Laminated wood block	Do not install	Asphalt, hot melt Asphalt, cutback Rubber base	Asphalt, hot melt Asphalt, cutback Rubber base	Asphalt, hot melt Asphalt, cutback Rubber base
Solid unit wood block	Do not install	Asphalt, hot melt Asphalt, cutback	Asphalt, hot melt Asphalt, cutback	Asphalt, hot melt Asphalt, cutback

* The adhesives listed are intended for each type of flooring; i.e., asphalt adhesives used for asphalt and vinyl tiles are not the same as asphalt adhesives used for wood blocks. There are a number of adhesives having special properties and characteristics, such as heat resistance, resistance to water spillage, and brush-on types not included in this table.

Wood subfloors, of sufficient strength to carry intended loads without deflection, should be covered with plywood or hardboard underlayments. These should be nailed 6 in c to c in perpendicular directions over the entire area with ringed or barbed nails. The nails should be driven flush with the underlayment surface without denting it around the nail head.

Adhesives commonly used to attach flooring to concrete and underlayment are listed in Table 11.12.

11.37 CARPETS

Extending from wall to wall, carpets are frequently used as floor coverings in residences, offices, and retail stores. They are often selected for the purpose because they offer foot comfort and, being available in many colors, patterns, and textures, attractive appearance. Rugs, often used as an alternative in residences, differ from carpets chiefly in being single pieces of definite shape and usually not covering an entire floor between walls.

A carpet is a thick, heavy fabric that is usually piled but could be woven or felted. Pile consists of closely placed loops of fiber, or tufts, that produce a raised surface on a backing to which they are locked. The tufts may be sheared to produce a soft, velvety surface with a wide variety of patterns and textures.

Sheared or unsheared, the piled fabric is very resilient, thus contributing to foot comfort. Nevertheless, thin pads, generally of foam rubber or plastic, often are placed under carpets, to improve resilience. They offer the additional advantage of absorbing minor irregularities in the floor surface that otherwise would cause rapid wear in local areas.

Fibers used for tufting indoor carpets include wool, acrylic, polyester, continuous-filament or heat-set spun nylon and nylon with antistatic treatment for high resistance to soiling. Pile weight generally ranges between 15 and 40 oz/yd^2. The primary backing, to which the pile is tufted and which provides dimensional stability to the carpet, usually is polypropylene weighing 3.5 oz/yd^2. A secondary backing, which generally is attached to the primary backing with a latex adhesive, is used to protect the underside of the carpet and improve other characteristics, such as resilience and noise absorption. The secondary backing usually is woven jute weighing 7 oz/yd^2, nonwoven polypropylene weighing 3.5 oz/yd^2, or $\frac{3}{16}$-in-thick, high-density foam rubber weighing 38 oz/yd^2, which eliminates the need for an underlying pad.

In selection of carpeting, consideration should be given to the intensity of traffic to which the covering will be subjected; availability of desired colors, patterns, and textures; colorfastness; resistance to crushing and matting; soil resistance; cleanability; resistance to fuzzing, beading, and pilling; as measured by bundle wrap and latex penetration on the underside of the primary backing; subfloor conditions; and installed cost of the carpet. Colorfastness may be judged by performance in an 80-hr xenon-arc fadeometer test and in wet-method cleaning in accordance with Federal Specification DDD-C-001559 and by negligible crocking (color transfer to a white cloth). Preference should be given to carpets that meet the following requirements:

Flammability. Flame spread rating (ASTM E84) of 75 or less; flame propagation index (floor chamber test) of 4.0 or less (see Underwriters Laboratories Subject 992); and corrected maximum specific optical density of 450 or less in the National Institute of Standards and Technology smoke-density-chamber test.

Static propensity. 3.0 kV or less.

Acoustical Properties. Impact noise rating of 30 or more; impact insulation class 81 or more; NC 30 masking level of 30 or less; and noise reduction coefficient, measuring airborne sound absorption, of 0.5 or more.

Tuft Bind. Average force of 10 lb or more required to pull out tufts from the face of the carpet (ASTM D1335).

Installation of Carpet. Carpet is supplied usually in widths of 12 or 15 ft in rolls in long lengths. It may be cut to desired sizes and shapes with a carpet knife. Strips of carpet are laid side by side to extend the covering from wall to wall. Joints may be stitched or taped.

Installation should conform to recommendations of the carpet manufacturer. In general, carpet may be laid on any firm, smooth floor.

Carpets with jute or synthetic secondary backing generally should be stretched over a good-quality pad, to eliminate bulges, and anchored at the walls with tacks or tackless strips. With this type of installation, carpets may be removed easily when replacement is necessary. However, they must still be cleaned in place, may require restretching, and can be difficult to repair. (Power stretchers should be used for carpets with synthetic secondary backing.) Alternatively, this type of carpet may be directly cemented to subfloors, eliminating an underlying pad and future restretching. But wearability may be lower and there may be a greater tendency to soil under heavy traffic.

Carpets with high-density foam-rubber backing also may be cemented directly to subfloors. Such carpets, however, are not suitable for carrying heavy traffic and may be difficult to remove when replacement is necessary.

In all cases, use of chair pads under castered chairs is desirable.

11.38 TERRAZZO

A Venetian marble mosaic, with portland cement matrix, terrazzo is composed of two parts marble chips to one part portland cement. Color pigments may be added. Three methods of casting in place portland-cement terrazzo atop structural concrete floor slabs are commonly used: sand cushion, bonded, and monolithic.

Sand-cushion (floating) terrazzo is used where structural movement that might injure the topping is anticipated from settlement, expansion, contraction, or vibration. This topping is at least 3 in thick. First, the underlying concrete slab is covered with a ¼- to ½-in bed of dry sand. Over this is laid a membrane, then wire-fabric reinforcing. The terrazzo underbed is installed to ⅝ in below the finished floor line. Next, divider strips are placed and finally, the terrazzo topping.

Bonded terrazzo has a minimum thickness of 1¾ in. After the underlying concrete slab has been thoroughly cleaned and soaked with water, the surface is slushed with neat portland cement to ensure a good bond with the terrazzo. Then, the underbed is laid, divider strips are installed, and terrazzo is placed.

Monolithic terrazzo is constructed by placing a ⅝-in topping as an integral part of a green-concrete slab. Adhesive-bonded monolithic terrazzo with an epoxy resin adhesive also has been used successfully, with a topping thickness of only ⅜ in.

Terrazzo may be precast. It generally is used in this form for treads, risers, platforms, and stringers on stairs.

Because of the large variety of color and surface textures that can be attained with terrazzo, it is used extensively as an exterior and interior decorative flooring. Portland-cement terrazzo, however, should not be used in areas subject to spillage, such as might be encountered in kitchens.

Details on selecting the proper type of terrazzo, marble-chip sizes, methods of applying, and finishing of the surface may be obtained from the National Terrazzo and Mosaic Association, 110 Market Street, Suite 200A, Leesburg, VA 20176. Also, specification sheets for terrazzo are published by the American Institute of Architects.

Other matrix materials used with marble chips include rubber latex, epoxy, and polyesters. Suppliers should be consulted for installation details.

11.39 CONCRETE FLOORS

A concrete topping may be applied to a concrete structural slab before or after the base slab has hardened. Integral toppings usually are ½ in thick; independent toppings about 1 in.

It is well to remember in specifying or installing a concrete floor that the difference between good and poor concrete lies in selection and grading of aggregates, proportioning of the mix, and the care with which the vital operations of placing, finishing, and curing are carried out. (See also Sec. 9.)

(ACI 302.1, "Guide for Concrete Floor and Slab Construction," American Concrete Institute.)

11.40 WOOD FLOORS

Both hardwoods and softwoods are used for floors. Hardwoods most commonly used are maple, beech, birch, oak, and pecan. Softwoods are yellow pine, Douglas fir, and western hemlock. The hardwoods are more resistant to wear and indentation than softwoods.

Hardwood strip floorings are available in thicknesses of 11⁄32, 15⁄32, and 25⁄32 in and in widths of 1½, 2, 2¼, and 3¼ in.

Softwood strip flooring usually is 25⁄32 in thick and can be obtained in widths of 2⅜, 3¼, and 5 3⁄16 in.

Solid-unit wood blocks for floors are made from two or more units of stripwood flooring fastened together with metal splines or other suitable devices. A block usually is square. Tongued and grooved, either on opposite or adjacent sides, it is held in place with nails or an asphalt adhesive (Table 11.12). Blocks 25⁄32 in thick are made up of multiples of 1½- and 2¼-in strips; blocks ½ in thick are composed of multiples of 1½- or 2-in strips.

A laminated block is formed with plywood comprising three or more plies of wood glued together. The core or cross bonds are laid perpendicular to the face and back of the block. Usually square, the block is tongued and grooved on either opposite or adjacent sides. The most common thickness is ½ in, but other thicknesses used are ⅜, 7⁄16, ⅝, and 13⁄16 in. Laminated blocks are installed with adhesives (Table 11.12).

Average moisture content of wood flooring at time of installation should be 6% in dry southwestern states, 10% in damp southern coastal states, and 7% in the rest of the United States ("Moisture Content of Wood in Use," U.S. Forest Products Laboratory Publication No.1655, Madison, Wis.). The U.S. Forest Products Laboratory also recommends heating the building before installing any type of wood flooring, except when outdoor temperatures are high. Bundles of flooring should be opened and stored in the building before installation. Leave at least 1 in of expansion space at walls and columns.

Specifications for wood floors on concrete, gymnasium floors, or other special designs or conditions may be obtained from associations of wood flooring manufacturers and installers.

11.41 INDUSTRIAL FLOORS

The primary purpose of a floor covering in an industrial building is to protect the structural floor from foot and truck traffic and from corrosive affluents. The flooring also must provide a durable surface that will not be detrimental to plant operations.

A good-quality concrete floor is adequate if factory conditions are dry and the surface has to withstand only foot and truck traffic. A cast-iron grid filled with concrete on ¼-in-thick steel plates may be used in areas where heavy equipment or materials are dragged continually. End-grain wood blocks may be used in areas of heavy trucking of heavy castings, to protect both the structure and castings from impact damage. Asphalt mastic floors also are used in areas with heavy truck traffic.

If the factory process is wet and corrosive, the designer may have to choose between a less-resistant flooring that has to be replaced periodically and a flooring with low maintenance costs but high initial cost. Table 11.13 rates the relative resistance to liquids of some floor toppings and bedding and jointing materials for

TABLE 11.13 Resistance of Floor Toppings and of Bedding and Jointing Material to Various Liquids*

Material	Water	Organic solvents	Oils	Acids	Alkalies
Floor topping:					
Portland-cement concrete	VG	G	F	VP	G
High-alumina cement concrete	G	G	F–G	VP	F
Pitch (coal tar) mastic	VG	F	F	F–G	G
Asphalt mastic	VG	VP	P	F–G	G
Epoxy	VG	G	G	G	G
Polyester	VG	G	G	G	F
Bedding and jointing materials for clay tiles and bricks:					
Portland-cement mortar		As above for concrete			
High-alumina cement mortar		As above for concrete			
Silicate cement	F	G	G	G	VP
Sulfur cement	VG	G	F	G	G
Epoxy			As above		
Furan	VG	VG	VG	VG	VG

VG = very good; G = good; F = fair; P = poor; VP = very poor.

*This table is intended for broad comparisons, as the items under various headings may need qualifications for particular conditions, such as temperature, and concentration of the liquids and acids that are oxidizing agents.

clay tiles and bricks. In addition to selecting the most suitable materials, the designer should provide adequate slope and drainage, a liquid-tight layer below the finished floor as a second line of defense, and a nonslip surface. Selection and laying of chemical-resistant materials are a specialized operation on which specialists should be consulted.

11.42 CONDUCTIVE FLOORING

Where explosive vapors are present, sparks resulting from accumulation of static electricity constitute a hazard. The most effective of several possible ways of mitigating this hazard is to keep electrical resistance so low that dangerous voltages never are attained.

Most objects normally rest or move on the floor and therefore can be electrically connected through the floor. Flooring of sufficiently low electrical resistance (conductive flooring) thus is of paramount importance in elimination of electrostatic hazards. But the electrical resistance must be high enough to eliminate electric shock from faulty electrical wiring or equipment.

Electrical conductivity of flooring is improved by addition of acetylene black (carbon). In ceramic, rubber, and vinyl floors, the carbon is finely dispersed in the material during manufacture; in latex terrazzo, concrete terrazzo, and setting-bed cement for ceramic tile, the carbon is uniformly dispersed in the dry powder mixes, placed in containers, and shipped for on-the-job composition (''Conductive Flooring for Hospital Operating Rooms,'' Monograph 11, National Institute of Standards and Technology, 100 Bureau Drive, Stop 3460, Gaithersburg, MD 20899-3460).

For linoleum flooring, brass seam connectors with projecting points are used for electrical intercoupling between sheets. For vinyl tiles, copper foil is placed between the adhesive and tile for electrical intercoupling.

When flammable gases are in use, everyone and everything must be electrically intercoupled via a static conductive floor at all times. To ensure this, constant vigilance, inspection by testing, and a high standard of housekeeping are required. Wax or dirt accumulation on the floor and grounding devices can provide high resistance to electrical flow and cancel the effect of conductive flooring.

11.43 SPECIFICATIONS AND STANDARDS FOR FLOORING

Federal specifications are written to establish minimum standards for purposes of competitive bidding and to ensure that government agencies will receive quality material. Some flooring materials, however, cannot be classed under these specifications because only one manufacturer makes the products. Prices of the federal specifications may be obtained from the General Services Administration, Washington, DC 20405, or the nearest GSA regional office.

Commercial Standards are specifications that establish quality levels for manufactured products in accordance with the principal demands of the trade. The National Institute of Standards and Technology, 100 Bureau Drive, Stop 3460, Gaithersburg, MD 20899-3460, will supply a price list.

WINDOWS

Selection of a proper window for a building entails many considerations. Functional requirements are usually most important. However, size, type, arrangement, and materials very often establish the character of the building, and this external show of fenestration is an integral part of design and expression.

11.44 WINDOW SELECTION

Distribution and control of daylight, desired vision of outdoors, privacy, ventilation control, heat loss, and weather resistance are all-important aspects of good design principles. Most building codes require that glass areas be equal to at least 10% of the floor area of each room. Nevertheless, it is good practice to provide glass areas in excess of 20% and to locate the windows as high in the wall as possible to lengthen the depth of light penetration. Continuous sash or one large opening in a room provides a more desirable distribution of light than separated narrow windows. Either arrangement eliminates the dark areas between openings.

Location, type, and size of window are most important for natural ventilation. The pattern of air movement within a building depends to a great extent on the angle at which the air enters and leaves. It is desirable, particularly in summer, to direct the flow of air downward and across a room at a low level. However, the type and location of windows best suited to ventilation may not provide adequately for admission of light and clear vision, or perhaps proper weather protection. To arrive at a satisfactory relationship, it may be necessary to compromise with these functional requirements.

While building codes may establish a minimum percentage of glass area, they likewise may limit the use of glass and also require a fire rating in particular locations. In hazardous industrial applications subject to explosions, scored glass is an added precaution for quick release of pressure.

Heat transmittance is of economic importance and can also affect comfort. Weather stripping or the use of windows with integral frame and trim can minimize air infiltration. Double glazing or heat-absorbing glazing makes large glass areas feasible by materially reducing heat transmittance. Solar heating may be achieved by placement of glass areas so that the rays of the sun can be admitted during the winter.

11.45 WINDOW DEFINITIONS

Bar. Either vertical or horizontal member that extends the full height or width of the glass opening.

Blind Stop. A thin strip of wood machined so as to fit the exterior vertical edge of the pulley stile or jamb and keep the sash in place.

Casing. Molding of various widths and thicknesses used to trim window openings.

Check Rails. Meeting rails sufficiently thicker than the window to fill the opening between the top and bottom sash made by the check strip or parting strip in the frame. They are usually beveled and rabbeted.

Dado. A rectangular groove cut across the grain of a frame member.

Drip Cap. A molding placed on the top of the head casing of a window frame.

Extension Blind Stop. A molded piece, usually, of the same thickness as the blind stop, and tongued on one edge to engage a plow in the back edge of the blind stop, thus increasing its width and improving the weathertightness of the frame.

Frame. A group of wood parts so machined and assembled as to form an enclosure and support for a window or sash.

Jamb. Part of frame that surrounds and contacts the window or sash the frame is intended to support.

Side Jamb. The upright member forming the vertical side of the frame (Fig. 11.32).

Head Jamb. The horizontal member forming the top of the frame (Fig. 11.32).

Rabbeted Jamb. A jamb with a rectangular groove along one or both edges to receive a window or sash.

Jamb Liner. A small strip of wood, either surfaced four sides or tongued on one edge, when applied to the inside edge of a jamb, increases its width for use in thicker walls.

Measurements:

Between Glass. Distance across the face of any wood part that separates two sheets of glass.

Face Measure. Distance across the face of any wood part, exclusive of any solid mold or rabbet.

Finished Size. Dimension of any wood part overall, including the solid mold or rabbet.

Wood Allowance. The difference between the outside opening and the total glass measurement of a given window or sash.

Muntin. Any short light bar, either vertical or horizontal.

Parting Stop. A thin strip of wood let into the jamb of a window frame to separate the sash.

Pulley Stile. A side jamb into which a pulley is fixed and along which the sash slides.

Rails. Cross, or horizontal, pieces of the framework of a sash or screen.

Sash. A single assembly of stiles and rails made into a frame for holding glass, with or without dividing bars. It may be supplied either open or glazed.

Sill. The horizontal member forming the bottom of the frame (Fig. 11.32). Stiles. Upright, or vertical, outside pieces of a sash or screen.

Window. One or more single sash made to fill a given opening. It may be supplied either open or glazed.

Window Unit. A combination of window frame, window, weather strip, balancing device, and at the option of the manufacturer, screen and storm sash, assembled as a complete and properly operating unit.

11.46 MODULAR COORDINATION OF WINDOWS

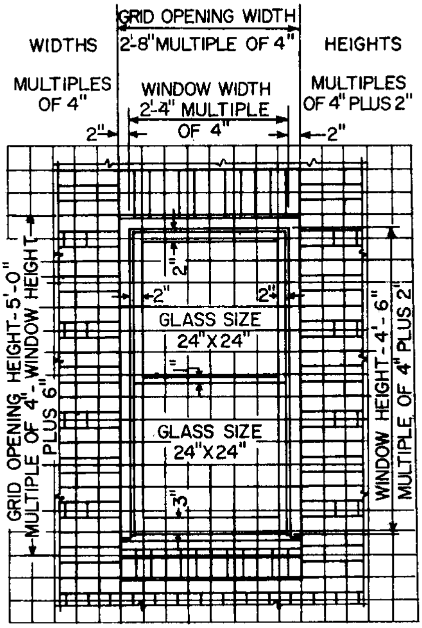


FIGURE 11.30 Relation of modular standard double-hung wood windows to grid opening in a brick wall.

Manufacturers have contributed substantially toward standardization of window sizes and greater precision in fabrication. The American National Standards Institute has established an increment of sizing generally accepted by the building industry (''Basis for the Coordination of Building Materials and Equipment,'' A62.1).

The basis for this standardization is a nominal increment of 4 in in dimension. However, it will be noted in Fig. 11.30, that for double-hung wood windows the 4-in module applies to the grid dimensions, whereas the standard window openings is 4 in less in width and 6 in less in height than the grid opening. Also, to accommodate 2- and 6-in mullions for multiple openings in brick walls, it is necessary to provide a 2-in masonry offset at one jamb (Fig. 11.31).

Use of modular planning effects maximum economies from the producer and simplification for the building industry. At the same time, a given layout does not confine acceptable products to such a limited range.

11.47 WINDOW SASH MATERIALS

Window frames are generally made of wood or metal. Plastics have been employed for special services.

Use of metal in window construction has been highly developed, with aluminum and steel most commonly used. Bronze, stainless steel, and galvanized steel are also extensively used for specific types of buildings and particular service. Use of metal windows is very often dictated by fire-resistance requirements of building codes.

11.47.1 Wood Windows

These can be used for most types of construction and are particularly adaptable to residential work. The most important factor affecting wood windows is weather exposure. However, with proper maintenance, long life and satisfactory service can be expected. Sash and frames have lower thermal conductivity than metal.

The kinds of wood commonly used to resist shrinking and warping for the exposed parts of windows are white pine, sugar pine, ponderosa pine, fir, redwood, cedar, and cypress. The stiles against which a double-hung window slides should

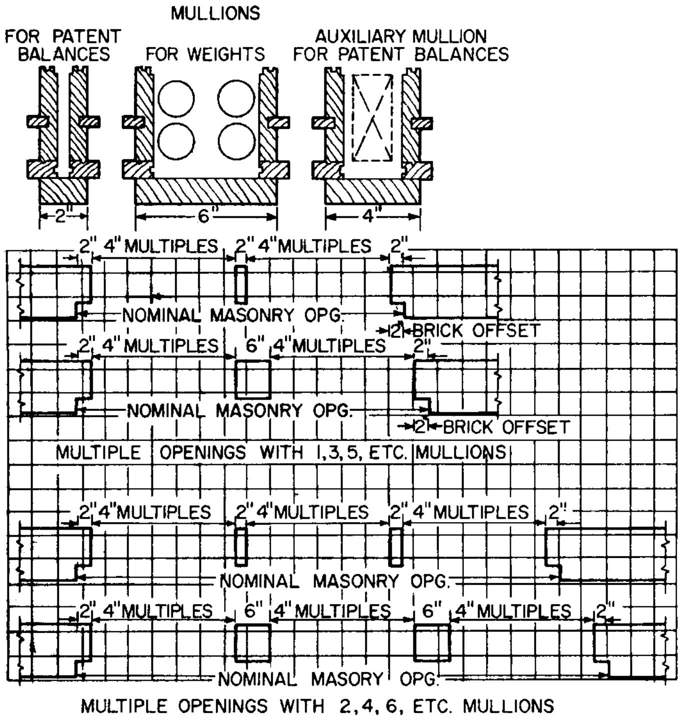


FIGURE 11.31 Dimensions for multiple modular openings for double-hung wood windows.

be of hard pine or some relatively hard wood. The parts of a window exposed to the inside are usually treated as trim and are made of the same material as the trim. (See also Fig. 11.32.)

11.47.2 Steel Windows

These are, in general, made from hot-rolled structural-grade new billet steel. However, for double-hung windows, the principal members are cold-formed from new billet strip steel. The principal manufacturers conform to the specifications of The Steel Window Institute, which has standardized types, sizes, thickness of material, depth of sections, construction, and accessories.

The life of steel windows is greatly dependent on proper shop finish, field painting, and maintenance. The more important aspects of proper protection against corrosion are as follows:

Shop Paint Finish. All steel surfaces should be thoroughly cleaned and free from rust and mill scale. A protective treatment of hot phosphate, cold phosphate-chromate, or similar method such as bonderizing or parkerizing is necessary to

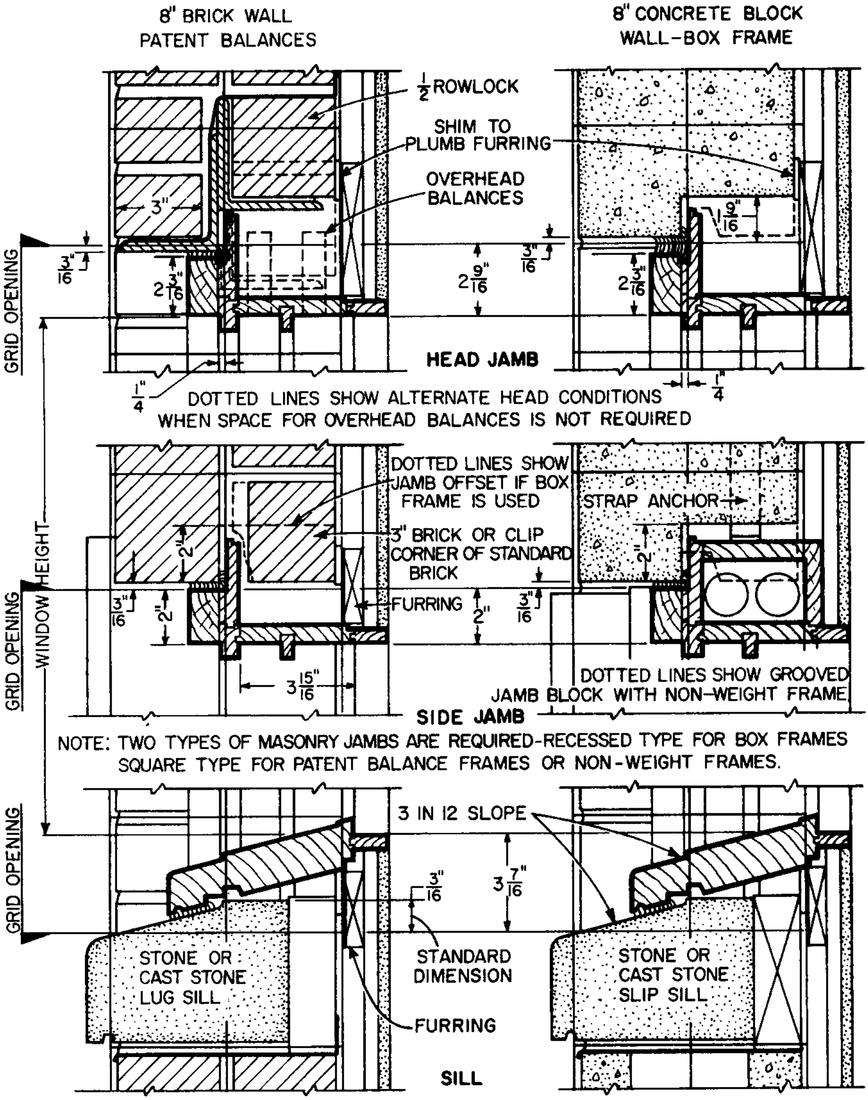


FIGURE 11.32 Details of installation of double-hung windows.

protect the metal and provide a suitable base for paint. All windows should then be given one shop coat of rust-inhibitive primer, baked on.

Field Painting. Steel windows should receive one field coat of paint either before or immediately after installation. A second coat should then be applied after glazing is completed and putty set.

Hot-Dipped Galvanized. Assembled frames and assembled ventilators should be galvanized separately. Ventilators should be installed into frames after galvanizing and bonderizing. Specifications must guard against distortion by the heat of hot dipping, abrasion in handling, and damage to the zinc galvanizing by muriatic acid used to wash brickwork. Painting is optional.

11.47.3 Aluminum Windows

Specifications set up by the Aluminum Window Manufacturers' Association are classified as residential, commercial, and monumental. These specifications provide for a minimum thickness of metal and regulate stiffness of the component parts, as well as limiting the amount of air infiltration.

The manufacturers offer about the same window types that are available in steel. However, in addition to these standard types, substantial progress has been made in the development of aluminum windows as an integral part of the walls of a building. With the exception of ventilator sections, which are shop-fabricated, some windows are completely assembled at the job. The wide range of extruded aluminum sections now manufactured has made it feasible to treat large expanses of glass as window walls. Picture windows with many combinations of ventilating sash are also furnished in aluminum. Many features are available, such as aluminum trim and casing, weather stripping of stainless steel or Monel metal, combination storm sash and screens, sliding wicket-type screens, and metal bead glazing.

Aluminum windows should be protected for shipment and installation with a coating of clear methacrylate lacquer or similar material able to withstand the action of lime mortar.

11.47.4 Stainless-Steel and Bronze Windows

These are high-quality materials used for durability, appearance, corrosion resistance, and minimum maintenance. Stainless steel is rustproof and extremely tough, with great strength in proportion to weight. Weather stripping of stainless steel is quite often used for wood and aluminum sash.

Bronze windows are durable and decorative and used for many fine commercial and monumental buildings.

11.47.5 Weather Stripping and Storm Sash

Weather stripping is a barrier against air leakage through cracks around sash. Made of metal or a compressible resilient material, it is very effective in reducing heat loss.

Storm sash might be considered an overall transparent blanket that shields the window unit and reduces heat loss. Weather stripping and storm sash also reduce condensation and soot and dirt infiltration, in addition to decreasing the amount of cold air near the floor.

Storm sash and screens are often incorporated in a single unit.

11.48 GLAZING

Article 4.31 describes various types of glass available for use in windows.

Thickness. Figure 11.33 can be used as a guide to estimate thickness of plate, float, or sheet glass for a given glass area, or the maximum area for a given thickness to withstand a specified wind pressure. Based on minimum thickness permitted by Federal Specification DD-G-451c, the wind-load chart provides a safety factor of 2.5. It is intended for rectangular lights with four edges glazed in a stiff, weathertight rabbet.

For example, determine the thickness of a 108 × 120-in (90-ft^2) light of polished plate glass to withstand a 20-lb/ft^2 wind load. Since the 20-lb/ft^2 and 90-ft^2 ordinates intersect below the ⅜-in glass thickness line, the thickness to use is ⅜ in.

The correction factors in Table 11.14 also allow Fig. 11.33 to be used to determine the thickness for certain types of fabricated glass products. The table, however, makes no allowance for the weakening effect of such items as holes, notches, grooves, scratches, abrasion, and welding splatter.

The appropriate thickness for the fabricated glass product is obtained by multiplying the wind load, lb/ft^2, by the factor given in Table 11.14. The intersection of the vertical line drawn from the adjusted load and the horizontal line drawn from

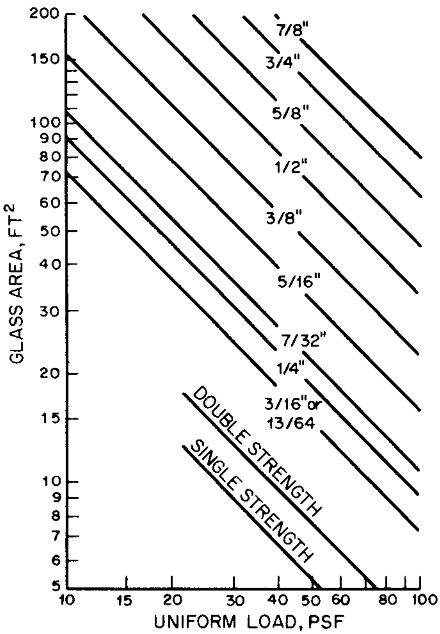


FIGURE 11.33 Wind-load chart indicates maximum glass area for various nominal thicknesses of plate, float, or sheet glass supported on four sides to withstand specified wind pressures, with design factor of 2.5.

TABLE 11.14 Resistance of Glass to Wind Loads

Product	Factor*
Plate, float, or sheet glass	1.0
Rough rolled plate glass	1.0
Sand-blasted glass	2.5
Laminated glass†	2.0
Sealed double glazing:‡	
Metal edged, up to 30 ft^2	0.667
Metal edged, over 30 ft^2	0.556
Glass edged	0.5
Heat-strengthened glass	0.5
Fully tempered glass	0.25

*Enter Fig. 11.33 with the product of the wind load in psf multiplied by the factor.

†At 70°F or above, for two lights of equal thickness laminated to 0.015-in-thick vinyl. At 0°F, factor approaches 1.

‡For thickness, use thinner of the two lights, not total thickness.

the glass area indicates the minimum recommended glass thickness. (See also Art. 11.48.3.) Glass producers should be consulted for more accurate thickness recommendations.

Table 11.15 gives the overall thermal conductance, or *U* factor, and weight of glass for several thicknesses. Table 11.16 presents typical sound-reduction factors for glass, and for comparison, for other materials. As a sound barrier, glass, inch for inch, is about equal to concrete and better than most brick, tile, or plaster. Double glazing (Fig. 11.34) is particularly effective where high resistance to sound transmission is required. Unequal glass thicknesses minimize resonance in this type of glazing, and a nonreflective mounting reduces sound transmission. For optimum performance, sound-isolation glazing should be carefully detailed and constructed, and should be mounted in airtight, heavy walls with acoustically treated surfaces.

11.48.1 Glazing Compounds

Putty, glazing compound, rubber, or plastic strips and metal or wood molds are used for holding glass in place in sash. Metal clips for metal sash (Fig. 11.35*e*) and glazing points for wood sash also are employed for this purpose.

TABLE 11.15 Overall Conductance and Weight of Glass

Thickness, in	*U* factor	Weight, psf
⅛	1.14	1.65
¼	1.13	3.29
⅜	1.12	4.94
½	1.11	6.58
1-in insulating glass	0.55	7.00

TABLE 11.16 Sound Reduction—Glass and Other Materials*

Material thickness, in	Sound transmission classification rating
Glass:	
0.087 (single strength)	26
0.118 (double strength)	29
⅛	29
3⁄16	29
¼	27
5⁄16	29
⅜	30
½	33
1	32
¼ laminated (up to 0.045 plastic layer)	33
1-in sealed double glazing, ½-in. air space	27
Other materials:	
¼ plywood	22
½ fiberboard	21
¼ lead	45
2 solid vermiculite plaster on metal lath	30
Hollow wall, 2 × 4 studs, ½-in gypsum plaster on metal lath on two sides	33

*Courtesy Libby-Owens-Ford Company, Toledo, Ohio.

Putty and glazing compounds are generally classified in relation to the sash material and should be used accordingly for best results.

Bedding of glass in glazing compound is desirable, because it furnishes a smooth bearing surface for the glass, prevents rattling, and eliminates voids where moisture can collect (Commercial Standards, U.S. Department of Commerce). Glazing terminology relative to putty follows:

Face Puttying (Fig. 11.35*a*). Glass is inserted in the glass rabbet and securely wedged where necessary to prevent shifting. Glazing points are also driven into the wood to keep the glass firmly seated. The rabbet then is filled with putty, the putty being beveled back against the sash and muntins with a putty knife.

Back Puttying (Fig. 11.35*b*). After the sash has been face-puttied, it is turned over, and putty is run around the glass opening with a putty knife, thus forcing putty into any voids that may exist between the glass and the wood parts.

Bedding (Fig. 11.35*c*). A thin layer of putty or bedding compound is placed in the rabbet of the sash, and the glass is pressed onto this bed. Glazing points are then driven into the wood, and the sash is face-puttied. The sash then is turned over, and the excess putty or glazing compound that emerged on the other side is removed.

Wood-Stop or Channel Glazing (Fig. 11.35*d*). A thin layer of putty or bedding compound is placed in the rabbet of the sash, and the glass is pressed onto this bed. Glazing points are not required. Wood stops are securely nailed in place. The

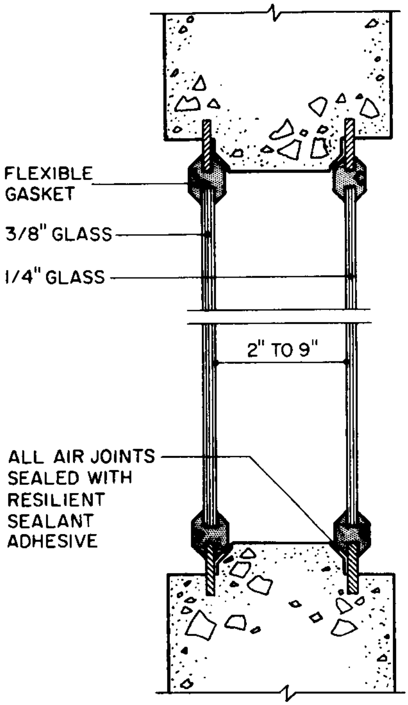


FIGURE 11.34 Details of a double-glazed window installed in a massive concrete wall to obtain high resistance to sound transmission.

sash then is turned over, and the excess putty or glazing compound that emerged on the other side is removed.

Glazing Beads (Fig. 11.35*f*). These are designed to cover exterior glazing compound and improve appearance.

Continuous Glazing Angles (Fig. 11.35*g*). These angles or similar supports for glass usually are required for "labeled windows" by the National Board of Fire Underwriters.

Table 11.17 lists some commonly used glazing compounds and indicates the form and method in which they usually are used. Other compounds used for special service include silicone rubber, butadiene-styrene (GR-S) rubber, polyethylene, nitrile rubbers, polyurethane rubbers, acrylics, and epoxy.

11.48.2 Factory-Sealed Double Glazing

This is a factory-fabricated, insulating-glass unit composed of two panes of glass separated by a dehydrated airspace. This type of sash is also manufactured with

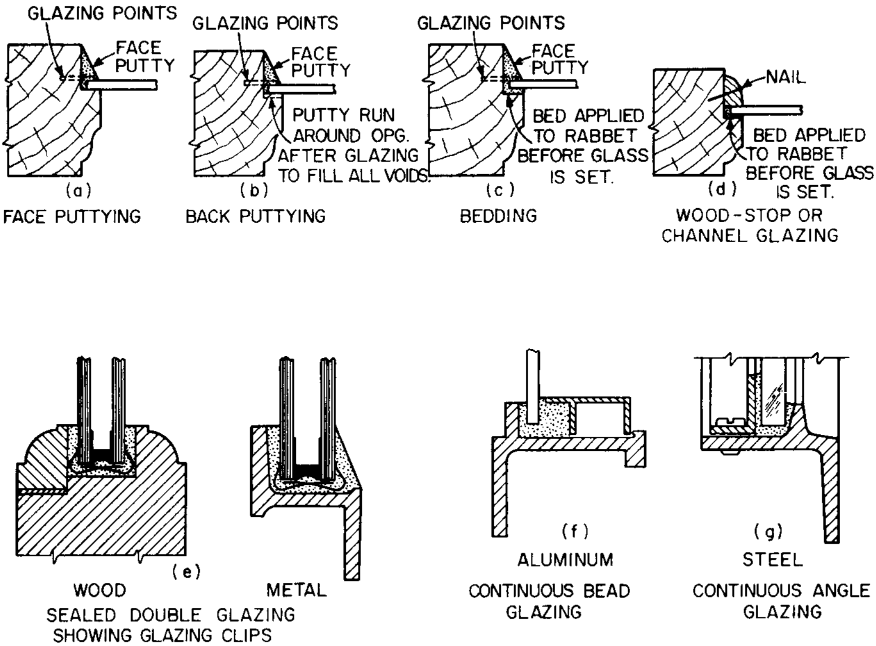


FIGURE 11.35 Glazing details.

TABLE 11.17 Commonly Used Glazing Compounds

Compound	Type of material	Final form	Type of glazing
Vegetable oil base (skin-forming type)	Gun, knife	Hard	Channel bedding, face
Vegetable oil-rubber or nondrying oil blends (polybutene) etc.	Gun, knife	Hard, plastic	Face, channel, bedding
Nondrying oil types	Gun, knife, tacky tape	Plastic	Channel, bedding
Butyl rubber or polyisobutylene	Tacky tape	Plastic, rubber	Bedding, channel
Polysulfide rubber	Gun	Plastic, rubber	Bedding, channel
Neoprene (polychloroprene)	Gun, preformed gasket	Rubber	Channel
Vinyl chloride and copolymers	Preformed gasket	Hard, plastic	

three panes of glass and two airspaces, providing additional insulation against heat flow or sound transmission. (See Fig. 11.35*e*.)

Heat loss and heat gain can be substantially reduced by this insulated glass, permitting larger window areas and added indoor comfort. Heat-absorbing glass often is used for the outside pane and a clear plate or float glass for the inside. However, there are many combinations of glass available, including several patterned styles. Thickness of glass and airspace between can be varied within prescribed limitations. In the selection of a window for double or triple glazing, accommodation of the overall glass thickness in the sash is an important consideration.

11.48.3 Gaskets for Glazing

Structural gaskets, made of preformed and cured elastomeric materials, may be used instead of sash for some applications to hold glass in place. Gaskets are extruded in a single strip, molded into the shape of the window perimeter, and installed against the glass and window frame. A continuous locking strip of harder elastomer is then forced into one side of the gasket as a final sealing component. Fit and compression of the gasket determine weathertightness. With proper installation, calking is not ordinarily required; but should it be necessary, sealants are available that are compatible with the material of which the gasket is made.

There are many variations in the design of lockstrip gaskets, some of which are shown in Fig. 11.36. The two most commonly used types are the H and reglet types. The H gasket fits over a flange on the surrounding frame (Fig. 11.36*c* and *d*), whereas the reglet gasket fits into a recess in the frame (Fig. 11.36*a* and *b*). When gaskets are used in concrete wall panels, the entire opening should be cast within one panel. In all cases, the smoothness, tolerance, and alignment of the contact surfaces are very important. The gaskets shown in Fig. 11.36*e* and *f* for use with double glazing require weepholes to allow water that may collect in the gaskets to drain.

The maximum glass area recommended for glazing with standard H-type lockstrip gaskets may be obtained from Fig. 11.37. Loads for the chart are based on minimum glass thicknesses allowed in Federal Specification DD-G-451c. Glass producers should be consulted to obtain the latest thickness recommendations.

11.49 WINDOW TYPES

A wide range of window types are available to satisfy the ever-increasing scope of architectural requirements. There are many materials, sizes, arrangements, details, and specific features from which to choose.

Types of windows (see symbols Fig. 11.38) include:

Pivoted windows, an economical, industrial window used where a good tight closure is not of major importance (Fig. 11.39). Principal members of metal window units are usually 1⅜ in deep, with frame and vent corners and muntin joints riveted. However, when frame and vent corners are welded, principal members may be 1¼ in deep. Vents are pivoted about 2 in above the center. These windows are adaptable to multiunits, both vertical and horizontal, with mechanical operation. Bottom of vent swings out and top swings in. No provision is made for screening. Putty glazing is placed inside.

Commercial projected windows, similar to pivoted windows (Fig. 11.40). These are an industrial-type window but also are used for commercial buildings where economy is essential. Vents are balanced on arms that afford a positive and easy control of ventilation and can be operated in groups by mechanical operators. Maximum opening is about 35°. Factory provision is made for screens.

Security windows, an industrial window for use where protection against burglary is important, such as for factories, garages, warehouses, and rear and side

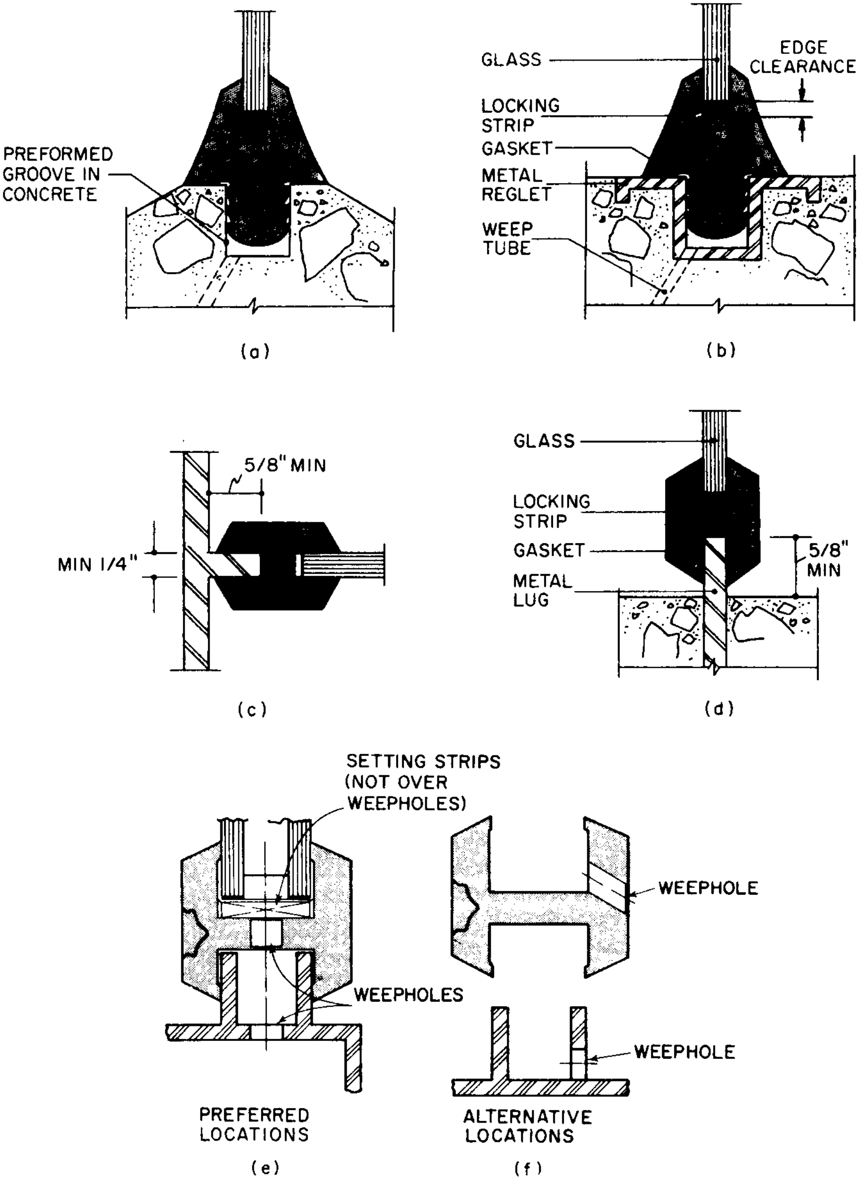


FIGURE 11.36 Structural gasket glazing: (*a*) and (*b*) gasket fitted into a groove; (*c*) and (*d*) H shape locked to continuous metal fin; (*e*) and (*f*) weep holes for factory sealed double-glazed window.

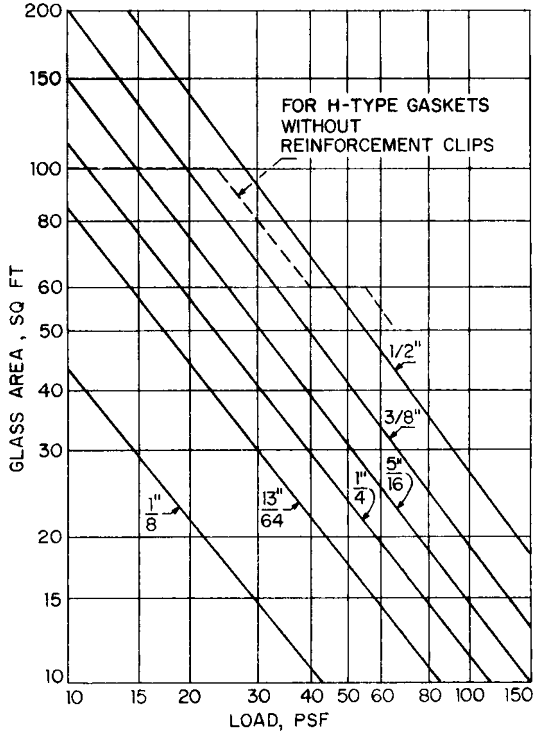


FIGURE 11.37 Maximum permissible areas of plate float, or sheet glass, with design factor of 2.5, for various wind loads on vertical windows supported on four sides and having standard H-type lockstrip gaskets. Loads apply to glass lights with a length-to-width ratio of 3 or less.

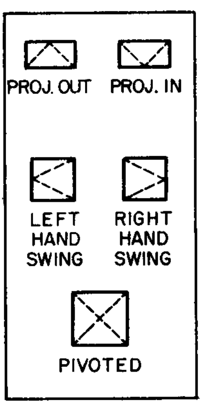


FIGURE 11.38 Symbols for common window types (viewed from outside).

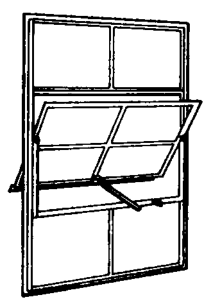


FIGURE 11.39 Pivoted window. Vent bottom swings out, top swings in.

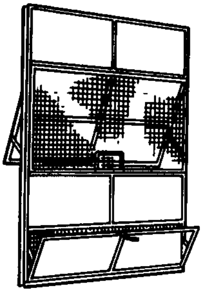


FIGURE 11.40 Commercial projected window.

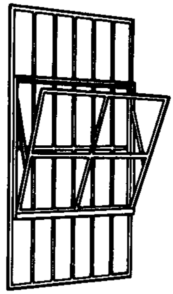


FIGURE 11.41 Security window with continuous muntins.

elevations of stores (Fig. 11.41). They eliminate the need for separate guard bars. They consist of a grille and ventilated window in one unit. Maximum grille openings are 7 × 16 in. The ventilating section, either inside or outside the grille, is bottom-hinged or projected. Muntins are continuous vertically and horizontally. Factory provision is made for screening. Glazing is placed from the inside.

Basement and utility windows, economy sash designed for use in basements, barracks, garages, service stations, areaways, etc. (Figs. 11.42 and 11.43). Ventilator opens inward and is easily removed for glazing or cleaning, or to provide a clear opening for passage of materials. Center muntin is optional. Screens are attached on the outside.

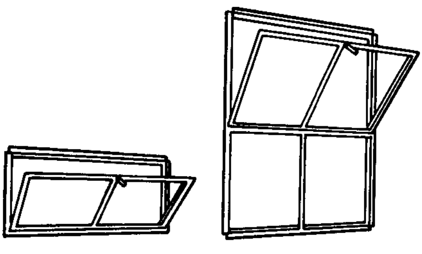


FIGURE 11.42 Basement and utility window.

Architectural projected windows, a medium-quality sash used widely for commercial, institutional, and industrial buildings (Figs. 11.44 and 11.45). Ventilator arrangement permits cleaning from inside and provides a good range of ventilation control with easy operation. Steel ventilator sections are usually 1¼ in deep, with corners welded. Frames may be 1⅜ in deep when riveted or 1¼ in deep when welded. Screens are generally furnished at extra cost. Glazing may be either inside or outside.

Intermediate projected windows, high-quality ventilating sash used for schools, hospitals, commercial buildings, etc. (Figs. 11.46 and 11.47). When made of metal, corners of frames and ventilators are welded. Depth of frame and vent sections varies from "intermediate" to "heavy intermediate," depending on the manufacturer. Each vent is balanced on two arms pivoted to the frame and vent. The arms are equipped with friction shoes arranged to slide in the jamb sections. Screens are easily attached from inside. All cleaning is done from the inside. Glazing is set from the outside. Double insulating glass is optional.

Psychiatric projected windows, for use in housing mental patients, to provide protection against exit but minimizing appearance of restraint (Fig. 11.48). Ventilators open in at the top, with a maximum clear opening of 5 to 6 in. Glazing is set outside. Screens also are placed on the outside but installed from inside. Metal

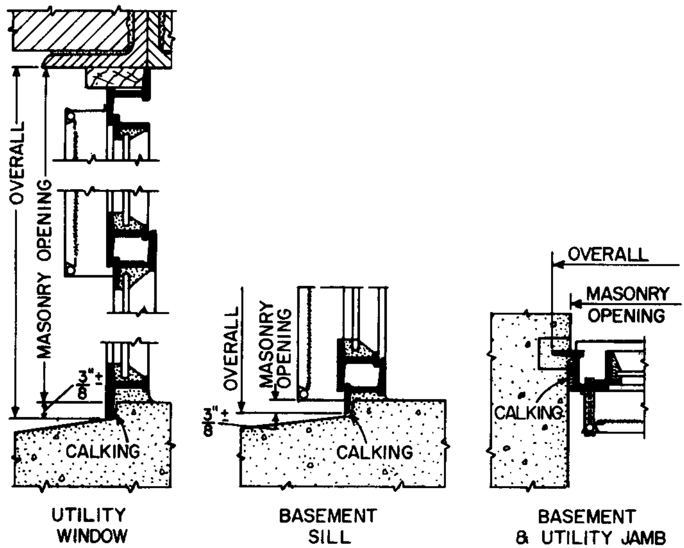


FIGURE 11.43 Details of installation of basement and utility windows.

casing can be had completely assembled and attached to window ready to install. Outside glass surfaces are easily washed from the inside.

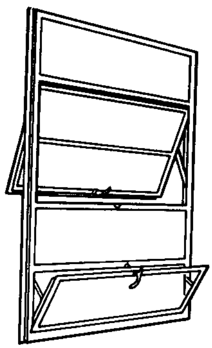


FIGURE 11.44 Architectural projected window.

Detention windows, designed for varying degrees of restraint and for different lighting and ventilating requirements. The guard type (Fig. 11.49) is particularly adaptable to jails, reform schools, etc. It provides security against escape through window openings. Ventilators are attached to the inner face of the grille and can be had with a removable key-locking device for positive control by attendants. Screens are installed from inside between vent and grille. Glazing is done from outside, glass being omitted from the grille at the vent section.

Residential double-hung windows (Figs. 11.30 to 11.32 and 11.50), available in different designs and weights to meet various service requirements for all types of buildings. When made of metal, the frame and ventilator corners are welded and weathertight. These windows are also used in combination with fixed picture windows for multiple window openings. They are usually equipped with weather stripping, which maintains good weathertightness. Screens and storm sash are furnished in either full or half sections. Glazing is done from outside.

Residence casements, available in various types, sizes, and weights to meet service requirements of homes, apartments, hotels, institutions, commercial buildings, etc. (Fig. 11.51). Rotary or lever operations hold the vent at the desired po-

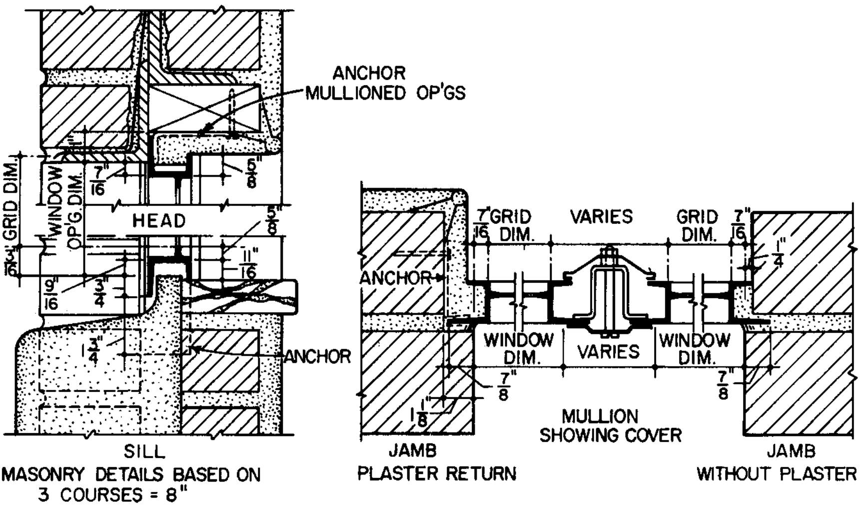


FIGURE 11.45 Details of installation of architectural projected windows.

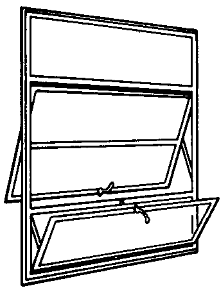


FIGURE 11.46 Intermediate projected window.

sition, up to 100% opening. Screens and storm sash are attached to the inside of casement. Extended hinges on vents permit cleaning from inside. Glazing is done from outside.

Intermediate combination windows, with side-hinged casements and projected-in ventilators incorporated to furnish flexibility of ventilation control, used extensively for apartments, offices, hospitals, schools, etc., where quality is desired (Fig. 11.52). They are available in several weights with rotary or handle operation. When made of metal, corners of vents and frames are welded. Factory provision is made for screens. All cleaning is done from inside. Glazing is set from outside. Special glazing clips permit use of double insulating glass.

Intermediate casements, a heavier and better quality than residence casements, used particularly for fine residences, apartments, offices, institutions, and similar buildings (Fig. 11.53). Frames and ventilators of metal units have welded corners.

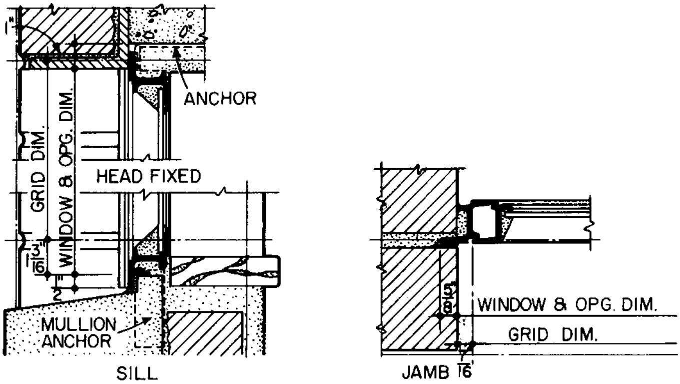


FIGURE 11.47 Details of installation of intermediate projected window.

Easy control of ventilation is provided by rotary or handle operation. Extended hinges permit safe cleaning of all outside surfaces from inside. Screens are attached or removed from inside. Single or double glazing is set from outside.

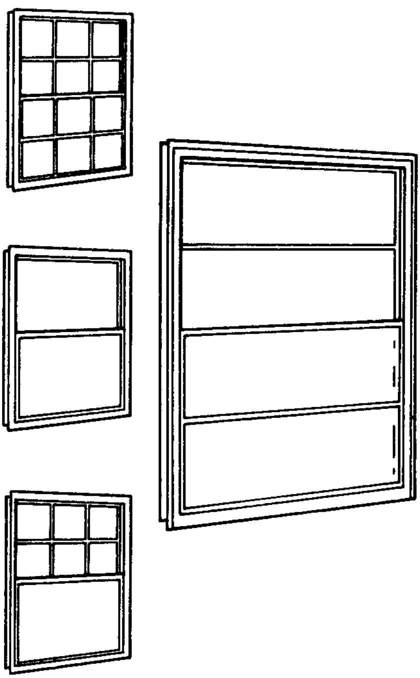


FIGURE 11.50 Double-hung windows.

Awning windows, suitable for residential, institutional, commercial, and industrial buildings (Fig. 11.54), furnishing approximately 100% opening for ventilation. Mechanical operation can provide for the bottom vent opening prior to the other vents, which open in unison. This is desirable for night ventilation. Manual operation can be had for individual or group venting. All glass surfaces are easily cleaned from inside through the open vents. Glazing is set from outside, storm sash and screens from inside.

Jalousie windows (Fig. 11.55) combine unobstructed vision with controlled ventilation and are used primarily for sunrooms, porches, and the like where protection from the weather is desired with maximum fresh air. The louvers can be secured in any position. Various kinds of glass, including obscure and colored, often are used for privacy or decoration. They do not afford maximum weathertightness but can be fitted with storm sash on the inside. Screens are furnished interchangeable with storm sash.

Ranch windows, particularly suited to modern home design and also used effectively in other types of buildings where more light or better view is desired (Fig. 11.56). When made of metal, corners of frames and vents are welded. Depth of

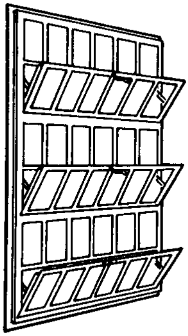


FIGURE 11.48 Psychiatric projected window.

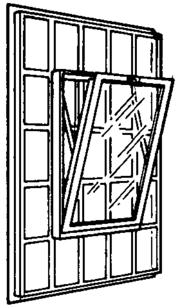


FIGURE 11.49 Guard-type detention window.

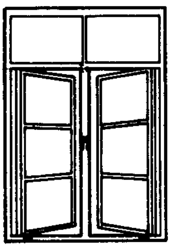


FIGURE 11.51 Residence casement window.

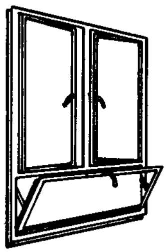


FIGURE 11.52 Intermediate combination window.

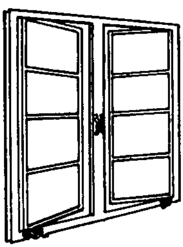


FIGURE 11.53 Intermediate casement window.

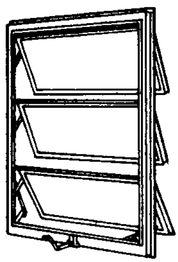
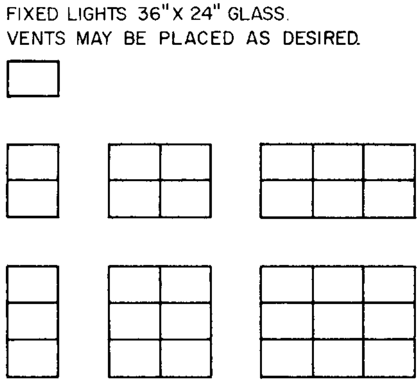


FIGURE 11.54 Awning window.

sections vary with manufacturers. These windows are designed to accommodate insulating glass or single panes. Screens are attached from inside.

Continuous top-hung windows, used for top lighting and ventilation in monitor and sawtooth roof construction (Fig. 11.57). They are hinged at the top to the structural-steel framing members of the building and swing outward at the bottom. Two-foot lengths are connected end to end on the job. Mechanical operators may be either manual or motor-powered. Sections may be installed as fixed windows. Glazing is set from outside.



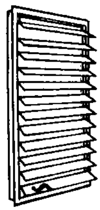


FIGURE 11.55 Jalousie window.

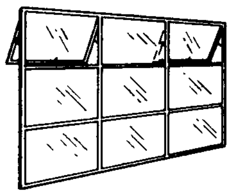


FIGURE 11.56 Ranch windows.

Additional types of windows (not illustrated) include:

Vertical pivoted, which sometimes are sealed with a rubber or plastic gasket.

Horizontal sliding sash usually in aluminum or wood for residential work.

Vertical folding windows, which feature a flue action for ventilation.

Double-hung windows with removable sash, which slide up and down, or another type which tilts for ventilation but does not slide.

Austral type, with sash units similar to double-hung but which operate in unison as projected sash. The sash units are counterbalanced on arms pivoted to the frame, the top unit projecting out at bottom and the bottom unit projected in at top.

Picture windows, often a combination of fixed sash with or without auxiliary ventilating units.

Store-front construction, usually semicustom-built of stock moldings of stainless steel, aluminum, bronze, or wood.

11.50 WINDOWS IN WALL-PANEL CONSTRUCTION

In the development of thin-wall buildings and wall-panel construction, windows have become more a part of the wall rather than units to fill an opening. Wall panels of metal and concrete incorporate windows as part of their general makeup; a well-integrated design will recognize this inherent composition.

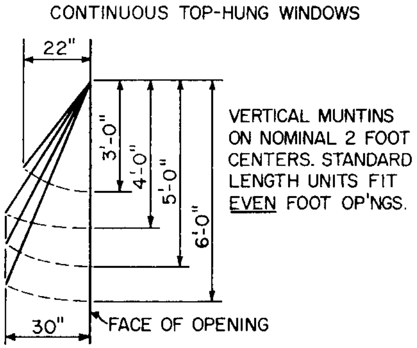


FIGURE 11.57 Continuous top-hung window.

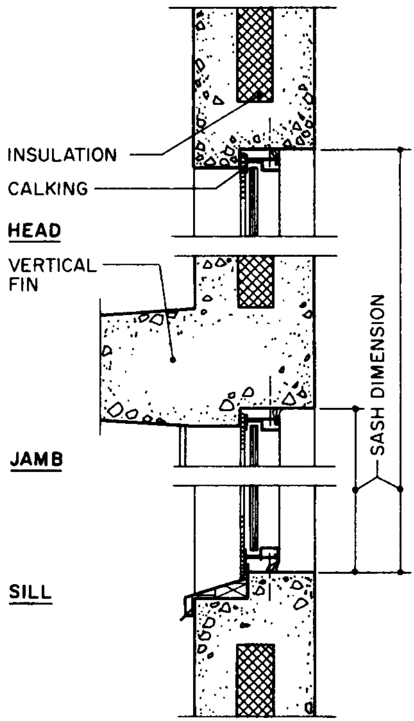


FIGURE 11.58 Window installed in precast-concrete sandwich wall panel.

Manufacturers of metal wall panels can furnish formed metal window frames specifically adapted to sash type and wall construction.

In panel walls of precast concrete, window frames can be cast as an integral part of the unit or set in openings as provided (Fig. 11.58). The cast-in-place method minimizes air infiltration around the frame and reduces installation costs on the job. Individual units or continuous bands of sash, both horizontal and vertical, can be readily adapted by the proper forming for head, jamb, and sill sections.

11.51 MECHANICAL OPERATORS FOR WINDOWS

Mechanical operation for pivoted and projected ventilators is achieved with a horizontal torsion shaft actuated by an endless hand chain or by motor power. Arms attached to the torsion shaft open and close the vents.

Two common types of operating arms are the lever and the rack and pinion (Fig. 11.59). The lever is used for manual operation of small groups of pivoted vents where rapid opening is desirable. The rack and pinion is used for longer runs of

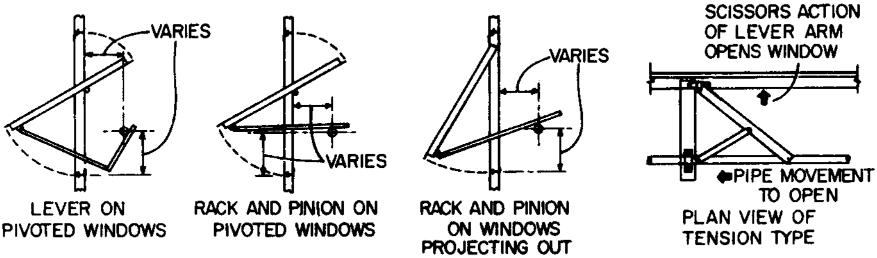


FIGURE 11.59 Levers, rack-and-pinion, and tension-type window operators.

vents and can be motor powered or manually operated. The opening and closing by rack and pinion are slower than by lever arm.

Usually one operating arm is furnished for each vent less than 4 ft wide and two arms for each vent 4 ft or more wide. Mechanical operators should be installed by the window manufacturer before glazing of the windows.

Continuous top-hung windows are mechanically controlled by rack-and-pinion or tension-type operators (Fig. 11.59).

DOORS

The purpose of doors is to close openings that are needed in walls and partitions for access to building interior spaces, when closing is required to prevent trespass by unauthorized persons, to provide privacy, to protect against weather, drafts, and noise, and to act as a barrier to fire and smoke. Many types of doors are available for this. They may be hinged on top or sides to swing open and shut, they may slide horizontally or vertically, or they may revolve about a vertical axis in the center of the opening.

A large variety of materials also is available for door construction. Wood, metal, glass, plastics, and combinations of these materials with each other and with other materials, in the form of sandwich panels, are in common use.

Selection of a type of door and door material depends as much on other factors as on the primary function of serving as a barrier. Cost, psychological effect, fire resistance, architectural harmony, and ornamental considerations are but a few of the factors that must be taken into account.

Doors may be classified as ordinary or special purpose. Ordinary doors are those used to protect openings up to about 12 ft high or wide. Often, such doors are available in stock or standard sizes. Larger doors may be considered special purpose, because they are generally custom designed and built and require specially designed framing.

In either case, a door system consists of a door proper, hardware for control of door movement (Arts. 11.65 to 11.67), a door frame around the wall opening to support the door and trim the opening, and structural framing, such as a lintel, to support the wall and other building components directly over the opening.

11.52 TRAFFIC FLOW AND SAFETY

Openings in walls and partitions must be sized for their primary function of providing entry and exit to or from a building or its interior spaces, and doors must be sized and capable of operating so as to prevent or permit such passage, as required by the occupants of the building. In addition, openings must be adequately sized to serve as an exit under emergency conditions. (See Art. 3.5.10.) In all cases, traffic must be able to flow smoothly through the openings.

To serve these needs, doors must be properly selected for the use to which they are to be put, and properly arranged for maximum efficiency. In addition, they must be equipped with suitable hardware for the application. (See also Arts. 11.65 to 11.67 and Art. 11.55.)

Safety. Exit doors and doors leading to exit passageways should be so designed and arranged as to be clearly recognizable as such and to be readily accessible at all times. A door from a room to an exit or to an exit passageway should be the swinging type, installed to swing in the direction of travel to the exit.

Code Limitations on Door Sizes. To ensure smooth, safe traffic flow, building codes generally place maximum and minimum limits on door sizes. Typical restrictions are as follows:

No single leaf in an exit door should be less than 28 in wide or more than 48 in wide. Minimum nominal width of opening should be at least:

36 in for single corridor or exit doors

32 in for each of a pair of corridor or exit doors with central mullion

48 in for a pair of doors with no central mullion

32 in for doors to all occupiable and habitable rooms

44 in for doors to rooms used by bedridden patients and single doors used by patients in such buildings as hospitals, sanitariums, and nursing homes

32 in for toilet-room doors

Jambs, stops, and door thickness when the door is open should not restrict the required width of opening by more than 3 in for each 22 in of width.

Nominal opening height for exit and corridor doors should be at least 6 ft 8 in. Jambs, stops, sills, and closures should not reduce the clear opening to less than 6 ft 6 in.

For a specific type of occupancy, the number of exit doors required in each story of a multistory building and the minimum width permitted for each door can be determined from the maximum capacity listed in Art. 3.5.10. The maximum sizes of openings permitted in fire barriers are given in Table 11.19, p. 11.119.

Safety at Entrances. Because of the heavy flow of traffic at building entrances, safety provisions at entrance doors are an important design consideration. Account must be taken of the location of such doors in the building faces, flow of outdoor traffic, and type and volume of traffic generated by the building. Following are some design recommendations:

Arc of a door swing should exceed 90°.

An entrance should always be set back from the building face.

Hinge jambs of swinging doors should be located at least 6 in from a wall perpendicular to the building face.

If hinge jambs for two doors have to be placed close together, there should be enough distance between them to permit the doors to swing through an arc of 110°.

If several doors swinging in the same direction are placed close together in the same plane, they should be separated by center lights and should also have sidelights, to enable the doors to swing through 110° arcs.

If doors hung on center pivots are arranged in pairs, they should be hinged at the side jambs and not at the central mullion.

The floor on both sides of an exit door should be substantially level for a distance on each side equal to at least the width of the widest single leaf of the door. If, however, the exit discharges to the outside, the level outside the door may be one step lower than inside, but not more than 7½% in lower.

11.53 STRUCTURAL REQUIREMENTS FOR OPENINGS AND DOORS

A wall or partition above a door or window opening must be adequately supported by a structural member. In design of such a member, stiffness as well as strength must be taken into account. Excessive deflection could interfere with door operation.

It is common practice to install a frame along the perimeter of a door opening, to support the door. Anchored to the wall, the frame usually also serves as trim around the opening. In design of door framing, wind loads are generally more critical than dead loads imposed by the wall or partition above. Wind load should be taken as at least 15 lb/ft^2. Under this loading, maximum deflection of framing members should not exceed ¾ in or $1/175$ the clear span. The design should take into account the fact that wind forces acting outward may be larger than those acting inward. Door framing should generally be made independent of other framing.

11.54 ORDINARY DOORS

Ordinary doors may be classified as exterior or interior doors. Exterior doors are those that are installed in an opening in a wall that separates an interior space from outdoors. Serving as an entrance or an exit door, or both, these doors must be capable of excluding weather but usually need not be fire rated. Interior doors are those installed in an opening in a wall or partition between two interior spaces. Such doors are not required to exclude weather but may be required to bar passage of fire and smoke.

11.54.1 Exterior Doors

Entrance and exit doors in exterior walls should be suitably selected and located for smooth traffic flow and safety. Choice of door movement, for example, should take into account in which direction persons are likely to turn immediately before or after they enter a doorway. Proper swing of door will not only smooth traffic flow but also reduce wear and tear on the doors by decreasing impact loading on the hardware from persons who lean on it to change directions.

Also, selection of entrance doors should take not only esthetics into account but also traffic volume. The heavier traffic volume will be, the more rugged the doors should be to withstand wear.

Water Exclusion at Exterior Doors. Exterior doors are subjected to all the effects of natural forces, as are walls and windows, including solar heat, rain, and wind. For ordinary installations, closed doors cannot be expected to completely exclude water or stop air movement under all conditions. One important reason for this is that clearances must be provided around each door. These are necessary to permit easy operation and thermal expansion and contraction of doors.

Exterior doors, however, can be made less vulnerable to water penetration by setting them back from the building face, or by providing overhead protection, such as a canopy, marquee, or balcony. These measures also will help reduce collection of snow and ice at door thresholds. In addition, provision of an entrance vestibule is desirable, because it can serve as a weather barrier. Also, weatherstripping around doors assists in preventing passage of water and air past closed doors.

At the bottom of a door opening for an exterior door is a sill (Fig. 11.60), which forms a division between the finished floor on the inside and the outside construction. The sill generally also serves as a step, for the door opening usually is raised above exterior grade to prevent rain from entering. The top of the sill is sloped to drain water away from the interior. Also, it may have a raised section in the plane of the door or slightly to the rear, so that water dripping from the door will fall on the slope. The raised section maybe integral with the sill or a separate threshold. In either case, the rear portion covers the joint between sill and floor. In addition, all joints should be sealed.

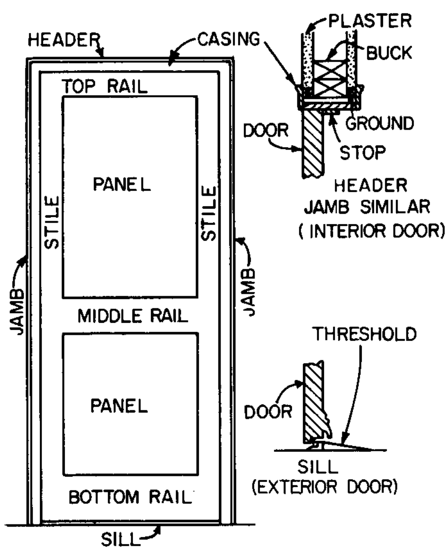


FIGURE 11.60 Typical paneled wood door.

Control of Air Movements at Entrances. In design of entrances to buildings, consideration should be given to the effects in those areas of outdoor winds. These may impose pressures or suctions on exterior doors. As a result, doors may be held partly open or may be violently opened beyond their design limits and severely damaged. To avoid such occurrences, doors should be set back from the building face or provided with a wind shield. Also, design of the building facade should be checked, if necessary by wind-tunnel tests, to ensure that it will not create objectionable air movements.

Also, in tall buildings, there is likely to be a difference in air pressure between the inside and outside at entrances. This pressure results from air movements through stairways and shafts. When the building is heated in cold weather, warm air rises in the vertical passageways. When the building is cooled in warm weather, cool air flows downward through these passageways. The resulting pressure differential varies with building height and difference between indoor and outdoor temperatures. In many cases, this stack effect causes large airflows through entrance doors, significantly increases heating and cooling loads, and may make entrance-door operation difficult.

A commonly used means of reducing such loads is provision of an entrance vestibule with one set of doors leading outdoors and another set leading to the inside. In some cases, however, traffic flow is so great that at least one door of both sets of doors may be partly open simultaneously, permitting air to flow through the vestibule between the inside and outside of the building. Thus, the effectiveness of the vestibule is decreased. The loss of effectiveness may be reduced, however, by venting the vestibule to outdoors and providing compensating heating or cooling.

Another means of reducing air movements due to stack effect is installation of revolving doors (Art. 11.56). While in continuous contact with its enclosure, a revolving door permits entry and exit without extra force to offset the differential pressure between indoors and outdoors. (Building codes, however, require some swinging doors in conjunction with revolving doors.)

Where stack effects make operation of swinging doors difficult, operation may be made easier by hanging the doors on balanced pivots or equipping the doors with automatic operators. In some cases, it may be advantageous to replace the doors with automatic, horizontally sliding doors.

Automatic Entrances. Power-operated doors may be used to speed traffic flow at entrances to buildings with heavy traffic volume, such as retail stores, hospitals, and public buildings. Not only are such doors convenient for persons carrying packages or pushing carts, but they also are advantageous for physically handicapped persons. The doors are activated to open fully by persons approaching when their weight is applied to a floor mat or when they are detected by microwave or optical-electronic sensors. The doors are kept open until the persons are safely past, even if traffic stops or moves slowly. (ANSI A156.10, ‘‘Power-Operated Pedestrian Doors,’’ American National Standards Institute.)

As an alternative to solid doors, an automatic entrance can be formed with an air curtain. At such an entrance, air is blown upward past a floor grate to the top of the door opening, to keep outdoor air from entering the building interior and prevent loss of interior air. Yet, human traffic can readily penetrate the curtain.

11.54.2 Door Materials

Wood is used in several forms for doors. When appearance is unimportant and a low-cost door is required, it may be made of boards nailed together. When the boards are vertical and held together with a few horizontal boards, the door is called a batten door. Better-grade doors are made with panels set in a frame or with flush construction.

Paneled doors consist of solid wood or plywood panels held in place by verticals called **stiles** and horizontals known as **rails** (Fig. 11.60). The joints between panels and supporting members permit expansion and contraction of the wood with atmospheric changes. If the rails and stiles are made of a single piece of wood, the paneled door is called solid. When hardwood or better-quality woods are used, the doors generally are veneered; rails and stiles are made with cores of softwood sandwiched between the desired veneer.

Tempered glass or plastic may be used for panels. In exterior doors, the lights should be installed to prevent penetration of water, especially in veneered doors. One way is to insert under the glass a piece of molding that extends through the door and is turned down over the outside face of the door to form a drip. Another way is to place a sheet-metal flashing under the removable outer molding that holds the glass. The flashing is turned up behind the inside face of the glass and down over the exterior of the door, with only a very narrow strip of the metal exposed.

Flush doors also may be solid or veneered. The veneered type has a core of softwood, while the flat faces may be hardwood veneers. When two piles are used for a face, they are set with grain perpendicular to each other.

Flush doors, in addition, may be of the hollow-core type. In that case, the surfaces are made of plywood and the core is a supporting grid. Edges of the core are solid wood boards.

Metal doors generally are constructed in one of three ways: cast as a single unit or separate frame and panel pieces; metal frame covered with sheet metal; and sheet metal over a wood or other type of insulating core. (See ''ANSI Standard Nomenclature for Steel Doors and Steel Door Frames,'' A123.1, and ''Recommended Standard Details, Steel Doors and Frames,'' Steel Door Institute, 30200 Detroit Rd., Cleveland, OH 44145-1967.)

Cast-metal doors are relatively high-priced. They are used principally for monumental structures.

Hollow metal doors may be of flush or panel design, with steel faces having a thickness of at least 20 ga. Flush doors incorporate steel stiffeners; or an insulation core, such as hydrous calcium silicate, polyurethane foam, or polystyrene foam; or a honeycomb core as a lightweight support for the faces (Figs. 11.61 and 11.62). Voids between stiffeners may be filled with lightweight insulation. Panel doors may be of stile-and-rail or stile-and-panel construction with insulated panels. Also, a light-duty, 24-ga, steel-faced door with an insulated core is available.

Metal-clad (Kalamein) doors are of the swinging type only. They may be of flush or panel design, with metal-covered wood cores for stiles and rails and insulated panels covered with steel 24 ga or lighter.

Other Materials. Doors may be made wholly or partly transparent or translucent. Lights may be made of tempered glass or plastic. Doors made completely of glass are pivoted at top and bottom because the weight makes it difficult to support them with hinges or butts.

Sliding doors of the collapsible accordian type generally consist of wood slats or a light steel frame covered with textile. Plastic coverings frequently are used.

11.54.3 Swinging Doors

These are doors hinged near one edge to rotate about a vertical axis. Swinging doors are hung on butts or hinges (Art. 11.65). The part of a doorway to which a

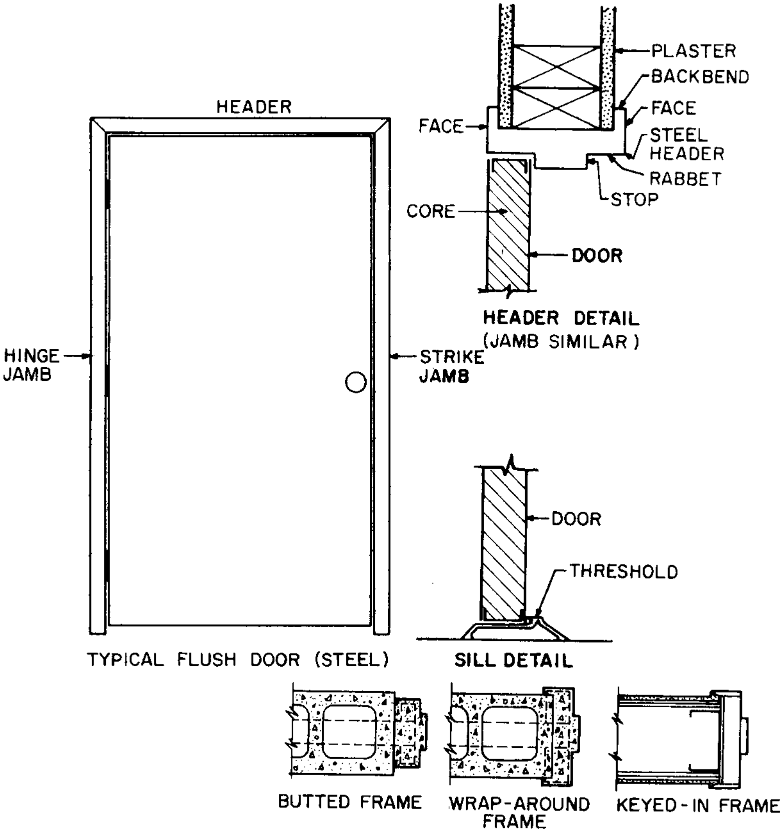


FIGURE 11.61 Typical steel flush door.

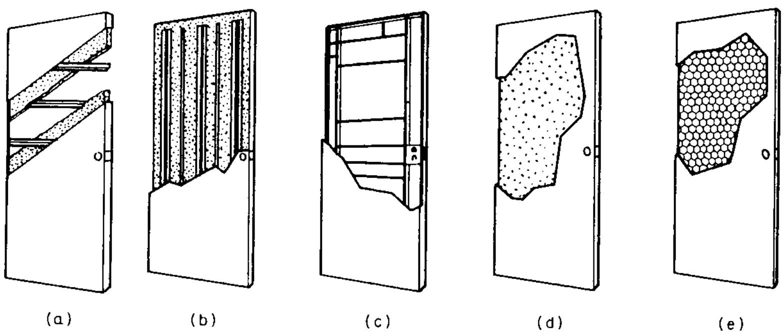


FIGURE 11.62 Some types of bracing used for hollow steel doors: (*a*) horizontal stiffeners; (*b*) vertical stiffeners; (*c*) grid of horizontal and vertical stiffeners; (*d*) rigid insulation core; (*e*) honeycomb core.

door is hinged and against which it closes is known as the door frame. It consists of two verticals, commonly called jambs, and a horizontal member, known as the header (Figs. 11.60 and 11.61). **Single-acting doors** can swing 90° or more in only one direction; **double-acting doors** can swing 90° or more in each of two directions.

To stop drafts and passage of light, the header and jambs have a stop, or projection, extending the full height and width, against which the door closes. The projection may be integral with the frame, or formed by attaching a stop on the surface of the frame, or inset slightly.

Door frames for swinging wood doors generally are fastened to rough construction members known as rough bucks, and the joints between the frame and the wall are covered with casings, or trim. For steel door frames, the trim is often integral with the frame, which is attached to the wall with anchors. (''Recommended Standard Details, Steel Doors and Frames,'' SDI 111, Steel Door Institute, 30200 Detroit Rd., Cleveland, OH 44145-1967.)

Swinging doors are constructed in a variety of ways: usually flush (Fig. 11.61); stile and rail, with one or more recessed panels (Fig. 11.60); or stile and panel, with a wide center panel between hinge and lock stiles. Flush doors may be solid or hollow. Hollow doors usually are braced internally. Some of the types of bracing used for steel doors are shown in Fig. 11.62. Those with steel stiffeners (Fig. 11.62*a* to *c*) normally are thermally or acoustically insulated with a bat-type material or sprayed insulation. The core types (Fig. 11.62*d* and *e*) may have heavy-paper honeycomb, rigid foamed insulation, solid structural mineral blocking, or other bracing laminated to the door facings. (See also Art. 11.54.2.)

Wood or steel swinging doors and frames for them are available for ordinary applications in several stock sizes. Standard door thicknesses for these are 1⅜ in and 1¾ in. The doors are fabricated to fit in openings with heights of 6 ft 8 in, 7 ft, or 7 ft 2 in. Standard opening widths for single doors are 24, 28, 30, 32, and 36 in. Single 1¾-in stock doors are also available for opening widths of 40, 42, 44, and 48 in and heights of 8 ft. Standard opening widths for pairs of doors are twice as large as for single doors. (See SDI 100, ''Recommended Specifications for Standard Steel Doors and Frames,'' Steel Door Institute, 30200 Detroit Rd., Cleveland, OH 44145-1967.)

Nonstandard sizes are obtainable on special order, but certain precautions should be observed: Size and number of butts or hinges and offset pivots should be suitable for the door size. For rail-and-stile doors, check with the manufacturer to ensure that face areas will not be excessive for the stile width. Large doors should not be used where they will be exposed to strong winds. To prevent spreading of stiles of tall doors, push bars or other intermediate bar members should be attached to both stiles of doors over 8 ft high.

Package entrance doors are available from several manufacturers. The package includes a single door or pair of doors, door frame, and all hardware. Such doors offer the advantages of integrated design, assumption by the manufacturer of responsibility for satisfactory performance, usually quick delivery, and often cost savings.

Recommended mounting heights for hardware for swinging doors are shown in Fig. 11.63. For specific installations, refer to hardware templates supplied by door manufacturers.

Hand of Doors. The direction of swing, or hand, of each door must be known and specified in ordering such hardware as latches, locks, closers, and panic hardware, because the hand determines the type of operation required of them. The hand is determined with respect to the outside or key, or locking, side, following the conventions illustrated in Fig. 11.64.

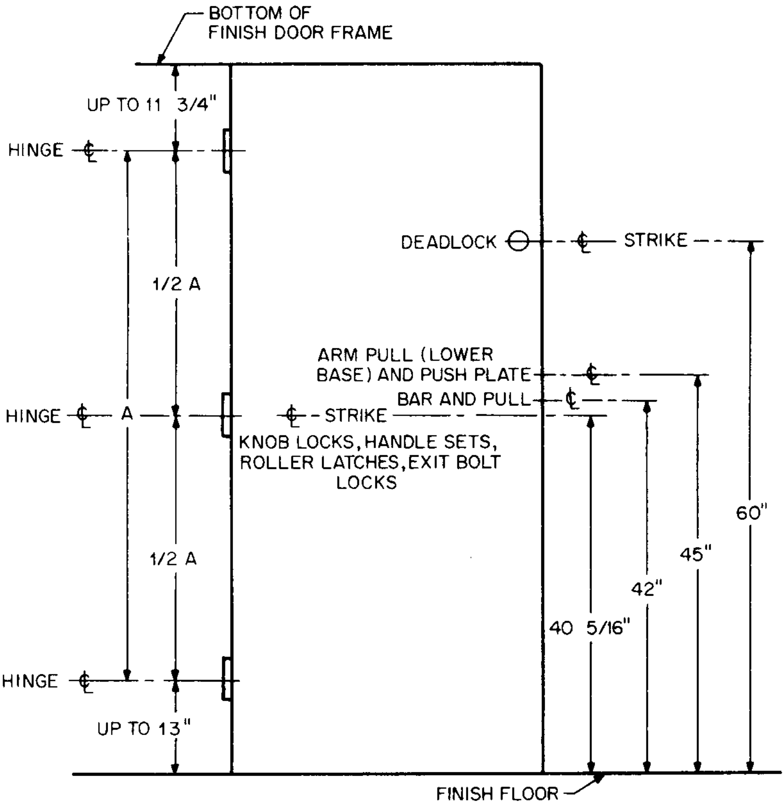


FIGURE 11.63 Recommended mounting heights for hardware for ordinary swinging doors.

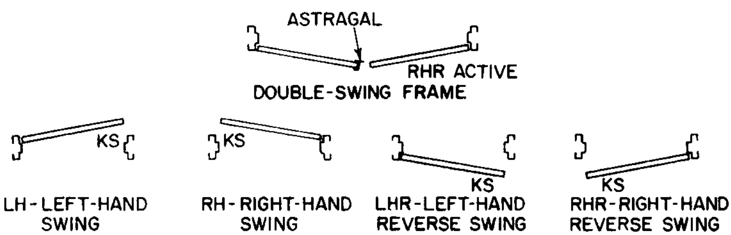


FIGURE 11.64 Swing of doors. *KS* indicates key, or locking, side.

Weatherstripping. To weatherproof the joint between the bottom of an exterior door and the threshold, a weatherstrip in the form of a hooked length of metal often is attached to the underside of the door. When the door is closed, the weatherstrip locks into the threshold to seal out water. Other types of weatherstripping, including plastic gaskets, generally are used for steel doors and may be installed on header and jambs ("Recommended Weatherstripping for Standard Steel Doors and Frames," SDI 111-E, Steel Door Institute, 30200 Detroit Rd., Cleveland, OH 44145-1967).

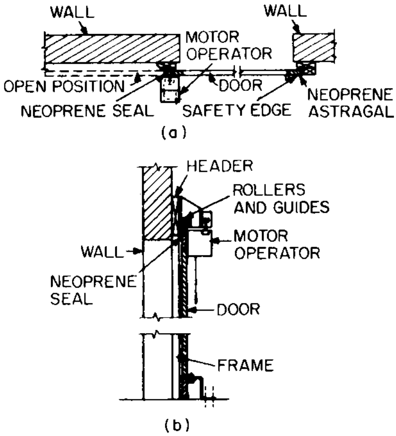


FIGURE 11.65 Horizontally sliding door: (*a*) horizontal section through the opening; (*b*) vertical section through the opening.

11.54.4 Ordinary Horizontally Sliding Doors

This type of door may roll on a track in the floor and have only guides at the top, or the track and rollers may be at the top and guides at the bottom (Fig. 11.65). Some doors fold or collapse like an accordion, to occupy less space when open. A pocket must always be provided in the walls on either or both sides, to receive rigid-type doors; with the folding or accordion types, a pocket is optional.

Horizontally sliding doors are advantageous for unusually wide openings, and where clearances do not permit use of swinging doors. Operation of sliding doors is not hindered by windy conditions or differences in air pressure between indoors and outdoors. Sliding doors, however, are not accepted as a means of egress.

11.54.5 Ordinary Vertically Sliding Doors

This type of door may rise straight up (Fig. 11.66), may rise up and swing in, or may pivot outward to form a canopy. Sometimes, the door may be in two sections,

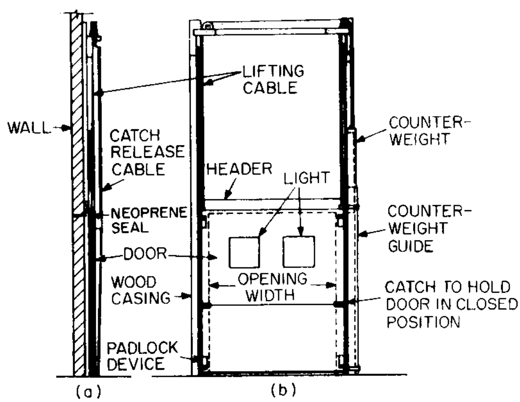


FIGURE 11.66 Vertically sliding door: (*a*) vertical section through the opening; (*b*) elevation of the door.

one rising up, the other dropping down. Generally, all types are counterweighted for ease of operation.

In design of structures to receive sliding doors, the clearance between the top of the doors and the ceilings or structural members above should be checked—especially the clearance required for vertically sliding doors in the open position. Also, the deflection of the construction above the door opening should be investigated to be certain that it will not cause the door to jam.

To keep out the weather, the upper part of a sliding door either is recessed into the wall above, or the top part of the door extends slightly beyond the inside face of the wall on the inside. Similarly, door sides are recessed into the walls or lap them and are held firmly against the inside. Also, the finished floor is raised a little above outside grade. Very large sliding doors require special study (Arts. 11.57 and 11.58).

11.55 FIRE AND SMOKESTOP DOORS

Building codes require fire-resistant doors in critical locations to prevent passage of fire. Such doors are required to have a specific minimum fire-resistance rating, and are usually referred to as fire doors. The codes also may specify that doors in other critical locations be capable of limiting passage of smoke. Such doors, known as smokestop doors, should have a fire-resistance rating of at least 20 min and should be tight fitting.

Fire protection of an opening in a wall or partition depends on the door frame and hardware, as well as on the door. All these components must be "labeled" or "listed" as suitable for the specific application. (See NFPA 80, "Fire Doors and Windows," National Fire Protection Association, 1 Batterymarch Park, Quincy, MA 02269.)

All fire doors must be self-closing or should close automatically when a fire occurs. In addition, they should be self-latching, so that they remain closed. Push-pull hardware should not be used. Exit doors for places of assembly for more than 100 persons usually must be equipped with fire-exit hardware capable of releasing the door latch when pressure of 15 lb, or less, is applied to the device in the direction of exit. Combustible materials, such as flammable carpeting, should not be permitted to pass under a fire door.

Fire-door assemblies are rated, in hours, according to ability to withstand a standard fire test, such as that specified in ASTM Standard E152. They may be identified as products qualified by tests by a UL label, provided by Underwriters Laboratories, Inc.; an FM symbol of approval, authorized by Factory Mutual Research Corp.; or by a self-certified label, provided by the manufacturer (not accepted by National Fire Protection Association and some code officials).

Openings in walls and partitions that are required to have a minimum fire-resistance rating must have protection with a corresponding fire-resistance rating. Typical requirements are listed in Table 11.18.

This table also gives typical requirements for fire resistance of exit doors, doors to stairs and exit passageways, corridor doors, and smokestop doors.

In addition, some building codes also limit the size of openings in fire barriers. Typical maximum areas, maximum dimensions, and maximum percent of wall length occupied by openings are given in Table 11.19.

TABLE 11.18 Typical Fire Ratings Required for Doors

Door use	Rating, hr*
Doors in 3- or 4-hr fire barriers	3†
Doors in 2- or 1½-hr fire barriers	1½
Doors in 1-hr fire barriers	¾
Doors in exterior walls:	
Subject to severe fire exposure from outside the building	¾
Subject to moderate or light fire exposure from outside the building	⅓
Doors to stairs and exit passageways	1½
Doors in 1-hr corridors	⅓
Other corridor doors	0‡
Smokestop doors	⅓§

* Self-closing, swinging doors. Normally kept closed.
† A door should he installed on each side of the wall.
‡ Should be noncombustible or 1¾-in solid wood-core doors. Some codes do not require self-closing for doors in hospitals, sanitariums, nursing homes, and similar occupancies.
§ May be metal, metal covered, or 1¾-in solid wood-core doors (1⅜ in in buildings less than three stories high), with 1296-in^2 or larger, clear, wire-glass panels in each door.

TABLE 11.19 Maximum Sizes of Openings in Fire Barriers

Protection of adjoining areas	Max area, ft^2	Max dimension, ft
Unsprinklered	120*	12†
Sprinklers on both sides	150*	15*
Building fully sprinklered	Unlimited*	Unlimited*

* But not more than 25% of the wall length or 54 ft^2 per door if the fire barrier serves as a horizontal exit.
† But not more than 25% of the wall length.
SOURCE: Based on National Building Code, American Insurance Association, New York.

Smokestop doors should be of the construction indicated in the footnote to Table 11.18.

They should close openings completely, with only the amount of clearance necessary for proper operation.

[''Standard for Fire Doors and Windows,'' NFPA No.80; Life Safety Code, NFPA No.101; ''Fire Tests of Door Assemblies,'' NFPA No.252, National Fire Protection Association, 1 Batterymarch Park, Quincy, MA 02269.

''Fire Tests of Door Assemblies,'' Standard UL 10(b); ''Fire Door Frames,'' Standard UL 63; ''Building Materials List'' (annual, with bimonthly supplements), Underwriters Laboratories, Inc., 333 Pfingsten Road, Northbrook, IL 60062.

''Factory Mutual Approval Guide,'' Factory Mutual Research, 1151 Boston-Providence Turnpike, Norwood, MA 02062.

''Hardware for Labeled Fire Doors,'' Door and Hardware Institute, 14150 Newbrook Dr., Suite 200, Chantilly, VA 20151.]

11.56 REVOLVING DOORS

This type of door is generally selected for entranceways carrying a continuous flow of traffic without very high peaks. They offer the advantage of keeping interchange of inside and outside air to a relatively small amount compared with other types of doors. They usually are used in combination with swinging doors because of the inability to handle large groups of people in a short period of time.

Revolving doors consist of four leaves that rotate about a vertical axis inside a cylindrical enclosure. Diameter of the enclosure generally is at least 6 ft 6 in, and the opening to the enclosure usually is between 4 and 5 ft.

Building codes prohibit use of revolving doors for some types of occupancies; for example, for theaters, churches, and stadiums, because of the limited traffic flow in emergencies. Where they are permitted as exits, revolving doors have limitations imposed on them by building codes. The National Fire Protection Association ''Life Safety Code'' allows only one-half unit of exit width per revolving door in computation of exit capacity, but some codes permit one unit per door. Also, revolving doors may not provide more than 50% of the required exit capacity at any location. The remaining capacity must be supplied by swinging doors within 20 ft of the revolving doors. Rotation speed must be controlled so as not to exceed 15 rpm. Each wing should be provided with at least one such bar and should be glazed with tempered glass at least $\frac{7}{32}$ in thick. Some codes also require the doors to be collapsible.

11.57 LARGE HORIZONTALLY SLIDING DOORS

Door leaves in the horizontally sliding type are equipped with bearing-type bottom wheels and ride rails in the floor while top rollers operate in overhead guides. Two variations are in common use—telescoping and folding.

Telescoping doors (Fig. 11.67) are frequently used for airplane hangars. Normally composed of several leaves, they may be center parting or open to one side only, as illustrated in Fig. 11.67. Open doors are stacked in pockets at ends of the opening. They are built of wood, steel, or a combination of the two.

Telescoping doors are frequently operated by motors located in the end pockets. The motors drive an endless chain attached to tops of closing leaves. Remaining leaves are moved by a series of interconnecting cables attached to the powered leaf and arranged so that all leaves arrive at open or closed position simultaneously. Motor size ranges from 1 to 10 hp, travel speed of leaves from 45 to 160 ft/mm.

The weight of the leaves must be taken by footings below the rails. Provision also must be made to take care of wind loads transmitted to the top guide channels by the doors and to carry the weight of these channels.

Folding doors (Fig. 11.68) are commonly used for subdividing gymnasiums, auditoriums, and cafeterias and for hangars with very wide openings. This type of door is made up of a series of leaves hinged together in pairs. Leaves fold outward, and when the door is shut, they are held by automatic folding stays. Motors that operate biparting doors usually are located in mullions adjacent to the center of the opening. The mullions are connected by cables to the ends of the opening, and when the door is to be opened, the mullions are drawn toward the ends, sweeping the leaves along. Travel speed may vary from 45 to 160 ft/mm.

Chief advantage of folding over telescoping types is that only two guide channels are required, regardless of width. Thus, less metal is required for guide channels

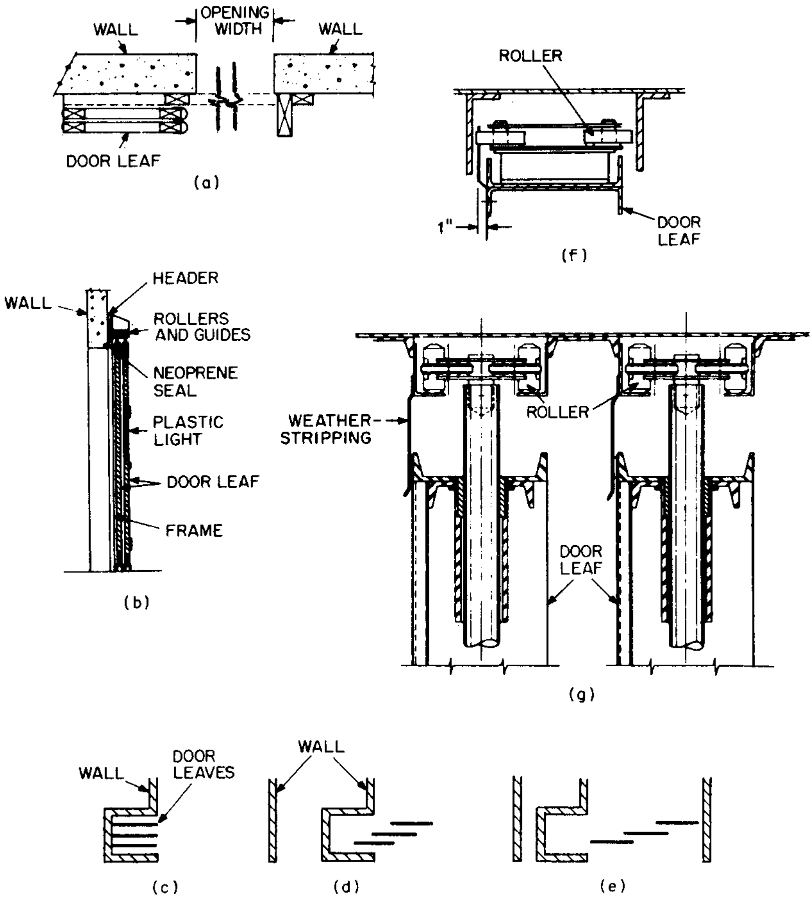


FIGURE 11.67 Horizontally sliding, telescoping door: (*a*) horizontal section through the opening; (*b*) vertical section through the opening; (*c*) door fully open; (*d*) door partly open (*e*) door closed; (*f*) and (*g*) alternative arrangements of top rollers.

and rails, and less material for the supporting members above. Also, since wind loading is applied to leaves that are always partly in folded position, the triangular configuration gives the door considerable lateral stiffness. Hence, panel thickness may be less for folding than for telescoping doors, and a lighter load may be used for designing footings.

11.58 LARGE VERTICALLY SLIDING DOORS

When space is available above and below an opening into which door leaves can be moved, vertically sliding doors are advantageous. They may be operated manually or electrically. Leaves may travel at 45 to 60 ft/mm. About 1½ ft in excess of leaf height must be provided in the pockets into which the leaves slide. So the

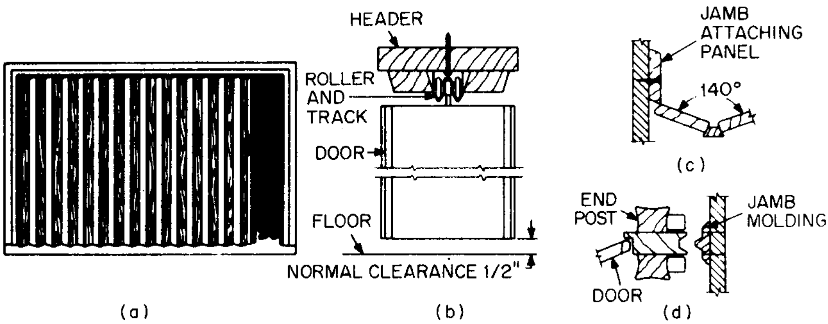


FIGURE 11.68 Wood folding door: (*a*) elevation of door nearly closed; (*b*) vertical section through the opening; (*c*) detail at the fixed end of the door; (*d*) detail at the strike jamb.

greater the number of leaves the less space needed for the pockets. Figure 11.69 illustrates a vertically sliding, telescoping door.

Vertically sliding doors normally are counterweighted. About 15 in of clear space back of the jamb line is needed for this purpose, but on the idler side only 4 in is required.

Vertical loads are transmitted to the door guides and then by column action to the footings. Lateral support is provided by the jamb and building walls.

11.59 LARGE SWINGING DOORS

When there is insufficient space around openings to accommodate sliding doors, swinging types may be used. Common applications have been for firehouses, where width-of-building clearance is essential, and railway entrances, where doors are interlocked with the signal system.

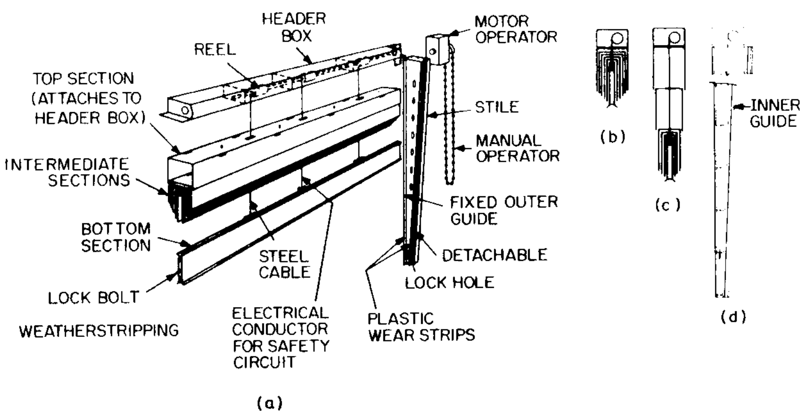


FIGURE 11.69 Vertically sliding, telescoping door: (*a*) door components; (*b*) door in open position; (*c*) door partly open; (*d*) door closed.

Common variations include single-swing (solid leaf with vertical hinge on one jamb), double-swing (hinges on both jambs), two-fold (hinge on one jamb and another between folds and leaves), and four-fold (hinges on both jambs and between each pair of folds).

The more folds, the less time required for opening and the smaller the radius needed for swing. Tighter swings make doors safer to open and allow material to be placed closer to supports.

11.60 HORIZONTALLY HINGED DOORS

Effective use of horizontally hinged swinging doors is made in such applications as craneway entrances to buildings. Widths exceeding 100 ft at or near the top of the building can be opened to depths of 4 to 18 ft. Frequently, horizontally sliding doors are employed below crane doors to increase the opening. If so, the top guides are contained in the bottom of the crane door; so the sliding door must be opened before the swinging door.

Top-hinged swinging doors are made of light materials, such as structural steel and exterior-grade plywood. The panel can be motor-operated to open in 1 min or less.

11.61 RADIATION-SHIELDING DOORS

These are used as a barrier against harmful radiation and atomic particles across openings for access to ‘‘hot’’ cells, and against similar radioactive-isotope handling arrangements and radiation chambers of high-energy x-ray machines or accelerators. Usually, they must protect not only personnel but also instruments even more sensitive to radiation than people.

Shielding doors usually are much thicker and heavier than ordinary doors, because density is an important factor in barring radiation. Generally, these special-purpose doors are made of steel plates, steel-sheathed lead, or concrete. To reduce thickness, concrete doors may be made of medium-heavy (240 lb/ft^2) or heavy (300 lb/ft^3) concrete, often made with iron-ore aggregate.

The heavy doors usually are operated hydraulically or by electric motor. Provision must be made, however, for manual operation if the mechanism should break down.

Common types of shielding doors include hinged, plug, and overlap. The hinged type is similar to a bank vault swinging door. The plug type, flush with the walls when closed, may roll on floor-mounted tracks or hang from rails. Overlap doors, surface-mounted, also may roll or hang from rails. In addition, vertical-lift doors sometimes are used.

BUILDERS’ HARDWARE

Hardware is a general term covering a wide variety of fastenings and devices for operating or controlling the operation of movable building components, such as doors and windows. By common usage, the term builders' hardware generally covers only finishing hardware, but some rough hardware is discussed in this section.

In point of cost, the finishing hardware for a building represents a relatively small part of the finished structure. But the judicious selection of suitable items of hardware for all the many conditions encountered in construction and use of any building can mean a great deal over the years in lessened installation and maintenance costs and general satisfaction.

To make the best selection of hardware requires some knowledge of the various alternates available and the operating features afforded by each type. In this section, pertinent points relating to selecting, ordering, and installing some of the more commonly used builders' hardware items are discussed briefly.

11.62 SELECTION OF HARDWARE

Finishing hardware consists of items that are made in attractive shapes and finishes and that are usually visible as an integral part of the completed building. Included are locks, hinges, door pulls, cabinet hardware, door closers and checks, door holders, exit devices and lock-operating trim, such as knobs and handles, escutcheon plates, strike plates, and knob rosettes. In addition, there are push plates, push bars, kick plates, door stops, and flush bolts.

Rough hardware includes utility items not usually finished for attractive appearance, such as fastenings and hangers of many types, shapes, and sizes-nails, screws, bolts, studs secured by electric welding guns, studs secured by powder-actuated cartridge guns, inserts, anchor bolts, straps, expansion bolts and screws, toggle bolts, sash balances, casement and special window hardware, sliding-door and folding-door supports, and fastenings for screens, storm sash, shades, venetian blinds, and awnings.

Template hardware is used for hardware items that are to be fastened to metal parts, such as jambs or doors. Template items are made to a close tolerance to agree exactly with drawings furnished by the manufacturer. The sizes, shapes, location, and size of holes in this type of hardware are made to conform so accurately to the standard drawings that the ultimate fit of all associated parts is assured. In the case of hinges or butts, holes that are template-drilled usually form a crescent-shaped pattern (Fig. 11.73).

Hardware for stock may be nontemplate; however, certain lines are all template-made, whether for stock or for a specific order. Nontemplate items may vary somewhat and may not fit into a template cutout.

For use on wood or metal-covered doors, template drilling is not necessary; nontemplate hardware of the same type and finish can be used. Generally, there is no price difference between template and nontemplate items.

The operating characteristics of hardware items govern their selection, according to the particular requirements in each case. Then, the question of material, such as plastics, brass, bronze, aluminum, or steel, can be settled, as well as the finish desired. Selection of material and finish depends on the architectural treatment and decorative scheme.

Wrought, forged, and stamped parts are available for different items. Finishes include polished, satin, and oxidized. When solid metal is desired rather than a surface finish that is plated on metal, the order should definitely so specify.

National standards defining characteristics, sizes, dimensions, and spacings of holes, materials, and finishes for many items can assist greatly in identification and proper fit of hardware items to the parts on which they will be mounted.

An important point to bear in mind in connection with selection of hardware for a new building is that, in many instances, it is one of the earliest decisions that should be made, particularly when doors and windows are to be of metal. This is true despite the fact that the finishing hardware may not actually be applied until near the end of the construction period.

11.63 EFFECTS OF CODES AND REGULATIONS ON HARDWARE

Building codes, NFPA 80, ''Standard for Fire Doors and Windows,'' and the ''Life Safety Code'' promulgated by the National Fire Protection Association, 1 Batterymarch Park, Quincy, MA 02269, contain many regulations directly affecting the use of builders' hardware. Some of these regulations permit tradeoffs in fire protection. For example, one regulation permits reduction or elimination of compartmentation of large floor areas in exchange for fully sprinklering a building.

Some of the major considerations of such regulations are life safety, security, and handicapped people (see Sec. 3). Life-safety requirements deal primarily with provision of safe egress in emergencies; requirements for disabled people deal with ease of circulation and use of facilities in buildings, and security requirements aim at making both unauthorized ingress and egress difficult. These requirements make conflicting demands on hardware. For example, local security ordinances often conflict with applicable building-code rules and may contain a clause exempting doors within means of egress from security requirements. Such an exemption, however, weakens security, because most doors are within a means of egress. The difficulty of designing or selecting hardware is further exacerbated when provisions for the disabled are superimposed on building-code and security ordinances.

Efforts are being made to find compromise solutions to the conflicting regulations. In the meantime, design professionals should be especially careful to keep abreast of the latest edition of all codes, regulations, and legislation governing the areas where their buildings are being erected.

11.64 STANDARDS FOR FINISHING HARDWARE

Several American National Standards present performance requirements for builders' hardware. These standards are available from the American National Standards Institute, Inc. (ANSI), 11 W. 42nd St., New York, NY 10036. The Builders Hardware Manufacturers Association, Inc., 355 Lexington Avenue, 17th Floor, New York, NY 10017, is the sponsor of the A156 series and submits additional standards or revisions of existing standards to ANSI for approval on a regular basis. The latest edition of the following should be consulted:

ANSI A156.1. Butts and Hinges

ANSI A156.2. Locks and Lock Trim

ANSI A156.3. Exit Devices

ANSI A156.4. Door Controls (Closers)

ANSI A156.5. Auxiliary Locks and Associated Products

ANSI A156.6. Architectural Door Trim

ANSI A156.7. Template Hinge Dimensions

ANSI A156.8. Door Controls (Overhead Holders)

ANSI A156.9. Cabinet Hardware

ANSI A156.10. Power-Operated Pedestrian Doors

ANSI A156.11. Cabinet Locks

ANSI/ASTM F 476. Standard Test Methods for Security of Swinging Door Assemblies

ANSI/ASTM F 571. Standard Practice for Installation of Exit Devices in Security Areas

In addition, there are a series of ANSI standards for the preparation of standard steel doors and frames to receive hardware—the Al 15 series, sponsored by the Door and Hardware Institute.

11.65 HINGES AND BUTTS

A hinge is a device permitting one part to turn on another. In builders' hardware, the two parts are metal plates known as leaves. They are joined together by a pin, which passes through the knuckle joints.

When the leaves are in the form of elongated straps, the device is usually called a hinge (Fig. 11.70 and 11.71). This type is suitable for mounting on the surface of a door.

When the device is to be mounted on the edge of a door, the length of the leaves must be shortened, because they cannot exceed the thickness of the door. The leaves thus retain only the portion near the pin, or butt end, of the hinge (Figs. 11.72 to

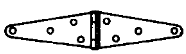


FIGURE 11.70 Heavy strap hinge.

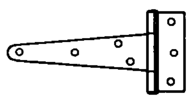


FIGURE 11.71 Heavy tee hinge.

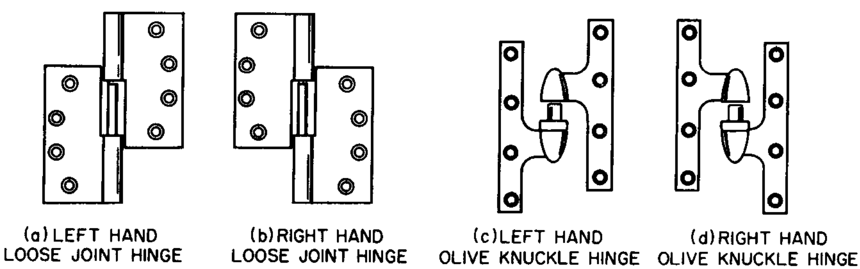


FIGURE 11.72 Special types of butt hinges that are handed. For hands of doors, see Fig. 11.79.

11.74). Thus, hinges applied to the edge of a door have come to be known as butts, or butt hinges.

Butts are mortised into the edge of the door. They are the type of hinge most commonly used in present-day buildings.

Sizes of butt hinges vary from about 2 to 6 in, and sometimes to 8 in. Length of hinge is usually made the same as the width; but they can be had in other widths. Sometimes, on account of projecting trim, special sizes, such as $4\frac{1}{2} \times 6$ in, are used.

For the larger, thicker, and heavier doors receiving high-frequency service, and for doors requiring silent operation, bearing butts (Fig. 11.73) or butts with Oilite bearings or other antifriction surfaces are generally used. It is also customary to use bearing butts wherever a door closer is specified.

Plain bearings (Fig. 11.74) are recommended for residential work. The lateral thrust of the pin should bear on hardened steel.

Unusual conditions may dictate the use of extra-heavy hinges or ball bearings where normal hinges would otherwise be used. One such case occurred in a group of college dormitories where many of the doors developed an out-of-plumb condition that prevented proper closing. It was discovered that the students had been using the doors as swings. Heavier hinges with stronger fastenings eliminated the trouble.

Two-bearing and four-bearing butt hinges should be selected, as dictated by weight of doors, frequency of use, and need for maintaining continued floating, silent operation. Because most types of butt hinges may be mounted on either right-hand or left-hand doors, it should be remembered that the number of bearing units actually supporting the thrust of the vertical load is only one-half the bearing units available. With a two-bearing butt, for example, only one of the bearings carries the vertical load, and with a four-bearing butt, only two carry the load. It should be noted, however, that some hinges (Fig. 11.72) are "handed" and must be specified for use on either a right-hand or left-hand door.

When butts are ordered for metal doors and jambs, "all machine screws" should be specified.

Location of Hinges. One rule for locating hinges for ordinary doors is to allow 5 in from rabbet of head jamb to top edge of top hinge and 10 in from finished floor line to bottom hinge. The third hinge should be spaced equidistant between top and bottom hinges. Another location for hinges is that of the standard steel frame and door (Fig. 11.63). The location varies a little among door manufacturers, but each is perfectly satisfactory from a functional standpoint.

Types of Hinge Pins. A very important element in the selection of hinges is the hinge pin. It may be either a loose pin or a fast pin.

Loose pins are generally used wherever practicable, because they simplify the hanging of doors. There are four basic pin types:

1. Ordinary loose pins

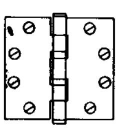


FIGURE 11.73 Bearing butt hinge.

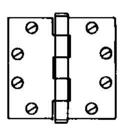


FIGURE 11.74 Plain bearing butt hinge.

2. Nonrising loose pins
3. Nonremovable loose pins
4. Fast (or tight) pins

The **ordinary loose pin** can be pulled out of the hinge barrel so that the leaves may be separated. Thus, the leaves may be installed on the door and jamb independently, with ease and ''mass-production'' economy. However, these pins have a tendency—with resulting difficulties—of working upward and out of the barrel of the hinge. This ''climbing'' is caused by the constant twisting of the pin due to opening and closing the door. Present-day manufacture of hinges has tended to drift away from this type of pin, which is now found only in hinges in the lowest price scale.

The **nonrising loose pin** (or self-retaining pin) has all the advantages of the ordinary loose pin; but at the same time, the disadvantage of ''climbing'' is eliminated. The method of accomplishing the nonrising features varies with the type of hinge and its manufacture.

The **nonremovable loose pin** is generally used in hinges on entrance doors, or doors of locked spaces, which open out and on which the barrel of the hinge is therefore on the outside of the door. If such a door were equipped with ordinary loose-pin hinges or nonrising loose-pin hinges, it would be possible to remove the pin from the barrel and lift the door out of the frame and in so doing overcome the security of the locking device on the door. In a nonremovable loose-pin hinge, however, a setscrew in the barrel fits into a groove in the pin, thereby preventing its removal. The setscrew is so placed in the barrel of the hinge that it becomes inaccessible when the door is closed. This type of hinge offers the advantage of the ordinary loose-pin type plus the feature of security on doors opening out. Some manufacturers achieve the same results using other means, such as a safety stud.

The **fast (or tight) pin** is permanently set in the barrel of the hinge at the time of manufacture. Such pins cannot be removed without damaging the hinge. They are regularly furnished in hospital- or asylum-type hinges. The fact that the leaves of this type of hinge cannot be separated, however, makes the installation more difficult and costly. However, the difficulty is not too great, because with this type of hinge it is only necessary to hold the door in position while the screws for the jamb leaf are being inserted.

Ends of pins are finished in different ways. Shapes include flat-bottom, ball, oval-head, modern, cone, and steeple. They can be chosen to conform with type of architecture and decoration. Flat-button tips are generally standard and are supplied unless otherwise specified.

How to Select Hinges. One hinge means one pair of leaves connected with a pin. The number of hinges required per door depends on the size and weight of the door, and sometimes on conditions of use. A general rule recommends two butt hinges on doors up to 60 in high; three hinges on doors 60 to 90 in high; and four hinges on doors from 90 to 120 in high.

Table 11.20 gives general recommendations covering the selection of suitable hinges. Figure 11.75 indicates how hinge width is determined when it is governed by clearance.

The proper operating clearance between the hinged edge of a door and the jamb is taken care of in the manufacture of the hinges by ''swaging'' or slightly bending the leaves of the hinge near the pin. Since the amount of such bending required is determined by whether one or both leaves are to be mortised or surface-mounted,

TABLE 11.20 Hinges for Doors

Door thickness, in	Door width, in	Minimum hinge height, in
⅞ or 1	Any	2½
1⅛	To 36	3
1⅜	To 36	3½
1⅜	Over 36	4
1¾	To 41	4½
1½	Over 41	4½ heavy
1¾ to 2¼	Any	5 heavy*

*To be used for heavy doors subject to high-frequency use or unusual stress.

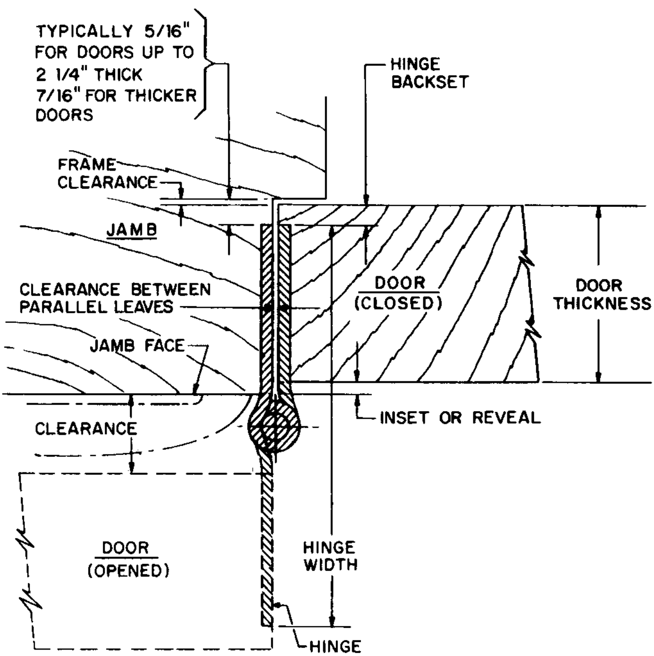


FIGURE 11.75 Determination of door hinge width for clearance. Width equals clearance plus inset (typically ½ in for doors up to 2¼ in thick and ⅜ in for thicker doors) plus twice the door thickness.

it is important in ordering hinges to specify the type of hinge needed to satisfy mounting conditions. If hinge leaves are to be mortised into both the edge of the door and the jamb, a full-mortise hinge is required (Fig. 11.76*a, c,* and *h*). If leaves are to be surface-applied to both the side of the door and the face of the jamb, a full-surface hinge is needed (Fig. 11.76*d*). If one leaf is to be surface-applied and the other mortised, the hinge is a half-surface hinge or a half-mortise hinge, depending on how the leaf for the door is to be applied—half-surface if applied to door surface (Fig. 11.76*b, e,* and *f*) and half-mortise if mortised in the door end (Fig. 11.76*g*).

Exterior doors should have butts of nonferrous metal. Although chromium plating does not tarnish, it is not considered to be satisfactory on steel for exterior use. Interior doors in rooms where dampness and steam may occur should be of nonferrous metal and should also have butts of nonferrous metal. Butts for other interior work may be of ferrous metal.

Ferrous-metal butts should be of hardened cold-rolled steel. Where doors and door frames are to be painted at the job site, butts should be supplied with a prime-coat finish. For doors and trim that are to be stained and varnished, butts are usually plated.

Other types of hinges include some with a spring that closes the door. They may be either single- or double-acting. The spring may be incorporated in a hinge mounted on the door in the usual manner, or it may be associated with a pivot at

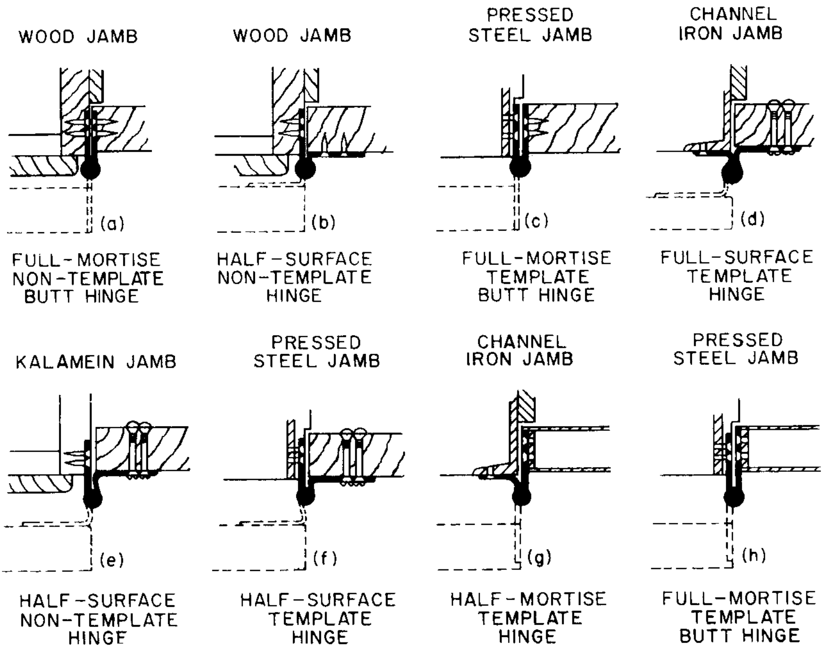


FIGURE 11.76 Hinge-mounting classification depends on where and how the hinge is fastened: (*a*), (*c*), and (*h*) full mortise; (*d*) full surface; (*b*), (*e*), and (*f*) half surface; and (*g*) half mortise.

the bottom of the door. In the latter case, the assembly may be of the type that is mortised into the bottom of the door, or it may be entirely below the floor.

11.66 DOOR-CLOSING DEVICES

These include overhead closers, either surface-mounted or concealed, and floor-type closers. These are some of the hardest-worked items in most buildings. To get the most satisfactory operation at low first cost and low maintenance cost, each closer should be carefully selected and installed to suit the particular requirements and conditions at each door.

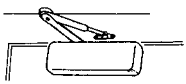


FIGURE 11.77 Door-closer spring closes the door, while a hydraulic mechanism (cylinder with piston) keeps the door from slamming.

Most of these devices are a combination of a spring—the closing element—and an oil-cushioned piston, which dampens the closing action, inside a cylinder (Fig. 11.77). The piston operates with a crank or a rack-and-pinion action. It displaces the fluid through ports in the cylinder wall, which are closed or open according to the position of the piston in the cylinder. Opening of the door energizes the spring, thus storing up closing power. Adjustment screws are provided to change the size of the ports, controlling flow of fluid. This management makes the closer extremely responsive to the conditions of service at each individual door and permits a quiet closure, which at the same time ensures positive latching of the door.

While the fluid type of closer is preferred, pneumatic closers are also used, particularly for light doors, like screen doors.

Overhead door closers are installed in different ways, on the hinge side of the door or on the top jamb on the stop side of the head frame or on a bracket secured to the door frame on the stop side. Various types of brackets are available for different conditions. Also, when it is desired to install a closer between two doors hung from the same frame, or on the inside of a door that opens out, an arrangement with a parallel arm makes this possible. Other types of closers may be mortised into the door or housed in the head above the door.

Closers may be semiconcealed or fully concealed. Total concealment greatly enhances appearance but certain features of operation are limited.

An exposed-type closer should be mounted on the hinge side or stop side of the door unless there is real need for a bracket or parallel-arm mounting.

Whereas the use of brackets reduces headroom and may become a hazard, a parallel-arm closer mounted on the door rides out with the door, leaving the opening entirely clear.

When surface-applied door closers are used, careful consideration should be given to the space required in order that doors may be opened at least 90° before the closers strike an adjacent wall or partition.

Semiconcealed door closers are recommended for hollow metal doors. These closers are mortised into the upper door rail.

Various hold-open features also are available in different closer combinations to meet specific requirements. Another available feature is delayed action. This allows plenty of time to push a loaded vehicle through the opening before the door closes and also permits disabled people time to maneuver through a door opening.

When floor-type checking and closing devices are used, floor conditions should be carefully determined in order that there will be sufficient unobstructed depth available for their installation.

To get maximum performance from any door closer, it must be of ample size to meet the conditions imposed on it. If abnormal conditions exist, such as drafts or severe traffic, a closer of larger than the normal capacity should be employed. Installing too small a closer is an invitation to trouble. Manufacturers' charts should be used to determine the proper sizes and types of closers to suit door sizes and job conditions.

It is very important that door closers be installed precisely as recommended by the manufacturer. Experience has shown that a large percentage of troubles with closers results from disregard of mounting instructions.

In response to various code requirements for room-to-corridor protection, closer manufacturers have produced products that provide automatic door closing but still allow flexibility. These units permit the door to be held open in many locations of hold-open and yet upon a signal from a smoke detector, the hold-open mechanism disengages and the closer causes the door to close. A similar type of unit incorporates a device allowing the door to swing free as though it were not equipped with a door closer. As with the multiple-point hold-open device just described, the 'swing-free' model, upon a signal from a smoke detector, cancels the closer nullifying device and the closer causes the door to close. These units are suitable in a variety of occupancies, particularly institutional.

Barrier-free provisions for disabled people dictate certain minimum opening resistance of doors. Depending upon the jurisdiction and location of doors, these forces range from a 5-lb force maximum to a 15-lb force maximum. There will be instances, because of the door size or air-pressure conditions, when the necessary closing force exerted by the closer to overcome these conditions will create opening resistance in excess of what is permitted. Power-operated doors or doors with a power assist specially made to solve this problem are recommended as a practical solution.

11.67 LOCKS, LATCHES, AND KEYS

The function of locks and latches is to hold doors in a closed position. Those known as rim locks or latches are fastened on the surface of the door. The ones that are mortised into the edge of the door are known as mortise locks (Fig. 11.78) or latches.

When the locking bolt is beveled, the device is usually referred to as a latch bolt; such a bolt automatically slides into position when the door is closed. A latch is usually operated by a knob or lever. Sometimes it may be opened with a key on the other side. Night latches came to be so called because they are generally used at night with other ordinary locks to give additional security.

Latches must take into account the **hand of the door** so the bevel will be right. A large percentage of latches are "reversible"—that is, they may be used on a right- or left-handed door (Art. 11.82). It is well, however, when ordering any lock to specify the hand of the door on which it is to be used.

If when you are standing outside the door the hinges are to your right and the door opens away from you, it is a right-hand, regular-bevel door; if the door opens toward you, it is a right-hand, reverse-bevel door. Similarly, if when you are outside

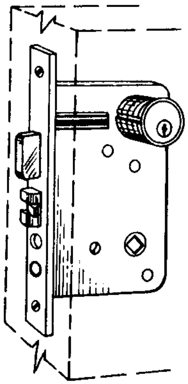


FIGURE 11.78 Mortise lock.

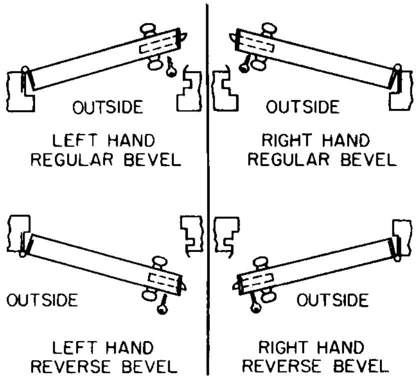


FIGURE 11.79 Conventional method of determining hand of doors and bevel.

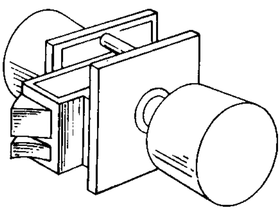


FIGURE 11.80 Unit lock.

the door, the hinges are to your left and the door swings away from you, it is a left-hand, regular-bevel door; if the door opens toward you, it is a left-hand, reverse-bevel door (Fig. 11.79).

When the locking bolt is rectangular in shape, it does not slide into position automatically when the door is closed; it must be projected or retracted by a thumb turn or key. This type of bolt is referred to as a dead bolt, and the lock as a dead lock. It may be worked with a key from one or both sides. Such a bolt is often used in conjunction with a latch. When the latch bolts and dead bolts are combined into one unit, it is known as a lock.

For keyed locks that do not have dead bolts, it is desirable that the latchbolt be equipped with a dead latch (Fig. 11.82). This is a small plunger or an auxiliary dead latch (Fig. 11.80) that is held depressed when the door is closed and "deadlocks" the latch bolt so that it cannot be retracted by a shim, card, or similar device inserted between latch and door frame.

Various combinations of latches, dead bolts, knobs and keys, and locking buttons are applied to all types and kinds of doors. The exact combination most suitable for any given door is determined by a careful analysis of the use to which the door is to be put.

A point to bear in mind is that a uniform size should be selected, if practicable, for a project, no matter what the individual functions of the different locks may be. This makes possible the use of standard-size cutouts or sinkages on each installation. When this is done, not only is the cost of installation reduced, but any changes that may be made in the drawings as the job progresses, or any changes that may have to be made later are simplified, and special hardware is avoided.

Unit locks (Fig. 11.80) are complete assemblies that eliminate most of the adjustments during installation that would otherwise be necessary. These locks have merely to be slipped into a standard notch cut into a wood door or formed in a metal door.

Bored-in locks are another type that can be installed by boring standard-size holes in wood doors or by having uniform circular holes formed in metal doors. These bored-in locks are often referred to as tubular-lock sets or cylindrical-lock sets depending on how the holes have to be bored to accommodate them.

Tubular locks have a tubular case extending horizontally at right angles to the edge of the door. This type of case permits a horizontal hole of small diameter to be bored into the door at right angles to the vertical edge of the door; another small hole is required at right angles to the first hole to take care of the latching mechanism. Most tubular locks now produced fit the standard bores in steel doors conforming to ANSI A115.2 and A115.3, just as do cylindrical locks.

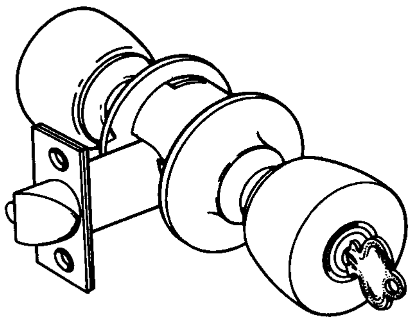


FIGURE 11.81 Cylindrical lock.

Cylindrical locks (Fig. 11.81), the other type of bored-in lock, have a cylindrical case requiring a relatively large-diameter hole in the door, bored perpendicular to the face of the door. This hole accommodates the main body of the lock. A hole of smaller diameter to take the latch bolt must be bored at right angles to the edge of the door.

When bored-in locks are used in hollow metal doors, a reinforcing unit is required in the door. This unit is generally supplied by the door manufacturer.

Exit devices are a special series of locks required by building codes and the National Fire Protection Association "Life Safety Code" on certain egress doors in public buildings. On the egress side, there is a horizontal bar running a minimum of one-half the width of the door. When pressed against, the bar releases the locking or latching mechanism, allowing the door to open. These devices are required to be labeled for safe egress by a nationally recognized independent testing laboratory. When used on fire doors, they must carry an additional label showing that the devices have also been investigated for fire. They then bear the name "fire exit hardware." These devices are available with various functions, including arrangements for having them locked from the outside and openable with a key. For all functions, however, they must be openable from the inside by merely depressing the cross bar.

Locking Bolts (Doors and Windows). Various types of bolts and rods are fastened to doors and windows for the purpose of securing them in closed position or to other doors and windows. Flush bolts and surface bolts, manual or automatic, are often used.

Top and bottom vertical bolts operated by a knob located at convenient height between them are known as **cremorne bolts.**

Keys. Locks are further classified according to the type of key required to retract the bolts. On all but the cheaper installations the principal type of key used is the cylinder key, which operates a pin-tumbler cylinder.

In the preceding locks, the locking cylinder, which is the assembly that supplies the security feature of the lock, is a cylindrical shell with rotatable barrel inside. The barrel has a longitudinal slot or keyway formed in it. The cross section of the keyway for every lock has a shape requiring a similarly designed key. Several holes (usually five or six) are bored through the shell and into the barrel at right angles to the axis of the barrel (Fig. 11.82). In each hole is placed a pair of pins—a driver pin in the shell end and a tumbler pin in the barrel end. Pins vary in length, and the combination of lengths differs from that of pins in other locks. A spring mounted in the shell end of each hole behind each driver pin forces these pins into the hole in the barrel, so that normally they are partly in the barrel portion of the hole and partly in the shell portion. Thus, the barrel is prevented from rotating in the shell to operate the bolt, and the door remains locked.

Keys have notches spaced along one side to correspond with the spacing and length of the pins. When a key is inserted in the slot in the barrel, each notch forces a tumbler pin back, against pressure from the spring. When the proper key is inserted in the slot, each notch pushes its corresponding pair of pins just far enough back into the shell to bring the junction point of that pair exactly at the circumference of the barrel. The barrel then can be rotated within the shell by merely turning the key.

Turning the key operates a cam attached to the end of the barrel. The cam withdraws the bolt from its locked position.

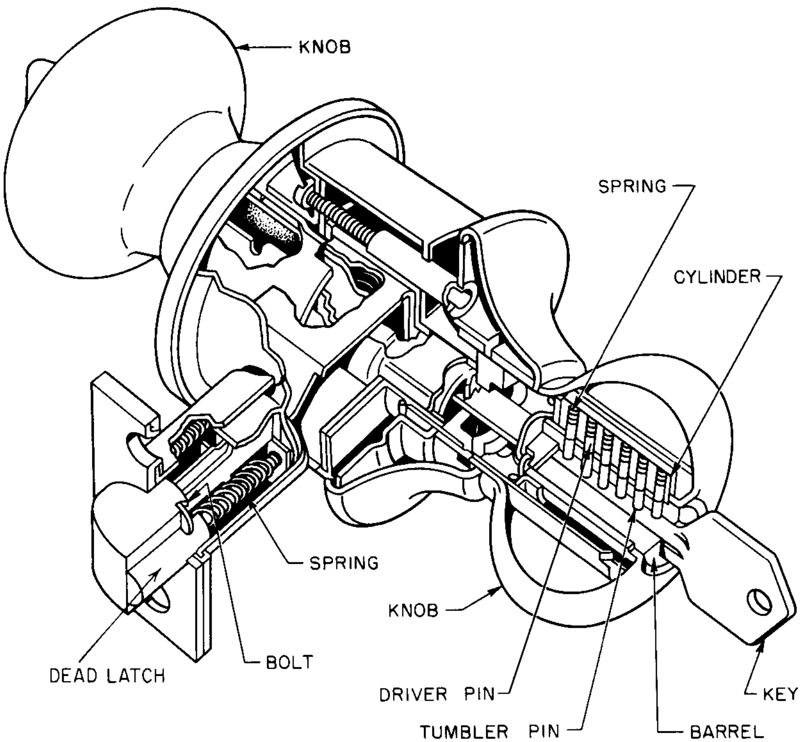


FIGURE 11.82 Mechanism of a cylindrical lock.

The security feature of the cylinder lock results from the fact that only one series of notches in the key will correspond to the respective lengths of the several individual pins. With as many as five or six tumblers, it is apparent that many combinations are available.

By using split pins, different keyways, and various sizes and arrangements of the pins, master keying and grand master keying of cylinder locks are made possible. Thus one master key may be made to open all the separate locks on each floor of a building, while a grand master key will open any lock in any floor of that building. In case there are a number of such buildings in a group, a great-grand master key can be made that will open any door on any building in the group.

Security Precautions. The security of a building from the standpoint of unauthorized entry and life safety is affected by the proper selection of hardware. Although locks are important for security, the total system, including the building design, must be considered. A lock installed in a door that is loosely fitted in the frame may be ineffective. Hollow metal and aluminum frames that are not reinforced and anchored properly are easily ''spread,'' and undetectable entry can result.

In high levels of master keying, more split pins must be used, and thus more ''shear lines'' are established. This makes the cylinder easier to pick. Hence, unnecessarily complicated master key systems should be avoided.

A good security lock is available with a dead bolt and a deadlocking latch bolt. Both bolts are retractable in one operation, merely by turning the inside knob. This satisfies requirements for security against unauthorized entry and life safety.

Hardware requirements for life safety and fire doors are covered by two National Fire Protection Association Standards, ''Life Safety Code'' and ''Fire Doors and Windows.'' Both are incorporated in many building codes.

11.68 WINDOW HARDWARE

Sash balances are commonly used with double-hung windows as counterweights instead of weights and pulleys. Some balances have tape or cable with clock-type springs, which coil and uncoil as the sash is raised and lowered. Another type employs torsion springs with one end fixed to the side jamb of the window and the other arranged to turn as the sash goes up or down. The turning device in this type of balance may be a slide working in a rotatable spiral tube, or it may be a slotted bushing attached to the free end of the spring and fitted around a vertical rod attached to the sash. This rod (Fig. 11.83) is a flat piece of metal twisted into a spiral shape. The up-and-down movement of the sash causes the slotted bushing to revolve on its spiral sliding rod, thus winding and unwinding the spring. Still another type utilizes a vertical tension spring of the ordinary coil variety. One end of the spring is fixed and the other is fastened to the sash; the spring stretches or compresses in a vertical direction as the sash is moved up or down.

Some sash balances combine weather-stripping with the balances. Others have friction devices to hold the sash in the desired position.

One patented type of sash balance known as the Unique sash balance incorporates a clever counterbalancing feature by making a change in the degree of pitch of the spiral rod from top to bottom, thereby controlling the increase and decrease of spring tension (Fig. 11.83). The pitch varies from 30 to 80°. As the spring turns, the changing spring tension is automatically compensated for by the variable pitch

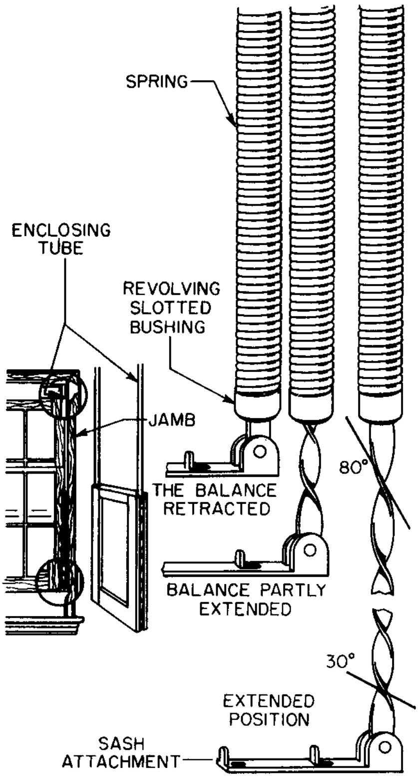


FIGURE 11.83 Constant-tension sash balance (*Unique Balance Co.*)

of the spiral rod sliding through the slotted bushing on the end of the spring. Thus the tension is equalized at every point of operation. This automatically prevents the sash from creeping or dropping of its own accord, without the necessity of introducing friction devices that interfere with easy operation.

Two sash balances are used per sash (one on each side) or four balances per double-hung window.

Other window hardware—locks, sash pulls, sash weights, and pulleys—are simple items, supplied as standard items with specific windows.

11.69 INSERTS, ANCHORS, AND HANGERS

Metal inserts of various types are cast into concrete floor slabs to serve as hangers or connectors for other parts of the structure that will be supported from the floor system. These inserts include electric conduit and junction boxes, supports for hung ceilings, slots for pipe hangers, fastenings for door closers to be set under the floor, and circular metal shapes for vertical pipe openings.

Metal anchors of various types are used in building construction. Each type is specifically shaped, according to the purpose served. These include anchors for securing stone facings to masonry walls, anchors for fastening marble slabs in place, column anchor bolts set in foundations, and anchor bolts for fastening sills to masonry.

Joist hangers are used for framing wood joists into girders and for framing headers into joists around stairwells and chimneys.

Various types of expansion bolts, screw anchors, and toggle bolts are available for securing fixtures, brackets, and equipment to solid material, such as masonry, brick, concrete, and stone. Anchors also can be had for fastening to hollow walls, such as plaster on metal lath in furred spaces and hollow tile. The best device to use depends on the requirements in each case.

For use with practically any materials, including soft and brittle ones, such as composition board, glass, and tile, fiber screw anchors with a hollow metal core find a universal application. These plugs with braided metal cores possess many advantages: They can be used with wood screws and with lag screws. The flexible construction permits the plug to conform to any irregularities. Because of this elastic compression, the fibers are compressed as the screw enters. Screws can be unscrewed and replaced. Shock and vibration have no effect on gripping power. The plugs come in about 40 sizes to fit anything from a No.6 screw to a ⅝-in lag screw. In practice, a hole is drilled first, the plug is driven into it, and then the screw is inserted, expanding the plug against the sides of the hole.

For some fastenings, one-piece drive bolts are hammered like a nail into prepared holes in masonry or concrete. Other types of expansion bolts have expansion shields or are calked into place. The expansion shield is expanded in the hole by a tapered sleeve forced against a cone-shaped nut by the tightening of a bolt threaded into the cone. These types are not recommended for soft or brittle materials.

For thin hollow walls, toggle bolts equipped with spring-actuated wings are used (Fig. 11.89). The wings will pass into the hole in folded position. After entering the hollow space, the wings open out, thereby obtaining a secure hold.

For fastening lightweight materials to nailable supports, stapling machines are extensively used. In one patented system, for example, staples secure acoustic tile to wood furring strips. In this system, invisible fastenings are obtained by using a full-spline suspension for the kerfed pieces of tile and a special stapling machine adjusted to function at the proper distance below the furring strips. The machine staples the splines (at the joints of the tiles) to the supporting strips, giving a speedy, economical, and secure fastening.

11.70 NAILS

Wire nails, made of mild steel, are commonly used for most nailing purposes. Cylindrical in shape, they are stronger for driving than cut nails and are not so liable to bend when driven into hardwoods.

Cut nails, sheared from steel plate, are flat and tapered. They have holding power considerably greater than wire nails. They are usually preferred to wire nails for fastening wood battens to plaster; also in places where there is danger that the nails may be drawn out by direct pull. Cut nails are frequently used for driving into material other than wood. They are generally used for fastening flooring. When driven with width parallel to grain of wood, they have less tendency to split wood than wire nails.

The length of cut and wire nails is designated by the unit ''pennies.'' Both cut and wire nails come in sizes from 2-penny (2d) which are 1 in long, to 60-penny (60d), which are 6 in long. Above 6 in, the fasteners are called **spikes.** They run in 7-, 8-, 9-, 10-, and 12-in lengths.

Various gages or thicknesses of nails, and different sizes and shapes of heads and points (Figs. 11.84 and 11.85), are available in both wire and cut nails. Certain types have distinguishing names. For example, the term **brads** is applied to nails with small heads, suitable for small finish work.

Common brads are the same thickness as common nails but have different heads and points. **Clout nails** have broad flat heads. They are used mostly for securing gutters and metalwork.

Casing nails are about half a gage thinner than common wire nails of the same length; **finishing nails,** in turn, are about half a gage thinner than casing nails of the same length. **Shingle nails** are half a gage to a full gage thicker than common nails of the same length.

Certain manufacturers have developed nails for special purposes that hold tighter and longer. Among these are threaded nails (Fig. 11.84), which combine the ease of driving of the ordinary nail with much greater holding power.

One type is a spiral-threaded flooring nail. These nails turn as they drive, minimizing splitting of the tongues of the floor boards. These nails are said to actually grip more firmly with the passage of time. A nailing machine is available for driving these nails. In one operation, it starts the nail, drives the joint between the flooring strips tight, and drives and sets the nail. With this machine, mashed tongues and marred edges of the wood are avoided.

Nails of aluminum and stainless steel are particularly useful in exposed locations where rust or corrosion of steel nails might cause unsightly stains to form on exterior finished surfaces. These nails are now made in most of the usual sizes, including special spiral-threaded nails.

Galvanized nails are used for fastening slate and shingles. These nails are sometimes used in exposed locations as protection against corrosion.

11.71 SCREWS

These are used for applying hardware of all descriptions; also for panel work, cabinet work, all types of fine finish work, and support of electric and plumbing fixtures. Screws have greater holding power than nails and permit easy removal and replacement of parts without injury to the wood or finish. Screws avoid danger of splitting the wood or marring the finish, when the screw holes are bored with a bit.

Screws are made in a large variety of sizes and shapes to suit different uses (Fig. 11.86) and they are made of different metals to match various materials. A much-used type of head, other than the ordinary single-slot type, is the **Phillips head,** which has two countersunk slots at right angles to each other. The head keeps the screwdriver exactly centered during driving and also transmits greater driving power to the screw, while holding the screwdriver firmly on the head. Phillips heads are smoother at the edges, because the slots in the head do not extend to the outer circumference.

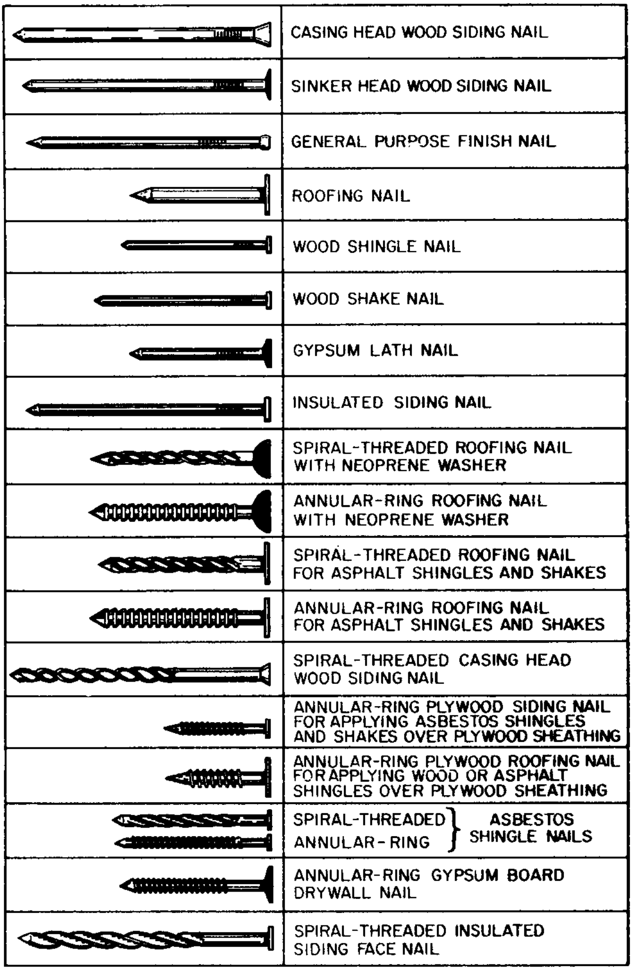


FIGURE 11.84 Nail heads and points.

Steel screws for wood vary in length from ¼ to 6 in. Each length is made in a variety of thicknesses. Heads may be ordinary flat (for countersinking), round, or oval.

Parker screws for securing objects to thin metal are self-threading when screwed into holes of exactly the correct size.

Sizes of screws are given in inches of length and the gage of the diameter. Lengths vary by eighths of an inch up to 1 in, by quarters from there up to 3 in, and by halves from 3 to 5 in. Unlike wire gages, the smallest diameter of a screw gage is the lowest number; the larger the number, the greater is the diameter in a screw gage. Gage numbers range from 0 to 30.

Lag screws are large, heavy screws used for framing timber and ironwork (Figs. 11.86 and 11.89). Lengths vary from 1½ to 12 in and diameters from 5⁄16 to 1 in.

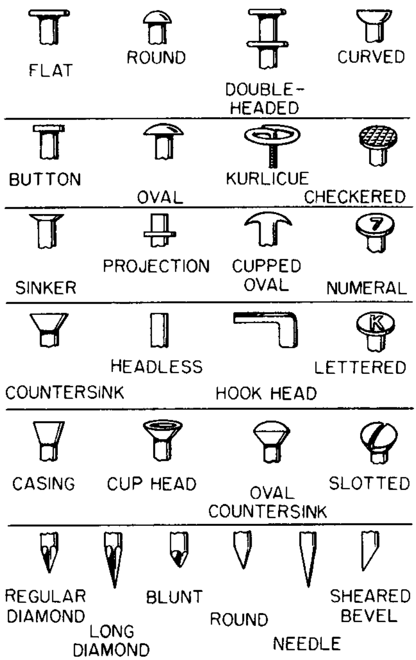


FIGURE 11.85 Typical nails.

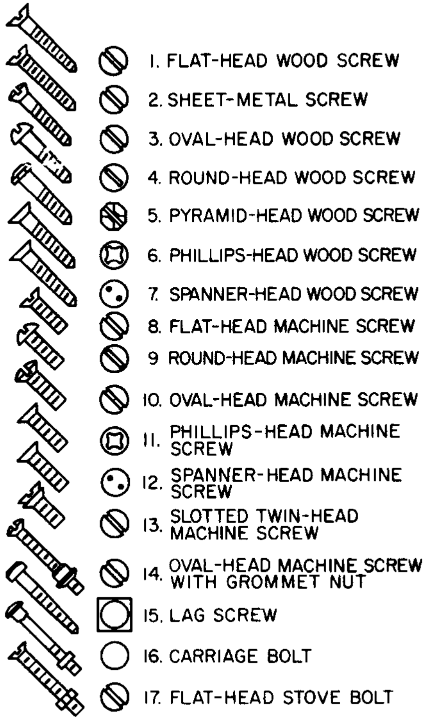


FIGURE 11.86 Typical screws.

Two holes should be bored for lag screws, one to take the unthreaded shank without binding and the other (a smaller hole) to take the threaded part. This smaller hole is usually somewhat shorter in length than the threaded portion. Lag screws usually have square heads and are tightened with a wrench.

11.72 WELDED STUDS

Studs electrically welded to the steel framework of a building are often used as the primary element for securing corrugated siding and roofing, insulation, metal window frames, ornamental outer skins, anchorages for concrete, and other items. The welded studs thus form an integral part of the basic structure.

Many types of studs or fasteners are available, each one being designed for a particular purpose. Most of the studs have threads formed on them, either externally or internally. Some of the studs are designed to have the material impaled over them and riveted to them.

The studs are designed so as to project the exact distance desired after they have been welded. Special sealing washers and nuts are usually placed on each stud over the flat sheet of material being fastened. Tightening the nut or expanding the head of the stud with a riveting hammer then makes the fastening complete, weathertight, and secure.

Studs are usually cadmium-plated mild steel or stainless steel. The latter is recommended for corrosive atmospheric conditions. Flux to assure a good weld is contained in the center of each stud at the welding end.

Equipment required for stud welding includes a stud-welding gun, a control unit for adjusting the amount of welding current fed to the gun, and a power source. The source of welding current may be a direct-current generator, a rectifier, or a battery unit. When a welding generator is used, the minimum National Electrical Manufacturers Association rating should be 400 A.

The welding gun usually has a chuck for holding the stud in position for welding (Fig. 11.87), and a leg assembly holding an adjustable-length extension sleeve into which the necessary arc-shielding ferrule is inserted. Expendable ceramic arc fer-

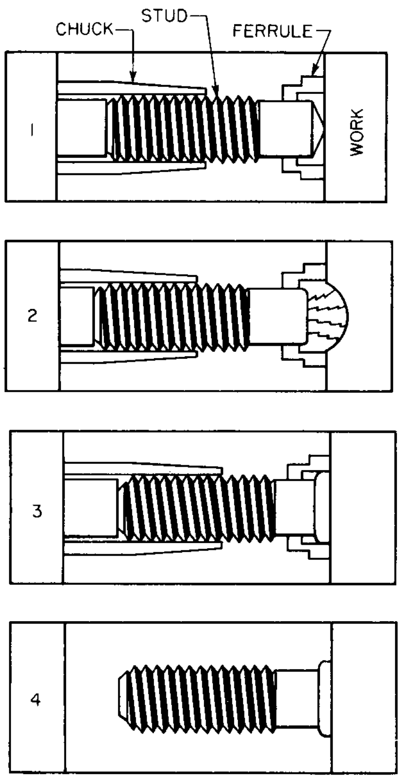


FIGURE 11.87 Steps in stud welding: (1) Press the welding end of the gun against the work plate. (2) Press the trigger to create an electric arc between the stud and the plate and melting portions of each. (3) The stud is automatically plunged into the molten pool. (4) Remove the gun and knock off the ferrule.

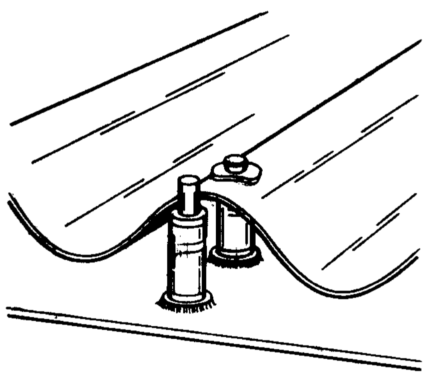


FIGURE 11.88 Corrugated metal impaled on and fastened in place with a welded stud.

rules are generally used to confine the arc and control the weld fillet. After each weld, the arc ferrule is broken and removed by a light tap with any convenient metal object. In some cases where the required finished stud is short, an extra length is provided on the stud as furnished, for proper chucking in the gun. A groove is provided so the extra length can be easily broken off after the stud is welded.

A method of fastening corrugated-metal sheet to steel framing is shown in Fig. 11.88. This method permits application of siding and roofing entirely from the outside. A worker is not required to be on the inside because there are no clips or fasteners on the interior. The expense of an interior scaffold is thus saved.

In securing corrugated metal, it is sometimes desirable to weld the studs to the steel frame in advance of placing predrilled sheets. In these cases, templates for quickly marking sheet and stud locations may be employed, as desired. Stud welding is applicable to any steel frame composed of standard structural steel. Steels of the high-carbon variety such as rerolled rail stock are not suitable for stud welding.

The manufacturer's recommendations should be followed in selecting the best type and size of stud for each specific installation. The leading manufacturers have direct field representatives in all areas who can supply valuable advice as to the best procedures to follow.

11.73 POWDER-DRIVEN STUDS

For many applications requiring the joining of steel or wood parts, or fastenings to concrete, steel, and brick surfaces, powder-actuated stud drivers are found to decrease costs because of their simplicity and speed. These drivers use a special powder charge to drive a pin or stud into relatively hard materials. The key to their efficiency is the proper selection of drive pins and firing charges. Because of the high velocity, the drive pin, in effect, fuses to the materials and develops the holding power.

Pullout tests of these driven studs prove remarkable holding power. Average pullout in 3500-psi concrete exceeds 1200 lb for 10-ga studs, and 2400 lb for ¼-in-diameter studs. In steel plate the pullout resistance is still greater.

All that is required is a stud driver, the correct stud, and the correct cartridge, as recommended by the manufacturer for each specific set of fastening conditions. There are about a half dozen different strengths of cartridge, each identified by color, and some two dozen varieties of studs. Some studs have external threads, others internal threads. A plastic coating protects the threads from damage while driving.

The drivers will force studs into steel up to about ½ in thick, into concrete through steel plates up to about ¼ in thick, into concrete through various thicknesses of woods, and into steel through steel up to ¼ in thick.

Powder-driven studs should never be driven into soft materials or into very hard or brittle materials, such as cast iron, glazed tile, or surface-hardened steel. Neither should they be used in face brick, hollow tile, live rock, or similar materials.

In driving studs a suitable guard must be used for each operation, and the driver must be held squarely to the work. If the driver is not held perpendicular, a safety device prevents firing of the charge. There also must be sufficient backup material to absorb the full driving power of the charge. Studs cannot safely be driven closer than ½ in from the edge of a steel surface, or closer than 3 in from the outside edge of concrete or brick surfaces.

11.74 BOLTS

A bolt is a cylindrical fastener that consists of a head shaped to facilitate turning with a wrench and a threaded shank of smaller diameter (Fig. 11.89). To fasten two or more building components together, the bolt is placed in a prepared hole that extends through the components and is slightly larger than the shank. A nut, usually of a type shown in Fig. 11.89, is threaded onto the shank and tightened to draw the parts together.

Bolts used in connections subjected to heavy loads, such as connections in structural framing, are described in Secs. 7 through 10.

A washer often is placed under the head of a bolt and under a nut. A washer can accomplish several purposes: (1) Distribute the compressive force exerted by a tensioned bolt over a wider area than that of the contact surface of the bolt head or nut. (2) Prevent the head or nut from turning and thus prevent the components of a connection from separating. (3) Serve as a seal against moisture penetration. (4) Insulate incompatible materials from each other. (5) Prevent the head or nut

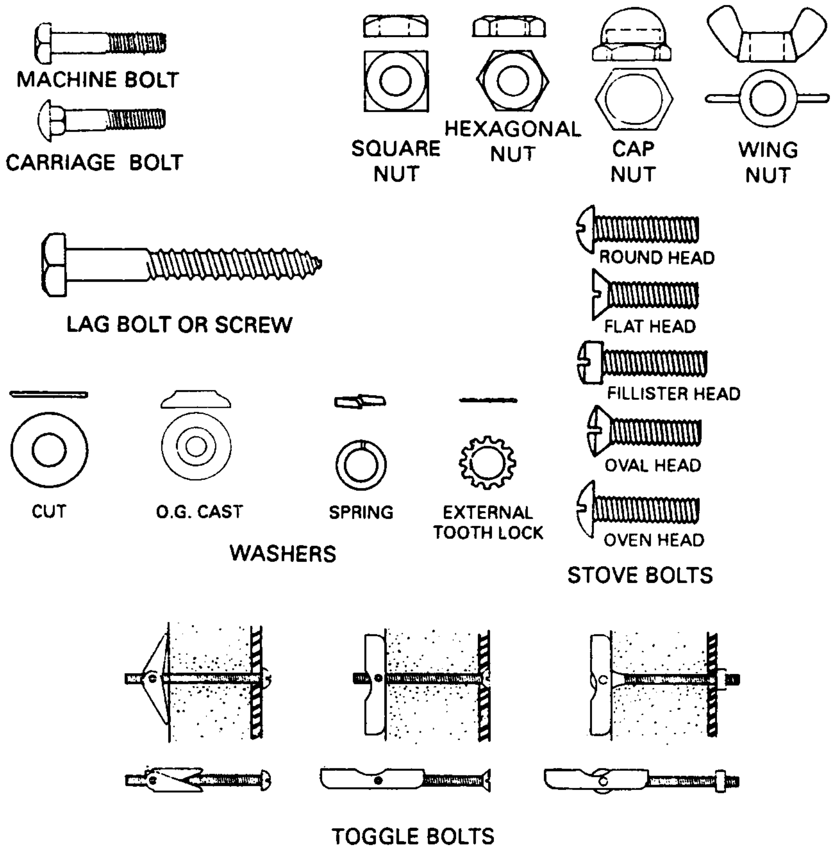


FIGURE 11.89 Types of bolts, nuts, and washers.

from being pulled into the hole when the hole has about the same diameter as the head or nut.

ACOUSTICS

Acoustics, derived from a Greek word meaning to hear, refers to generation, detection, transmission, absorption, and control of sounds. Acoustics is part science and part art, but modern studies are stripping away much of its mystique. As a result, it is possible to plan and predict the acoustics of finished spaces with reasonable certainty.

11.75 SOUND PRODUCTION AND TRANSMISSION

Sound is a vibration in an elastic medium. It is a simple form of mechanical energy, and can be described by the mathematics associated with the generation, transmission, and control of energy.

Almost any moving, vibrating, oscillating, or pulsating object is a potential sound source. Usually, though, vibratory sources radiate enough energy to be audible to humans or felt by them.

Sound waves in air (or other gases or fluids) travel outward from the source, transmitted by air molecules, like a rapidly expanding soap bubble. Any particular group of molecules behaves like a pulsating balloon, moving only slightly, while the wave progresses swiftly to great distances. Transmission (flow), or prevention of transmission of sound, and conversion of sound energy to a nonaudible form are the function of so-called acoustical materials.

11.76 NOMENCLATURE FOR ANALYSIS OF SOUND

Cycle. A complete single excursion of a vibrating molecule.

Frequency. The number of cycles of vibration in a given unit of time, usually cycles per second (cps) or hertz (Hz).

Sound Wave. The portion of a sound between two successive compressions or rarefactions.

Wavelength. The distance between two successive rarefactions or compressions in a sound wave.

Amplitude. Maximum displacement, beyond its normal, or rest, position, of a vibrating element. In most audible sounds, these excursions are very small, although low-frequency sound may cause large excursions (as would be observed in the motion of a loudspeaker cone reproducing very low frequency sounds at audible level). Amplitude of motion is related to the increased pressure created in the medium, and to the intensity of the energy involved.

Velocity. Speed at which a sound impulse travels (not the speed of movement of any particular molecule). In a given medium, under fixed conditions, sound velocity is a constant. Therefore, the relationship between velocity, frequency, and wavelength can be expressed by the equation:

$$\text{Velocity} = \text{frequency} \times \text{wavelength} \tag{11.8}$$

Because velocity is constant in air, low-frequency sound has long wavelengths, and high-frequency sound has short wavelengths. This is important to remember in acoustical design.

In addition to the longitudinal (compression or "squeeze") waves by which sound travels, there is another type of vibrational motion to which most building materials and construction systems are subjected, a **transverse wave** (Fig. 11.90). This is the familiar motion of a vibrating string or reed. This type of wave, too, transmits energy that can be felt or heard, or both.

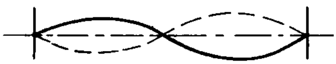


FIGURE 11.90 Transverse waves.

Sheets or panels, studs and joists, hangers and rods, and similar slender and somewhat flexible members are particularly apt to vibrate in a transverse mode and to transmit sound energy along their length, as well as radiating it from their surfaces to the surrounding air.

11.77 SOUND CHARACTERISTICS AND EFFECTS ON HEARING

Sound travels via elastic media. Hard, rigid, dense materials make excellent transmission paths, because they can accept much energy readily. Sound velocity is inversely proportional to the density of the medium, as can be seen from Eq. (11.9).

$$\text{Velocity} = k\sqrt{\frac{\text{modulus of elasticity}}{\text{density}}} \tag{11.9}$$

where k is a constant. Usually, however, dense materials often have a much larger modulus of elasticity than less dense materials, and the effect of the modulus more than offsets the effects of density. *Sound does not travel faster in dense media than in less dense media.* Table 11.21 lists the velocity of sound in some common materials.

Another characteristic of materials, very important to their acoustical performance, is acoustical **impedance.** This value is determined by multiplying the velocity of sound in the material by the density of the material. An examination of the units resulting from this operation will show that this is a way of measuring the rate at which the material will accept energy. Table 11.22 lists the acoustical impedance of several typical materials used in building construction.

In most cases of interest, a human is the "receiver" in the source-path-receiver chain. Hearing is the principal subjective response to sound. Within certain limits of frequency and energy levels, sound creates a sensation within the auditory equipment of humans and most animals.

At very low frequencies or at very high energy levels, additional sensations, ranging from pressure in the chest cavity to actual pain in the ears, are experienced.

TABLE 11.21 Velocity of Sound in Various Media

Material	Approximate sound velocity, ft per s
Air	1,100
Wood	11,000
Water	4,500
Aluminum	16,000
Steel	16,000
Lead	4,000

TABLE 11.22 Acoustical Impedance of Various Materials

Material	Acoustical impedance, psi per s
Rubber	100
Cork	165
Pine	1,900
Water	2,000
Concrete	14,000
Glass	20,000
Lead	20,500
Cast iron	39,000
Copper	45,000
Steel	58,500

Human sense of feeling is also affected by vibrations in building structures, a subject closely related to ordinary building acoustics but outside the scope of this section.

From a strictly mechanical standpoint, the ear responds in a relatively predictable manner to physical changes in sound. Table 11.23 relates the objective characteristics of sound to our subjective responses to those characteristics.

Loudness is the physical response to sound pressure and intensity. It is influenced somewhat by the frequency of the sound.

Pitch is the physical response to frequency. Low frequencies are identified as low in pitch, high frequencies as high in pitch. Middle C on the piano, for example, is 261 Hz; 1 octave below is 130 Hz; 1 octave above is 522 Hz.

An **octave** represents a 2:1 ratio of frequencies.

For practical purposes, humans can be considered to have a hearing range from about 16 Hz to somewhat less than 20,000 Hz. They usually are significantly deaf to low frequencies and very high frequencies. Human loudness response to sounds of identical pressure but varying frequency plots something like the curve in Fig. 11.91.

Any measure of loudness must, in some way, specify frequency as well as pressure or intensity to have any real significance in human acoustics. As shown in

TABLE 11.23 Subjective Responses to Characteristics of Sound

Objective (sound)	Subjective (hearing)
Amplitude Pressure Intensity	Loudness
Frequency	Pitch
Spectral distribution of acoustical energy	Quality

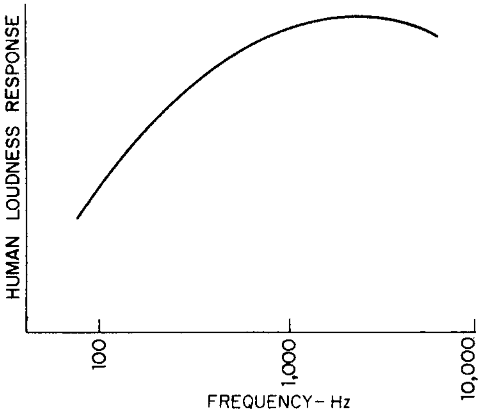


FIGURE 11.91 Human response to sounds of identical level but various frequencies.

Art. 11.78, measuring equipment and scales used are all modified to recognize this. Table 11.24 lists some of the significant frequency ranges.

Sounds generated by mechanical equipment may encompass the entire frequency range of human hearing. Jet aircraft, for example, have significant output throughout the entire range, and large diesel engines produce substantial energy from 30 to 10,000 Hz.

Wanted sound (signal), whatever its nature, communicates information to us. **Unwanted sound,** whatever its nature, is **noise.** When the signal becomes sufficiently louder than the noise, the signal can be detected and the information becomes available. Thus, the distinction between noise and communication is completely subjective, completely a matter of human desires and needs of the moment.

While very weak sounds can be heard in a very quiet background, the level of wanted sound may be increased to override the unwanted background (or noise);

TABLE 11.24 Significant Frequency Ranges

	Approximate frequency range, Hz
Range of human hearing	16–20,000
Speech intelligibility (containing the frequencies most necessary for understanding speech)	600–4,800
Speech privacy range (containing speech sounds that intrude most objectionably into adjacent areas)	250–2,500
Typical small table radio	200–5,000
Male voice	350*
Female voice	700*

*Frequency at about which energy output tends to peak.

but there is a significant noise level above which even loud (shouting) speech is scarcely intelligible. Such a level, if long continued, can prove damaging to the hearing mechanism. At still higher levels, pain can be experienced, and immediate physical damage (often irreversible) may occur.

Complete silence (if such a thing could occur) would be most unpleasant. Humans would quickly become disoriented and distressed. Somewhere between silence and the uncomfortably loud, however, is a wide range that humans find acceptable.

11.78 MEASUREMENT OF SOUND

Generally, absolute numbers obtained from measurements have little significance in acoustics. Instead, measurements are almost always compared with some base or reference, and they are usually quoted as **levels** above or below that reference level. The levels are usually ratios of observed values to the reference level, such as 2:1, 1:2, 1:10, because rarely are simple, linear relationships found between stimuli and effects in humans.

Zero level of sound pressure is not a true physical zero; that is, the absence of any sound pressure at all. Rather, zero level is something of an average threshold of human hearing, of sound at about 1000 Hz. The physical pressure associated with this threshold level is very small, 0.00002 Pa (N/m^2).

Changes in human response tend to occur according to a ratio of the intensity of the stimuli producing the response. In acoustics, the ratio of 10:1 is called a **bel,** and one-tenth of a bel, a **decibel** (dB). Thus, power and intensity levels, in dB, are computed from

$$\text{Level} = 10 \log_{10} \frac{\text{quantity measured}}{\text{reference quantity}} \tag{11.10}$$

Intensity level (IL), dB, for example, represents the ratio of the intensity being measured to some reference level, and is given by

$$\text{IL} = 10 \log_{10} \frac{I}{I_o} \tag{11.11}$$

where I = intensity measured, W/cm^2
I_o = reference intensity = 10^{-16} W/cm^2

Since intensity varies as the square of the pressure, intensity level also is given by

$$\text{IL} = 10 \log_{10} \frac{p^2}{p_o^2} = 20 \log_{10} \frac{p}{p_o} \tag{11.12}$$

where p = pressure measured, Pa
p_o = reference pressure = 0.00002 Pa

Sound pressure level (SPL), dB, to correspond with intensity level, is defined by

$$SPL = 20 \log_{10} \frac{p}{p_o} \tag{11.13}$$

Sound power level refers to the power of a sound source relative to a reference power of 10^{-12} W. *(Note:* At one time, 10^{-13} W was used; thus, it is imperative that the reference level always be explicitly stated.)

The ear responds in a roughly logarithmic manner to changes in stimulus intensity, but approximately as shown in Table 11.25.

Another comparison, which gives more meaning to various levels, is shown in Table 11.26.

Measurement Scales. Most measurements or evaluations of sound intensity or level are made with an electronic instrument that measures the sound pressure. The instrument is calibrated to read pressure levels in decibels (rather than volts). It can measure the overall sound pressure level throughout a frequency range of about 20 to 20,000 Hz, or within narrow frequency bands (such as an octave, third-octave,

TABLE 11.25 Subjective Effect of Changes in Sound Characteristics

Change in sound level, dB	Change in apparent loudness
3	Just perceptible
5	Clearly noticeable
10	Twice as loud (or ½)
20	Much louder (or quieter)

TABLE 11.26 Comparison of Intensity, Sound Pressure Level, and Common Sounds

Relative intensity	SPL dBA*	Loudness
100,000,000,000,000	140	Jet aircraft and artillery fire
10,000,000,000,000	130	Threshold of pain
1,000,000,000,000	120	Threshold of feeling
100,000,000,000	110	
10,000,000,000	100	Inside propeller plane
1,000,000,000	90	Full symphony or band
100,000,000	80	Inside automobile at high speed
10,000,000	70	Conversation, face-to-face
1,000,000	60	
100,000	50	Inside general office
10,000	40	Inside private office
1,000	30	Inside bedroom
100	20	Inside empty theater
10	10	
1	0	Threshold of hearing

* SPL as measured on A scale of standard sound level meter.

or even narrower ranges). Usually, the sound-level meter contains filters and circuitry to bias the readings so that the instrument responds more like the human ear—‘‘deaf’’ to low frequencies and most sensitive to the midfrequencies (from about 500 to 5000 Hz). Such readings are called A-scale readings. Most noise level readings (and, unless otherwise specifically stated, most sound pressure levels with no stated qualifications) are A-scale readings (often expressed as dBA). This means that actual sound pressure readings have been modified electrically within the instrument to give a readout corresponding somewhat to the ear’s response (Fig. 11.91).

For various measurements and evaluations of performance for materials, constructions, systems, and spaces, see Art. 11.81.

11.79 SOUND AND VIBRATION CONTROL

This process consists of:

1. Acoustical analysis
 - **a.** Determining the use of the structure—the subjective needs
 - **b.** Establishing the desirable acoustical environment in each usable area
 - **c.** Determining noise and vibration sources inside and outside the structure
 - **d.** Studying the location and orientation of the structure and its interior spaces with regard to noise and noise sources

2. Acoustical design
 - **a.** Designing shapes, areas, volumes, and surfaces to accomplish what the analysis indicates
 - **b.** Choosing materials, systems, and constructions to achieve the desired result

Sound and vibration sources are usually speech and sounds of normal human activity—music, mechanical equipment sound and vibration, traffic, and the like. Characteristics of these sound sources are well known or easily determined. Therefore, the builder or designer is usually most interested in the transmission paths for sound and vibration. These are gases (usually air); denser fluids (water, steam, oil, etc.); and solids (building materials themselves). During sound transmission in a building, some of the sound energy is absorbed or dissipated, some is reflected from various surfaces, and some is transmitted through the building materials and furnishings.

Sound control is accomplished by means of barriers and enclosures, acoustically absorbent materials, and other materials and systems properly shaped and assembled. Vibration control is accomplished by means of various resilient materials and assemblies, and by damping materials (viscoelastic materials of various types).

Airborne and structure-borne energy are controlled by somewhat different techniques, described in the following.

11.79.1 Airborne Sound Transmission

A sound source in a room sets the air into vibration. The vibrating air causes any barrier it touches (partitions, floors, ceilings, etc.) to vibrate. The vibrating barrier,

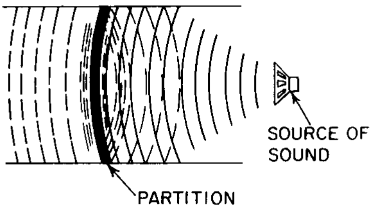


FIGURE 11.92 Sound transmission through a barrier.

in turn, sets into vibration the air on the opposite side of the barrier (Fig. 11.92).

The barrier, like any other body, resists motion because of its inherent inertia. Because it takes more force, and therefore more energy, to move a heavier (more massive) barrier, sound loss through the barrier depends directly on the mass of the barrier. The loss in energy level between the original signal striking the barrier and the level of the energy transmitted to the opposite side is called the **sound transmission loss** of the barrier.

Figure 11.93 shows graphically how a truly limp barrier of infinite width and height responds to sound energy of varying frequency (the *mass law,* straight-line vibration). In practice, however, no barrier is truly limp; a wall, floor, or ceiling always has a finite stiffness. Therefore, at low frequencies, barriers tend to have higher sound transmission losses than the mass law predicts. In some region of the spectrum, however, barriers tend to have lower sound transmission losses (pass sound more readily) than the mass law indicates (see curve for solid panel in Fig. 11.93).

This latter phenomenon results because the barrier, in addition to its back-and-forth motion, as shown in Fig. 11.92, moves in a simultaneous shear wave, like a rope being shaken (Fig. 11.90). At some frequency, the velocity of this shear wave in the barrier coincides with the velocity of the impinging sound wave in the air. Then, the partition is quite transparent to sound, and a deep coincidence dip in the sound transmission loss curve occurs (see curve for double wall in Fig. 11.93). At

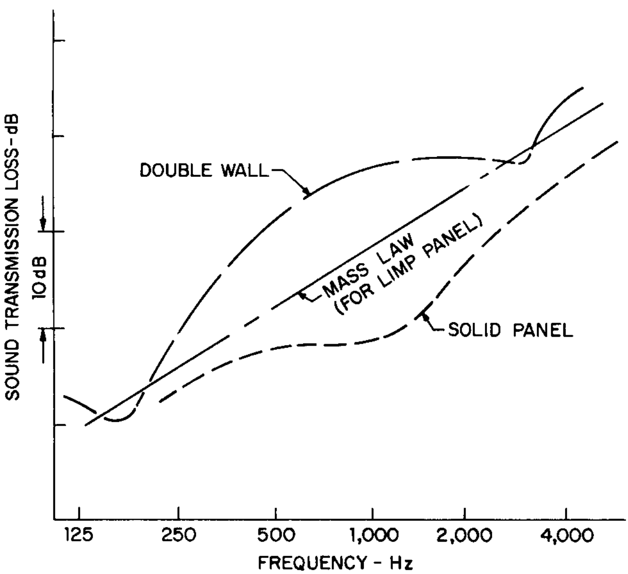


FIGURE 11.93 Sound transmission loss of barriers.

frequencies above the coincidence frequency, the curve tends to recover its preceding slope.

There are few practical limp materials useful for ordinary building panels. Soft sheet lead is occasionally used for specialized barriers, as described in Art. 11.80, or is applied to other panel material to increase the mass of the composite without increasing its stiffness. In addition, damping materials (Art. 11.79.4) can be applied to the panels to damp out their vibrations quickly and to increase the energy loss as the panels vibrate.

Figure 11.93 shows another characteristic of barriers that further complicates their performance. While single, solid panels have somewhat smaller transmission losses than the mass law predicts, a double wall, a barrier comprising separated wythes or leaves, of the same total weight produces greater transmission losses than the mass law predicts.

If the mass of a single, solid panel is divided into two separate, unconnected layers, the only energy transfer between them occurs via the air between the layers. Air is not stiff; it can sustain little of the shear wave, and it is not an efficient transmitter of the back-and-forth motion of one layer to the other (except at certain resonant frequencies). As a result, particularly in the midfrequencies, the sound transmission loss actually exceeds the mass-law values, often considerably. The greater the distance between layers, the better the performance. Theoretically, the sound transmission loss should increase about 6 dB for each doubling of the width of the airspace. In practice, however, the increase in decibels is somewhat less than this.

If a porous, sound-absorbent blanket is inserted in the void between layers, the standing waves in the air layers are minimized. Furthermore, such a blanket has the effect of reducing the stiffness of the air, as well as absorbing some of the energy of the air as it pumps back and forth through the blanket. The result is an additional increase in sound transmission loss.

The performance of various barriers, and rating systems for their performance, are shown in Table 11.27.

11.79.2 Bypassing of Sound Barriers

Rarely is a sound barrier the sole transmission path for the acoustic energy reaching it. Some energy invariably travels via the connecting structures (floors, ceilings, etc.), or through openings in or around the barrier.

TABLE 11.27 STC of Various Constructions

Construction	STC
¼-in plate glass	26
¾-in plywood	28
½-in gypsum board, both sides of 2 × 4 studs	33
¼-in steel plate	36
6-in concrete block wall	42
8-in reinforced-concrete wall	51
12-in concrete block wall	53
Cavity wall, 6-in concrete block, 2-in air space, 6-in concrete block	56

Structural flanking via edge attachments and junctions of walls, partitions, floors, and ceilings can seriously degrade the performance of a barrier. Figure 11.94 shows some typical flanking paths and how to avoid such flanking.

Even trivial openings through a sound barrier seriously degrade its performance. An opening with an area of only about 1 in^2 transmits as much acoustical energy as a 6-in-thick concrete block wall of 100-ft^2 area. Figure 11.95 shows the effect of openings of various sizes on walls of various effectiveness. (*Note:* Sound transmission class STC is a rating system described in Art. 11.80.) The better the wall, the more serious the effect of openings or leaks.

The more common points of leakage through or around barriers include perimeter of pipes, ducts, or conduits penetrating the barriers; relief grilles for return air; perimeter of doors or glazing; shrinkage or settlement cracks at partition heads or sills; joints between partitions and exterior curtain-wall mullions; joints around or openings through back-to-back electrical outlet boxes, medicine cabinets, etc.; common supply or return ducts with short, unlined runs between rooms; and operable windows opening to a common court. Such openings should be avoided, when possible, and all cracks, joints, and perimeters should be calked and sealed.

In some spaces (an open-plan school, "landscaped" office, etc.), screens, or partial-height barriers are used. Their effectiveness is much less than that of full-height partitions or walls. See also Art. 11.79.7.

11.79.3 Structure-Borne Sound Transmission

Acoustical energy transmission from sound sources to distant parts of the structure via the structure itself is often a major annoyance in building acoustics. One reason,

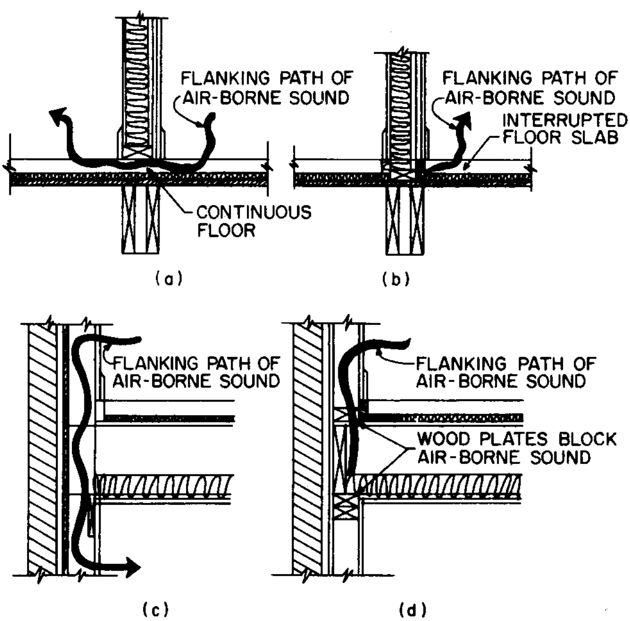


FIGURE 11.94 Structural flanking: (*a*) poor isolation at a partition; (*b*) adequate isolation at a partition; (*c*) poor isolation at an exterior wall (balloon framing); (*d*) adequate isolation (platform framing).

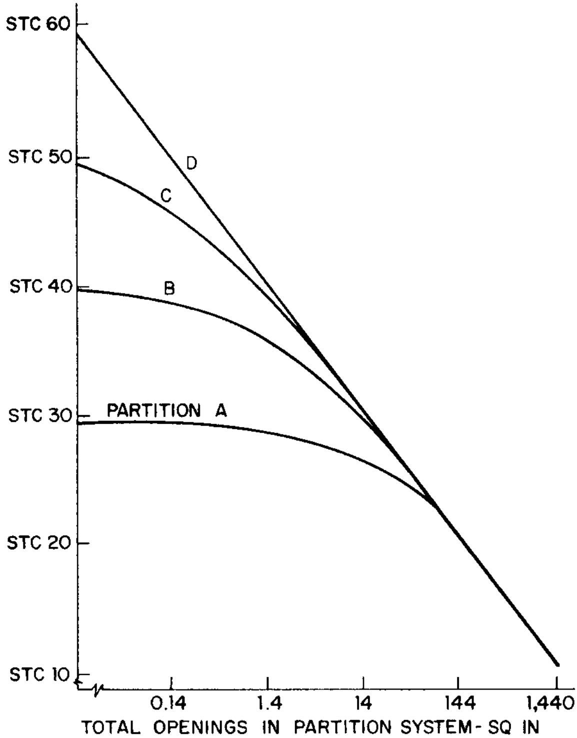


FIGURE 11.95 Effects of leaks on STC of partitions (for a 100 ft^2 test wall).

as discussed in Art. 11.79.2, is that structural flanking can seriously degrade the performance of sound barriers. Additional transmission paths include pipes, ducts, conduits, and almost any solid, continuous, rigid member in the building. Impact and vibrations can be transmitted through the floor-ceiling assemblies quite readily, if proper precautions are not taken.

Normally, in ordinary construction, a good carpet over a good pad will provide sufficient impact isolation against the sounds of footfalls, heel clicks, and dropped objects. Where carpet is not feasible, or in critical spaces, special floor-ceiling assemblies can be used. (See Art. 11.80 for various constructions and their impact isolation performance.)

Isolation against vibration or impact produced by machinery or other vibrating equipment is usually provided by use of special resilient or mounting systems. Springs, elastomeric pads, and other devices are used in such work. For a detailed discussion of such isolation, refer to the current ASHRAE "Guide," American Society of Heating, Refrigerating and Air-Conditioning Engineers, or other references on vibration and shock isolation.

Noise and vibration transmitted via plumbing and heating pipes, ducts, and conduits can be objectionable unless proper precautions are taken. Resilient connectors for rigid members, acoustically absorptive duct linings, and similar approaches are described in detail in the ASHRAE "Guide."

11.79.4 Damping of Vibrations

As a panel or object vibrates, it radiates acoustical energy to the air surrounding it and to solid surfaces touching it or attached to it. If the energy of vibration could be dissipated, the radiation would be reduced and the sound and vibration levels lowered. One way to do this is to attach firmly to a vibrating panel certain ‘‘lossy’’ substances (those with high internal friction or poor connections between particles) or viscoelastic materials (neither elastic nor completely viscous, such as certain asphaltic compounds). These damp the vibrations by absorbing the energy and converting it to heat.

In the assembly of barriers, damping can be accomplished with proper connections and attachments, use of viscoelastic adhesives, proper attachment of insulating materials, and similar means. Special viscoelastic materials for adhesive attachment or brush or spray application to panels are available.

11.79.5 Sound Absorption

The best-known acoustical materials are acoustical absorbents (although actually all materials are acoustical). Generally, these absorbents are lightweight, porous, ‘‘fuzzy’’ types of boards, blankets, and panels.

Acoustical absorbents act as energy transducers, converting the mechanical energy of sound into heat. The conversion mechanism involves either pumping of air contained within the porous structure of the material, or the flexing of thin panels or sheets. Most materials employ the first principle.

The internal construction of most absorbents consists of a random matrix of fibers or particles, with interconnected pores and capillaries (Fig. 11.96). It is necessary that the air contained within the matrix be able to move sufficiently to create friction against the fibers or capillaries. Nonconnected-cell or closed-cell porous materials are not effective absorbents.

Tuned chambers, with small openings and a restricted neck into the chambers, also are used for sound absorption; but they are somewhat specialized in design and function, and their use requires expert design in most instances.

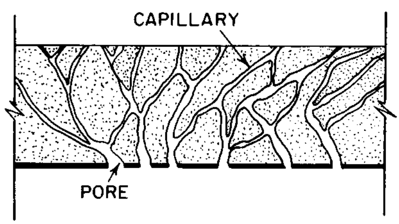


FIGURE 11.96 Cross section of sound absorbent (greatly enlarged).

The surface of absorbents must be sufficiently porous to permit the pressures of impinging sound waves to be transferred to the air within the absorbent. Very thin, flexible facings (plastic or elastomeric sheets) stretched over panels and blankets do not interfere significantly with this pressure transfer, but thick, rigid, heavy coatings (even heavy coatings of paint) may seriously restrict the absorption process. Perforated facings, if sufficiently thin and with sufficient closely spaced openings, do not appreciably degrade the performance of most absorbents.

The visible surface of absorbent panels and tiles may be smooth or textured, fissured or perforated, or decorated or ‘‘etched’’ in many ways. Figure 11.97 shows a typical commercial tile. Figure 11.98 illustrates an example of the use of both acoustical tiles and panels in a ceiling.

Absorbents are normally produced from vegetable or mineral fibers, porous or granular aggregates, foamed elastomers, and other products, employing either added

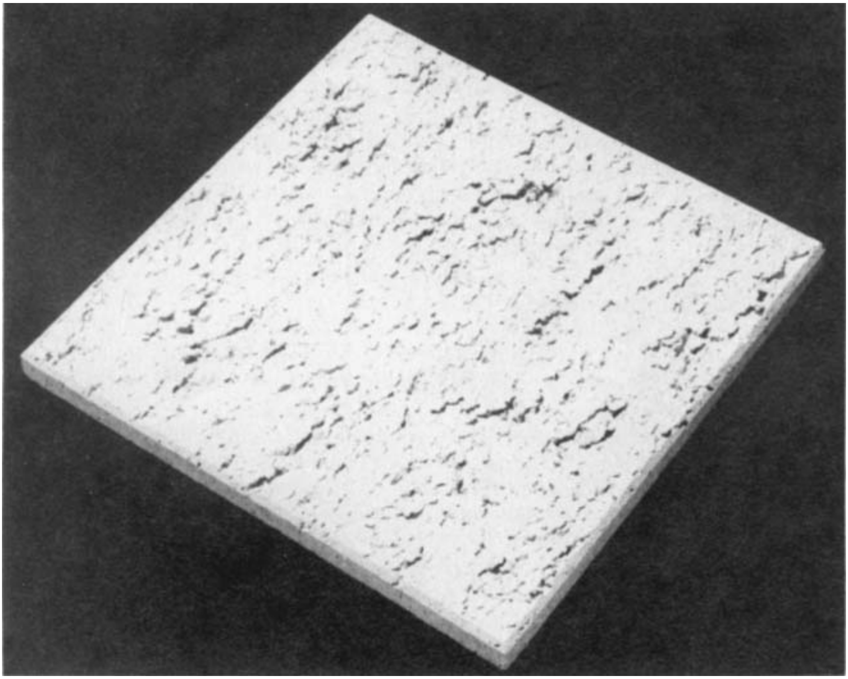


FIGURE 11.97 Fissured-surface acoustical tile with the appearance of travertine stone.

FIGURE 11.98 Library ceiling comprising both acoustical panels and acoustical tiles, integrated with lighting panels. (*U.S. Gypsum Company.*)

binders or their own structure to provide the structural integrity required. Because of their lightweight, porous structure, most such products are relatively fragile and must be installed where they are not subject to abuse; or they may be covered with sturdy perforated or porous facings to protect them.

Absorbents are chosen for their appearance, fire resistance, moisture resistance, strength, maintainability, and similar characteristics. Their performance ratings in respect to these characteristics are usually published in advertising materials and in various bulletins and releases of trade associations.

The acoustical property of absorbents most important to designers and builders is absorptive efficiency. [Sound transmission through most absorbents takes place readily. They are very poor in this respect and should never be used to attempt to improve the airborne sound isolation of a barrier. Sound transmission over the top of a partition, through a lightweight, mechanically suspended acoustical panel ceiling, is frequently a serious annoyance in buildings (Art. 11.79.7).] The absorptivity of a tile or panel is usually expressed as the fraction or percentage of acoustical energy absorbed from an impinging plane wave. If a perfectly absorptive plane surface represents 1.00 or 100%, the ratio of absorption of a given product to this perfect absorber is called the **sound absorption coefficient** of the product.

The absorptivity of a material varies with its thickness, density, porosity, flow resistance, and other characteristics. Further, absorptivity varies significantly with the frequency of the impinging sound. Usually, very thick layers of absorptive material are required for good absorption of low-frequency sound, while relatively thin layers are effective at higher frequencies. Little or no absorption, however, can be obtained with thin layers or flocked surfaces, textured but nonporous surfaces, or other products often mistakenly thought to be absorptive or claimed to break up the sound.

Generally, there is an optimum density and flow resistance for any particular family of materials (particularly fibrous materials). Usually, absorptivity increases with thickness of the material.

Performance data for absorbent materials are usually readily available from manufacturers and trade associations. Performance of some typical products is shown in Table 11.30. See also Arts. 11.79.6, 11.79.7, and 11.80.

11.79.6 Control of Reflection and Reverberation

Normally, acoustical absorbents are used to prevent or minimize reflections of sound from the surfaces of rooms or enclosures. Distinct reflections—**echoes**—are usually objectionable in any occupied space. Rapid, repeated, but still partly distinguishable echoes, such as occur between parallel sidewalls of a corridor—**flutter**—are also objectionable.

Reverberation comprises very rapid, repeated, jumbled echoes, blending into an indistinct but continuing sound after the source that created them has ceased.

Usually, reverberation is one of the major causes of poor intelligibility of speech within a room; but, within limits, it may actually enhance the sound of music within a space. Reverberation control is a necessary and important aspect of good acoustic design, but it is often greatly overemphasized. Good room proportions and configuration, control of echoes, and absorption of noise usually assure an acceptable reverberation time within a space. Where careful determination and control of reverberation are required in a room, the services of a competent acoustical consultant are always advisable.

Reflections from strategically located and properly shaped room surfaces may be highly desirable, because such reflections may strongly enhance the source signal. But excessively delayed or highly persistent reflections are usually undesirable. (For most purposes, and within the normal frequency range of importance to human hearing, it may be assumed that the angle at which sound waves, like light waves, reflect from a surface equals the angle of incidence. Because of the enormously longer wavelength of sound compared with light, however, this assumption is inexact but nevertheless it is acceptable for most acoustic design.)

In most rooms, absorption of most of the acoustical energy impinging on many of the surfaces (the floor, distant walls, etc.) is desirable to prevent buildup or increase of unintelligible or useless sound. For this purpose, sound absorbents may be placed on some or all of the surfaces. The difference in sound pressure level (or noise level) caused within a space by the introduction of absorbents can be calculated, and from such a calculation, it is possible to determine how effective such treatment will be.

Noise reduction (NR), dB, provided by adding acoustical absorbents in a space can be determined from

$$NR = 10 \log_{10} \frac{A_o + A_a}{A_o} \tag{11.14}$$

where A_o = original acoustical absorption present
A_a = added acoustical absorption

Acoustical absorption equals the sum of the products of each area (in consistent units) in the space times the absorption coefficient of the material constituting the surface of the area; for example, the floor area, $ft^2 \times$ its absorption coefficient, plus ceiling area, $ft^2 \times$ its absorption coefficient, plus total wall area, $ft^2 \times$ its absorption coefficient.

[*Note:* An anomalous but useful term is often used in advertising data, the **noise reduction coefficient** (NRC). This is the arithmetic average of the sound absorption coefficients of a material as determined at 250, 500, 1000, and 2000 Hz (Art. 11.79.5). Since these frequencies include the most significant speech and intelligibility ranges, such a figure is a reasonably good means of comparing similar materials; that is, materials with absorption characteristics not differing widely from one another within this frequency range. Often, NRC is used, instead of the absorption coefficients at various frequencies, to determine an average noise reduction from Eq. (11.14).]

Equation (11.14) indicates that the more absorption present originally the less the improvement provided by added absorption. Thus, in a very ‘‘hard,’’ bare room, addition of acoustical (sound-absorbent) tile to a full ceiling significantly reduces the noise level. But addition of the same ceiling tile in a room with a thick carpet, upholstered furniture, and heavy draperies would make little change.

Heavy carpet, upholstered furniture, heavy draperies, and similar materials are very effective absorbers. In residences, for example, rarely is additional acoustical absorption required in bedrooms, living rooms, and similar spaces. In kitchens, bathrooms, or recreation rooms, with normal hard floors and few additional furnishings or fabrics, however, an acoustical tile ceiling is helpful. This is equally true of offices and similar spaces. In theaters and auditoriums, the large expanse of upholstered seating and aisle carpets is normally adequate for most noise control, but added absorption on some wall surfaces may be required for control of echoes.

Reverberation Time. The reverberation within a space is usually expressed as the time required for a sound pulse to decay 60 dB (to one-millionth of its original level). For most purposes, reverberation time T, s, can be calculated from the simple Sabine formula:

$$T = \frac{0.049V}{A} \tag{11.15}$$

where V = volume of the space, ft^3
A = total acoustical absorption in the space

Equation (11.15) assumes a smooth, steady, logarithmic decay; random distribution of sound within the room, with the wave front striking every surface quickly and within the decay time; and no standing waves between surfaces that could support a persistent mode. These are idealized conditions and never exist, but the formula is sufficiently accurate for most purposes.

Because the absorption of an absorbent material varies with frequency of sound, it is necessary to calculate T for each significant frequency. For most reverberation calculations, determinations at 500 Hz are adequate. For concert halls, and critical spaces, calculations are usually made 2 octaves above and 2 octaves below 500 Hz as well.

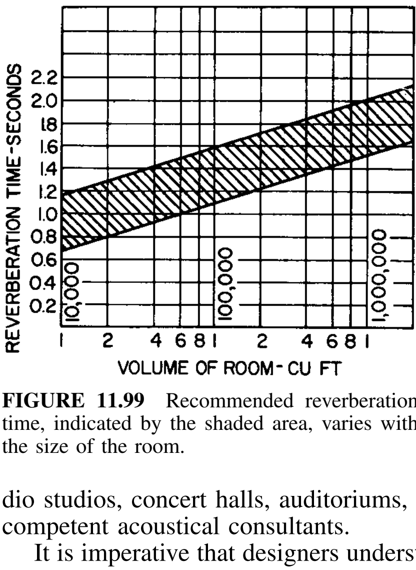


FIGURE 11.99 Recommended reverberation time, indicated by the shaded area, varies with the size of the room.

Optimum reverberation time for a room is a subjective determination, governed by speech intelligibility and the fullness and richness of musical sound desired. Figure 11.99 shows, within the shaded area, the acceptable range of reverberation times for normal spaces of varying volume. For critical spaces (radio studios, concert halls, auditoriums, etc.), it is advisable to obtain the advice of competent acoustical consultants.

It is imperative that designers understand that a reverberation-time determination is not an acoustical analysis, and that, in many instances, reverberation time is a trivial part of an acoustical study.

11.79.7 Installation of Absorbents

The amount, location, and installation method for absorbents are all significant in a room. As discussed in Art. 11.79.6, the material is located on surfaces from which reflections are undesirable and where it is reasonably free from damage. The amount of material required can be determined from noise-reduction and reverberation-time calculations. (For most simple spaces, a full ceiling treatment is acceptable.)

Acoustical absorbents can be cemented directly to a smooth, solid surface, nailed or stapled to furring strips, or suspended by any of a number of mechanical systems, such as that shown in Fig. 11.100.

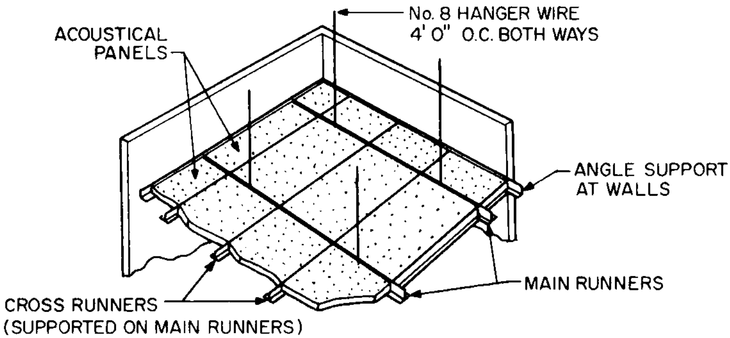


FIGURE 11.100 Typical suspended acoustical panels.

While acoustical absorbents are usually installed as, or on, flat, horizontal surfaces, various other configurations are used. Coffers, grids of hanging panels, and similar arrangements are often employed. The acoustical performance of each configuration must be tested to determine its effectiveness.

Sprayed-on and trowel-applied acoustical products are also employed, although their use is limited.

The structural, fire-resistance, and acoustical performance of most acoustical panels and tiles are significantly affected by the installation method. It is imperative that performance data be explicitly related to the specific installation method.

Partition Bypassing. When partitions or other sound barriers are constructed to (but not through) a suspended acoustical tile or panel ceiling, sound transmission through the tile from one space, over the top of the partition, into an adjacent space can be a serious annoyance. Figure 11.101 shows how sound can bypass a partition, and alternative methods of preventing this.

Similarly, structure-borne flanking transmission along the continuous metal runners of some suspension systems may seriously degrade the performance of an

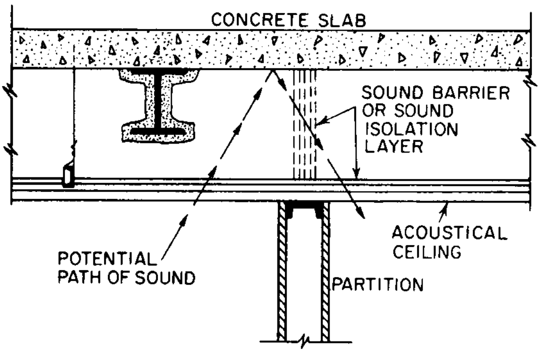


FIGURE 11.101 Prevention of sound transmission over partitions.

acoustical ceiling as a sound barrier. Performance data for most typical commercial ceilings are published in various bulletins and advertising matter.

11.80 ACOUSTICAL PERFORMANCE DATA

To simplify and standardize evaluation of the acoustical performance of materials and systems, various rating systems have been adopted. The best known and most widely used are those published by ASTM, 1916 Race St., Philadelphia, PA 19103.

Partitions, Floor-Ceiling Assemblies, and Barriers. Insulation (or isolation) of airborne sound provided by a barrier is usually expressed as its **sound transmission class** (STC). For a specific construction, STC is determined from a sound-transmission-loss curve obtained from a standardized test of a large-scale specimen. This curve is compared with a standard contour, and a numerical rating is assigned to the specimen (ASTM E90 test procedure and ASTM E413, Determination of Sound Transmission Class).

Table 11.27 lists typical STC ratings of several partition, wall, and floor-ceiling components or assemblies. Published data for almost any type of construction can be obtained from various sources.

A difference of one or two points between two similar constructions is rarely significant. Normally, constructions tend to fall into groups or classes with their median values about five points apart. In Table 11.28, the italic number represents the median of a performance group which includes the numbers on either side of the median.

The impact insulation (or isolation) provided by floor-ceiling assemblies is usually expressed as their impact noise rating (INR) or impact insulation (IIC). Like STC, INR and IIC values are obtained by comparing the curve of the sound spectrum obtained in a test with a standard contour (except that for INR and IIC the sound pressure level is measured in the room below the noise source). The entire procedure is controversial and far from widely accepted; but its use is so widespread that designers and builders should be aware of it. (See ASTM RM 14-4.)

Table 11.29 lists the impact isolation provided by several types of construction. Note particularly the enormous effect of certain floor coverings on the performance of the construction. (While IIC values are shown in Table 11.29, they can be converted to INR values by subtracting 51 points; for example, IIC 60 = INR 9, and IIC 45 = INR −6, etc.)

TABLE 11.28 STC Performance Groups

30	31	*32*	33	34
35	36	*37*	38	39
40	41	*42*	43	44
45	46	*47*	48	49
50	51	*52*	53	54
55	56	*57*	58	59

TABLE 11.29 IIC of Various Floor Constructions

Construction	IIC
Oak flooring on ½-in plywood subfloor, 2 × 10 joists, ½-in gypsum board ceiling	23
With carpet and pad	48
8-in concrete slab	35
With carpet and pad	57
2½-in concrete on light metal forms, steel bar joists	27
With carpet and pad	50

Acoustical Absorbents. Sound absorption coefficients and noise reduction coefficients of acoustical absorbents, including carpets and other furnishings, are usually readily available from manufacturers. The coefficients are normally obtained from laboratory tests of panel specimens of about 72- to 80-ft^2 area, tested according to ASTM C423. It is imperative that the test specimens be as nearly identical as possible, in construction system and detail, with actual field installations, since construction details enormously affect acoustical performance.

Table 11.30 lists performance ranges of typical absorbent materials. For specific data on specific materials or systems, always refer to specific tests by accredited test agencies.

The sound transmission loss through an acoustical ceiling (up and over a barrier) when the ceiling is used as a continuous membrane is often an important rating.

TABLE 11.30 Performance of Commonly Used Sound Absorbents

Absorbent	Thickness, in.	Density, lb per cu ft	Noise reduction coefficient
Mineral or glass fiber blankets	½–4	½–6	0.45–0.95
Molded or felted tiles, panels, and boards	½–1⅛	8–25	0.45–0.90
Plasters (porous)	⅜–¾	20–30	0.25–0.40
Sprayed-on fibers and binders	⅜–1⅛	15–30	0.25–0.75
Foamed, open-cell plastics, elastomers, etc.	½–2	1–3	0.35–0.90
Carpets	Varies with weave, texture, backing, pad, etc.		0.30–0.60
Draperies	Varies with weave, texture, weight, fullness		0.10–0.60

	Absorption coefficient per sq ft of floor area at frequencies. Hz:					
	125	250	500	1000	2000	4000
Seated audience	0.60	0.75	0.85	0.95	0.95	0.85
Unoccupied upholstered (fabric) seats	0.50	0.65	0.80	0.90	0.80	0.70

As might be expected, the effectiveness of acoustical absorbents as acoustical barriers is limited, and supplementary barriers or isolation are frequently required in normal construction.

Other Acoustical Materials. Performance ratings of damping materials, duct linings, vibration isolation materials and devices, etc., are available from various sources. Use of such materials is somewhat complex and specialized.

11.81 ACOUSTICAL CRITERIA

Acoustical performance criteria and environmental specifications are often part of building contract documents. Governmental agencies, lending institutions, owners, and tenants frequently require objective standards of performance.

To a large degree, acoustical criteria are subjective or are based on subjective response to acoustic parameters. This complicates attempts to provide objective specifications, but long experience has permitted acoustical experts to determine broad classes or ranges of criteria and standards that will produce satisfaction in most instances.

It is important to remember that one-point differences are normally insignificant in acoustical criteria. Usually, a tolerance of $\pm 2\frac{1}{2}$ points from a numerical value is acceptable in practice.

Tables 11.31 to 11.33 list some of the more common criteria for ordinary building spaces. They should, however, be used only as a guide. Obtain specific data or requirements whenever possible.

Acceptable Background Noise Levels. Steady, constant, unobtrusive sound levels that normally occur in typical rooms and that are acceptable as background noise are indicated in Table 11.31. For specific applications and in acoustically critical spaces, specific requirements should always be determined.

[*Note:* Levels are given in dBA, easily obtained numbers with simple measuring equipment (Art. 11.78). When noise criterion (NC) values are specified, they can be determined by subtracting about 7 to 10 points from dBA values; that is, dBA 50 = NC 40 to NC 43.]

TABLE 11.31 Typical Acceptable Background Levels

Space	Background level, dBA
Recording studio	25
Suburban bedroom	30
Theater	30
Church	35
Classroom	35
Private office	40
General office	50
Dining room	55
Computer room	70

Use of electronically generated masking sound, usually by means of speakers located above the ceiling, has become commonplace in open-plan spaces as a means of establishing a uniform background level. However, it is an expensive and complex procedure and should be handled only by acoustics experts.

Sound-Transmission-Loss Requirements. Acoustical performance requirements of sound barriers separating various occupancies may vary widely, depending on the particular needs of the particular occupants. Typical requirements for common occupancies in normal buildings are shown in Table 11.32.

In highly critical spaces, or where a large number of spaces of identical use are involved (as in a large hotel or multiple-dwelling building), it is always advisable to obtain expert acoustical advice.

Impact Isolation Requirements. Because the only standard test method available is controversial, impact isolation performance specifications are only broad, general suggestions, at best. The values in Table 11.33, however, are reasonably safe and economically obtainable with available construction systems.

TABLE 11.32 Sound Isolation Requirements between Rooms

Between: Room	and Adjacent area	Sound isolation requirement, STC
Hotel bedroom	Hotel bedroom	47
Hotel bedroom	Corridor	47
Hotel bedroom	Exterior	42
Normal office	Normal office	33
Executive office	Executive office	42
Bedroom	Mechanical room	52
Classroom	Classroom	37
Classroom	Corridor	33
Theater	Classroom	52
Theater	Music rehearsal	57

TABLE 11.33 Impact Isolation Requirements between Rooms

Between: Room	and Room below	Impact isolation requirement, IIC
Hotel bedroom	Hotel bedroom	55
Public spaces	Hotel bedroom	60
Classroom	Classroom	47
Music room	Classroom	55
Music room	Theater	62
Office	Office	47

Acoustical Absorption Requirements. It is ironic that requirements for the most widely used acoustical materials are the least well defined. So-called optimum reverberation time requirements (Fig. 11.99) are a reasonably safe specification for most rooms, but many additional requirements are often involved.

In general, where noise control is the significant requirement, the equivalent absorption of a full ceiling of acoustical tile providing a noise-reduction coefficient of about 0.65 to 0.70 is adequate. This absorption may be provided by carpet, furnishings, or other materials, as well as by acoustical tile. In many instances, however, no absorption at all should be applied to the ceiling of a room, because the ceiling may be a necessary sound reflector.

For important projects, always obtain the advice of competent acoustical consultants.

11.82 HELPFUL HINTS FOR NOISE CONTROL

A building encloses a myriad of activities and the equipment used in those activities. It is imperative that designers and builders consider the control of noise and vibration associated with such activities. While it is not practical to give here detailed solutions to the many potential acoustical conditions that may arise in the design of even one building, the more common situations encountered and the most likely palliatives for such problems are indicated in Tables 11.34 and 11.35.

Sound originates at a source and travels via a path to a **receiver.** Sound control consists of modifying or treating any or all of these three elements in some manner.

The most effective control measures often involve eliminating noise at the source. For example:

Balancing moving parts, lubricating bearings, improving aerodynamics of duct systems, etc.

Modifying parts or processes

Changing to a different, less noisy process

The most common sound control measures usually involve acoustical treatment to absorb sound; but equally important are:

Use of barriers to prevent airborne sound transmission

Interruption of the path with carefully designed discontinuities

Use of damping materials to minimize radiation from surfaces

Another important approach involves reinforcing the direct sound with controlled reflections from properly designed reflective surfaces.

Often, the most simple and effective approach involves protecting the receivers, enclosing them within adequate barriers, or equipping them with personal protection devices (ear plugs or muffs), rather than trying to enclose or modify huge sources or an entire room or building.

TABLE 11.34 Available Options in Noise Control

Objectives of sound-control efforts	Sound-control procedures*					
	Quiet the source†	Barrier or enclosures	Vibration isolation or damping	Absorption	Masking	Personal protection
Reduce the general noise level to:						
Improve communication	X		X	X‡		
Increase comfort	X		X	X‡		
Reduce risk of hearing damage	X		X	X‡		
Reduce extraneous, intruding noise to:						
Increase privacy		X‡			X	
Increase comfort		X‡	X			
Improve communication		X‡	X			
Protect many persons against localized source producing damaging levels	X	X‡	X	X		X
Protect many persons against many distributed sources producing damaging levels	X	X	X	X		X‡
Protect one person against localized source producing damaging levels	X	X§	X			X‡
Protect a few persons against many distributed sources producing damaging levels		X§				X‡
Eliminate echoes and flutter				X¶		
Reduce reverberation				X‡		
Eliminate annoying vibration			X‡			

*No mention has been made of another option, reinforcement, because its purpose is to increase levels. It is the only available option when the signal level must be increased.

†Always the best and simplest means of eliminating noise, if practical and economical.

‡Indicates the most likely solution(s).

§A closed booth or small room for the person(s) is often feasible.

¶Assumes that the configuration of the reflecting surface(s) cannot be modified.

TABLE 11.35 Typical Acoustical Problems and Likely Solutions

Problem	Possible causes	Solution
"It's so noisy, I can't hear myself think"	High noise levels	Absorption
	Excessive reverberation	Absorption
	Excessive transmission	Sound isolation
	Excessive vibration	Vibration isolation
	Focusing effects	Eliminate cause of focusing effects
"Speech and music are fuzzy, indistinct"	Excessive reverberation	Absorption
"Little sounds are most distracting"	Background level too low	Masking
	Room too "dead"	Optimum reverberation
"There's an annoying echo"	Echo	Proper room shape
	Flutter	Proper room shape
	Focusing effects	Eliminate cause of focusing effects
	Excessive reverberation	Absorption
"I can hear everything the fellow across the office says"	Room too "dead"	Optimum reverberation
	Background level too low	Masking
	Focusing or reflection	Eliminate focusing or reflection
"It doesn't sound natural in here"	Flutter	Alter room shape
		Add absorption
	Distortion caused by improper sound system	Proper sound system
	Selective absorption	Proper type and amount of absorption
	Room too "dead," low reverberation time	
"It feels oppressive"	Reverberation time too low	Proper amount of absorption
	Background sound level too low	Use of background and masking sound
"It's not loud enough at the rear of the room"	Room too large	Electronic amplification
	Improper shape	Alter room shape
	Lack of reflecting surface	Add reflecting surfaces
	Poor distribution	Eliminate absorption on surfaces needed for reflection
	Too much absorption	
"There are dead spots in the room"	Poor distribution	Reflecting surfaces
	Improper shape	Eliminate cause of focusing effects
	Echoes	Alter room shape

TABLE 11.35 (*Continued*)

Problem	Possible causes	Solution
"Sound comes right through the walls of these offices"	Sound leaks	Eliminate leaks
	Sound transmission	Sound isolation
	Vibration	Vibration isolation
	Receiving room too quiet	Masking
	Poor room location	Proper room layout
"I can hear machine noises and people walking around upstairs"	Vibration	Vibration isolation
	Sound transmission	Sound isolation
	Poor room location	Proper room layout
"Outside noises drive me crazy"	Poor room location	Proper acoustical environment
	Sound leaks	Eliminate leaks
	Sound transmission	Sound isolation

11.83 ACOUSTICS BIBLIOGRAPHY

L. L. Beranek, "Noise and Vibration Control," McGraw-Hill, Inc., New York.

P. D. Close, "Sound Control and Thermal Insulation of Buildings," Van Nostrand Reinhold Company, New York.

M. D. Egan, "Architectural Acoustics," McGraw-Hill, Inc., New York.

C. M. Harris, "Handbook of Acoustical Measurements and Noise Control," 3d ed., McGraw-Hill, Inc., New York.

P. M. Morse and K. U. Ingard, "Theoretical Acoustics," McGraw-Hill, Inc., New York.

L. E Yerges, "Sound, Noise and Vibration Control," Van Nostrand Reinhold Company, New York.