Concrete Masonry Handbook

for Architects, Engineers, Builders

Sixth Edition

J. A. Farny, J. M. Melander, and W. C. Panarese

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PCA Portland Cement Association

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ABSTRACT: This book reflects state-of-the-practice for concrete masonry construction, both in terms of design and construction. It includes descriptions of constituent materials like units, mortar, and grout, and provides an introduction to the structural behavior of masonry elements, including the types of loads acting on structures, how the loads are carried, key components of masonry walls, and a detailed description of placing masonry.

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Cover photos show a small sampling of representative colors and textures available in concrete masonry units. Beginning at the top center and moving clockwise, they are: IMG25756, IMG25757, IMG12681, IMG25030, IMG25758, IMG15609

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WARNING: Contact with wet (unhardened) concrete, mortar, cement, or cement mixtures can cause SKIN IRRITATION, SEVERE CHEMICAL BURNS (THIRD-DEGREE), or SERIOUS EYE DAMAGE. Frequent exposure may be associated with irritant and/or allergic contact dermatitis. Wear waterproof gloves, a long-sleeved shirt, full-length trousers, and proper eye protection when working with these materials. If you have to stand in wet concrete, use waterproof boots that are high enough to keep concrete from flowing into them. Wash wet concrete, mortar, cement, or cement mixtures from your skin immediately. Flush eyes with clean water immediately after contact. Indirect contact through clothing can be as serious as direct contact, so promptly rinse out wet concrete, mortar, cement, or cement mixtures from clothing. Seek immediate medical attention if you have persistent or severe discomfort.

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Over the years, many individuals and organizations within the concrete masonry industry have assisted in developing the previous editions and this expanded Sixth Edition of the *Concrete Masonry Handbook*. Trade associations, professional societies, manufacturers, architects, contractors, consultants, educators, and many others have provided research material and illustrations as well as manuscript reviews and commentary. We are particularly grateful for the assistance of the individuals listed below. This acknowledgment does not necessarily imply approval of the text by these individuals since the entire handbook was not reviewed by all those listed and since final editorial prerogatives have necessarily been exercised by the Portland Cement Association.

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Publications of the following organizations are frequently cited:

American Concrete Institute (ACI)

American Society for Testing and Materials (ASTM)

Brick Industry Association (BIA)

National Concrete Masonry Association (NCMA)

The Masonry Society (TMS)

Preface

Concrete masonry is a versatile, durable, and economical construction material. Since the beginning of the U. S. concrete masonry industry, in 1882, when the first concrete block was molded, the units have become a staple of construction. Concrete masonry is used to support structural loads and provide aesthetic appeal. And new technology has increased the variety of configurations and finishes available with the material, which is used in residential, commercial, and industrial structures, plus many special applications such as pavements, sound barrier walls, and retaining walls.

The *Concrete Masonry Handbook* has been the primary reference on concrete masonry since it was first published in 1951. As with past editions that reflected progress and advances in the masonry industry, the Sixth Edition also presents new developments and engineering concepts that have occurred since the Fifth Edition was originally published in 1991. Notably, there has been more attention placed on masonry's performance during earthquakes and high wind events. The handbook gives a more comprehensive discussion of building codes, structural design, and the interrelationship between them.

The layout of the book is the same as that of the previous edition. A greater emphasis has been placed on requirements of the new *Building Code Requirements and Specifications for Masonry Structures* (MSJC 2005). We continue the tradition of citing ASTM standards and have updated the list of them that appears following the References.

This Sixth Edition has a new appearance. In terms of graphics, full-color images have replaced all but a few of the black-and-white images. Tables and charts have a new look. The References have now been listed in the author-date style, which is more meaningful to those familiar with the technical literature on this topic and something that readers should find helpful.

The authors are grateful for contributions made to the Sixth Edition by leading experts in the field of concrete masonry (see Acknowledgments). They have attempted to make this edition a current and concise reference on concrete masonry technology. Readers are encouraged to submit comments to improve future printings and editions of this book.

Table of Contents

General Information on Concrete Masonry Units

CHAPTER 1

Concrete masonry is widely used to construct small and large structures because of its attractive appearance, minimum maintenance, safety, and economy. Concrete masonry provides an effective barrier to sound and reduces internal temperature variations and peak loads on heating and cooling systems. It provides architectural freedom and versatility with striking esthetic appeal. Almost any shape of structure is possible to construct as demonstrated in Fig. 1-2.

Concrete masonry is not easily damaged. It resists weathering and vandalism. Concrete masonry's durability and minimal maintenance requirements extend a building's useful life, providing an enduring, high-quality appearance. Special architectural units require no costly additional architectural treatments.

The concrete masonry units (CMUs) discussed throughout this publication often are referred to as concrete block or concrete brick. Concrete block is usually a relatively large unit with hollow cores. Though sizes vary, a typical concrete block is the rectangular 8x8x16-in. (203x203x406-mm) unit. Concrete brick basically matches the size and scale of regular clay brick. It is often difficult to distinguish high-quality concrete brick from clay brick.

Concrete masonry units (block and brick) are available in sizes, shapes, colors, textures, and profiles for practically every conceivable need and convenience in masonry construction. A few are pictured in Fig. 1-1. CMUs may be used to create attractive patterns and designs to produce an almost unlimited range in architectural treatments of wall surfaces. The list of current applications is lengthy, but some of the more prominent uses are for:

- Exterior load-bearing walls (below and above grade)
- Interior load-bearing or non-load-bearing walls

Fig. 1-1

Concrete masonry units are available in a wide variety of sizes and shapes. Photo courtesy of the Besser Company. (IMG5057)

Above: The most common type of concrete masonry unit is a standard gray block with a nominal size of 8x8x16 in. (203x203x406 mm). (IMG25645) Right: The concrete masonry used on this residence is well suited to its natural setting and complements other building materials. (IMG24759)

Fig. 1-2

Walls of varying shapes and geometries—like the curved, angled, and straight walls shown here—are easily constructed with concrete masonry units. Surface texture is a result of the split-face finish on the block. (IMG15666)

- Fire walls, party walls, curtain walls
- Partitions, panel walls, solar screens
- Backing for brick, stone, stucco, and exterior insulation and finish systems
- Veneer or nonstructural facing for wood, steel, concrete, or masonry
- Fire protection of structural steel members
- Firesafe enclosures of stairwells, elevator shafts, storage vaults, or fire-hazardous work areas
- Piers, pilasters, columns
- Bond beams, lintels, sills
- Retaining walls, slope protection, ornamental garden walls, and highway and railway sound barriers
- Chimneys and fireplaces (indoor and outdoor)
- Catch basins, manholes, valve vaults
- Paving and turf block

Specifications and Codes

As with every type of building material, a multitude of specifications and codes are available to guide or regulate manufacturers, designers, and builders. To supplement the information in this book, the reader is strongly encouraged to obtain copies of the Most recent edition of the Masonry Standards Joint Committee *Building Code Requirements for Masonry Structures* (*MSJC Code*), *Specification for Masonry Structures* (*MSJC Specification*), and the *Commentaries* to these documents (MSJC 2005). Other prominent references on the design and construction of masonry structures are listed at the end of this book.

In 1994, the International Code Council (ICC) was established as a nonprofit organization dedicated to developing a single set of comprehensive and coordinated national building codes. The ICC founders—the Building Official and Code Administrators (BOCA), the International Conference of Building Officials (ICBO), and the Southern Building Code Congress International (SBCCI)—created the ICC in response to technical disparities among the three sets of model codes then in use in the United States. ICC now offers a single, complete set of construction codes without regional limitations—the International Codes. This set includes the *International Building Code* (IBC) (ICC IBC 2006) and the *International Residential Code* (IRC) (ICC IRC 2006). The IBC adopts the *MSJC Code* by reference and, while the IRC primarily delineates prescriptive construction criteria, it also permits masonry to be designed according to the *MSJC Code*.

General Requirements

In the United States, concrete masonry units are manufactured to conform to requirements of the American Society for Testing and Materials (ASTM). Currently, there are six ASTM standard specifications for concrete masonry units as shown in Table 1-1.

Table 1-1. ASTM Standards for Concrete Masonry*

Type of unit	ASTM designation
Concrete Building Brick	C55
Calcium Silicate Face Brick	C73
Loadbearing Concrete Masonry Units	C90
Nonloadbearing Concrete Masonry Units	C129
Catch Basins and Manhole Units	C139
Prefaced Concrete Units	C744
Concrete Facing Brick	C1634

* See References for complete titles of these ASTM standard specifications.

Previous editions of these ASTM specifications classified concrete masonry units by grade and type. The grade described the intended use of the concrete masonry units, while the type described the moisture content condition of the units at the time of delivery. Except as noted below, grade and type designations have been eliminated from the current editions of the ASTM specifications for concrete masonry units.

In previous editions of ASTM C90, there were two grades of block, N and S, distinguishable only by differences in compressive strength and water absorption requirements. Grade N, having greater strength and lower absorption, provided greater resistance to severe weathering and was appropriate for facing applications. Grade S offered moderate strength and resistance to weathering. These type designations have been discontinued and today C90 block requirements correspond to old Grade N provisions. ASTM C55 now addresses requirements for concrete building brick, which correspond to the old Grade S provisions. ASTM C1634 is the specification for concrete facing brick, and corresponds to old Grade N concrete brick.

ASTM C73 has a Grade SW for severe weathering exposure and MW for moderate weathering exposure.

Two types of concrete masonry units were designated in previous editions of ASTM C90, C55, and C129: they were indicated as either Type I, moisture-controlled units, or Type II, nonmoisture-controlled units. Type I units were specified in situations where drying shrinkage of the block due to loss of moisture could result in excessive stress and cracking of walls.

Like many building materials, concrete shrinks slightly with loss of moisture. The amount of moisture loss is affected by the relative humidity of the surrounding air. After concrete has dried to constant moisture content at one atmospheric condition, a decrease in humidity causes it to lose moisture or an increase causes it to gain. However, air-dry concrete at equilibrium with a given relative humidity is influenced by many factors and is not significantly related to the total absorbed water in a saturated block (see Menzel 1957). When moist units are placed in a wall and the inherent shrinkage is restrained, as it often is, tensile and shearing stresses are developed that may cause cracks in the wall.

Requirements for Type I moisture controlled units limited moisture content at the time of delivery on the basis of total absorption, linear drying shrinkage of the unit, and average annual relative humidity of the geographical region. However, requirements for moisture controlled units were difficult to understand and nearly impossible to verify during construction. In recognition of these difficulties and the fact that Type I units were not available in many regions, more conservative control joint spacing quidelines have been developed for concrete masonry construction consistent with anticipated total volume changes rather than specified moisture content. Since the Type I requirements no longer influence control joint spacing or other crack control strategies, these requirements have been eliminated from ASTM specifications for concrete masonry units.

Compressive strength is an important property of concrete masonry. Strength requirements are given in Table 1-2. To understand the significance of the different ASTM strength requirements, note that net area and shape play an important role. First, the concrete strength requirements for solid and hollow block or for concrete brick are essentially the same. However, "solid" block—masonry units in which the voids do not exceed 25% of the cross-sectional area at any plane parallel to the bearing surface—have more material to resist load than "hollow" block with about 50% solid material. Also, a flat concrete brick will have a considerably higher crushing strength than the shell of a hollow block, just as a 2¼-in.-high (57-mm) column 4 in. (102 mm) wide will be stronger than an 8-in.-high (203-mm) column 1¼ in. (32 mm) wide.

The economic use of concrete masonry over a wide range of applications is made possible by the availability of units with a wide range of strengths. Units called "high-strength block" are gaining in popularity. Their manufacture is slightly different from regular units; they have to be produced more slowly and selection of the block mixture must be made more carefully.

High-strength block are not yet defined by a national specification, but high-strength block can be manufactured by all block producers with most aggregates or combinations of aggregates. A higher strength than that required by ASTM C90 may be specified where required by design. Check with local suppliers to determine availability of units of higher compressive strength. High-strength block is usually limited to applications where the units are required to minimize wall thickness in buildings over 10 stories high. Drying shrinkage of high-strength units may be twice that of

Table 1-2. Strength and Absorption Requirements for Concrete Masonry Units

Type of Unit	ASTM designation	Number of units tested	Minimum compressive strength, psi (MPa), on minimum net area	Maximum water absorption, pcf (kg/m³), based on oven-dry weight of concrete† Lightweight concrete, less than 105 (1680)	Medium weight concrete, 105 to less than 125 (1680 to less than 2000)	Normal weight concrete, 125 (2000) or more
Concrete brick	C55	Average of three units	2500 (17.3)*	18 (288)	15 (240)	13 (208)
		Individual unit	2000 (13.8)*	20 (320)	17 (272)	15 (240)
Hollow and solid load-bearing block	C90	Average of three units	1900 (13.1)**	18 (288)	15 (240)	13 (208)
		Individual unit	1700 (11.7)	20 (320)	17 (272)	15 (240)
Hollow and solid nonload-bearing block	C129	Average of three units	600 (4.1)**	—	—	—
		Individual unit	500 (3.5)**	—	—	—
Concrete facing brick	C1634	Average of three units	3500 (24.1)	15 (240)	13 (208)	10 (160)
		Individual unit	3000 (20.7)	17 (272)	15 (240)	12 (192)

* Concrete brick tested flatwise.

** Minimum compressive strength on average net area.

† Absorption based on oven-dry weight of concrete.

units made under ASTM C90. On the other hand, absorption decreases with strength and density of the units (see Holm 1972).

The amount of water absorption is related to the density of concrete masonry units as shown in Table 1-2. These properties affect construction, insulation, acoustics, appearance, porosity, painting, etc. Absorption characteristics of CMUs affect the quality of mortar needed. If a masonry unit absorbs water too fast, the mortar will need to have more water retentivity. This is necessary to give the mason time to place and adjust the unit before the mortar stiffens, and to achieve a strong mortar bond. Absorption is a specification requirement for CMUs that conform with ASTM C55, C90, and C1634. The procedure for determining absorption of CMUs is provided in ASTM C140.

Architectural concrete masonry units for interior use should comply with the requirements of ASTM C90 for hollow and solid load-bearing units. Architectural concrete masonry units for exterior use are specified to conform with the requirements for concrete facing brick, ASTM C1634.

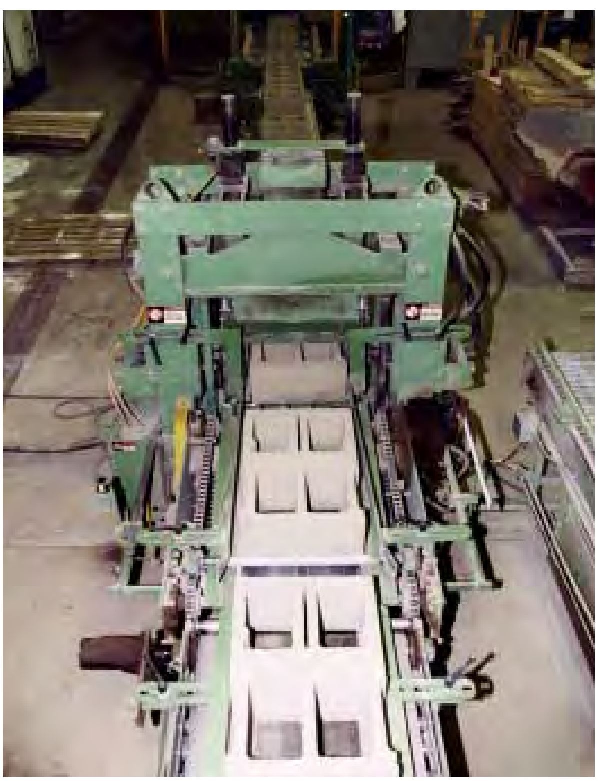


Fig. 1-3

A modern block plant in operation. Blocks move along conveyor throughout the plant. (IMG15914)

The ASTM specifications for concrete masonry do not fix features such as the weight, color, surface texture, fire resistance, thermal transmission, or acoustical properties of the units. Local producers should be consulted on availability of units having the desired features.

Manufacture

Concrete masonry units consist mainly of portland cement, graded aggregates, and water. Depending upon specific requirements, the concrete mixture may also contain other ingredients such as air-entraining agents, coloring pigments, siliceous and pozzolanic materials, and water repellents.

Mass production contributes to the relatively low cost of concrete masonry units. In many production plants some phases of the manufacturing process are completely automated.

The manufacturing process involves the machine-molding of very dry, no-slump concrete into the desired shapes, which are then subjected to an accelerated curing procedure. This is generally followed by a storage or drying phase where the moisture content of the units reaches equilibrium with ambient conditions. The concrete mixture must be carefully proportioned and its consistency controlled so that texture, color, dimensional tolerances, and other desired physical properties are consistently obtained. High-strength units are made with concrete mixtures with higher cement contents and more water, but these mixtures still have no slump. Machines are available to consolidate and compact these concretes by vibration and pressure, and mold approximately one thousand 8x8x16-in. (203x203x406-mm) masonry units (or their equivalent in other sizes) per hour.

Two types of accelerated curing—low-pressure and high-pressure steam curing—are used by the concrete masonry industry, with variations according to local plant requirements and raw materials. The more common curing procedure involves heating the block in a steam kiln at atmospheric pressure to temperatures ranging from 120°F to 180°F (49°C to 82°C) for up to 18 hours (see ACI 517 1992). Atmospheric pressure methods may require subsequent accelerated drying treatment or a period of natural drying in the storage yard under protective cover. A variation of low-pressure curing includes a carbonation stage to reduce the shrinkage of the masonry units.

Another curing method that is rarely used today for CMUs is autoclaving or high-pressure steam curing (see Fig. 1-4 and ACI SP-32 1972). In this process the units are subjected to saturated steam at 325°F to 375°F (163°C to 191°C) and 80 psig to 170 psig (0.55 MPa to 1.17 MPa) maximum pressure in a large cylindrical pressure vessel for up to 12 hours. The time interval at maximum temperature is preceded by a period of 1 to 4 hours and by a pressure-buildup over approximately 3 hours. At the end of the steaming cycle it is common practice to drain the condensate and reduce the cylinder pressure as rapidly as possible—within 20 to 30 minutes. Using this procedure, stored heat quickly lowers the absorbed moisture content of the units to specification requirements.

For storage or shipment to the building site the units are generally placed in small stacks or "cubes" consisting of layers with fifteen to eighteen 8x8x16-in. (203x203x406-mm) units per layer, or an equivalent volume in other sizes. The cubes, typically 48x48x48 in. (1.22x1.22x1.22 m), may be assembled on wooden pallets or banded with the bottom layer of block having cores positioned horizontally. Most delivery trucks are equipped with a fork-lift device for unloading the cubes at storage areas on the building site. The number of units per pallet or cube varies with the size of the unit; a pallet of 8x8x16-in. (203x203x406-mm) block will have about 100 units, while a pallet of regular concrete brick will have about 500 units.

Fig. 1-4

Exit from curing chamber. (IMG15912)

Types

Units are available in a wide variety of weights, sizes, shapes, and exposed surface treatments for virtually any architectural or structural function. Manufacturers or related associations can supply literature that describe available types of units (see TEK 2-1A 2002). In advance of any detailing the designer should determine the sizes, shapes, textures, and other properties of the masonry units required for the proposed construction as well as their availability from local producers.*

Normal-Weight and Lightweight Masonry Units

The terms "dense or normal-weight" and "lightweight" are derived from the density of the aggregates used in the manufacturing process. The normal-weight aggregates used are sand and gravel, crushed stone, and air-cooled blast-furnace slag. The lightweight aggregates include expanded shale, clay, and slate; expanded blast-furnace slag; sintered fly ash; coal cinders; and natural lightweight materials such as pumice and scoria. In 1988-89, the United States saw the debut of a cold-bonded, pelletized-fly ash aggregate (agglomerated) consisting of fly ash, cement or lime, and admixtures. This fly ash aggregate (Fig. 1-5) can be used in lightweight or normal-weight masonry units.

In general, local availability determines the use of any type of aggregate. In some locations the term "concrete block" has been used to designate only those units made with sand and gravel or crushed stone aggregates. Generally speaking, however, concrete block can made with any of the aggregates listed in Table 1-3.

The weight class of a concrete masonry unit is based upon the density or oven-dry weight per cubic foot of the concrete it contains. A unit is considered lightweight if it has a density or unit weight of 105 pcf (1680 kg/m^3) or less, medium-weight if it has a density between 105 pcf and 125 pcf (1680 kg/m^3 and 2000 kg/m^3), and normal-weight if it has a density of more than 125 pcf (2000 kg/m^3). Concrete containing various aggregates range in unit weight as shown in Table 1-3.

* *To obtain a list of local producers, consult the yellow pages of the telephone directory and contact the National Concrete Masonry Association, 13750 Sunrise Valley Drive, Herndon, Virginia, 20171-3499, Phone: 703-713-1900, Fax: 703-713-1910.*

Table 1-3. Ranges in Unit Weight of Concrete Made with Various Aggregates

Concrete	Unit weight, pcf (kg/m³)
Sand and gravel concrete	130-145 (2080-2320)
Crushed stone and sand concrete	120-140 (1920-2240)
Air-cooled slag concrete	100-125 (1600-2000)
Coal cinder concrete	80-105 (1280-1680)
Expanded slag concrete	80-105 (1280-1680)
Pelletized-fly ash concrete	75-125 (1200-2000)
Scoria concrete	75-100 (1200-1600)
Expanded clay, shale, slate, and sintered fly ash concretes	75-90 (1200-1440)
Pumice concrete	60-85 (960-1360)
Cellular concrete	25-44 (400-700)

Fig. 1-5

Pelletized aggregate made from fly ash and cement. (IMG15667)

In addition to concrete density, the weight of a concrete masonry unit depends upon the volume of concrete in the unit. The design of the unit in turn affects its concrete volume. Approximate weights of various hollow masonry units may be determined from Fig. 1-6.

Use of lightweight aggregates can reduce the weight by 20% to 45%, compared with the weight of similar units made of normal-weight aggregates, without sacrificing structural properties. Whether the designer or builder chooses lightweight or normal-weight units generally depends upon availability and the requirements of the structure. Another consideration is

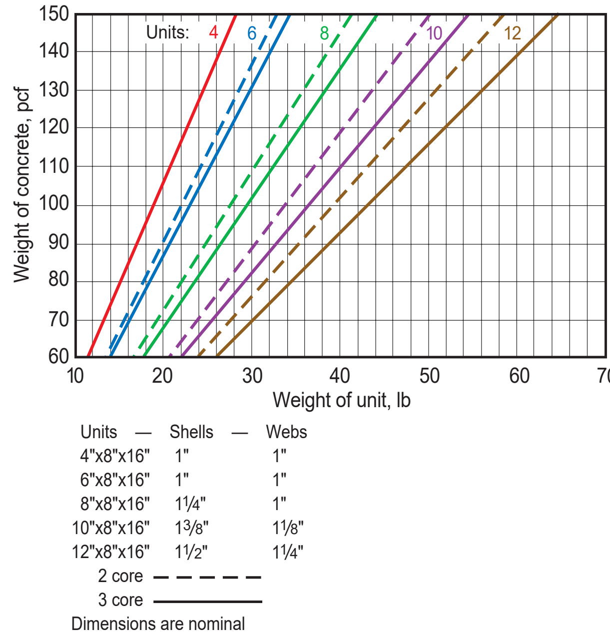


Fig. 1-6

Weights of some hollow units for various concrete densities.

worker efficiency—workers are more efficient with lightweight block than normal-weight block.

Hollow and Solid Units

Concrete block are classified as hollow or solid. In 1990, ASTM made several changes to its C90 specification, the most important being the incorporation of both hollow and solid units. ASTM C145 for solid load-bearing concrete masonry units was discontinued. Architects specifying concrete masonry units should therefore call for "ASTM C90 hollow units" or "ASTM C90 solid units." For more information on these changes, see Hanley-Wood 1991.

A hollow unit is defined as one in which the net concrete cross-sectional area in every plane parallel to the bearing surface is less than 75% of the gross cross-sectional area measured in the same plane. Units having net concrete cross-sectional areas of 75% or more are classified as solid units (ASTM C90 and C129). The net concrete cross-sectional areas of most concrete masonry units range from 50% to 70% (30% to 50% core area) depending on unit width, face-shell and web thicknesses, and core configuration. Because of their reduced weight and ease of handling, hollow units are in greater use than solid units. Fig. 1-8 illustrates the various parts of a hollow block.

Table 1-4. Minimum Thickness of Face Shells and Webs*

Nominal width of unit, in. (mm)	Minimum face-shell thickness, in. (mm)**	Web thickness	
		Minimum web, in. (mm)†	Minimum equivalent web, in./lin.ft. (mm/lin.m)††
3 and 4 (76 and 102)	¾ (19)	¾ (19)	1⅝ (136)
6 (152)	1 (25)	1 (25)	2¼ (188)
8 (203)	1¼ (32)	1 (25)	2¼ (188)
10 (254)	1⅜ (35) (1¼) (32)++	1⅛ (29)	2½ (209)
12 (305)	1½ (38) (1¼) (32)++	1⅛ (29)	2½ (209)

* Adapted from ASTM C90. Note that face-shells and webs may be slightly tapered or flared (thicker at the top of the unit than the bottom) to allow for better gripping by the mason, to provide a broader base for mortar bedding, and to facilitate stripping during the manufacturing process (Fig. 1-9c).

** Average of measurements on three units taken at the thinnest point. Split faced units are permitted to have a maximum of 10% of split face shell area with thicknesses less than those shown, but not less than ¾ in (19 mm). When units are solid grouted, the minimum face shell thickness is ¾ in. (19 mm), and the 10% limit does not apply apply to split faced units.

† The minimum web thickness for units closer than 1 in. (25.4 mm) apart is ¾ in (19 mm).

†† Sum of measured thickness of all webs in a unit times 12 divided by length of unit. Equivalent web thickness does not apply to the portion of the unit to be filled with grout. The length of that portion is deducted from the overall length of the unit for the calculation of equivalent web thickness.

++ This face-shell thickness is applicable where the allowable design load is reduced in proportion to the reduction in thickness from the basic face-shell thickness shown, except that allowable design loads on solid grouted units is not reduced.

Fig. 1-7

Load-bearing concrete masonry walls are used in this structure. (IMG24166)

For structural reasons some standards governing concrete masonry units stipulate minimum face-shell and web thicknesses as shown in Table 1-4. Non-load-bearing hollow units (ASTM C129) are not required to meet these minimum thicknesses, except that the face shell cannot be less than ½ in. (13 mm) thick.

Solid masonry units are used only for special needs, such as for structures having higher than usual design stresses, for the top or bearing course of load-bearing walls, for increased fire protection, or for catch basin or manhole construction. Some concrete units are made 100% solid (without cores), although some concrete brick designs include a shallow depression, often called a "frog," in one bearing face (Fig. 1-11d). However, the net volume of the frog should be not more than 15% of the gross volume of the unit. The purpose of the frog is to reduce weight, provide for better mechanical bond, and prevent the unit from floating when laid in the wall.

Modular Sizes

Concrete masonry unit dimensions are for the most part based on some module, usually 4 in. or 8 in. (102 mm or 203 mm). From common usage the ⅜-in.-thick (10-mm) mortar joint has become standard. Accordingly, the exterior dimensions of modular units are reduced by the thickness of one mortar joint, that is

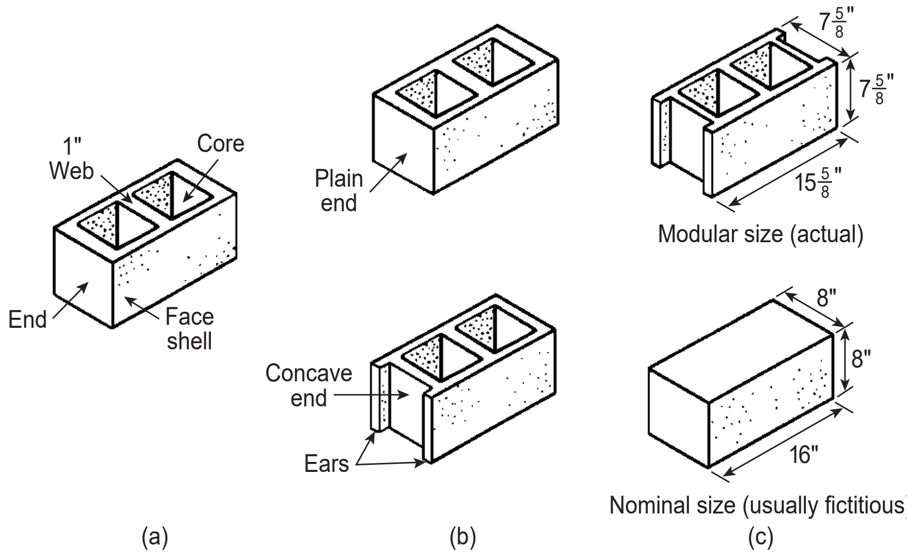


Fig. 1-8

(a) Parts of hollow block. Each block has two face shells, two ends, and one or more webs. (b) Common end types. Special ends are illustrated in Figs. 1-10 through 1-12. (c) Block size nomenclature.

⅜ in. (10 mm). Thus, when laid in a wall the modular units produce wall lengths, heights, and thicknesses that are multiples of the given module. This permits the designer to plan building dimensions and wall openings that will minimize the expense of cutting (sizing) units on the job.

Common practice in specifying concrete block is to give the block width first, the height second, and the length third, followed by the name of the unit. Dimensions given are nominal, with actual unit dimensions being ⅜ in. (10 mm) less. Fig. 1-8c shows the dimensional details for an 8x8x16-in. (203x203x406-mm) unit, the nominal block size that dominates the industry.

Block is commonly available in widths of 2, 4, 6, 8, 10, and 12 in. (51, 102, 152, 203, 254, and 305 mm). Typical nominal block heights are 4 in. and 8 in. (102 mm and 203 mm), but 12-in. (305-mm) units are also available. Half-length units and low or half-height units are made as companion items for the mason's convenience in completing various patterns. In some areas the 4-in. (102-mm) module is popular with nominal unit lengths of 8, 12, 16, 20, and 24 in. (203, 305, 406, 508, and 610 mm).

Some manufacturers may make units in full nominal dimensions or in stated dimensions other than modular. Whether units are modular or nonmodular, ASTM standards require that tolerances from the manufacturer's catalogued dimensions not exceed ±⅛ in. (3 mm). The control in block plants is such, however, that actual variations are seldom greater than ±1⁄16 in. (2 mm). The width of split-block units should not be specified within these tolerances. The close tolerances and uniformity of manufactured concrete masonry units makes it easier for a mason to build structures with uniform mortar-joint thickness, which results in a more pleasing final appearance of the structure.

Core Types

There are many masonry unit design variations. For example, units can be either two-core or three-core. While three-core units were common in the past, most manufacturers now only provide two-core units.

Fig. 1-9 shows some of the variations in core and end designs for 8x8x16-in. (203x203x406-mm) concrete masonry units. Some producers make regular stretcher units with flanged ends in the 8-, 10-, and 12-in. (203-, 254-, and 305-mm) widths. Others have adopted, for regular production, single and double plain-ended designs, thereby meeting needs for stretcher, corner, or pier units from single stocks of a given width. In general, all 4-in.- (102-mm-) and most 6-in.-wide (152-mm-) hollow units are made with plain ends, but may contain either two or three cores.

The cores of hollow units are tapered to facilitate stripping in the machine molding process. Some core designs also include a degree of flaring of the face or web to give a broader base for mortar bedding and for better gripping by the mason. The face shells are some-

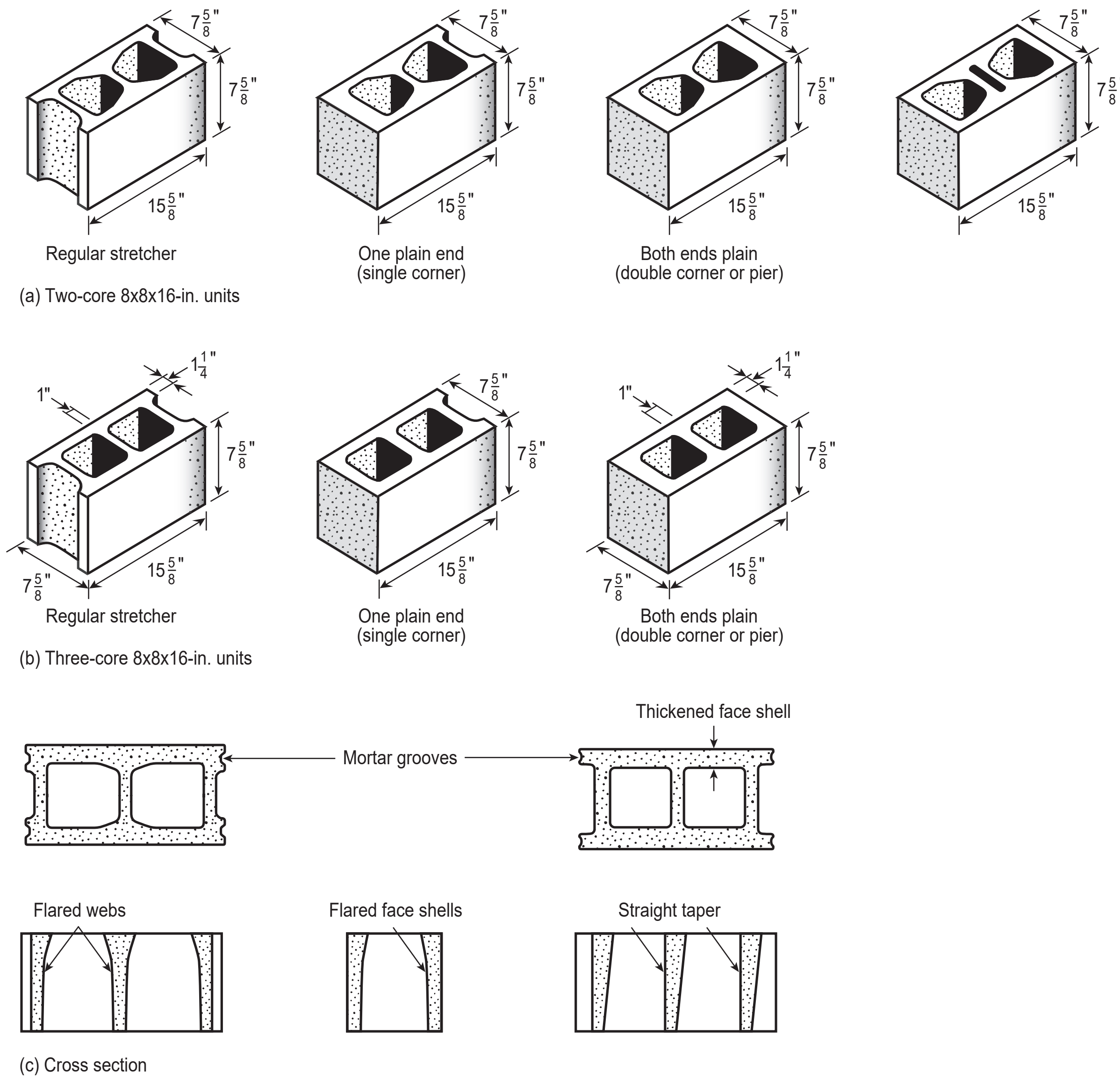


Fig. 1-9

Variations in core and end details of 8x8x16-in. (203x203x406-mm) units. Core types shown are used also for 4-, 6-, 10-, and 12-in.-wide (102-, 152-, 254-, and 305-mm) units. Generally, 4- and 6-in. units are made with both ends plain. *Consult local producers for specific available units.*

times thickened as indicated in Fig. 1-9c; this is done to provide greater tensile strength at these regions in the finished wall (see Menzel 1958 and Hedstrom 1966). End flanges may be grooved or plain.

Size and Shape Variations

Fig. 1-9 and the remainder of the drawings in this chapter present a sampling of the large number of sizes and shapes of concrete masonry units from which the designer may choose to build economical and attractive concrete masonry structures. A complete listing is not possible here as some plants produce several hundred different items. Some sizes and shapes are limited to certain areas or are made only on special order. Naturally, there are added costs involved in stocking numerous sizes and shapes, especially if demand is limited. This is why there may be limited availability.

Fig. 1-9 shows stretcher and corner units employed in conventional concrete masonry wall construction. Fig. 1-10 includes some of the shapes that are available

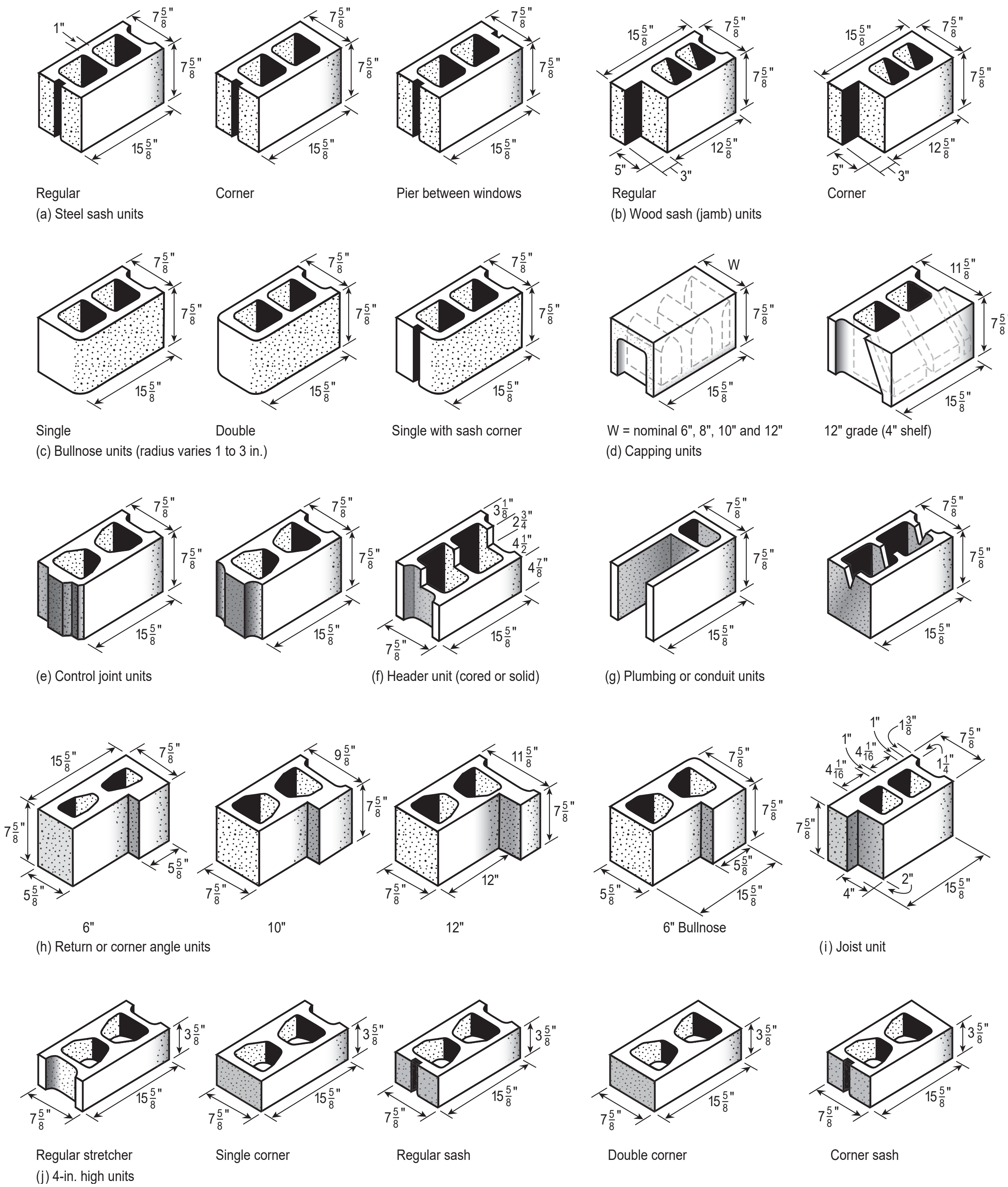


Fig. 1-10

Some sizes and shapes of concrete masonry units for conventional wall construction. Dimensions shown are actual and used for modular construction with 3/8-in. (10-mm) joints. Half-length units are generally available in shapes shown. Widths range from 4 to 12 in. nominal (102 to 305 mm) in 2-in. (51-mm) increments for some shapes. *Consult local producers for availability before specifying.* Slide No. K-17344 [for (a)-(d) only].

for the builder's convenience for conventional concrete masonry walls or for a particular need. Half-length units are generally available in most of the shapes shown. Alternately, an easily split slotted two-core unit may be used (see far right unit in Fig. 1-9a) or a masonry saw may be used to cut special shapes or shorter lengths from whole units.

Corner blocks have one flush end for use in pilaster, pier, or exposed corner construction. Bullnose blocks have one or more small radius-rounded corners and are used instead of square-edged corner units to minimize chipping. Jamb or sash blocks are used to facilitate the installation of windows or other openings. Capping blocks have solid tops for use as a bearing surface in the finishing course of a wall. Header blocks have a recess to receive the header unit in a composite masonry wall although these units are essentially no longer used in new construction of exterior walls. Return or corner-angle blocks are used in 6-, 10-, and 12-in.-thick (152-, 254-, and 305-mm-) walls at corners to maintain horizontal coursing with the appearance of full-length and half-length units.

Fig. 1-11a shows a number of block types available for partition construction and facing unit backup. Solid units and cap or paving units (Fig. 1-11b and c) are manufactured in a variety of sizes for use as capping units for parapet and garden walls and for use in stepping stones, patios, fireplaces, barbecues, or veneer (other units of this type are shown in Chapter 8). They may be used both structurally and nonstructurally. When they are used in reinforced walls, the reinforcing steel is generally placed in grout spaces between wythes (each continuous vertical section of a wall one masonry unit in thickness).

Some typical concrete brick units are shown in Figs. 1-11d, and 1-12 through 1-14. Concrete brick is sized to be laid with ⅜-in. (10-mm) mortar joints, resulting in modules of 4-in. (102-mm) widths and 8-in. (203-mm) lengths. These brick are typically only 2¼ in. (57 mm) high. The thickness of mortar joints is increased slightly so that three courses (three brick and three bed joints) lay up 8 in. (203 mm) high.

Slump units (Fig. 1-11d and e) are produced by using a concrete mixture finer and wetter than usual. The concrete brick or block unit is squeezed to give a bulging effect. The rounded or bulging faces resemble handmade adobe, producing a pleasing appearance (Fig. 1-15).

Split brick or block (Fig. 1-11d, f, g, and h) are solid or hollow units that are fractured (split) lengthwise or crosswise by machine to produce a rough stone-like texture (Fig. 1-16). The fractured face or faces, which are exposed when the units are laid, are irregular. When the units are split, aggregates are exposed in the planes of fracture. By varying the cements, aggregates, color pigments, and unit size, a wide variety of interesting colors, textures, and shapes are produced. The nominal length of split units is 16 in. (406 mm), but half-length units, return corners, and other multiples of 4 in. (102 mm) are obtainable. The solid units are nominally 4 in. (102 mm) wide and available in various modular heights ranging from 1⅝ in. to 7⅝ in. (41 mm to 194 mm). Split solid units are used as a veneering or facing material. Ribbed hollow units, which can be split to produce unusual effects, are widely used for through-the-wall applications indoors or out.

Fig. 1-17 shows some of the specialized shapes for constructing window sills, copings, bond beams, and lintels. Reinforced bond beams are useful to minimize cracking in walls due to temperature and moisture change (Figs. 1-18 and 1-19). In areas of recurring earthquakes or hurricanes, where there is a high probability of structures being subjected to extreme loads from wind or ground motion, reinforced bond beams and vertical and horizontal wall reinforcement are mandatory. Reinforced lintels are necessary to bridge over openings for windows and doors. The various sizes and shapes of lintels shown in Fig. 11-17g are for different load capacities, spans, wall widths, and window or door types.

Figs. 1-20 and 1-21 illustrate some types of units made for the construction of pilasters, columns, and chimneys.

Fig. 1-22 shows some typical masonry unit shapes made for the construction of sewer manholes, catch basins, valve vaults, and other underground structures. Some unit designs include matching tongue and groove ends. In some areas a similar type of concrete masonry unit may be available for use in the construction of silos and similar containers that must resist internal pressures. These units may be equipped with not only matching tongue and groove ends, but also slots in the bed planes for keyed horizontal joints. Depending upon the service requirements, the whole structure might also be hooped with steel bands.

Although used less frequently today, screen block or grille units are ideal as decorative and functional masonry. A few designs are shown in Fig. 1-23. The units available have a wide range of sizes from 4 in. to

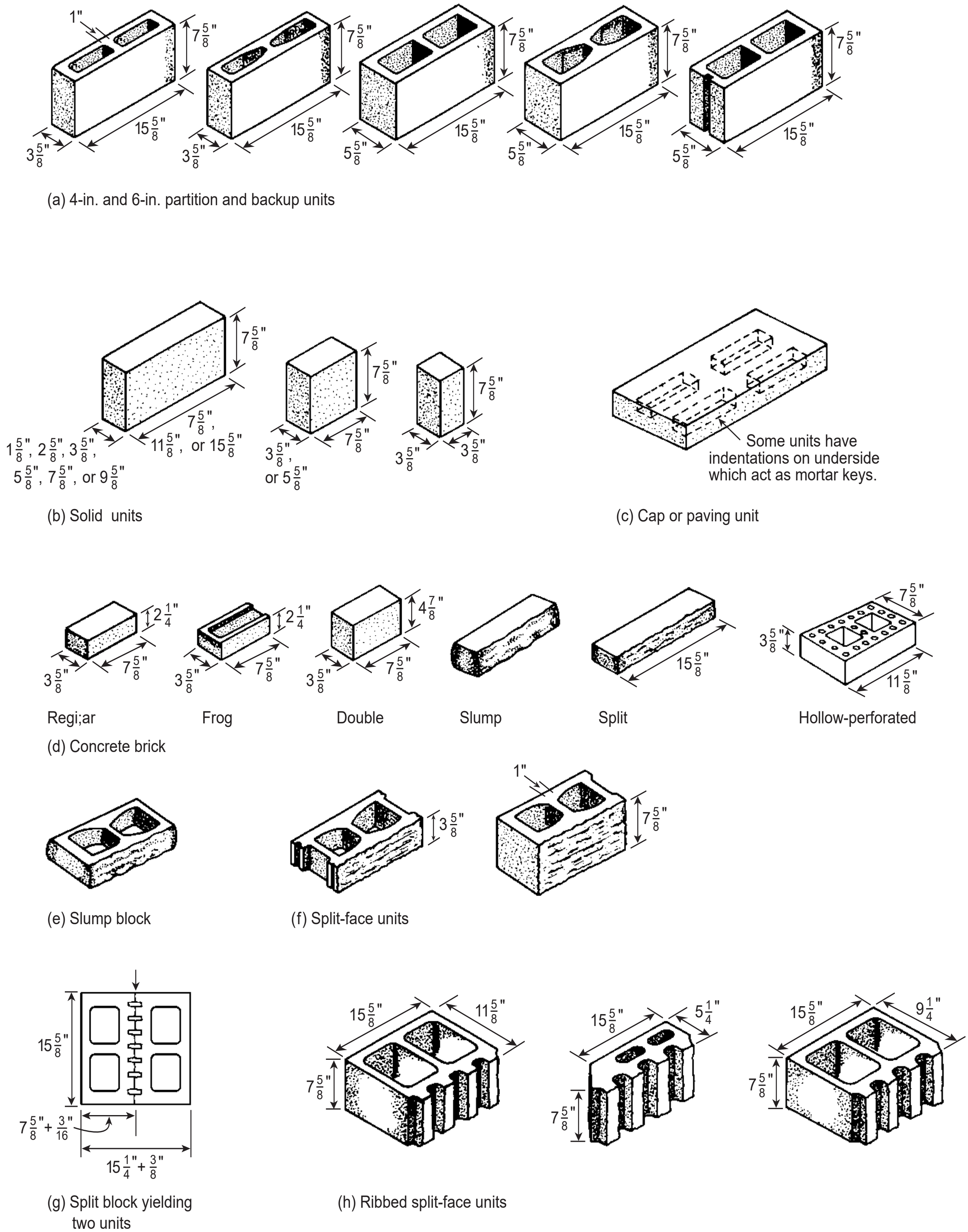


Fig. 1-11

Some sizes and shapes of concrete masonry units for partition and backup block, solid and cap or paving block, concrete brick, and slump and split units. *Consult local producers for specific available units.*

Fig. 1-12

Regular sized concrete brick. (IMG16997)

Fig. 1-13

Rusticated concrete brick has a rough, rugged texture. (IMG15082)

Fig. 1-15

Slump-block garden wall. (IMG17396)

Fig. 1-14

Rusticated concrete brick pavers are popular in residential and commercial construction. (IMG15214)

Fig. 1-16

Exterior wall of 4-in.-high (102-mm) split-face units. (IMG15911)

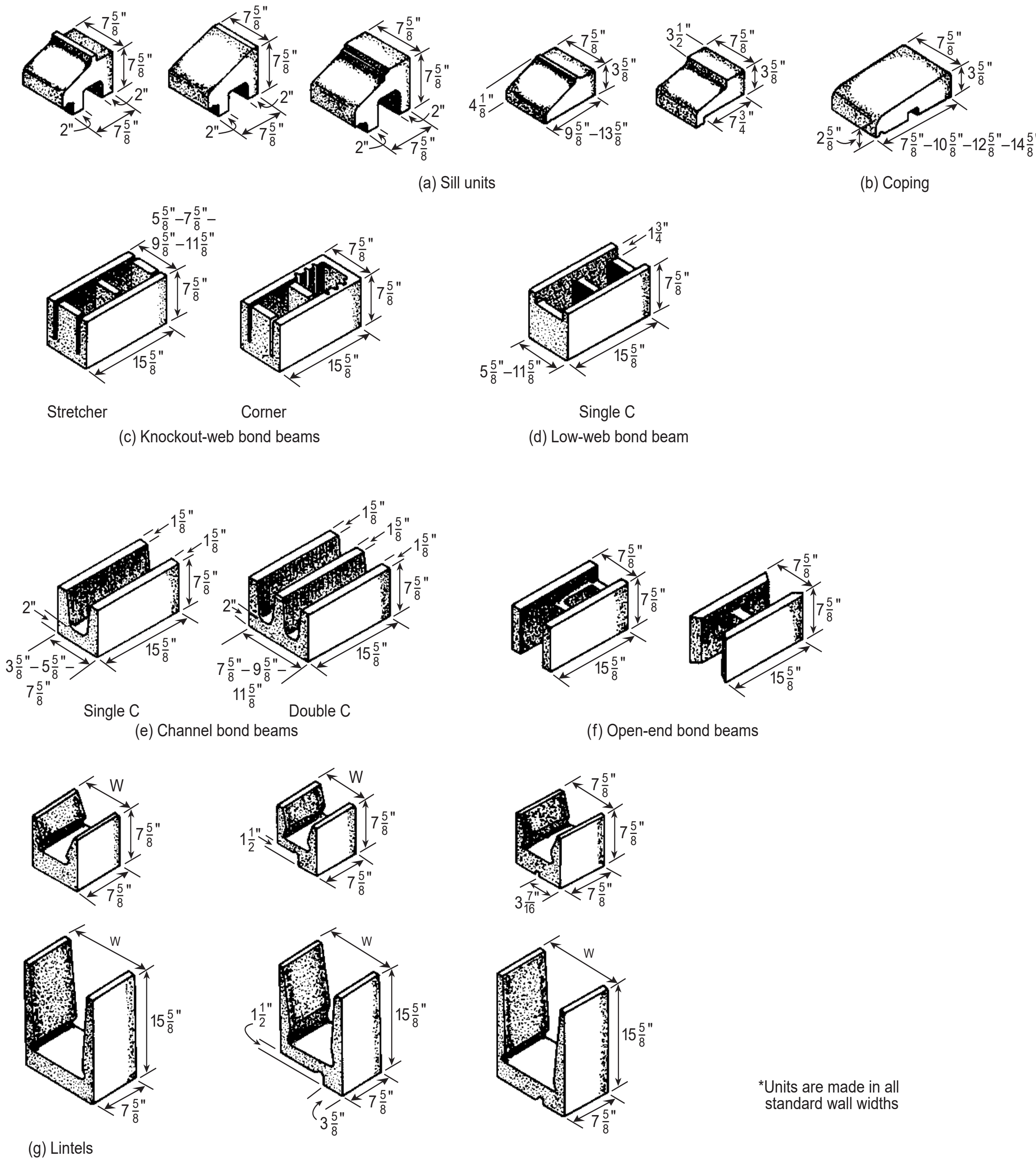


Fig. 1-17

Some sizes and shapes of concrete masonry units for sills, copings, bond beams, and lintels. *Consult local producers for specific available units.*

Fig. 1-18

Channel bond beam. (IMG4025)

Fig. 1-19

This architectural unit has low-web bond beam knock-outs. (IMG24197)

16 in. (102 mm to 406 mm) square to meet nearly every need. Though often used mainly for their aesthetic value, they also provide excellent balance between privacy and vision from within or without (Fig. 1-24). They diffuse strong sunlight, provide a wind break, and yet permit free flow of air. The decorative value of the units is enhanced by the effects that variations in light and shade produce on their patterns. The principal uses are for decorative building facades, ornamental room dividers and partitions, garden fences, and patio screens. Construction details are given in Chapter 8.

Although there is nearly an endless variety of possible patterns for screen block, the availability in any locality may be limited. When a pattern is not available locally, it is often possible for the block plant to rent the mold from the block machine manufacturer or another block producer. The numerous screen block designs available, coupled with the possibility of using several orientations of a particular unit in a wall, give the designer nearly unlimited opportunity for producing beautiful screen wall effects. Although a wide range of designs with screen block can be obtained, basically the designs include:

1. Units that are a complete pattern in themselves. When laid, the wall forms a panel of small individual repetitive patterns.
2. Units that form part of a pattern. The pattern may require two or sometimes four units to be completed. The designer should consider the aesthetic effects of an incomplete pattern if the dimensions of the wall are not a multiple of the dimensions of the pattern.
3. Various types of units that can form an overall pattern in a wall with interesting and varied effects. Several different patterns are possible using only two types of units.
4. Conventional solid or hollow block units, which can be used quite successfully in screen walls if laid with spaces between the units. Hollow block laid on their ends or sides also provide interesting and attractive screen walls (see Figs. 4-38 and 8-16).

Architectural concrete masonry units, sometimes known as customized masonry or sculptured units, offer additional opportunities for architectural freedom. Some of the possibilities are indicated in Fig. 1-25. Patterns and profiles in the block can be achieved with vertical scoring, fluted or ribbed faces, molded angles or curves, projected or recessed faces (Fig. 1-26), or combinations of these surfaces. The designer may select virtually any shape that can be molded vertically within the bounds of the 18x26-in. (457x660-mm) metal pallet under the block machine. A few block machines have larger pallets. Usually the vertical height of the unit is limited to 7⅝ in. (194 mm), though some block manufacturers produce units 11⅝ in. high (295 mm).

With architectural concrete masonry the selection of the unit profile desired may be closely related to the architectural design of the building. The architect may use:

- Surface color and texture
- Exposed aggregates
- Type of aggregates to be exposed
- White or buff-colored cement or color pigments
- Unit dimensions

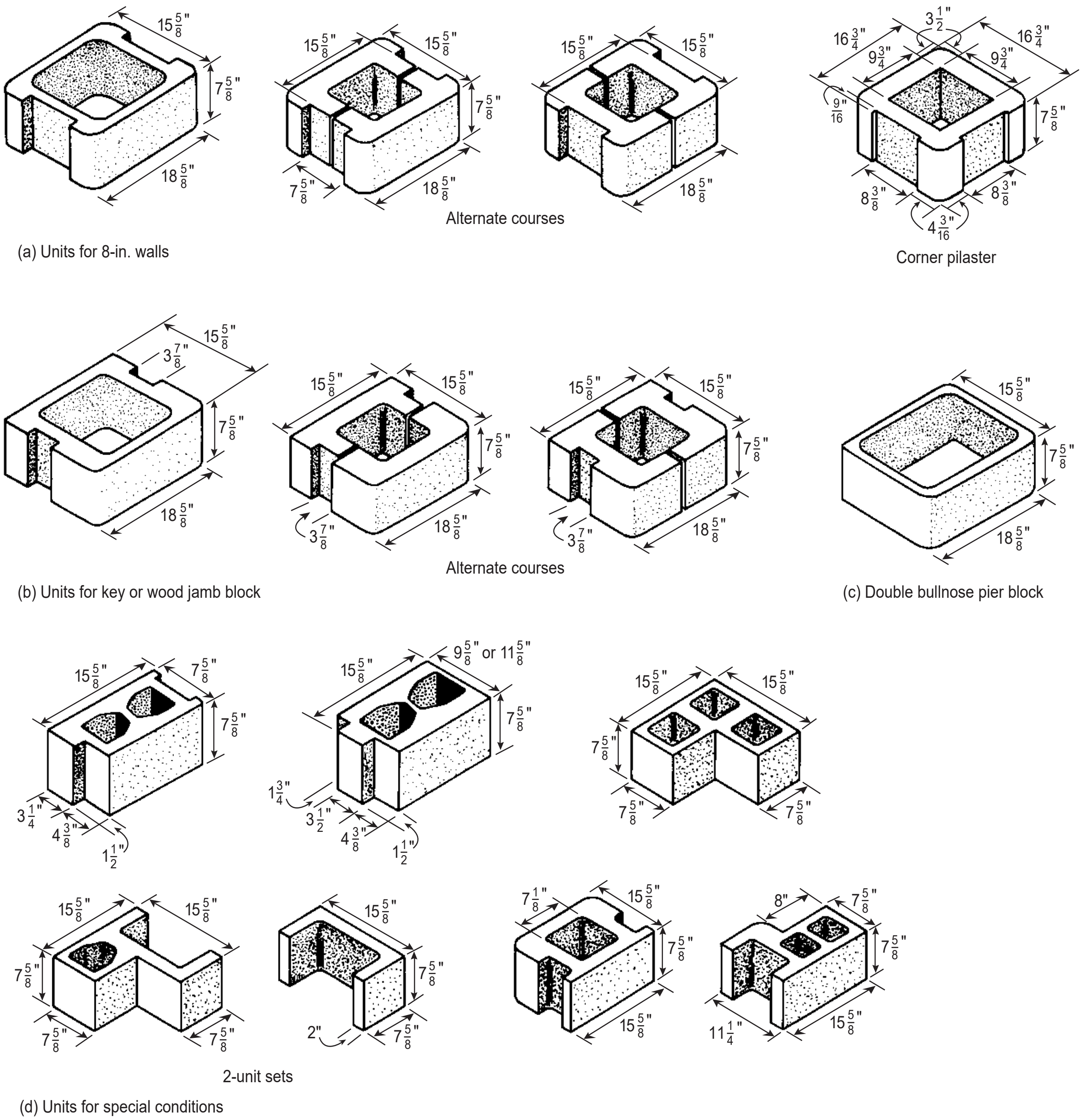


Fig. 1-20

Pilaster units. *Consult local producers for specific available units.*

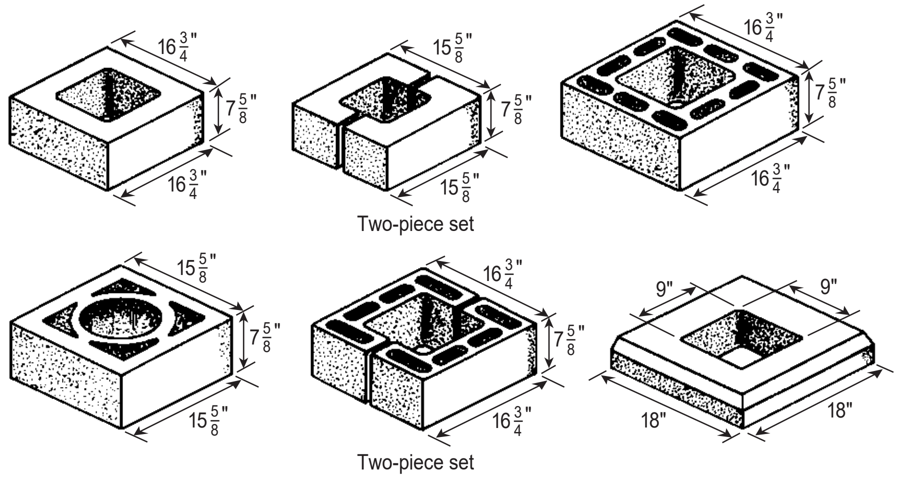


Fig. 1-21

Customized column and chimney units and chimney caps. *Consult local producers for specific available units.*

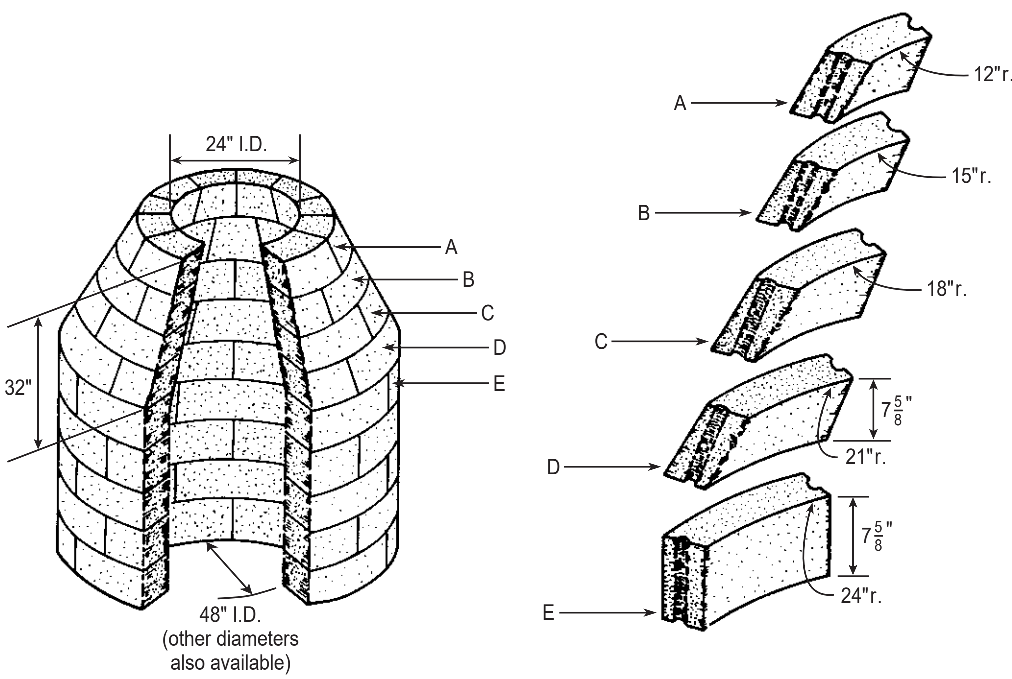


Fig. 1-22

Manhole, catch basin, and valve vault units. *Consult local producers for specific available units.*

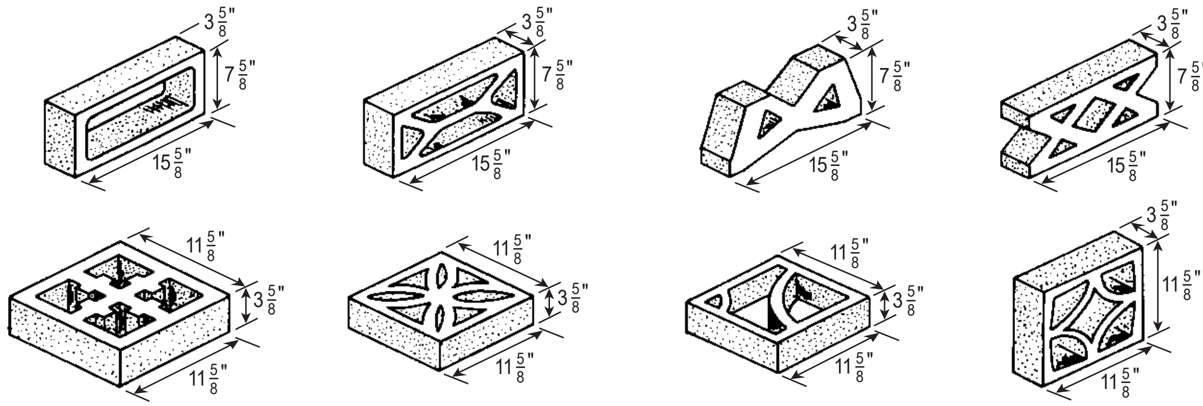


Fig. 1-23

Screen wall units. *Consult local producers for specific available units.*

Fig. 1-24

Masonry units create a decorative look for this garden wall. (IMG15611)

Special effects also can be created by using the same block design in different pattern bonds. The play of light and shade on the profiled faces can be varied according to the projected or recessed position in which each block (of the same pattern) is laid. By use of sculptured units alone or in combination with plain units, a variety of geometric patterns in relief can be designed.

Other Sizes, Shapes, and Types

Block scoring (Fig. 1-27) is a process where a single block face can be divided into several areas. The divisions, which create a new apparent face size, are achieved by saw cutting the face of the block either horizontally or vertically, or by molding depressions that look like mortar joints into the face. With scoring it is possible to achieve any number of patterns. For example, scored block may be used to achieve ashlar patterns. Another popular design involves scoring 8x16-in. (203x406-mm) block vertically at the middle to give the appearance of two 8x8-in. (203x203-mm) block; the 8x16-in. units are then use to build walls with an apparent square stacking pattern (Fig. 4-16n).

A patented slotted block (Fig. 1-28a) provides unusually high sound energy absorption. The slotted openings molded into the face of the units conduct sound into the cores, which act as damped resonators. Especially effective with sound in the middle and high frequencies, these block are very useful in gymnasiums, factories, bowling alleys, or other places where noise can be a problem.

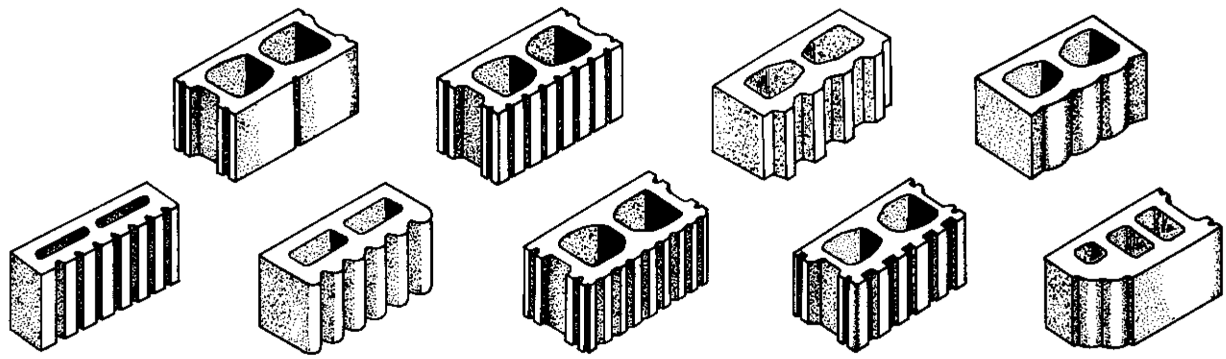
Special lightweight block are made of lightweight insulating concrete in a variety of sizes (Fig. 1-28b). The weight of an 8x12x24-in. (203x305x610-mm) light-weight unit is comparable to that of a normal-weight 8x8x16-in. (203x203x406-mm) concrete block. With a similar weight, but larger dimensions, walls can be placed at a faster rate by the mason.

A special H-shaped block (Fig. 1-28c) is made especially for reinforced grouted masonry. These units can be easily placed around or between tall reinforcing bars.

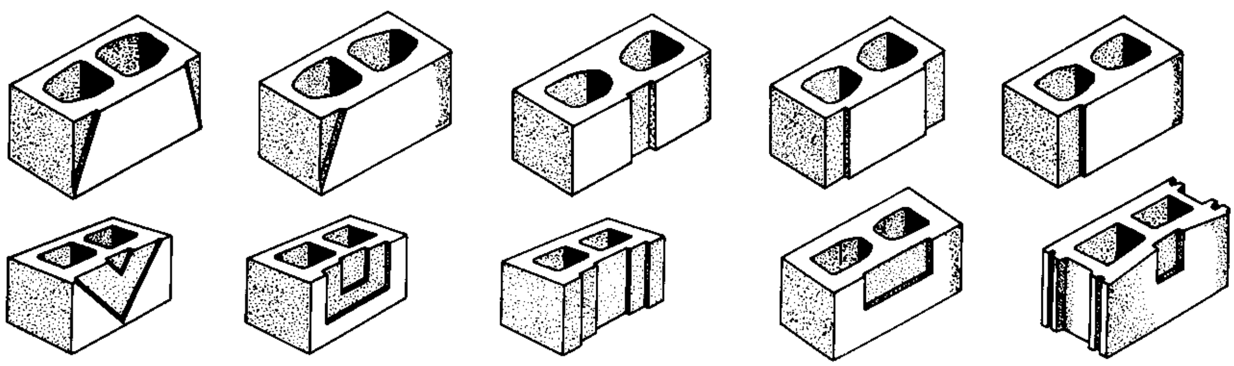
Other specialized shapes for retaining walls, chimneys, foundations, and paving are discussed in Chapter 8.

Prefacing

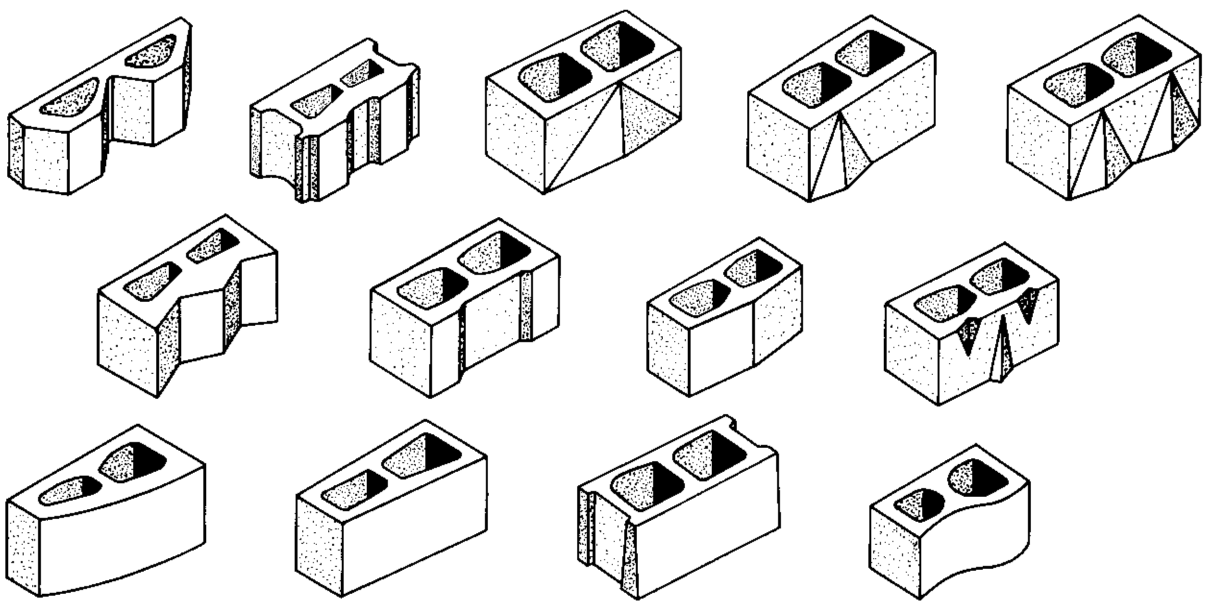
Prefaced concrete masonry units are standard, modular concrete blocks with a permanent glazed facing on one or more sides. The blocks may be lightweight- or



(a) Scored, ribbed and fluted faces



(b) Recessed faces



(c) Angular and curved faces

Fig. 1-25

Architectural concrete masonry units. *Consult local producers for specific available units.*

Fig. 1-26

A dynamic effect is achieved by using recessed-face block in this wall for a commercial building. (IMG15910)

Fig. 1-27

Vertical scoring creates an 8 in. by 8 in. pattern on this standard block used to add architectural interest and variety on this wall of split-faced units. (IMG16998)

normal-weight units, load-bearing, or non-load-bearing.

Prefaced concrete masonry units offer design opportunities for a wide range of color, scale, pattern, and texture for interior or exterior use. The facing provides a smooth, satin finish surface, and is applied to all standard widths of concrete block—2 in. to 12 in. (51 mm to 305 mm)—and virtually all block shapes. A few examples of prefaced concrete masonry units are shown in Fig. 1-29.

The applicable specification for prefaced units is Standard Specification for Prefaced Concrete and Calcium Silicate Masonry Units, ASTM C744. The specification applies to units "with the exposed-to-view-in-place surfaces covered at the point of manufacture with resin, resin and inert filler, or cement and inert filler, to produce a smooth resinous tile facing." At this time only faces of resin with inert filler are being manufactured.

There are several variations in the resin formulation and the methods employed in manufacture. Generally, the facings are applied in a glazing plant to fully-cured concrete masonry units. A measured amount of slurry is put into a flat mold and evenly distributed by shaking and vibrating. A concrete block is placed face down on top of the slurry, some of which penetrates into the block—conveyed through external heat—where the slurry cures into a finished glazed surface. By this process the facing is integrally bonded to the block. The mold is easily removed from the hardened facing. Generally, the height and length of the molded facing is ⅛ in. (3 mm) greater than the height and length of the modular concrete block to which it is bonded. As a result, the exposed mortar joints between faces must

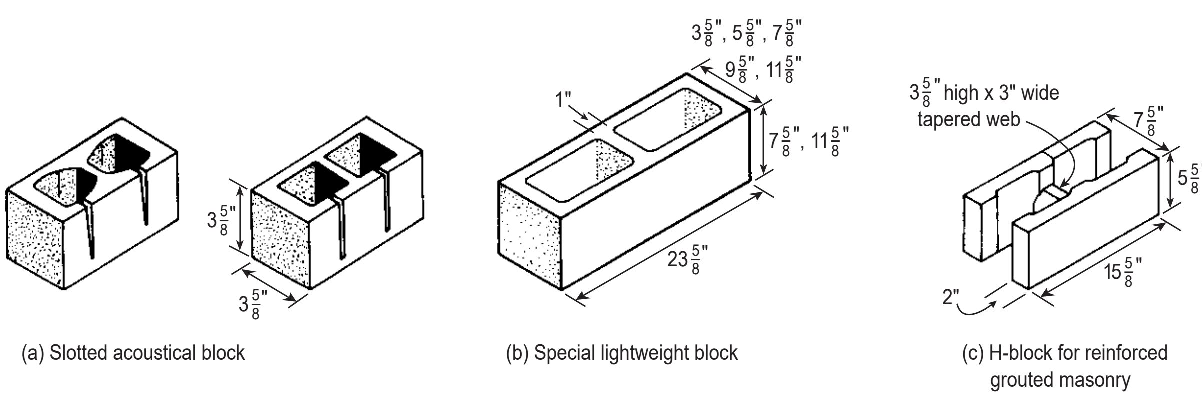


Fig. 1-28

Some special units. *Consult local producers for specific available units.*

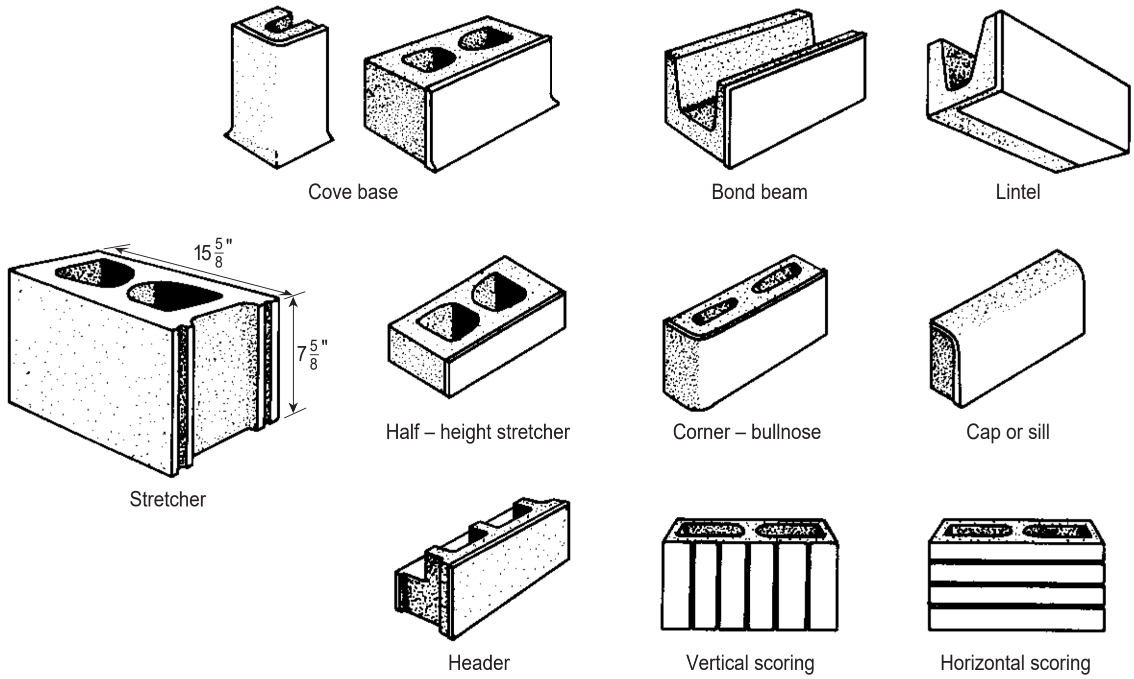


Fig. 1-29

Prefaced units. *Consult local producers for specific available units.*

be ¼ in. (6 mm) thick—rather than the usual ⅜ in. (10 mm) thick—to preserve modular dimensioning of the masonry wall.

Because the facings are resistant to soiling, chemicals, moisture penetration, and abrasion, prefaced units are used in walls and partitions where decoration, cleanliness, and low maintenance are desirable. Typical applications are school corridors and locker rooms, bottling plants and food processing facilities, and hospitals and laboratories. Many architects have achieved striking effects by combining colored glazed units with conventional concrete block, or with special types of units such as those shown in Fig. 1-25.

Prefaced units provide design flexibility and proven performance, and offer the design and construction advantages of basic concrete masonry construction. Operational and life-cycle costs of prefaced masonry walls are historically low. The satisfactory use of prefaced masonry has been proven in many types of buildings, interior and exterior.

Surface Texture

The surface texture of concrete masonry may be varied to satisfy aesthetic requirements or to suit a desired physical requirement. Various degrees of smoothness can be achieved with any aggregate by making changes in aggregate grading, mixture proportions, wetness of the mixture, and the amount of compaction in molding.

Textures are classified somewhat loosely and with considerable overlap as open, tight, fine, medium, and coarse. A texture regarded as fine in one locality may be considered medium in another.

An open texture is characterized by numerous closely spaced and relatively large voids between the aggregate particles. Conversely, a tight texture is one in which the spaces between aggregate particles are well filled with cement paste; it has few pores or voids of the size readily penetrated by water and sound.

Fine, medium, and coarse describe the relative smoothness or graininess of the texture. A fine texture is not only smooth but made up of small, very closely spaced granular particles. A coarse texture is noticeably large-grained and rough, resulting from the presence of many

Fig. 1-30

Glazed concrete masonry units are used for the walls of swimming pools and other buildings where sanitation and a permanently attractive finish are needed. Photo courtesy of Trenwyth.

large-size aggregate particles in the surface. Usually, but not necessarily, a coarse texture will contain voids of substantial size between aggregate particles. A medium texture is intermediate between fine and coarse. Examples of several of these textures are shown in Fig. 1-31.

If the concrete masonry surface is to serve as a base for stucco or plaster, a coarse texture is desirable for good bond. Coarse and medium textures provide sound absorption even when painted. The paint, however, must be applied in a manner that does not close all of the surface pores; spray painting is best. A fine texture is preferred for ease of painting.

In regular plant production the texture of concrete masonry units will be fairly uniform from day to day and shipment to shipment, but absolute uniformity is not attainable. The expected range in texture can best be determined from a sample of 10 or more units taken at random from the manufacturer's stockpile.

With a few exceptions manufacturers limit their regular production of concrete masonry units to a single texture for each aggregate type. Otherwise they could not operate economically because of the problems and expense connected with making, stockpiling, and merchandising several classes of units based on small differences in texture. Whether the texture adopted is fine, medium, or coarse will depend to a large extent upon local practice and preference. Some manufacturers will produce other textures on special order provided the order is large enough and the texture desired can be produced with the material and equipment available, and at a price acceptable to the customer.

A popular texturing process is to grind the block faces (Fig. 1-32). Ground-face masonry units are produced from normal-weight or lightweight units by grinding off a 1⁄16-in. to 1⁄8-in. (2 mm to 3 mm) layer of concrete from one or both face shells. The process results in a smooth, open-textured surface that shows aggregate particles of varying color. Variations in aggregate size, type, and color, and the use of integral pigments offer many opportunities for adding interest. Ground-face units in natural or tinted colors are often used in constructing partition walls and corridor walls that are to be exposed without further finishing, except perhaps the application of wax or a colorless sealer. In lieu of grinding, concrete masonry units may be sandblasted before or after they are placed.

Color

The natural color of concrete masonry varies from light to dark grey to tints of buff, red, or brown, depending upon the color of the aggregate, cement, and other mixture ingredients. The method of curing may also affect color. Color uniformity of masonry units is not controlled unless by special customer order. There may be some variations in the color of any given day's production even though all conditions are apparently alike.

Units also are subject to temporary and permanent changes in color. Colored surfaces are more vivid and darker when wet than when dry. Units made with dark-colored aggregate will slowly become darker with

Fig. 1-31

Examples of concrete masonry textures (from left to right): fine, medium and coarse. (IMG24195) age when subject to weathering because the surface film of cement paste erodes away, exposing more of the aggregate. While stockpiled at the plant or at the jobsite for long periods of time, units may undergo slight color changes due to dust and soot lodging in the surface pores. Despite the numerous factors that may affect color, units of a specific type of aggregate and method of curing are generally uniform in color within acceptable limits. This is particularly true when the units for the project are all from the same manufacturer.

Much concrete masonry construction is painted for architectural or service exposure reasons (see Chapter 7). In these cases uniformity of color of the block is not an important factor. On the other hand, highly pleasing effects have been achieved in building interiors with delicate differences in shades of unpainted units (Fig. 1-33). Obviously, such units should be free of stains and other blemishes.

In recent years a noticeable trend has developed toward the use of colored mortar joints for laying concrete masonry. Many architects prefer mortar joints that are identical to or harmonize with the color of the masonry units. Colored mortar is discussed in detail in Chapter 2 and in PCA IS247 1995.

The use of locally available natural sands, cements, and coarse aggregates to produce concrete block of the desired color is recommended where possible. This will result in a more easily duplicated color in the event of future additions to a structure.

Fig. 1-32

Ground-face units expose the natural color of the aggregate. (IMG17000)

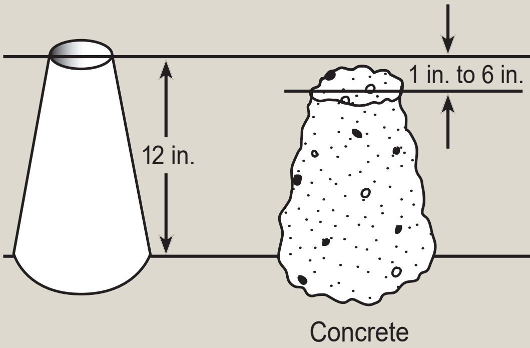
Integrally colored concrete masonry units are manufactured by adding mineral oxide pigments to the concrete before molding. An ever-increasing variety of colored concrete masonry products are being offered. This trend started with pigmented standard building block and has since spread to such products as concrete brick, split block, slump block, paving and patio block, screen block, and architectural concrete masonry units.

Standard colors for integrally colored concrete masonry units are tan, buff, red, brown, pink, yellow, and black or grey. Green can be produced—and it's quite permanent—but expensive, except in light shades. Blue also is expensive, but not uniform or permanent.

Pigmented concrete masonry units should not be stored in the open. Keep masonry units stored at jobsites covered and on pallets placed in well-drained locations. Slight variations in color can be counteracted by distributing concrete masonry units to random locations at the jobsite, thus intermingling the different shades of units.

Fig. 1-33

Quietness and beauty are achieved in this church with walls of concrete masonry. (IMG16996)



Mortar and Grout

CHAPTER 2

Mortar for concrete masonry (Fig. 2-1) not only joins masonry units into an integral structure with predictable performance properties, but also: (1) creates a tight seal between units against the entry of air and moisture; (2) bonds with joint reinforcement, metal ties, and anchor bolts, if any, so that they perform integrally with the masonry; (3) provides an architectural quality to exposed masonry structures through color contrasts or shadow lines from various joint-tooling procedures (Fig. 2-2); and (4) compensates for slight size variations in the units by providing a bed to accommodate dimensional tolerances.

Grout is an essential element of reinforced concrete masonry. In reinforced load-bearing masonry wall construction, grout is usually placed only in those wall spaces containing steel reinforcement. The grout bonds the masonry units and steel together so they act compositely to resist imposed loads. In some reinforced load-bearing masonry walls, all cores—with and without reinforcement—are grouted to further increase the wall's resistance to loads. Grout is sometimes used in nonreinforced, load-bearing masonry wall construction to give added strength. This is accomplished by filling a portion or all of the cores.

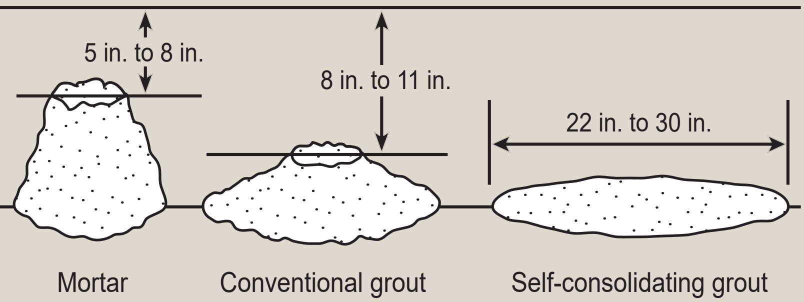
Mortar is not grout. Grout and mortar are used differently, have different characteristics, and are handled differently. Thus, the two are not interchangeable.

Fig. 2.2

This entry displays a banding effect created by placing blocks in a saw-tooth pattern every fourth course. (IMG24168)

Fig. 2-1

Mortar is an integral part of concrete masonry. (IMG24167)



Above: Slump test comparison of cement-based materials – see Fig. 2-22. Right: Mortar cubes are cast in 2-in. (50-mm) brass molds for compressive strength testing. (IMG12450)

Mortar

Masonry mortar is composed of one or more cementitious materials, clean well-graded masonry sand, and enough water to produce a plastic, workable mixture. By modern specifications the ratios range, by volume, from 1 part of cementitious material to 2¼ to 3½ parts of damp, loose mortar sand.

Probably the most important quality of a masonry mortar is workability because of its influence on other important mortar properties in both the plastic and hardened states. Since mortar is an integral part of concrete masonry construction—and some characteristics of mortar materially affect the quality of workmanship—the mortar should be designed and specified with the same care as the masonry unit itself.

One important product that is specifically manufactured to produce mortar for masonry is called masonry cement. It requires a minimum of field proportioning, just mixing with sand and water, to yield good mortar characteristics. Typically, masonry cements consist of a combination of portland or blended hydraulic cement, plasticizing materials, and other materials to provide desired properties and performance. The ASTM specifications for this and other typical cementitious materials used to make mortar are given later in this chapter under "Components."

Desirable Properties of Fresh, Plastic Mortar

Good mortar is necessary for good workmanship and proper structural performance of concrete masonry. Since mortar must bond masonry units into a strong, durable, weathertight structure, it must have a number of desirable properties, and the mortar materials must comply with specifications. Desirable properties of mortar while plastic include workability, water retentivity, and a consistent rate of hardening.

Workability

This property of plastic mortar is difficult to define because it is a combination of a number of independent, interrelated properties. The properties that have the greatest influence on workability are: consistency, water retentivity, setting time, weight, adhesion, and cohesion.

The experienced mason judges the workability of mortar by the way it adheres to or slides from his

Fig. 2-3

Mortar of proper workability is soft, but with good body. It spreads readily and extrudes without smearing or dropping away. (IMG15809) trowel. Mortar of proper workability should spread easily on the concrete masonry unit, cling to vertical surfaces, extrude readily from joints without dropping or smearing, and permit easy positioning of the unit without subsequent shifting due to its weight or the weight of successive courses (Fig. 2-3). Mortar consistency should change with weather to help in laying the units. A good workable mixture should be softer in summer than in winter to compensate for water loss.

Water Retentivity

This is the property of mortar that resists rapid loss of mixing water (prevents loss of plasticity) to the air on a dry day or to an absorptive masonry unit. Rapid loss of water causes the mortar to stiffen quickly, thereby making it practically impossible to obtain good bond and weathertight joints (see Isberner RD024 1974).

Water retentivity is an important property and is related to workability. A mortar that has good water retentivity remains soft and plastic long enough for the masonry units to be carefully aligned, leveled, plumbed, and adjusted to the proper line without danger of breaking the intimate contact or bond between the mortar and the units. When low-absorption units such as split block are in contact with a mortar having too much water retentivity, the units may float. Consequently, the water retention of a mortar should be within tolerable limits.

Water adds workability to the mortar; entrained air or extremely fine aggregate or cementitious materials not only add workability or plasticity to the mortar, they also increase its water retentivity.

Consistent Rate of Hardening

Mortar hardens when cement reacts chemically with water in a process called hydration. The rate of hardening of mortar is the speed at which it develops resistance to an applied load. Rapid hardening may interfere with the use of the mortar by the mason. Slow hardening, on the other hand, may impede the progress of the work by causing the mortar to flow from the completed masonry. During winter construction, slow hardening may also subject mortar to early damage from frost action. A well-defined, consistent rate of hardening assists the mason in laying the masonry units and in tooling the joints at the same degree of hardness. Uniform joint color reflects proper hardening and consistent tooling times.

Hardening is sometimes confused with stiffening, which is more a loss of workability, caused by rapid loss of water, as in the case of low water-retentive mortars with highly absorptive units. Also, mortar tends to stiffen more rapidly than usual during hot and dry weather. In this case the mason may find it advisable to lay shorter mortar beds and fewer units in advance of tooling.

Desirable Properties of Hardened Mortar

The desirable properties of mortar after hardening include good durability, a suitably high compressive strength, sufficient bond to withstand the tensile and flexural forces on the structure, minimum mortar volume change (shrinkage) or sufficient creep of mortar (ductility) to accommodate any shrinkage, and good appearance or overall uniformity of color and shade of the mortar joints.

Durability

The durability of masonry mortar is its ability to endure the exposure conditions. Although aggressive environments and the use of unsound materials may contribute to the deterioration of mortar joints, the major destruction is from water entering the concrete masonry and freezing.

In general, damage to mortar joints by frost action has not been a problem in concrete masonry wall construction above grade. In order for frost damage to occur, the hardened mortar must first be water-saturated or nearly so. After being placed, mortar becomes less than saturated due to the absorption of some of the mixing water by the units. The saturated condition does not readily return except under special conditions, such as: (1) the masonry is constantly in contact with saturated soils; (2) downspouts leak; (3) there are heavy rains; or (4) horizontal ledges form where the joints have been improperly tooled. Under these conditions the masonry units and mortar may become saturated and undergo freeze-thaw deterioration.

High-compressive-strength mortars usually have good durability. Because air-entrained mortar will withstand hundreds of freeze-thaw cycles, its use provides good insurance against localized freeze-thaw damage. Masonry cement mortar has a higher air content and therefore better freeze-thaw resistance than non-air-entrained portland cement and lime mortar. Mortar joints that have deteriorated due to freezing and thawing present a serious maintenance problem; generally, tuckpointing is required to correct the problem.

When sulfates come in contact with masonry mortar, they can react with the cement paste, creating expansion that can lead to deterioration of the mortar. Sulfate resistance is usually not a concern for masonry above ground; however, in some parts of the country, masonry can be exposed to sulfate from seawater, soil, ground water, or industrial processes. Sulfate-resistant materials should be used when in contact with soils containing more than 0.1% water-soluble sulfate ($S0_4$) or water containing more than 150 ppm of sulfate. Without the use of sulfate-resistant mortar or use of a protective treatment, sulfates attack and deteriorate masonry.

Masonry cements, sulfate-resistant portland cements (Type II or V), or sulfate-resistant blended cements should be used in mortar exposed to sulfates. Masonry cement mortars have demonstrated excellent resistance to sulfate expansion. One study demonstrated that masonry cement is significantly more sulfate resistant than a Type II cement and lime mortar when tested in accordance with ASTM C1012 (at 13 weeks, portland cement-lime mortars exhibited expansions of 0.16% to 0.37% compared to 0.03% to 0.12% for masonry cement mortars). See Dubovoy SN1884 1990 for more information.

Expansion in mortars due to unsound ingredients can cause serious disintegration of masonry. Soundness of a cementitious material is measured by the autoclave expansion test (ASTM C151). This test produces reactions in unsound ingredients (particularly free lime and periclase) and simulates a long period of in-place exposure. ASTM specifications for masonry cement (C91), mortar cement (C1329), and portland cement (C150) limit acceptable changes in length of the test specimen to ensure that no serious expansion of the hardened mortar will occur in a wall. While a method for measuring soundness of hydrated lime has been developed, correlation of results to field performance has not yet been established. Thus, soundness of this material is generally assured by limiting the unhydrated oxide content of the hydrated lime to a maximum of 8%.

Compressive Strength

The principal factors affecting the compressive strength of concrete masonry structures are the compressive strength of the masonry units, the proportions of ingredients within the mortar, the design of the structure, workmanship, and the degree of curing. Although the compressive strength of concrete masonry may be increased by using a stronger mortar, the increase will not be proportional to the increased compressive strength of the mortar.

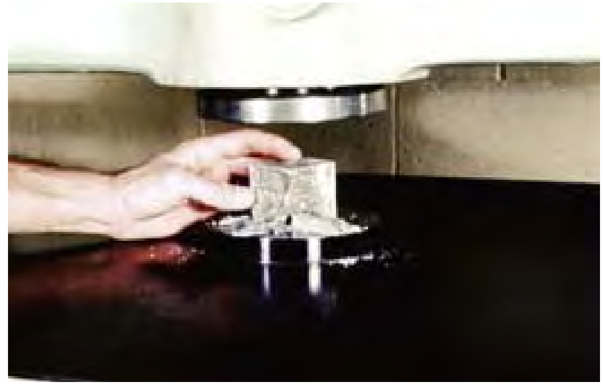


Fig. 2-4

The compressive strength test for mortar uses a 2-in. (51-mm) cubical specimen. (IMG14091)

Tests have shown that concrete masonry wall compressive strength increases only about 10% when mortar cube compressive strength (Fig. 2-4) increases 130%. Composite wall compressive strength increases only 25% when mortar cube compressive strength increases 160% (Fishburn 1961).

Compressive strength of mortar is largely dependent on the type and quantity of cementitious material used in preparing the mortar. It increases with an increase in cement content and decreases with an increase in air entrainment, lime content, or water content.

The portland cement in mortar requires a period of time in the presence of moisture (curing) to develop its full strength potential. In order to obtain optimum curing conditions, the mortar mixture should be made with the maximum amount of mixing water possible with acceptable workability. Lean, oversanded mixtures should be avoided. Freshly laid masonry should be protected from the sun and drying winds. With severe drying conditions it may be necessary to fog the exposed mortar joints with a fine water mist daily for about 4 days, or to cover the masonry structure with a polyethylene plastic sheet, or both.

Bond

The general term “bond” refers to a specific property that can be subdivided into two categories: (1) the extent of bond, or the degree of contact of the mortar with the concrete masonry units; and (2) the bond strength, or the force required to separate the units. A chemical and a mechanical bond exist in each category.

Good extent of bond (complete and intimate contact) is important to watertightness and tensile bond strength. Poor extent of bond at the mortar-to-unit interface may lead to moisture penetration through the unbonded areas. Good extent of bond is obtained with a workable and water-retentive mortar, good workmanship, full joints, and masonry units having a medium initial rate of absorption (suction).

Bond strength is usually measured as tensile or flexural bond strength. In determining direct tensile bond strength, specimens representing unit and mortar are pulled apart (Fig. 2-5). Test methods for measuring flexural (more properly termed flexural tensile) bond strength place a more complex load on the mortar-to-unit interface, but can be applied to full-sized specimens. For example, ASTM Method C1072 (Fig. 2-6) uses a bond wrench apparatus and loading configuration to induce failure of prisms constructed from full-sized masonry units. ASTM Method C1357 provides methods for sampling, fabricating, curing, and testing specimens using the ASTM C1072 bond wrench apparatus. Other standard methods used to measure bond strength of masonry include ASTM E518, C952, and E72.

Fig. 2-6

The C 1072 bond wrench test being run. (IMG24170)

While bond strength is an important property of masonry, current methods of testing for bond strength are considered impractical as a basis for quality control at the jobsite, due to the high variability of test results. There has been considerable research on bond testing —see Dubovoy SN1928a 1990; Hedstrom, Tarhini and Kassim 1990; Lange and Ahmed 1995; McGinley SN1921 1993; McGinley SN1970 1993; McGinley SN1970a 1993; McGinley 1996; and Wood 1995.

Many variables affect bond, including: (1) mortar ingredients, such as type and amount of cementitious materials, water retained, and air content; (2) characteristics of the masonry units, such as surface texture, suction, and moisture content; (3) workmanship, such as pressure applied to the mortar bed during placing; and (4) curing conditions, such as temperature, relative humidity, and wind.

All other factors being equal, mortar bond strength is related to mortar composition, especially cement content. The bond strength of mortar increases as cement content increases (Melander and Conway 1993).

Bond strength is low on smooth, molded surfaces, such as glass or die skin surfaces of clay brick or tile. Good bond is achieved on concrete block or on wire-cut or textured surfaces of clay brick. While bond strengths with high absorption clay brick can be increased by wetting the units prior to laying them, concrete masonry units should not be wetted before use.

Fig. 2-5

ASTM C1072 bond wrench apparatus. (IMG25759)

There is a distinct relationship between mortar flow (water content) and bond strength. For all mortars, bond strength increases as water content increases, within reasonable limits. The optimum bond strength is obtained by using a mortar with the highest water content compatible with workability, even though mortar compressive strength may decrease (Isberner RD019 1974).

Workmanship is paramount in determining bond strength. The time lapse between the spreading of mortar and the placing of the masonry units should be kept to a minimum because the water content of the mortar is reduced through suction of the masonry unit on which the mortar is first placed. If too much time elapses before the upper unit is placed, the bond between the mortar and the unit will be reduced due to the previously noted relationship between bond strength and water content. The mason should not realign, tap, or otherwise move units after initial placement, leveling, and alignment. Movement disrupts the bond between unit and mortar, after which the mortar will not reestablish bond with the masonry units. See Melander and Ghosh 1992 for more information on bond; PCA IS245 2001 and PCA IS246 2001 for more information on workmanship; and Conway and Ghosh 1995 for more information on the other properties of mortar (other than bond).

Volume Change

A popular misconception is that mortar shrinkage can be extensive, leading to leaky structures. Actually, the maximum shrinkage across a mortar joint with properly proportioned mortar is usually minuscule and therefore not troublesome. This is even truer with weaker mortars. They have greater creep, that is, extensibility, and so are better able to accommodate drying shrinkage.

As available water in mortar is absorbed by the masonry units and lost through evaporation, some drying shrinkage occurs. Though generally not a problem in masonry construction, extreme drying shrinkage can result in development of cracks in the mortar. Since drying shrinkage is related to the amount of water lost by the mortar, factors that increase water content of a mortar tend to increase its drying shrinkage. For example, air-entrained mortars tend to have a lower water demand than non-air-entrained mortars at an equivalent flow and thus exhibit less drying shrinkage. However, this principle should not be misinterpreted to mean that water content of mortar should be arbitrarily reduced. As previously noted, workability and bond are directly related to the flow of the mortar and should be given priority in determining the water content of field mixed mortar.

On projects where minimizing drying shrinkage is desirable, masonry cement mortar should be considered. The shrinkage of mortar can be tested in accordance with ASTM C1148. In a study using this test, masonry cement mortar had half the shrinkage of cement-lime mortar (0.07% at 25 days for masonry cement mortar versus 0.12% to 0.14% for cement-lime mortar). See Dubovoy SN1884 1990 for more information.

Appearance

Uniformity of color and shade of the mortar joints greatly affects the overall appearance of a concrete masonry structure (Figs. 2-2 and 2-7). Atmospheric conditions, admixtures, and initial rate of absorption (suction) of the masonry units are some of the factors affecting the color and shade of mortar joints. Others are of proportions of the mortar mixture, water content, and time of tooling the mortar joints.

Careful measurement of mortar materials and thorough mixing are important to maintain uniformity from batch to batch and from day to day. As the number of ingredients to be combined at the mixer increases, control of this uniformity becomes more difficult. Pigments, if used, will provide more uniform color if premixed with a stock of cement sufficient for

Fig. 2-7

Split-faced ribbed concrete masonry wall. (IMG16998) the needs of the entire project. In many areas, colored masonry cements are available; they provide better color uniformity.

Tooling of mortar joints at like degrees of setting is important in ensuring a uniform mortar shade in the finished structure. If the joint is tooled when the mortar is relatively hard, a darker shade results than if the joints are tooled when the mortar is relatively soft. Some masons consider mortar joints ready for tooling after the mortar has stiffened but is still thumb-print-hard, with the water sheen gone. For a more detailed discussion of mortar color, and controlling the appearance of mortar joints, see PCA IS247 1995.

Tooling white cement mortar with metal tools may darken the joint. A glass or plastic joint tool should be used. For a further discussion of tooling, as well as the types of mortar joints, see "Tooling Mortar Joints" in Chapter 6.

Specifications and Types

Mortars are selected and prepared in accordance with either the proportion or the property specifications of ASTM C270, Specification for Mortar for Unit Masonry. Mortar types are identified by either proportion or property specifications, but not both. An interplay of property and proportion specifications is not intended or recognized by the specification.

Mortar has traditionally been classified as Type M, S, N, O, or K (every other letter from the phrase "MASON WORK"). Type K is not used in new construction, but may be used in certain tuckpointing applications (see "Tuckpointing," Chapter 9).

The current specifications for mortars for unit masonry are shown in Tables 2-1 and 2-2. The proportion specification identifies mortar type through various combinations of portland cement, masonry cement, and lime. The proportion specification should govern when ASTM C270 is referred to without noting which specification—proportion or property—is to be used.

Mortar type classification under the property specification is dependent on the compressive strength of 2-in. (51-mm) cubes, water retention, and air content measured using standard laboratory tests in accordance with ASTM C270. These test requirements of the property specifications for laboratory mortar do not apply to job-made mortar. Laboratory test cubes are prepared with less water than will be used in mortar prepared on the job. The standard consistency for laboratory mortars is determined using a laboratory flow table (Fig. 2-8). In this test, a truncated cone of mortar is subjected to twenty-five ½-in. (13-mm) drops of a laboratory flow table plate. The diameter of the disturbed sample is compared to the original diameter of the conical sample. The allowable flow ranges from 105% to 115% for ASTM C270 testing. This consistency is not

Table 2-1. Proportion Specifications for Mortar*

Mortar type	Parts by volume					
	Portland cement or blended cement	Masonry or mortar cement type			Hydrated lime or lime putty	Aggregate
		M	S	N		
M	1	—	—	1	—	4½ to 6
	—	1	—	—	—	2¼ to 3
	1	—	—	—	¼	2¹³⁄₁₆ to 3¾
S	½	—	—	1	—	3⅜ to 4½
	—	—	1	—	—	2¼ to 3
	1	—	—	—	Over ¼ to ½	**
N	—	—	—	1	—	2¼ to 3
	1	—	—	—	Over ½ to 1¼	**
O	—	—	—	1	—	2¼ to 3
	1	—	—	—	Over 1¼ to 2½	**

* Adapted from ASTM C270. Note that under ASTM C270, aggregate is measured in a damp, loose condition and 1 cu. ft. of masonry sand by damp, loose volume is considered equal to 80 lb. of dry sand. (In SI units 1 cu.m of damp, loose sand is considered equal to 1280 kg of dry sand.)

** The total aggregate shall be equal to not less than 2¼ and not more than 3 times the sum of the volumes of the cement and lime used.

Table 2-2. Property Specifications for Laboratory-Prepared Mortar*

Mortar type	Minimum 28-day compressive strength, psi (MPa)	Minimum water retention, %	Maximum air content, %*	
			Masonry cement	Portland-lime or Mortar cement
M	2500 (17.2)	75	18	12
S	1800 (12.4)	75	18	12
N	750 (5.2)	75	20**	14†
O	350 (2.4)	75	20**	14†

* Adapted from ASTM C270. Note that the total aggregate shall be equal to not less than 2¼ and not more than 3½ times the sum of the volumes of the cement and lime used.

** When structural reinforcement is incorporated in masonry cement mortar, the maximum air content shall be 18%.

† When structural reinforcement is incorporated in portland-lime or mortar cement mortars, the maximum air content shall be 12%.

Fig. 2-8

Flow test. (IMG14093)

suitable for laying masonry units in the field. Rather, it is intended to approximate the flow and properties of field mixed mortar after it has been placed in contact with absorptive masonry units. Flow values of 130% or higher are common for the initial consistency of mortar used in actual construction.

Cube tests are not intended to be made on the job. Instead, mortar in the field is tested according to ASTM C780, Standard Test Method for Preconstruction and Construction Evaluation of Mortars for Plain and Reinforced Unit Masonry. For more details, see "Testing Project Mortar" in Chapter 6.

Another requirement of property specifications is the water retention limit. In the laboratory it is measured using a "flow-after-suction" test (described in ASTM C1506, Standard Test Method for Water Retention of Hydraulic Cement-Based Mortars and Plasters), which simulates the action of absorptive masonry units on the plastic mortar. A flow test is conducted both before and after absorptive suction; the flow after suction must equal or exceed 75% of the original flow.

A third property requirement, air content, is determined by filling a standard 400-mL cup with laboratory prepared mortar (see Fig. 2-9). The mass of mortar contained by the cup is measured. Since the mass of individual mortar ingredients, including water, and the density of these ingredients are known, the volume percentage of air contained in the mortar can then be calculated. The air content limits of ASTM C270 vary, depending on mortar type and cementitious materials as shown in Table 2-2.

The ratio of cementitious material to aggregate in the mixture under the property specification may be less than under the proportion specification. This is to encourage preconstruction mortar testing; an economic reward is possible if less cement is required in a mixture to meet the strength requirement of the property specification. The testing portion of this specification is limited to preconstruction evaluation of mortars.

In both the proportion and property specifications, the amount of water used on the job is the maximum that

Fig. 2-9

Air content test. (IMG15606)

will produce a workable consistency during construction. This is unlike conventional concrete practice where the minimum amount of water is used that will produce a workable mixture and the water-cement ratio is carefully controlled.

Selection

Once the design loads, type of structure, and masonry units have been determined, the mortar type can be selected. No one mortar type will produce a mortar that rates highest in all desirable mortar properties. Adjustments to the mixture to improve one property often are made at the expense of others. For this reason, the properties of each mortar type should be evaluated, and the mortar type chosen that will best satisfy the end-use requirements. For additional guidance on selecting and specifying mortar, see the following: Dubovoy SN1928a 1990; Dubovoy SN1906 1991; Dubovoy SN1909 1991; Dubovoy and Ribar 1990; Dubovoy and Ribar 1992; Fishburn SN1379 1961; Hedstrom Tarhini and Kassim 1990; Hedstrom Tarhini and Thomas 1991; McGinley SN1921 1993; McGinley SN1970 1993; Melander Ghosh and Dubovoy 1993; PCA IS181 2001; PCA IS275 1998; PCA IS282 2002; and PCA PA163 1990.

The Masonry Standards Joint Committee's *Building Code Requirements for Masonry Structures* (*MSJC Code*) and *Specification for Masonry Structures* (*MSJC Specification*) have been adopted by the *International Building Code*. Specifiers should be familiar with both the design requirements of the *MSJC Code* and the provisions of the *MSJC Specification*. The *MSJC Code* makes several distinctions in the structural characteristics of masonry constructed using Type N mortar compared to that of masonry constructed using Type S or M mortar. In addition, for masonry design that takes into consideration the flexural tensile resistance of masonry, allowable flexural tensile stresses are different for non-air-entrained portland cement-lime or mortar cement mortars than for air-entrained portland cement-lime mortars or for masonry cement mortars. The specifier should confirm that mortar types and materials indicated in project specifications are consistent with structural design requirements of the masonry.

In the United States, mortar is selected based on the compressive strength of the masonry, type of masonry unit, type and location of building segment, loading conditions, and exposure conditions. Table 2-3, adapted from ASTM C270, provides guidelines for selecting mortar for nonreinforced (plain) masonry. In general, a useful guideline to follow in selecting and specifying mortar is to use a Type N mortar unless there is a structural or construction reason for choosing a different mortar type.

Special attention to mortar selection must be given when severe exposure conditions, special masonry applications, or reinforced masonry applications are considered. Type O mortar should not be used in saturated freezing conditions. For severe frost action, such as exterior mortared paving applications, Type S or M

Table 2-3. Guide to the Selection of Mortar Type*

		Mortar type	
Location	Building Segment	Recommended	Alternative
Exterior, above grade	Load-bearing walls Non-load-bearing walls Parapet walls	N O** N	S or M N or S S
Exterior, at or below grade	Foundation walls, retaining walls, manholes, sewers, pavements, walks, and patios	S†	M or N†
Interior	Load-bearing walls Non-load-bearing partitions	N O	S or M N

* Adapted from ASTM C270. This table does not provide for specialized mortar uses, such as chimney, reinforced masonry, and acid-resistant mortars.

** Type O mortar is recommended for use where the masonry in unlikely to be frozen when saturated or unlikely to be subjected to high winds or other significant lateral loads. Type N or S mortar should be used in other cases.

† Masonry exposed to weather in a nominally horizontal surface is extremely vulnerable to weathering. Mortar for such masonry should be selected with due caution.

Note: For tuckpointing mortar, see "Tuckpointing," Chapter 9.

mortar should be considered. Air-entrainment should be used to improve freeze-thaw durability, although it may reduce bond and compressive strength.

Mortar should also be compatible with the masonry unit. For example, a masonry unit with a high rate of absorption is compatible with a mortar having a high water retentivity. It is typically not necessary to use Type M mortar for high-strength masonry, because Type S can provide comparable strength of masonry. Moreover, Types S and N generally have more workability, water retention, and extensibility. The selection of mortar for reinforced masonry is based on the strength requirements of the masonry structure as well as the strength of the masonry unit, exposure conditions, and masonry application.

White and Colored Mortar

White or colored mortars can provide color contrast and harmony between masonry units and joints to create pleasing architectural effects.

White mortar is made with white masonry cement, or with white portland cement and lime, and white sand. For colored mortars, the use of white masonry cement or white portland cement instead of the normal grey cements not only produces cleaner, brighter colors but is essential for making pastel colors such as buff, cream, ivory, pink, and rose.

Integrally colored mortar may be obtained through the use of pigments, colored masonry cements, or colored sand. Brilliant or intense colors are generally not attainable in masonry mortars. The color of the mortar joints will depend not only on the pigment used, but also on the cementitious materials and aggregates used, and on the water-cement ratio and tooling.

Pigments must be thoroughly dispersed throughout the mixture. To determine if mixing is adequate, some of the mixture is flattened under a trowel. If streaks of color are present, additional mixing is required. For best results, the pigment should be premixed with the cementitious materials in large, controlled quantities. Colored masonry cements—produced by cement plants—are available in many areas.

As a rule, pigments should be of mineral oxide composition and contain no dispersants that will slow or stop the portland cement hydration. Iron, manganese, chromium, and cobalt oxides have been used successfully. Zinc and lead oxides should be avoided because they may react with the cement. Carbon black may be used as a coloring agent to obtain dark grey or almost black mortar, but lampblack should not be used. Carbon black should be limited to 1% or 2% by weight of cement for masonry cement or cement-lime mortars, respectively, since larger amounts could decrease the mortar's durability. In addition, the color of mortar using carbon black pigment rapidly fades with exposure to weathering.

Use only those pigments that have been found acceptable by testing and experience. Following is a guide to selection of coloring materials:

Red, yellow, brown, black or grey	Iron oxide
Green	Chromium oxide
Blue	Cobalt oxide

Only the minimum quantity of pigment that will produce the desired shade should be used. An excess of pigment—more than 10% of the portland cement, or 5% of the masonry cement, by weight—may be detrimental to the strength and durability of the mortar. The quantity of water used in mixing colored mortar should be accurately controlled. The more water, the lighter the color. Likewise, retempering or the addition of water while using colored mortar should be done cautiously. Mortar stiffness while tooling can also affect color.

Variations in the color of the materials are such as to make a color formula only approximate. Best results are obtained by experiment. Test panels should be made using the same materials and proportions intended for use in the actual work. The panels should be stored for about 5 days under conditions similar to those at the jobsite. Panels will have a darker shade when wet than when dry.

Discoloration of mortar joints may be caused by efflorescence, the formation of a white film on the surface (Fig. 2-10). Efflorescence is more visible on a colored surface. The white deposits are caused by soluble salts that have emerged from below the surface, or by calcium hydroxide, which is liberated during the setting of the cement and then combines with atmospheric carbon dioxide to form carbonate compounds. Good pigments do not effloresce or contribute to efflorescence. Efflorescence may be removed with water, a stiff-bristle brush, a light sandblasting, or an acid wash. For more information see "Efflorescence" in Chapter 9, and PCA IS239 2004 and TEK 8-3A 2003.

Figure 2-10

A severe case of efflorescence. (IMG15607)

Components

Foremost among the factors that contribute to good mortar is the quality of the mortar ingredients.

Cementitious Materials

The cementitious materials used in mortar and the applicable ASTM material specifications are:

- Portland cement—ASTM C150 (Types I, IA, II, IIA, III, or IIIA)
- Masonry cement—ASTM C91 (Types M, S, or N)
- Mortar cement—ASTM C1329 (Types M, S, or N)
- Blended hydraulic cement—ASTM C595 [Types IS, IS-A, IP, or IP-A]*
- Hydraulic cement—ASTM C1157 [Types GU, HE, MS, HS, MH, or LH]
- Hydrated lime for masonry purposes—ASTM C207 (Types S, SA, N, or NA)**
- Quicklime for structural uses (for lime putty)—ASTM C5

Masonry Sand

Large quantities of sand are required to make mortar. Since the water and cement occupy voids between the sand particles in mortar, almost 1 cu ft (1 cu m) of damp, loose sand is needed to make 1 cu ft (1 cu m) of mortar. Any material constituting such a large proportion of the mortar will have considerable influence on the mortar properties.

Masonry sand for mortar should comply with the requirements of ASTM C144 (Standard Specification for Aggregate for Masonry Mortar). This specification includes both natural and manufactured sands. Mortar sand should be clean, well graded, and meet the gradation requirements listed in Table 2-4 for conventional ⅜ in. (10-mm) mortar joints.

Sands with less than 5% to 15% passing the Nos. 50 (300 mm) and 100 (150 mm) sieves generally produce harsh or coarse mortars with poor workability; they also result in mortar joints with low resistance to moisture penetration. On the other hand, sands finer than those permitted by ASTM C144 may yield mortars with excellent workability, but they may be weak and porous.

For mortar joints that are less than the conventional ⅜-in. (10-mm) thickness, 100% of the sand should pass the No. 8 (2.36 mm) sieve and 95% the No. 16 (1.18 mm) sieve. For joints thicker than 3⁄8 in. (10 mm), the mortar sand selected should have a fineness modulus approaching 2.5, or a gradation within the limits of concrete sands (fine aggregate) shown in ASTM C33. (Fineness modulus equals the sum of the cumulative percentages retained on the standard sieves, divided by 100. The higher the fineness modulus, the

Table 2-4. Aggregate Gradation for Mortar Sand

	Gradation specified, percent passing	
	ASTM C144*	
Sieve size No.	Natural sand	Manufactured sand
4	100	100
8	95 to 100	95 to 100
16	70 to 100	70 to 100
30	40 to 75	40 to 75
50	10 to 35	20 to 40
100	2 to 15	10 to 25
200	—	0 to 10

*Additional requirements: Not more than 50% shall be retained between any two sieve sizes nor more than 25% between No. 50 and No. 100 sieve sizes. Where an aggregate fails to meet the gradation limit specified, it may be used if the masonry mortar will comply with the property specification of ASTM C270 (Table 2-2).

** Slag cement Types S or SA can also be used, but only according to the property specifications.*

*** Types N and NA lime may be used only if tests or performance records show that these limes are not detrimental to the soundness of mortar.*

coarser the sand.) See PCA IS241 1992 for more information on mortar sand.

Water

Water intended for use in mixing mortar should be clean and free of appreciable amounts of oils, acids, alkalies, salts, organic materials, or other substances that are deleterious to mortar or any metal in the wall. Typically, water that is drinkable and has no pronounced taste or odor can be used in mixing mortar. Some waters that are not fit for drinking may be acceptable for mortars. In general, information on the quality of water to be used in concrete is relevant to the evaluation of water for use in mortar. Chapter 4 of *Design and Control of Concrete Mixtures* (Kosmatka, Kerkhoff and Panarese 2002) provides a synopsis of information related to evaluating water quality for use in concrete.

Admixtures

ASTM C270 indicates that admixtures are not to be used in mortar unless specified. If specified, admixtures other than pigments should meet the requirements of ASTM C1384, Standard Specification for Admixtures for Masonry Mortars. This specification provides requirements for admixtures intended to modify specific mortar properties. These admixtures include bond enhancers, workability enhancers, set accelerators, set retarders, and water repellents. Admixtures are qualified for use with mortars of applicable type and cementitious materials on the basis of comparing the properties of a reference mortar to a mortar containing the recommended dosages under laboratory testing conditions.

Caution should be exercised in the use of admixtures in masonry mortars, since improper admixture selection or use may produce adverse effects on the normal chemical reaction between cement and water. This is especially true during the early periods after mixing when water is most needed for hydration of the portland cement.

Hardened properties are also affected. To avoid metal corrosion, admixtures containing chloride (such as calcium chloride) or admixtures containing other corrosive substances must not be used. ASTM C1384 contains a provision that limits the increase in chloride content of a mortar due to addition of an admixture to a maximum of 65 ppm water-soluble chloride or 90 ppm acid-soluble chloride at maximum recommended dosage. The *MSJC Specification* limits the chloride ion content of admixtures to a maximum of 0.2 percent.

Set-controlling admixtures have been reliably used to produce ready-mixed (or extended-life) mortar. See "Ready-Mixed Mortar" later in this chapter. Regular retarders, as used in concrete, are undesirable because they reduce strength development and increase the potential for efflorescence.

Air-entrainment increases workability and freeze-thaw durability. However, addition of an air-entraining admixture at the mixer on a jobsite is not recommended, due to the sensitivity of the admixture and the likelihood of poor control in monitoring air content. Materials with factory controlled amounts of air-entraining agent—such as masonry cement, mortar cement, air-entraining portland cement, or air-entraining lime—should be used if air-entrainment is desired.

Air-entraining admixtures and accelerators are discussed in Chapter 5 as admixtures for cold-weather masonry construction. Also, see "Modified Mortars" discussed later in this chapter.

Material Storage

All cementitious materials, aggregates, and admixtures should be stored in a manner that will prevent wetting, deterioration, or intrusion of foreign material. Brands of cementitious materials and admixtures, and the sand source should remain the same throughout the entire job.

Measuring Mortar Materials

Measurement of masonry mortar ingredients should be completed in a manner that will ensure the uniformity of mixture proportions, yields, workability, and mortar color. Aggregate proportions are generally expressed in terms of loose volume, but experience has shown that the amount of sand can vary due to moisture bulking.

Fig. 2-11 shows how loose sand with varying amounts of surface moisture occupies different volumes. Fig. 2-12 has the same data in another form for masonry sands, and shows the density of the sand. While dry sand or saturated sand typically has a unit weight of over 100 pcf (1600 kg/m^3), damp loose sand generally contains 80 pcf (1280 kg/m^3) of dry sand, plus the weight of the water. ASTM C270 procedures for proportioning mortar ingredients are based on the premise that sand will be used in a damp, loose condition at the jobsite. Thus, to conform with specification require-

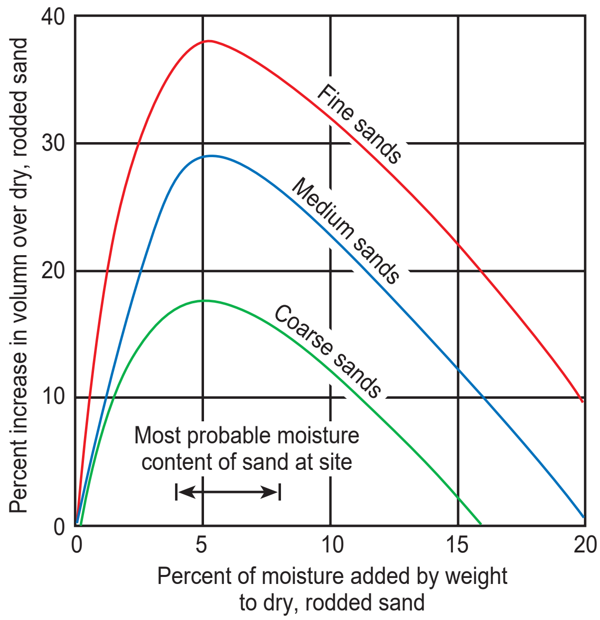


Figure 2-11

Volume of loose, damp sand. Derived from ACI 1923, PCA ST20 1935, PCA MJ172 1955.

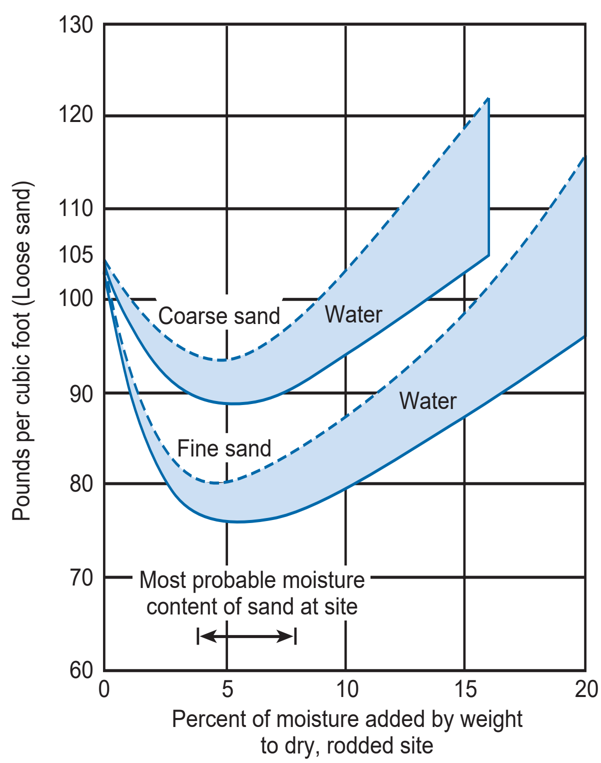


Fig. 2-12

Weight of loose, damp sand. Derived from ACI 1923, PCA ST20 1935, PCA MJ172 1955.

ments, and to assure consistent volumetric batching, sand stocks should be maintained in a damp, loose condition. The sand pile at the jobsite should be covered to reduce evaporation and provide protection from rain or snow (Fig. 2-13).

Ordinary sands will absorb water amounting to 0.4% to 2.3% of the weight of the sand. In the field, damp sands usually have 4% to 8% moisture, so most of the water is on the surface of the sand.

Mortar ingredients other than sand are often sold in bags labeled only by weight. Since mortar is proportioned by volume, it is necessary to know the unit weights of the cementitious materials listed in Table 2-5.

Recognizing that cements used in mortar are proportioned by volume, a bag of portland, masonry, or mortar cement is 1 cu ft by volume or 28 liters (approx. 0.03 m^3). ASTM C270 defines the bulk density of hydrated lime as 40 lb per cu ft (640 kg/m^3). Thus, if hydrated lime is packaged in 50-lb bags (22.7-kg),

Fig. 2-13

Sand piles should be covered to assure consistent mortar quality. (IMG15816)

one bag would contain 1¼ cu ft by volume or 35 liters (approx. 0.04 m^3).

Sand is commonly added to the mortar mixer using a shovel. However, some positive control should be

Table 2-5. Unit Weights of Cementitious Materials

	Bag size, lb (kg)	Unit weight, pcf (kg/m^3)
Portland cement	94 (42)	94 (1510)
Masonry & mortar cements Type N Type S Type M	 70 (32) 75 (34) 80 (36)	 70 (1120) 75 (1200) 80 (1280)
Blended cement*	85-94 (38-42)	85-94 (1360-1510)
Hydrated lime (dry)	40 (18)	40 (640)
Hydrated lime (putty)	80 (36)	80 (1280)

*See weight on bag.

established to assure that the proper volume of sand is used. That can be accomplished by periodically checking the required shovel count with a 1-cu-ft or 28-liter (approx. 0.03-m^3) measuring box (Fig. 2-14) or using the measuring box to add sand to the mixer. The measuring box can be attached to the mortar mixer with a hinge to facilitate one-man operation.

Special techniques that overcome mixture adjustment and jobsite variability problems include dry batching, packaged dry mortar, ready-mixed mortar, and silo-mixed mortar. These techniques are presented later in this chapter.

Mixing of Mortar

To obtain good workability and the other desirable properties of masonry mortar, the ingredients must be thoroughly mixed.

Mixing by Machine

With the possible exception of very small jobs, mortar should be machine-mixed. A typical mortar mixer (Fig. 2-15) has a capacity of 4 cu ft to 7 cu ft (approx. 0.1 m^3 to 0.2 m^3). Conventional mortar mixers are of rotating, spiral- or paddle-blade design with tilting drum. *After all batched materials are together, they should be mixed from 3 to 5 minutes.* Less mixing time may result in nonuniformity, poor workability, low water retention, and less than optimum air content. Longer mixing times may adversely affect the air contents of mortars containing air-entraining cements, particularly during cool or cold weather. Longer mixing times may also reduce the strength of the mortar.

Batching procedures will vary with individual preferences. Experience has shown that good results can be obtained when about three-fourths of the required water, one-half the sand, and all the cementitious materials are briefly mixed together. The balance of the sand is then charged and the remaining water added. The amount of water added should be the maximum that is consistent with satisfactory workability. Mixing is carried out most effectively when the mixer is charged to its design capacity. Overloading can impair mixing efficiency and mortar uniformity. The mixer drum should be completely empty before charging the next batch.

Fig. 2-14

A cubic foot box can be used to verify sand volumes when sand is added to the mixer by shovel. (IMG15668)

Fig. 2-15

For best results, mortar should be mixed with a power mixer. (IMG15814)

Mixing by Hand

When hand-mixing of mortar is necessary, typically on small jobs, all the dry materials should first be mixed together by hoe, working from one end of a mortar box (or wheelbarrow) and then from the other. Next, two-thirds to three-fourths of the required water is mixed in with the hoe and the mixing continued as above until the batch is uniformly wet. Additional water is carefully mixed in until the desired workability is attained. The batch should be allowed to stand for approximately 5 minutes and then thoroughly remixed with the hoe.

Retempering

Fresh mortar should be prepared at the rate used, so that its workability will remain about the same throughout the day. Mortar that has been mixed but not used immediately tends to dry out and stiffen. Loss of water by absorption and evaporation on a dry day can be reduced by wetting the mortarboard and covering the mortar box, wheelbarrow, or tub.

If necessary to restore workability, mortar may be retempered by adding water; thorough remixing is then necessary (Fig. 2-16). Although small additions of water may slightly reduce the compressive strength of the mortar, the result is acceptable. Masonry built using plastic mortar has better bond strength than masonry built using dry, stiff mortar.

Mortar that has stiffened because of hydration should be discarded. Since it is difficult to determine by sight or feel whether mortar stiffening is due to evaporation or hydration, the most practical method of determining the suitability of mortar is on the basis of time elapsed after mixing. Mortar should be used within 2½ hours after mixing.

Fig. 2-16

To restore workability, mortar may be retempered. (IMG13630)

Retemper colored mortar cautiously to avoid color changes. Water content and stiffness of mortar during tooling can also affect color.

Mixing During Hot or Cold Weather

The key to successful and satisfactory construction of masonry in any weather—hot or cold—lies in advanced planning and careful preparation. All-weather construction involves some change in procedures and additional equipment and supplies. Both hot and cold weather significantly influence the entire masonry construction industry. Hot-weather problems often have been encountered but not recognized, resulting in some sacrifice of quality or increase in construction costs. On the other hand, greater extension of the construction season into the winter months in recent years has resulted in better utilization of manpower and has encouraged innovative construction techniques. Chapter 5 goes into more detail on these matters.

Special Mortar Production Techniques

There are a number of proprietary techniques that simplify mortar quality control, batching, and delivery, including:

- packaged-dry mortar materials
- dry-batching
- silo-mixed mortar
- extended-life mortar
- modified mortar

These techniques should not be used without the consent of the project engineer.

Packaged-Dry Mortar Materials

Packaged, combined, dry mortar ingredients have been available since 1936. The bag of dry mortar contains cementitious materials and dry sand accurately proportioned and blended at a manufacturing plant. Only water and mixing are required at the jobsite. The mortar is available in Types M, S, and N. Packaged dry mortar is very useful on small jobs, such as projects needing 1 cu ft to 5 cu ft (0.03 m³ to 0.14 m³) of mortar, or jobs with limited space to store mortar ingredients. This mortar should meet the requirements of ASTM

C387, Specification for Packaged, Dry, Combined Materials for Mortar and Concrete. This document uses property specifications similar to those in Table 2-2.

Dry-Batching

The process of dry-batching all mortar ingredients avoids the need to adjust the mixture for sand moisture content. In dry-batching, the cementitious materials and dry sand are accurately weighed and blended at a central plant before delivery to the jobsite in a sealed container or truck, where the mixture is conveyed into a sealed, weathertight hopper (Fig. 2-17). When mason contractors are ready for mortar, they simply draw material from the hopper into the mixer, add water, and mix. In a variation of this basic concept, the premixed, dry-mortar materials are delivered to the jobsite in bulk-pack, moisture-resistant bags (Fig. 2-17 and Schierhorn 1996). Dry-batching offers convenience, consistent proportions/uniform mortar, possible productivity gains (especially in cold weather), and a cleaner jobsite.

Fig. 2-17

A forklift lowers a bulk-pack, moisture-resistant bag of premixed, dry mortar materials into a silo-dispensing system, which discharges the material into a conventional mortar mixer. Mortar can be stored on-site in a storage silo and then mixed with a mobile mortar mixer. (IMG15810)

Silo-Mixed Mortar

Silo mixers consist of a screw (auger) mixer that is fed dry mortar ingredients from a silo. Single-bin silos use preblended mortar ingredients (cementitious materials and dry sand), whereas multi-compartment silos house mortar ingredients separately. For example, two compartment silos have one compartment for sand and one compartment for cementitious materials. The silo is filled with mortar ingredients at a central plant (Fig. 2-18), delivered to the jobsite by truck, and erected. Mortar ingredients are accurately weighed and preblended as needed at the plant to meet specific project requirements. At the jobsite, the unit merely needs to be connected to a pressurized water source and electricity. Mixing at the jobsite is computer controlled; the contractor simply presses a button when

Fig. 2-18

The storage bin/batcher at this central plant stores individual mortar ingredients (cement, lime, and sand) in separate compartments. The computer controlled plant batches the dry ingredients by weight and dry blends them prior to discharge into a silo. (IMG24171)

Fig. 2-19

When connected to water and electricity at the jobsite, a silo mixer is ready to produce mortar as needed. (IMG14096)

mortar is needed. The mortar is usually placed in a portable tub or wheelbarrow for easy distribution around the jobsite (Fig. 2-19). As with the dry-batching techniques mentioned above, silo-mixed mortar provides accurate batching of mortar materials, reduces jobsite waste, and requires very little space.

Extended Life Mortar

Extended life (sometimes called ready-mixed or trowel-ready) mortar is batched at a central location, usually a ready-mixed concrete or mortar batch plant, mixed in the plant, and delivered to the jobsite in trowel-ready condition. Extended life mortar is made with essentially the same ingredients as conventional mortar, except the mortar contains a special retarding, set-controlling admixture that keeps the mortar plastic and workable for an extended period of time. The ingredients, including a retarding, set-controlling admixture and enough water to provide the desired field consistency, are mixed at a central location using either stationary mixers or truck mixers. Extended life mortar should meet the requirements of ASTM C1142, Specification for Extended Life Mortar for Unit Masonry. The mortar types are designated as Type RM, RS, RN, and RO. Table 2-6 lists the property specifications for these mortars.

The design of ready-mixed mortar is usually based on a performance specification and, therefore, proper preliminary laboratory testing is required to determine ingredient proportions. Once laboratory proportions are established, they should not be changed throughout the job except for admixture adjustments required to compensate for temperature changes to maintain a consistent setting period or board life.

Trowel-ready mortar is delivered to the jobsite in ready-mix trucks, mortar transports, mortar containers, or hoppers (Fig. 2-20). The mortar is stored in ¼-cu-yd to ⅓-cu-yd (0.19-m^3 to 0.25-m^3) protected metal or

Table 2-6. Property Specifications for Ready-Mixed Mortar*

Mortar type	Minimum compressive strength at 28 days, psi (MPa)**	Minimum water retention %	Maximum air content % †
RM	2500 (17.2)	75	18
RS	1800 (12.4)	75	18
RN	750 (5.2)	75	18
RO	350 (2.4)	75	18

* Adapted from ASTM C1142.

** The strength values are standard 2-in (50-mm) cube strength values. Intermediate values may be specified in accordance with project requirements. Two by four inch or 3x6 in. (50x100 mm or 75x150 mm) cylindrical specimens can also be used as long as their strength relationship to cube strength is documented. The 28-day time period starts when the specimens are cast, not when the mortar is initially mixed.

† When structural reinforcement is incorporated in mortar, the maximum air content shall be 12% or bond strength test data shall be provided to justify higher air content.

plastic containers to minimize evaporation and avoid temperature extremes. The retarding, set-controlling admixture delays the initial hydration of the cement, causing the mortar to remain plastic and workable for up to 24 to 36 hours.

Extended life mortar is used the same way as conventional mortar in reinforced and non-reinforced masonry. If the mortar stiffens due to evaporation or absorption of water, the mortar can be retempered with additional water to restore workability. However, the mortar should not be used beyond its predetermined expectancy.

When the mortar is placed between masonry units, the units absorb water from the mortar, thereby removing the set-controlling admixture from solution, at which time the ready-mixed mortar proceeds to set like normal mortar. Therefore, masonry walls can be constructed at the same rate as walls with normal mortar. Like normal mortar, enough water should be in the mortar to develop proper strength gain; however, special precautions should be taken to reduce evaporation on hot and windy days.

Extended life mortar should be used with caution with nonabsorbent units such as glazed units and glass block. Extended life mortar should be retarded for no more than 10 hours for nonabsorbent units.

Fig. 2-20

Extended-life mortar may be delivered in mortar containers (tubs) on a flatbed truck. The mortar-filled containers are unloaded and left at the jobsite. (IMG14082)

The cautions and concerns of using normal mortar are also applicable to extended life mortar. Special information about the use of extended life mortar, including jobsite storage requirements, useful life, and allowable extent of retempering, should be provided by the producer.

Modified Mortar

Occasions arise when modified masonry mortar may be beneficial. Modified mortars are conventional masonry mortars altered by either the addition of an admixture at the mixing location or the replacement of one of the basic mortar ingredients. Benefits are determined from laboratory testing of comparative mortars and testing of walls containing comparative mortars.

ASTM C270 permits admixtures when specified, and ASTM C1384 provides qualification criteria for five different classifications of admixtures, as previously discussed. Some of the concerns with respect to the indiscriminate use of admixtures are discussed in the appendix to ASTM C270.

ASTM C270 does not currently address the use of replacement modifiers. Such mortars are typically qualified by evaluation service reports issued by model code organizations.

Modifiers considered for use in masonry are similar to those used in concrete. Concrete technology, however, must be tempered for masonry applications and the benefits assessed prior to use. Modifiers having varying degrees of acceptance in the masonry industry are listed in Table 2-7.

Selection and use of a mortar modifier should be based on field performance and laboratory testing. Manufacturers of mortar modifiers should be asked to provide data supporting claims about performance of their products under the anticipated climatic conditions that will prevail during use. Modifiers, be they admixtures or replacements, must not be used indiscriminately.

Table 2-7. Modifiers for Mortar

Modifier	Primary benefits	Possible concerns
ASTM C1384 admixtures:		
Bond	Wall tensile (and flexural) bond strength	Reduced workability, bond strength regression upon wetting, corrosive properties
Workability enhancer	Workability, economy	Effect on hardened physical properties under field conditions
Set accelerator	Early strength development	Effectiveness at cold temperatures, corrosive properties, effect on efflorescence potential of masonry
Set retarder	Workability retention	Effect on strength development, effect on efflorescence potential of masonry
Water repellent	Weather resistance	Effectiveness over time
Other admixtures and additives:		
Air-entraining	Freeze-thaw durability, workability	Effect on compressive and bond strengths
Coloring	Esthetic versatility	Effect on physical properties, color stability over time
Plasticizing	Workability, economy	Effect on hardened physical properties under field conditions
Pozzolanic	Increase density and strength	Effect on plastic and hardened physical properties under field conditions
Water reducing	Strength, workability	Effect on strength development under field conditions with absorptive units

Estimating Mortar Quantities

It's easy for a beginner to be fooled when estimating the quantity of mortar for a masonry job. The novice will probably estimate too low. If a low estimate is used to order cement and sand for a job, the mason will have to call in for more material, and the job may be delayed.

An estimator might start by calculating how much mortar there is in a typical 8x8x16-in. (203x203x406-mm) concrete block wall. It is customary to use only face-shell bedding with 3/8-in.-thick (10-mm) joints. A typical 8-in. (203-mm) concrete block would have 1.25-in.-thick (32-mm) face shells, so the mortar for each block (2 bed and 2 head joints) would amount to:

2 x 0.375 in. x 1.25 in. x 23.62 in. = 22.1 cu in. per block.

There are 112.5 block (8x8x16-in.) in 100 sq ft of wall, for which the amount of mortar would be:

22.1 x 112.5 ÷ 1728 = 1.44 cu ft (0.04 m^3)

Allowing 10% for waste, the estimator would then order materials for:

1.10 x 1.44 = 1.6 cu ft of mortar for each 100 sq ft of wall, or in SI metric units:

(1.10 x 0.041 = 0.045 m^3 of mortar for each 10 m^2 of wall)

What the estimator does not know is that most mason contractors order several times as much. Mortar is a small part of the total cost of a wall, but it is critical to the success of a masonry job. Thus, it does not pay to figure quantities too closely. Following are some practical reasons for allowing plenty of overage when ordering materials for mortar:

Mortar width. The face-shell thickness may be 50% greater on top than the average or minimum thickness quoted.

Droppings. A certain amount of mortar falls to the ground and cannot be reclaimed.

Accuracy. The mason cannot apply mortar with the precision of a machine.

Sticking. Mortar sticks to the mixer, tub, wheelbarrow, and mortar board.

Dumping. Sand is usually dumped on the ground and cannot all be used.

Spilling. Some cement, lime, or mortar is bound to be spilled, spoiled, or lost.

Stopping. Mortar left at the end of the day or during work breaks must be discarded.

Weather. A sudden turn in the weather can cause a job shutdown or spoiled mortar.

Change orders. Misfits of openings, dimensions, etc., discovered at the last minute.

Jambs. Door and window jambs are filled with mortar.

Solid courses. Cores filled solid with mortar for anchor bolts and where joists bear.

First course. The bottom course rests on a generous ¼-in. to ¾-in.-thick (6.4-mm to 19-mm) mortar bedding.

Cutouts. Plumbing and electrical openings to be closed with mortar.

Tolerances. If all block in a wall were 1⁄16 in. (1.6 mm) undersize, all mortar joints would have to be about 17% thicker.

Sloughing. Mortar thrown into a wall cavity rather than back onto the mortar board.

Timing. Mortar setting up before being used.

Inspection. Mortar rejected because the mixture was not right.

Judgment. On small jobs, contractors don't calculate quantities, they just "order from experience."

Rounding. When 9.2 cu yd (m^3) of sand are needed, 10 are ordered. When 84 bags of cement are needed, 90 are ordered.

Variations. Sand quality is not always uniform.

Proportioning. Sand quantity may vary from 2¼ to 3 times the sum of the volume of cementitious material depending on the units and job conditions.

Others. It is not difficult to find other job problems and peculiarities that may require more mortar than the estimate. Human error causes a variety of wastes.

Probably a lot of contractors have forgotten why they order as much mortar as they do. Some of them might say they allow 10% for waste. What they call waste doesn't begin to account for a lot of good reasons for ordering much more than the theoretical quantity. Table 2-8 gives recommendations for the amount of mortar to order for single-wythe walls of various thicknesses using 8-in.-high by 16-in.-long (203x406-mm) units. For more details on estimating the quantity of mortar and other materials in concrete masonry, see "Quantity Takeoffs" in Chapter 6.

Grout

Grout is an essential element of reinforced brick or concrete block construction. The grout bonds the masonry units to the steel reinforcement so they act together to resist loads. Either cores in the masonry units or the spaces between wythes are grouted. Reinforced masonry is essential in earthquake- and hurricane-prone areas (Fig. 2-21).

Grouting of brick or block walls serves several purposes: (1) it increases the cross-sectional area of the wall and aids in resisting vertical loads and lateral shear loads; (2) it bonds the wythes together in multi-wythe wall construction; and (3) it transfers stresses from the masonry to the reinforcing steel when a wall is subjected to lateral forces due to wind, earthquake, or earth pressure.

Table 2-8. Estimate of Mortar Quantites to be Ordered

Nominal wall thickness, in. (mm)	Nominal size (width x height x length) of concrete masonry units, in. (mm)	Material quantities for 100 sq ft (10 m^2) of wall area	
		Number of units	Mortar, cu ft (m^3)
4 (100)	4x8x16 (100x200x400)	112.5 (12.1)	10.1 (0.29)
6 (150)	6x8x16 (150x200x400)	112.5 (12.1)	10.1 (0.29)
8 (200)	8x8x16 (200x200x400)	112.5 (12.1)	10.1 (0.29)
12 (300)	12x8x16 (300x200x400)	112.5 (12.1)	10.1 (0.29)

* TEK 4-2A 2004 recommends adding a 5% allowance for waste and breakage, which translates to 119 units for 100 sq ft (10 m^2) of wall area.

Fig. 2-21

Grout is an essential part of reinforced masonry. (IMG15599)

Grouted unreinforced masonry walls are similar to reinforced masonry walls but do not contain reinforcement. Grout is sometimes used in load-bearing wall construction to give added strength to hollow walls by filling a portion or all of the cores. It is also used for filling bond beams and occasionally the collar joint (space between wythes) in two-wythe wall construction.

Grout Selection

While mortar is placed between units as they are laid, grout is poured or pumped into cores or into cavities between wythes of masonry walls already in place. The grout must uniformly fill these spaces, harden to provide desired compressive strength, and bond to steel and masonry units. In order to satisfactorily meet these performance requirements, the flowability, aggregate size, and proportions of a grout mixture must be compatible with the application.

Masonry grout is composed of a mixture of cementitious material and aggregate to which sufficient water is added to cause the mixture to flow readily into the masonry cores and cavities without segregation. Unless otherwise specified, grout mixture proportions are selected to conform to the requirements of ASTM C476 (Table 2-9). ASTM C476 also provides for specification of grout by compressive strength as an alternate to specifying by proportions.

The fineness or coarseness of a grout is selected on the basis of the size of the grout space to be filled as well as the height of the grout pour (Table 2-10). Fine and coarse grout and aggregate size and gradation are defined in ASTM C476 and C404. Building codes and standards sometimes differ on specific values of maximum grout aggregate size versus clear opening, so the governing document should be consulted.

For fine grout (grout without coarse aggregate), the smallest space to be grouted should be at least ¾ in. (19 mm) wide, as should occur in the collar joint of two-wythe wall construction.

In high-lift grouting—where the smallest horizontal dimension of the space to be grouted is about 3 in. (76 mm)—a coarse grout with ½-in. (13-mm) maximum-size coarse aggregate (or pea gravel) may be used. Some specifying agencies allow ¾-in. (19-mm) maximum-size coarse aggregate when the grout space is 4 in. (102 mm) or greater. The maximum size of aggregate and consistency of the mixture should be selected considering the particular job conditions to ensure satisfactory placement of the grout and proper embedment of the reinforcement.

Table 2-9. Masonry Grout Proportions by Volume*

Type	Parts by volume of portland cement or blended cement	Parts by volume of hydrated lime or lime putty	Aggregate, measured in a damp, loose condition: Fine	Aggregate, measured in a damp, loose condition: Coarse
Fine grout	1	0 to 1/10	2¼ to 3 times the sum of the volumes of the cementitious materials	
Coarse grout	1	0 to 1/10	2¼ to 3 times the sum of the volumes of the cementitious materials	1 to 2 times the sum of the volumes of the cementitious materials

* Adapted from ASTM C476. Applicable material standards are portland cement—ASTM C150; blended cement—ASTM C595 and ASTM C1157; hydrated lime—ASTM C207; lime putty—ASTM C5; fly ash or raw calcined natural pozzolan—ASTM C618; granulated blast furnace slag—ASTM C989; aggregate—ASTM C404.

Table 2-10. Grout Space Requirements

Specified grout type*	Maximum grout pour height, ft (m)	Minimum width of grout space, in. (mm)**†	Minimum grout space dimensions for grouting cells of hollow units, in. (mm)‡
Fine	1 (0.3)	¾ (19)	1½x2 (38x51)
Fine	5 (1.5)	2 (51)	2x3 (51x76)
Fine	12 (3.7)	2½ (64)	2½x3 (64x76)
Fine	24 (7.3)	3 (76)	3x3 (76x76)
Coarse	1 (0.3)	1½ (38)	1½x3 (38x76)
Coarse	5 (1.5)	2 (51)	2½x3 (64x76)
Coarse	12 (3.7)	2½ (64)	3x3 (76x76)
Coarse	24 (7.3)	3 (76)	3x4 (76x102)

*Fine and coarse grouts and aggregates are defined in ASTM C476 and C404.

**For grouting between wythes.

† Grout space dimension is the clear dimension between any masonry protrusion and should be increased by the diameters of the horizontal reinforcing bars within the cross section of the grout.

‡ Area of vertical reinforcement shall not exceed 6% of the area of the grout space. Adapted from *MSJC Specification* (MSJC 2005).

Specifications and Codes

Grout for use in masonry walls should comply with the requirements of Specification for Grout for Masonry, ASTM C476 (Table 2-9); the *MSJC Building Code Requirements for Masonry Structures*, and the *MSJC Specification for Masonry Structures* (MSJC 2005).

Materials

The grout ingredients should meet the requirements of ASTM C150, C595, or C1157 for cement, C207 for hydrated lime, and C404 for aggregates. Fly ash or natural pozzolans meeting the requirements of ASTM C618 and ground granulated blast furnace slags meeting the requirements of ASTM C989 are also permitted, but only under the strength requirements of ASTM C476. All of the materials included in ASTM C476 are satisfactory for use in grout. Projects using large volumes of grout may obtain the grout from a ready-mixed concrete producer; the use of lime then becomes uneconomical because of the expense in handling.

Admixtures

Grout admixtures may be used to modify grout properties. Examples are pumping aids or admixtures to reduce shrinkage. The manufacturer of such admixtures should provide data substantiating the performance of the products, referencing applicable ASTM standards. Do not use chloride-based admixtures in grout. Chlorides contribute to corrosion of steel reinforcement and accessories.

Strength

As an alternative to grout proportioning by volume (Table 2-9), ASTM C476 grout may be proportioned to have a compressive strength equal to or exceeding the specified compressive strength of the masonry (f'_m), but not less than 2000 psi (13.8 MPa). Grout strength is to be determined in accordance with ASTM C1019.

The mixture proportions in Table 2-9 will produce grouts with a compressive strength of 1000 to 2500 psi (6.9 to 17.2 MPa) at 28 days, depending on the amount of mixing water used and when tested by conventional laboratory methods using nonabsorptive molds. However, the actual in-place compressive strength of grout generally will exceed 2500 psi (17.2 MPa) because, under ordinary conditions, some of the mixing water will be absorbed by the masonry after the grout is placed and prior to setting and hardening. This absorption reduces the water-cement ratio of the in-place grout and increases the compressive strength. Furthermore, the moisture absorbed and held by the surrounding masonry during the period immediately following placement of grout helps to maintain the grout in the moist condition needed for satisfactory cement hydration and strength gain (curing). Therefore, ASTM C1019 requires forming grout test specimens in absorptive molds formed from actual masonry units, as described later in this chapter.

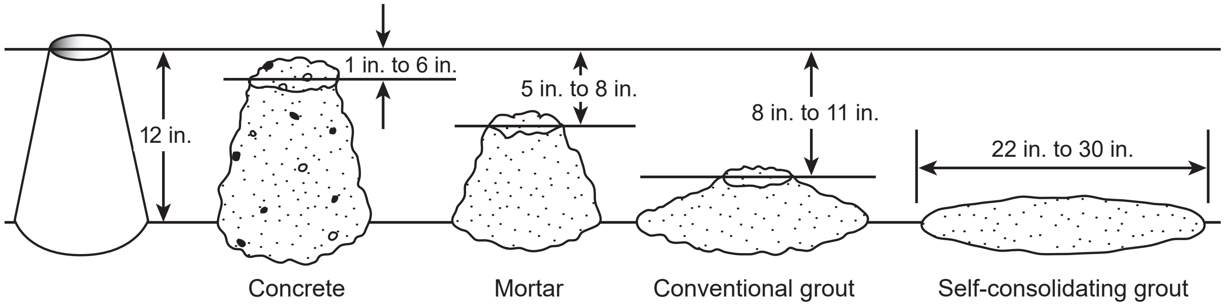


Figure 2-22

Slump test comparison of concrete, mortar, conventional masonry grout, and self-consolidating grout (slump flow) (1 in. = 25.4 mm).

Consistency (Slump)

All grout should be of a fluid consistency, but only fluid enough to pour or pump without segregation. It should flow readily around the reinforcing steel and into all crevices and joints in the masonry, leaving no voids. There should be no bridging or honeycombing of the grout.

The consistency of grout as measured by the slump test (ASTM C143) should be based on the rate of absorption of the masonry units and on the temperature and humidity conditions at the jobsite. As noted in Fig. 2-22, the slump of grout should be between 8 and 11 in. (203 to 279 mm); use about 8 in. (203 mm) for masonry units with low absorption and about 10 in. (254 mm) for units with high absorption.

Mixing

Whenever possible, grout should be batched, mixed, and delivered in accordance with the requirements for ready-mixed concrete (ASTM C94). Because of its relatively high slump, ready-mixed grout should be continuously agitated after mixing and until placement to prevent segregation.

Mixing of masonry grout on the jobsite should be by mechanical mixer. When a batch mixer is used on the jobsite, all materials should be mixed thoroughly for a minimum of 5 minutes. Hand mixing of grout may be used on small jobs with written approval of the project engineer, who should outline the hand-mixing procedure to be used. Grout not placed within 1½ hours after water is first added to the batch should be discarded.

Placing

Even though masonry grout is quite fluid, it is a good practice to consolidate the grout by rodding or vibration to ensure that it encompasses all the reinforcing steel and completely fills the voids. Grout pours up to 12 in. (305 mm) high are consolidated by vibration or rodding (puddling). Grout pours more than 12 in. (305 mm) high are consolidated by vibration and reconsolidated after settlement and initial water loss occurs.

Because grout mixture water is absorbed by the masonry units, there is a slight volume reduction of the grout. Therefore, use of a shrinkage-compensating admixture or expansive cement is sometimes recommended on high-lift grouting operations. The expansion of this type of grout counteracts the volume change due to loss of water to the masonry units.

Masonry grout is usually delivered in ready-mix trucks, and pumps are used to place the grout in the walls (Fig. 2-23). By meeting certain conditions—masonry has cured for at least 4 hours, the grout slump is 10 in. to 11 in. (250 mm to 275 mm), and there are no intermediate bond beams—grout can be placed in lifts up to 12.67 ft (3.86 m). Otherwise the maximum grout lift height is 5 ft (1.52 m).

Fig. 2-23

Pumping ready-mixed grout. (IMG13582)

Curing

The high water content of masonry grout and the partial absorption of this water by the masonry units will generally provide adequate moisture within the masonry for curing both mortar and grout. In dry areas where the masonry is subjected to high winds, some moist curing (such as fogging or protection with plastic sheeting) may be necessary.

Because of its high water content, grout placed during cold weather is particularly vulnerable to freezing during the early period after grouting. To offset cold temperatures, the sand and water used in grout should be heated, and heated enclosures or covers should be used to protect masonry when ambient temperatures are below 40°F (4.4°C).

Sampling and Testing

ASTM standard C1019 can be used for quality control of uniformity of grout during construction, to select grout proportions required to achieve specified grout strength, or to verify grout strength. Grout specimens for compressive strength tests are prepared according to C 1019 rather than cast in the cylinder molds used for concrete. The standard uses molds formed with actual masonry units having the same absorption characteristics and moisture content as the units used in the construction (Fig. 2-24). This simulates in-the-structure conditions, where water from the grout is freely absorbed by the units, thus reducing the water-cement ratio of the grout and increasing its compressive strength. Because of the high water content of grout, samples cast in conventional molds would result in lower strengths that would not be indicative of actual in-the-wall strengths.

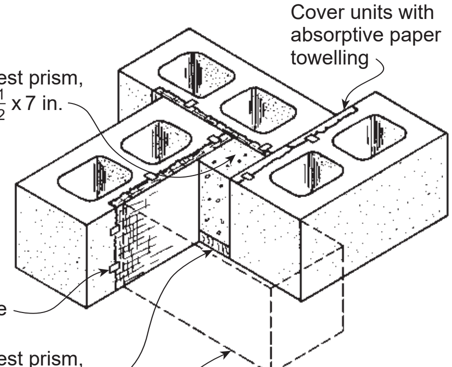


Fig. 2-24

ASTM C1019 method of using masonry units to form a prism for compression-testing of masonry grout.

A minimum of ½ cu ft (0.014 m^3) of grout should be sampled for slump and strength tests. The sample should be obtained as the grout is placed into the wall. The grout strength test specimen should be a nominal 3 in. (76 mm) or larger square prism with a height of twice the width. Three test prisms should be used to represent one grout sample.

When required, grout samples should be taken and tested in accordance with ASTM C1019 for each 5000 sq ft (465 m^2) of masonry. Also, a sample should be taken whenever there is any change in mixture proportions, method of mixing, or materials used.

The duties and responsibilities of testing agencies are described in ASTM Practice C1093.

New Developments

Self-consolidating and conventional grouts have similar hardened properties but differ in their fresh properties (Atkinson-Noland 2004). Where conventional grouts contain large amounts of water to provide flowability so that the grouts can be placed, self-consolidating grouts (SCGs) generally have lower water contents and instead contain a new type of superplasticizing admixture (polycarboxylates) to impart a high degree of workability. The highly fluid SCG mixtures are easier to place, do not require consolidation (mechanical vibration), and generally lead to better filling of masonry cavities. SCGs can be fine or coarse grouts, but are generally coarse.

Specifying SCGs

ASTM C476, Standard Specification for Grout for Masonry, allows for both proportion and strength requirements. With SCGs, fresh and hardened properties should be quantified. Grout spread should be 22 in. to 30 in. (see "Testing and Inspecting SCGs" below). Grout strength should be 2000 psi minimum at 28 days. Shear-bond strength or pullout strength of grout have also been tested and could be specified if needed for certain projects.

Testing and Inspecting SCGs

As an example of the properties of self-consolidating grout, several physical parameters of a specific formulation are shown in Table 2-11 (Atkinson-Noland 2004).

Table 2-11. Properties of an Example Self-Consolidating Grout Formulation

Property*	Results (averages)
Slump flow, (within 10 minutes)	26 in.
Temperature, °F	60.7
Water loss (w/c at 5 minutes and beyond)	stabilized at 0.5 with little subsequent change
Compressive strength, psi	5020
Grout-unit shear-bond strength, psi	498
Reinforcement pullout strength, psi	67,600

* Measured after the truck arrives at the jobsite.

Testing fresh SCG requires a different method than the slump test. The slump flow is a simple yet effective quality control method developed for assessing workability and cohesiveness of SCG. The slump flow, or spread, of this material is similar to the concrete slump test. On a stable, flat surface, a slump cone is filled, then removed, resulting in a large pat of material. Pat diameter is measured at two places (at right angles to each other) and the average is recorded as the slump flow or spread (Fig. 2-25). SCGs should have a spread of anywhere from 22 in. to 30 in. (560 mm to 760 mm). At the same time, there should be no evidence of segregation: no bleed water forming around the edges of the pat and no clumps of aggregate. If either condition is occurring, it indicates non-cohesive behavior. That could lead to poor grout quality in place. Slump flow is checked before sending the grout out to a site. Workability retention is high, so retesting at the jobsite is not mandatory.

The temperature of the SCG should be checked as delivered. The temperature reading is a fast check for anything unusual that might be happening in the mix. Typical grout temperature will be near 73°F (22.8°C). Typical recommendations for protecting fresh grout during hot and cold weather should be followed.

Compressive strength specimens should be made as specified in ASTM C1019, the Standard Test Method for Sampling and Testing Grout, as shown in Fig. 2-24. A note in C1019 indicates that alternate methods of forming specimens may be used provided that they are first verified by comparative testing with the standard C 1019 mold. One compressive sample that has been used as an alternative to the standard is a core drilled from a regular concrete masonry unit that has been grouted with SCG. Three-in. (76 mm) diameter cores that meet the required height-to-diameter aspect ratio can be obtained from grouted standard size concrete masonry units having nominal dimensions of 8x8x16 in.

The *MSJC Spec* permits the use of grouting procedures that exceed the limitation on maximum pour heights if a grout demonstration panel is constructed to verify that the proposed grouting will adequately fill the spaces (MSJC 2005). The building code requires clean-out openings to verify that cores are not obstructed with debris.

The inspecting agency should be made aware of the test panels prior to the job pour. This affords inspectors the opportunity to view the demonstration so they can compare the actual construction to it. The most important aspect of grouting will be making sure that the cells that are intended to be filled are actually filled. The grout characteristics that describe the performance of the hardened grout should have already been verified by lab testing. Specifiers can accept test results from the grout supplier.

Fig. 2-25

A slump flow test is done on a flat surface using a standard slump cone. After filling, the cone is lifted and the diameter of the resulting pat is measured. (IMG24172)

Properties of Concrete Masonry Walls

CHAPTER 3

A wall does more than merely enclose a building in an attractive fashion. It must have strength to support floors and roofs and to resist the buffeting of nature. It must be a shield against noise, heat or cold, and fire. This chapter assists architects, engineers, and builders in the design and construction of concrete masonry walls that fill these needs.

Strength and Structural Stability

Modern concrete masonry wall construction is of two general types: unreinforced (plain) and reinforced. These classifications are characterized by some differences in mortar type requirements, use of reinforcing steel, and erection techniques. Both types are usually subject to the provisions of applicable building codes.

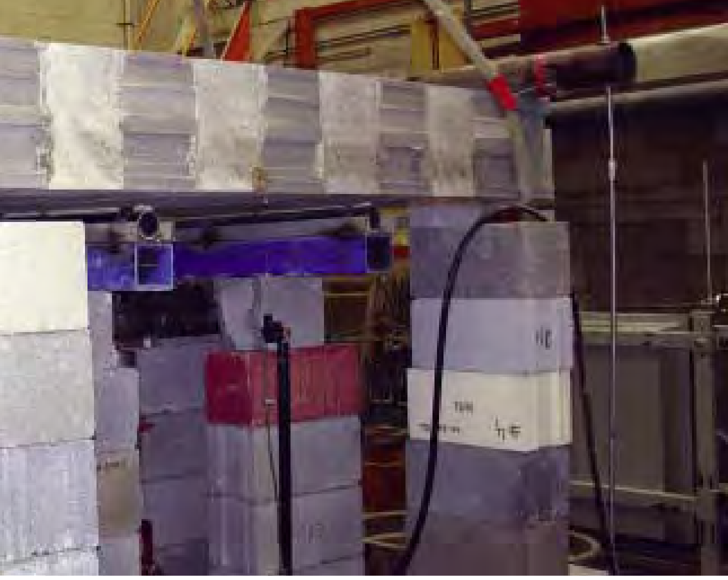
Unreinforced (plain) concrete masonry is the most common type, and it has been in use for many years. Essentially unreinforced, any steel reinforcement used in this type of concrete masonry is generally of light gage and placed in relatively small quantities in the horizontal joints.

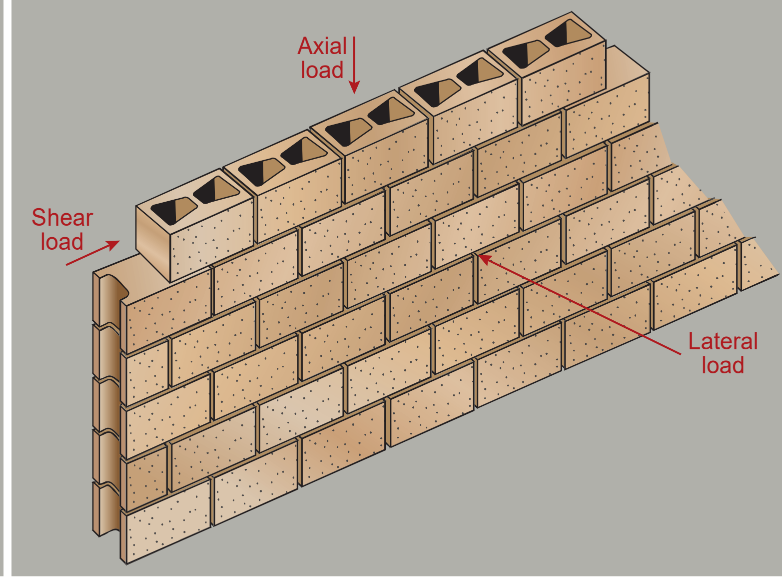
Reinforced concrete masonry on the other hand contains reinforcing steel so placed and embedded that the masonry and steel act together in resisting forces. This structural behavior is obtained by placing deformed steel bars in the vertical and horizontal cores or cavities of the masonry, then filling these spaces with properly consolidated portland cement grout. Structural bond develops between the hardened grout, the bars, and the masonry units, permitting reinforced concrete design theory to be adapted to produce buildings of reinforced concrete masonry.

Fig. 3-1

Reinforced concrete masonry. Steel is placed in the vertical and horizontal cavities before they are filled with grout. (IMG24886)

Reinforced concrete masonry is used where the compressive, flexural, and shear loads are higher than can be accommodated with plain concrete masonry. It is required by code in areas of recurring hurricane winds or earthquake activity where major damage to buildings could be expected.





Above: A fully grouted masonry panel being prepared for flexural strength testing. See Fig. 3-3 for the panel in a deflected (loaded) condition. Photo courtesy of the National Concrete Masonry Association. (IMG24885)
Right: Loads acting on masonry walls are described as axial, shear, and lateral loads. See Fig. 3-8.

Fig. 3-2

Load-bearing walls of concrete masonry form the façade of this ten-story condominium. Use of steel reinforcement in the grouted block cavities allows for taller and thinner walls than in the past, even in high seismic areas. (IMG25238)

Structural Tests

Extensive testing of representative concrete masonry assemblages over a period of many years has established concrete masonry wall construction as a reliable and predictable structural system. Some of the test methods developed during structural research studies of concrete masonry and other wall forms have been adopted as standards and are described in ASTM E72, *Standard Methods of Conducting Strength Tests of Panels for Building Construction* (also see Yokel, Mathey and Dikkers 1970). Some other tests that are commonly used in analyzing masonry include ASTM E514, E519, C1314, and C1357.

Analyses of accumulated test data have produced useful, reproducible relationships between the strength of masonry components and the strength of completed walls. From these relationships, building code authorities have established allowable design stresses under various loading conditions or formulas for their calculation. Furthermore, structural research has enabled the development of quality control criteria to ensure fulfillment of design requirements in the completed structure, and methods of determining the compressive strength of in situ masonry have been evaluated (PCA SN1982 1993).

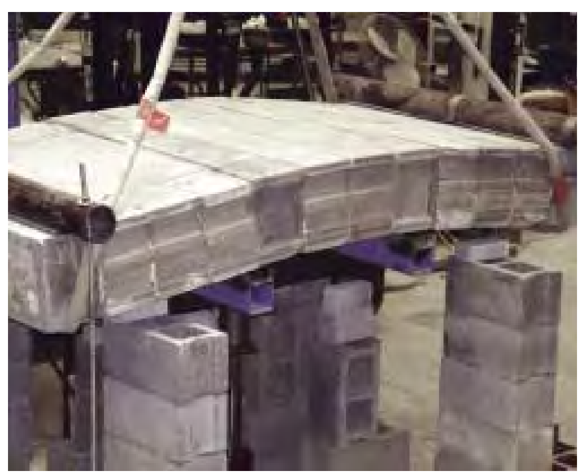


Fig. 3-3

Concrete masonry walls are tested for flexural strength in accordance with ASTM E72, Standard Test Methods of Conducting Strength Tests of Panels for Building Construction. Ungrouted walls are typically tested in the vertical orientation, but grouted walls may be tested horizontally or vertically. Photo courtesy of the National Concrete Masonry Association. (IMG24887)

Design Methods

Design methods for concrete masonry are well established. However, there is continuing research to ensure that these methods are updated to keep pace with progress in the construction industry.

Masonry Building Codes and Specifications: History and Development

MSJC Code and Specification. In 1988, the Masonry Standards Joint Committee (MSJC) published *Building Code Requirements for Masonry Structures* (ACI 530/ASCE 5), *Specifications for Masonry Structures* (ACI 530.1/ASCE 6), and corresponding commentaries on each of these documents (*MSJC Code and Specification* 1988, MSJC *Commentaries* 1988). This was a breakthrough in masonry design because for the first time in the United States, a unified design approach for both clay masonry and concrete masonry was available to the design professional. Prior to this time, separate and dissimilar design methodologies were being promoted for clay and concrete masonry. In addition, there had been no clear guidance available for the design of multiwythe masonry walls consisting of clay brick with a concrete block backup. As a result, masonry design had been unnecessarily complicated, requiring two different approaches for the most common masonry materials, and lacking provisions for design of composite or multiwythe walls.

Fig. 3-4

Concrete masonry units are evaluated for shrinkage in order to determine appropriate crack control provisions for structures. Specimens of whole units or face shells (pictured) are saturated, then subjected to oven drying to an equilibrium weight and length in accordance with ASTM C426, the Standard Test Method for Linear Drying Shrinkage of Concrete Masonry Units. For measuring the change in linear dimension of regular concrete masonry units, a 10-in. (254-mm) gage length is recommended. (IMG24888)

Even though the 1988 documents were the result of many years of hard work and compromise, it soon became apparent that these standards would need periodic updating and revision to incorporate corrections and improvements noted by users of these documents. Accordingly, the MSJC, organized under the auspices of the American Concrete Institute (ACI), the American Society of Civil Engineers (ASCE), and The Masonry Society (TMS), published revised editions of the *MSJC Code*, the *MSJC Specification*, and their related *Commentaries* in 1992, 1995, 1999, 2002, and 2005 (MSJC 1992, MSJC 1995, MSJC 1999, MSJC 2002, and MSJC 2005). The *MSJC Code* and *MSJC Specification* are now on a three-year cycle, with the next edition to be dated 2008.

Over the years since 1988, significant improvements have been made to the documents, including reorganization of the *MSJC Code and Specification*, extensive revision of *Code* seismic design requirements, and addition of chapters on glass block masonry, veneer, strength design, prestressed masonry, and an appendix on autoclaved aerated concrete masonry. Additionally, minimum criteria for quality assurance were more clearly defined. Three levels of quality assurance are included, based on the design procedure used and whether the structure is identified as essential or non-essential.

Model Codes. Parallel to development of the *MSJC Code and Specification*, significant changes were made to the model building codes that had traditionally been referenced in local and regional building ordinances. Prior to 2000 local jurisdictions referenced one of three model building codes: the *Uniform Building Code* (predominant in the west), the *Standard Building Code* (predominant in the southeast), and the *BOCA National Building Code* (predominant in the northeast). The *Standard Building Code*, and the *BOCA National Building Code* referenced the 1988 *MSJC Code* for masonry design provisions after it was published. However, the *Uniform Building Code* continued to retain embedded masonry design provisions, primarily because the *MSJC Code* did not contain a strength design method and had significantly different seismic design criteria. However, in 1994 representatives from the three model code sponsoring organizations agreed to form the International Code Council (ICC) and, in April 2000, the ICC published the first edition of the *International Building Code* (ICC IBC 2000), which referenced MSJC 1999 for masonry design provisions. Subsequent editions of the IBC have continued to reference the *MSJC Code and Specification* for design and construction of masonry, for example the 2006 edition of *IBC* references MSJC 2005. Therefore, the *MSJC Code and Specification* have become accepted as the basis for masonry design and construction requirements by most local and regional building code jurisdictions.

Basic Concepts

Building codes provide three different procedures for use in the design of concrete masonry: empirical design, allowable stress design, and strength design. Empirical design is a prescriptive procedure for sizing and proportioning unreinforced masonry elements, based on historical performance of masonry. It provides a convenient design method for simple structures subjected to fairly light wind loads and located in areas of low seismic risk (MSJC 2005, TEK 14-8A 2001).

Engineered design of masonry is either based on the allowable stress method, or the strength design method. Both methods enable the designer to efficiently design safe masonry structures. While allowable stress has a longer history of use in the design of masonry structures, strength design may be more familiar to some engineers and architects because it is also used in concrete construction (TEK 14-4A 2002, TEK 14-7A 2004, Prokopy 2006, TMS MDG5 2007).

In the design of concrete masonry using either the allowable stress method or the strength design method, the determined compressive strength of the masonry, f_{mt}, must equal or exceed the specified compressive strength of masonry, f'_m, used in the structural design. Strengths are expressed in psi (MPa). The compressive strength of masonry depends on the strength of the units and mortar in the joints (and grout, if used). According to the *MSJC Specification* two methods may be used to determine masonry strength for a particular mortar type and masonry unit:

1. Prism test method. Masonry prisms representative of the masonry wall are constructed as shown in Fig. 3-5. If the structure is to have grouted cores, the masonry unit cores in the prism are filled with grout. No reinforcement is used in the prisms, but a two-wythe prism may contain metal ties. The test procedure, apparatus, and data should comply with requirements of ASTM C1314, which replaces ASTM E447 in 1999 and later editions of the *MSJC Specification*. The compressive strength, f_{mt} , is calculated by dividing the ultimate test load by the solid cross-sectional area of the prism, including the area of any grout-filled cavities. The standard notes that reducing the length of units prior to constructing prisms makes it easier to fabricate, transport, and test the prisms and provides a more accurate assessment of strength. Additional details are given in the *Commentary on Specification for Masonry Structures* (MSJC 2005), ASTM C1314, and in PCA IS276 1993 and Thomas and Scolforo 1995.

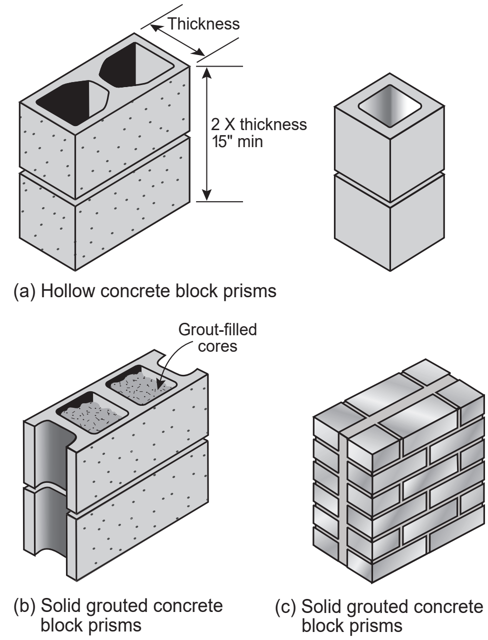


Fig. 3-5

Fig. 3-5. Concrete masonry compression-test prisms.

2. Unit strength method. If no prism tests are conducted, compressive strength may be assumed based on tables given in building codes and specifications, such as Table 3-1, adapted from the *MSJC Specification* (MSJC 2005). The relationship between masonry unit strength and specified masonry compressive strength is illustrated in Fig. 3-6.

Table 3-1. Compressive Strength of Masonry Based on the Compressive Strength of Concrete Masonry Units and Type of Mortar in Construction*

Net area compressive strength of concrete masonry units, psi (MPa)		Net area compressive strength of masonry, psi** (MPa)
Type M or S mortar	Type N mortar	
1250 (8.62)	1300 (8.96)	1000 (6.90)
1900 (13.10)	2150 (14.82)	1500 (10.34)
2800 (19.31)	3050 (21.03)	2000 (13.79)
3750 (25.86)	4050 (27.92)	2500 (17.24)
4800 (33.10)	5250 (36.20)	3000 (20.69)

* Adapted from MSJC 2005.

** For units less than 4 in. (102 mm) high, use 85 percent of the values listed.

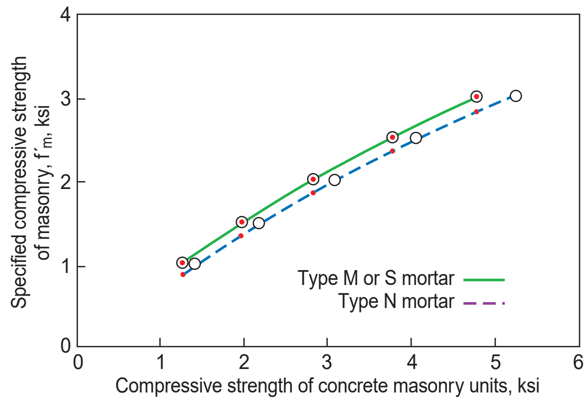


Fig. 3-6

Value of specified compressive strength of masonry, f'_m, based on strength of individual concrete masonry units. Adapted from MSJC 2005.

Tests of masonry prisms may be considered conceptually analogous to concrete cylinder tests in concrete construction. In concrete, the variability of test results is taken into consideration based on criteria using standard deviation calculations. For masonry, it is not possible at this time to provide similar criteria because of lack of sufficient test data. Currently, when using the prism test method, the compressive strength is determined as the average of test results of at least three masonry prisms. This average strength must equal or exceed f'_m.

In allowable stress design, calculations are performed to determine stresses in a member under the action of service loads prescribed in building codes or *MSJC Code* referenced documents. Calculated stresses are limited to allowable levels of stress prescribed by the codes. The calculations are based on the assumption of material behavior following a linear relationship between stress and strain. For a purely flexural member, such as a masonry lintel, the distribution of strain and stress under the prescribed service load is assumed to be as shown in Fig. 3-7a.

Strength design methods using factored loads and strength reduction factors have made their way into masonry building codes and design manuals. As early as 1988, the *Uniform Building Code* permitted the design of concrete masonry slender walls and shear walls to be based on these methods (ICBO 1997). In 2002, the Masonry Standards Joint Committee added strength design requirements into the *MSJC Code* (MSJC 2002). The method requires that design strength of masonry elements equal or exceed required strength. Required strength is determined using strength design (factored) load combinations of the legally adopted building code or *MSJC Code* referenced documents. Design strength of structural elements is the nominal strength reduced by the appropriate strength reduction factor (MSJC 2005, TEK 14-4A 2002). Under factored loads, material within the member is assumed to be at the point of failure. For example, concrete masonry is assumed to be at the point of crushing and steel at the point of yield. To account for conditions that include variability in material strength and tolerances in member dimensions, calculated strength is multiplied by strength reduction factors prescribed by code.

Note that while calculations are performed assuming conditions at failure, code prescribed load factors and strength reduction factors provide the safety margin intended by code for the design of the member. For a purely flexural member, such as a masonry lintel, the distribution of strain and stress is assumed to be as shown in Fig. 3-7b.

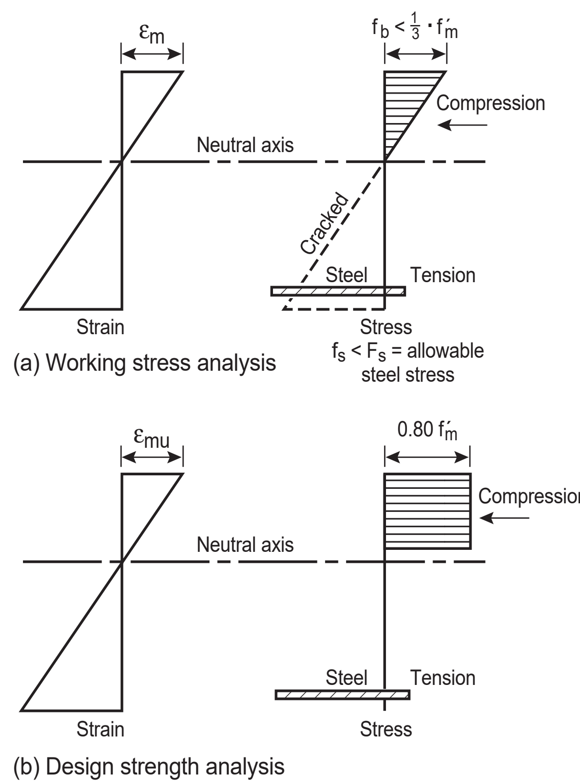


Fig. 3-7

Strain and stress distributions at cross section of a concrete masonry flexural element.

Under both working stress and strength design methods, calculations must be performed to check serviceability conditions, such as estimating deflections and evaluating the possibility of excessive cracking. In

Fig. 3-7b, a rectangular stress distribution is used to reflect the nonlinearity of stress and strain in concrete or masonry near failure. Stress distribution and assumptions used for concrete masonry are currently almost the same as those used for concrete. Additional research may yield a revision of these assumptions for concrete masonry.

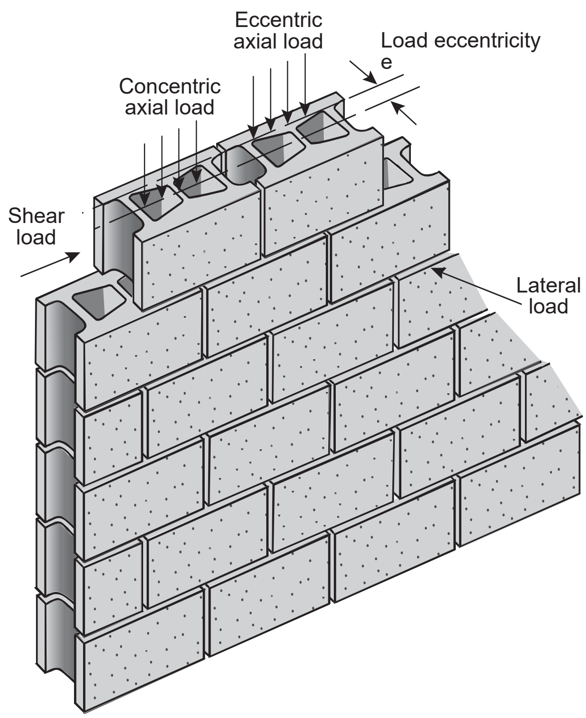


Fig. 3-8

Types of loads acting on a masonry wall.

Effect of Loads

Forces acting on a member can be described as axial loads, lateral loads, or shear loads as illustrated in Fig. 3-8. The type and position of loads acting on a masonry wall affect its design and proportioning.

Axial Loads. The allowable concentric axial load on an unreinforced laterally supported concrete masonry wall depends on such features as wall height, wall thickness, and masonry compressive strength (see MSJC 2005, TMS MDG5 2007). To facilitate selection of proper wall dimensions, design aids such as Table 3-2 are available. The loads given in this table are concentrically applied and no lateral load such as wind or earthquake is assumed to be acting.

It is assumed for all the allowable wall loads shown in the tables and graphs of this section that proper engineering or architectural supervision of construction (quality assurance) will take place. Inspection of engineered concrete masonry is necessary to ensure that its performance potential will be realized.

Vertical loads on load-bearing walls include the weight of floors, walls, and roof above, as well as the weight of the wall itself. When vertical loads are not centered on the wall, additional stresses due to bending are created. The combination of axial and bending stresses can be calculated and compared with allowable stresses given in building codes. For eccentric loads, design aids such as Table 3-3 may be used to facilitate selection of wall dimensions (also see NCMA 1971, NCMA TR 121 2000).

Lateral Loads. Lateral loads induce significant bending stresses in masonry walls. Basement walls are subject to lateral soil pressures. Also, if proper drainage has not been provided around the base of the foundation, hydrostatic pressure outside the wall will increase bending stresses in the wall. Table 3-4 gives the maximum allowable height of unbalanced backfill for empirically designed foundation walls. Because this information is based on empirical design, it can only be used when certain criteria are met, including: adequate lateral support along the wall's height and length, free-draining backfill and proper surface drainage grading away from the wall, lateral support at the top of the wall prior to backfilling, and masonry laid in running bond pattern with Type M or S mortar. See MSJC 2005 for specific requirements. If these conditions are not satisfied, the wall must be designed by allowable stress or strength design methods or as prestressed masonry.

Wind and earthquakes also cause lateral forces on masonry walls (ASCE 7-02 2002, ASCE 7-05 2005, ICC IBC 2006). Wind pressures are prescribed by building codes and range from 5 psf to 35 psf (239 Pa to 1675 Pa).

In seismic regions building codes call for lateral loads for ductile reinforced masonry ranging from 5% to 20% of the dead weight of the wall. In some extreme cases for unreinforced masonry, the maximum may be over 60%. While wind loads are only applicable for exterior walls, earthquake loads act on both exterior and interior walls.

For a discussion of the performance of masonry structures in a recent major earthquake and hurricane, see Klingner 1994 and Samblanet 1996, respectively.

Concrete masonry walls resist lateral loads in the horizontal or vertical spans, depending on the support

Table 3-2. Allowable Concentric Axial Loads on Single-Wythe Hollow Concrete Masonry Walls – Ungrouted with Face Shell Bedding

Wall height, ft	(m)	Allowable concentric axial load, kips/ lin. ft. (kN/m) 6 in.	(150 mm)	8 in.	(200 mm)	10 in.	(250 mm)	12 in.	(300 mm)
0	(0.0)	9.00	(131.3)	11.25	(164.1)	11.25	(164.1)	11.25	(164.1)
1	(0.30)	8.98	(131.1)	11.24	(164.0)	11.24	(164.0)	11.25	(164.1)
2	(0.61)	8.94	(130.4)	11.21	(163.5)	11.22	(163.8)	11.23	(163.9)
3	(0.91)	8.86	(129.3)	11.16	(162.8)	11.19	(163.3)	11.21	(163.5)
4	(1.22)	8.76	(127.7)	11.09	(161.7)	11.15	(162.6)	11.18	(163.1)
5	(1.52)	8.62	(125.7)	10.99	(160.4)	11.09	(161.8)	11.14	(162.5)
6	(1.83)	8.45	(123.3)	10.88	(158.7)	11.01	(160.7)	11.09	(161.8)
7	(2.13)	8.25	(120.4)	10.75	(156.8)	10.93	(159.5)	11.03	(160.9)
8	(2.44)	8.02	(117.0)	10.59	(154.5)	10.83	(158.0)	10.96	(159.9)
9	(2.74)	7.76	(113.2)	10.42	(152.0)	10.72	(156.4)	10.88	(158.8)
10	(3.05)	7.47	(109.0)	10.22	(149.2)	10.60	(154.6)	10.80	(157.5)
11	(3.35)	7.15	(104.3)	10.01	(146.0)	10.46	(152.6)	10.70	(156.2)
12	(3.66)	6.80	(99.2)	9.77	(142.6)	10.31	(150.4)	10.60	(154.6)
13	(3.96)	6.42	(93.6)	9.51	(138.8)	10.14	(148.0)	10.49	(153.0)
14	(4.27)	6.00	(87.6)	9.24	(134.8)	9.97	(145.4)	10.36	(151.2)
15	(4.57)	5.56	(81.1)	8.94	(130.4)	9.78	(142.7)	10.23	(149.3)
16	(4.88)	5.09	(74.2)	8.62	(125.8)	9.57	(139.7)	10.09	(147.3)
17	(5.18)	4.58	(66.9)	8.28	(120.8)	9.36	(136.5)	9.94	(145.1)
18	(5.49)	4.09	(59.7)	7.92	(115.6)	9.13	(133.2)	9.79	(142.8)
19	(5.79)	3.67	(53.5)	7.54	(110.0)	8.89	(129.7)	9.62	(140.3)
20	(6.10)	3.31	(48.3)	7.14	(104.2)	8.63	(125.9)	9.44	(137.8)
22	(6.71)	2.74	(39.9)	6.28	(91.6)	8.08	(117.9)	9.06	(132.2)
24	(7.32)	2.30	(33.6)	5.35	(78.0)	7.48	(109.1)	8.65	(126.2)
26	(7.92)	1.96	(28.6)	4.56	(66.5)	6.83	(99.6)	8.20	(119.6)
28	(8.53)	1.69	(24.7)	3.93	(57.3)	6.12	(89.3)	7.71	(112.5)
30	(9.14)	1.47	(21.5)	3.42	(49.9)	5.37	(78.4)	7.18	(104.8)
32	(9.75)	1.29	(18.9)	3.01	(43.9)	4.72	(68.9)	6.62	(96.6)
34	(10.36)	1.15	(16.7)	2.67	(38.9)	4.18	(61.0)	6.03	(87.9)
36	(10.97)	1.02	(14.9)	2.38	(34.7)	3.73	(54.4)	5.40	(78.8)
38	(11.58)	0.92	(13.4)	2.13	(31.1)	3.35	(48.9)	4.85	(70.8)
40	(12.19)	0.83	(12.1)	1.93	(28.1)	3.02	(44.1)	4.38	(63.9)
42	(12.80)	0.75	(11.0)	1.75	(25.5)	2.74	(40.0)	3.97	(57.9)
44	(13.41)	0.68	(10.0)	1.59	(23.2)	2.50	(36.4)	3.62	(52.8)
46	(14.02)	0.63	(9.1)	1.46	(21.2)	2.29	(33.3)	3.31	(48.3)
48	(14.63)	0.58	(8.4)	1.34	(19.5)	2.10	(30.6)	3.04	(44.4)
50	(15.24)	0.53	(7.7)	1.23	(18.0)	1.91	(27.9)	2.80	(40.9)

NOTES:
1. Self weight of wall must be included as part of load.
2. Wall is braced laterally at top and bottom.
3. Allowable axial load (P_a) is based on the formula $P_a = F_a A_n$
Where: $F_a = 0.25 f'_m (1 - (h/140r)^2)$ for $h/r \leq 99$, psi
$F_a = 0.25 f'_m (70r/h)^2$ for $h/r > 99$, psi
h = wall height (in.)
r = radius of gyration (in.)
A_n = net cross-sectional area of masonry (in.^{2}/lin ft) based on ungrouted face shell bedding.
4. f'_m = 1500 psi.
5. Cross-section properties based on NCMA TEK 14-1B (2007) using minimum face shell thickness and face shell bedding.
6. Loads in SI units obtained from loads in English units using a conversion factor of 14.59.
7. Construction is ungrouted with face shell bedding.
8. Other factors such as eccentricity of load, wind, or earthquake will significantly reduce the tabulated loads.

Table 3-3. Allowable Axial Load of Eccentrically Loaded URM Walls

Axial load capacity of eccentrically loaded ungrouted face-shell bedded URM walls, kips/lin. ft. (kN/m)									
Eccentricity of axial load, in. (mm)		6 in. (150 mm) Wall thickness		8 in. (200 mm) Wall thickness		10 in. (250 mm) Wall thickness		12 in. (300 mm) Wall thickness	
0.0	(0)	6.80	(99.2)	9.77	(142.6)	10.31	(150.4)	10.60	(154.6)
0.1	(3)	6.61	(96.4)	9.54	(139.2)	10.12	(147.6)	10.44	(152.3)
0.2	(5)	6.42	(93.7)	9.32	(136.0)	9.94	(145.0)	10.29	(150.1)
0.3	(8)	6.25	(91.2)	9.11	(132.9)	9.76	(142.4)	10.14	(147.9)
0.4	(10)	6.08	(88.8)	8.91	(130.0)	9.59	(139.9)	9.99	(145.8)
0.5	(13)	5.93	(86.5)	8.72	(127.2)	9.43	(137.5)	9.85	(143.7)
0.6	(15)	5.78	(84.3)	8.54	(124.5)	9.27	(135.2)	9.71	(141.7)
0.7	(18)	5.64	(82.3)	8.36	(122.0)	9.11	(133.0)	9.58	(139.8)
0.8	(20)	5.51	(80.3)	8.19	(119.5)	8.96	(130.8)	9.45	(137.9)
0.9	(23)	5.38	(78.5)	8.03	(117.1)	8.82	(128.7)	9.33	(136.1)
1.0	(25)	5.26	(76.7)	7.87	(114.9)	8.68	(126.7)	9.20	(134.3)
1.1	(28)	5.14	(75.0)	7.72	(112.7)	8.55	(124.7)	9.08	(132.5)
1.2	(30)	5.03	(73.3)	7.58	(110.6)	8.42	(122.8)	8.97	(130.8)
1.3	(33)	4.92	(71.8)	7.44	(108.5)	8.29	(120.9)	8.85	(129.2)
1.4	(36)	4.82	(70.3)	7.30	(106.6)	8.17	(119.2)	8.74	(127.5)
1.5	(38)	4.72	(68.9)	7.17	(104.7)	8.05	(117.4)	8.63	(126.0)
1.6	(41)	4.63	(67.5)	7.05	(102.9)	7.93	(115.7)	8.53	(124.4)
1.7	(43)	4.53	(66.2)	6.93	(101.1)	7.82	(114.1)	8.42	(122.9)
1.8	(46)	4.45	(64.9)	6.81	(99.4)	7.71	(112.5)	8.32	(121.4)
1.9	(48)	4.36	(63.7)	6.70	(97.8)	7.60	(110.9)	8.23	(120.0)
2.0	(51)	4.28	(62.5)	6.59	(96.2)	7.50	(109.4)	8.13	(118.6)
2.2	(56)	2.56	(37.4)	6.38	(93.1)	7.30	(106.5)	7.95	(115.9)
2.4	(61)	1.48	(21.5)	6.19	(90.3)	7.11	(103.8)	7.77	(113.3)
2.6	(66)	1.04	(15.1)	6.00	(87.6)	6.93	(101.1)	7.60	(110.9)
2.8	(71)	0.80	(11.6)	5.83	(85.1)	6.76	(98.7)	7.44	(108.5)
3.0	(76)	0.65	(9.5)	4.05	(59.1)	6.60	(96.3)	7.28	(106.2)
3.2	(81)	0.55	(8.0)	2.43	(35.5)	6.45	(94.0)	7.13	(104.1)
3.4	(86)	0.47	(6.9)	1.74	(25.3)	6.30	(91.9)	6.99	(102.0)
3.6	(91)	0.00	(0.0)	1.35	(19.7)	6.16	(89.8)	6.85	(100.0)
3.8	(97)	0.00	(0.0)	1.10	(16.1)	6.02	(87.9)	6.72	(98.1)
4.0	(102)	0.00	(0.0)	0.93	(13.6)	5.00	(73.0)	6.59	(96.2)
4.2	(107)	0.00	(0.0)	0.81	(11.8)	3.12	(45.5)	6.47	(94.4)
4.4	(112)	0.00	(0.0)	0.71	(10.4)	2.26	(33.0)	6.35	(92.7)
4.6	(117)	0.00	(0.0)	0.64	(9.3)	1.78	(25.9)	6.24	(91.0)
4.8	(122)	0.00	(0.0)	0.10	(1.5)	1.46	(21.3)	6.13	(89.4)
5.0	(127)	0.00	(0.0)	0.00	(0.0)	1.24	(18.1)	6.02	(87.9)
5.2	(132)	0.00	(0.0)	0.00	(0.0)	1.08	(15.7)	3.83	(55.9)
5.4	(137)	0.00	(0.0)	0.00	(0.0)	0.95	(13.9)	2.80	(40.9)
5.6	(142)	0.00	(0.0)	0.00	(0.0)	0.86	(12.5)	2.21	(32.3)
5.8	(147)	0.00	(0.0)	0.00	(0.0)	0.78	(11.3)	1.83	(26.6)
6.0	(152)	0.00	(0.0)	0.00	(0.0)	0.24	(3.6)	1.55	(22.7)

NOTES:
1. f'_m = 1500 psi.
2. Type S Masonry cement mortar or air-entrained PCL mortar.
3. Allowable flexural tension stress = 15 psi (ungrouted).
4. Height = 12 ft (3.7 m) between lateral supports.
5. Values shown are the lowest of three limits from the MSJC 2005 Code (flexural tension, unity equation and Euler buckling).
6. Eccentricity (e) is the distance from the centroid of the wall to the resultant load e can also be taken as the out-of-plane bending moment due to lateral loads divided by the axial load. In this case, if the lateral load is due to wind or earthquake, the allowable load can be increased by 33%.

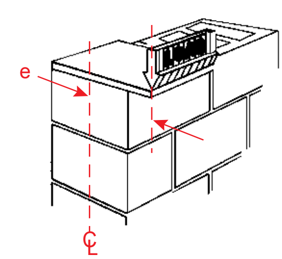


Table 3-4. Foundation Wall Construction

Wall construction	Nominal wall thickness, in. (mm)	Maximum depth of unbalanced backfill, ft (m)
Hollow unit masonry	8 (203) 10 (254) 12 (305)	5 (1.52) 6 (1.83) 7 (2.13)
Solid unit masonry	8 (203) 10 (254) 12 (305)	5 (1.52) 7 (2.13) 7 (2.13)
Fully grouted masonry	8 (203) 10 (254) 12 (305)	7 (2.13) 8 (2.44) 8 (2.44)

Adapted from MSJC 2005.

conditions. A wall supported at the top by a roof or floor diaphragm and at its base by a foundation spans vertically. A wall constructed between cross walls or vertical pilasters can be designed to span horizontally. It is possible for a wall to be supported on all four edges, and such a wall can resist more lateral load than one that spans either horizontally or vertically.

Fig. 3-9 illustrates the eccentric axial load capacity of a 12 ft. (3.7 m) tall vertically spanning unreinforced masonry wall. As the eccentricity increases, the axial loadcarrying capacity of the wall decreases in every case. Fig. 3-10 shows the reduction of concentric axial load capacity with wall height for unreinforced masonry. Figs. 3-9 and 3-10 also demonstrate grout's ability to improve the load-carrying capacity of the wall, especially for smaller eccentricities and shorter walls.

If a wall resists lateral loads and spans vertically, a concentric compressive vertical load on the wall will

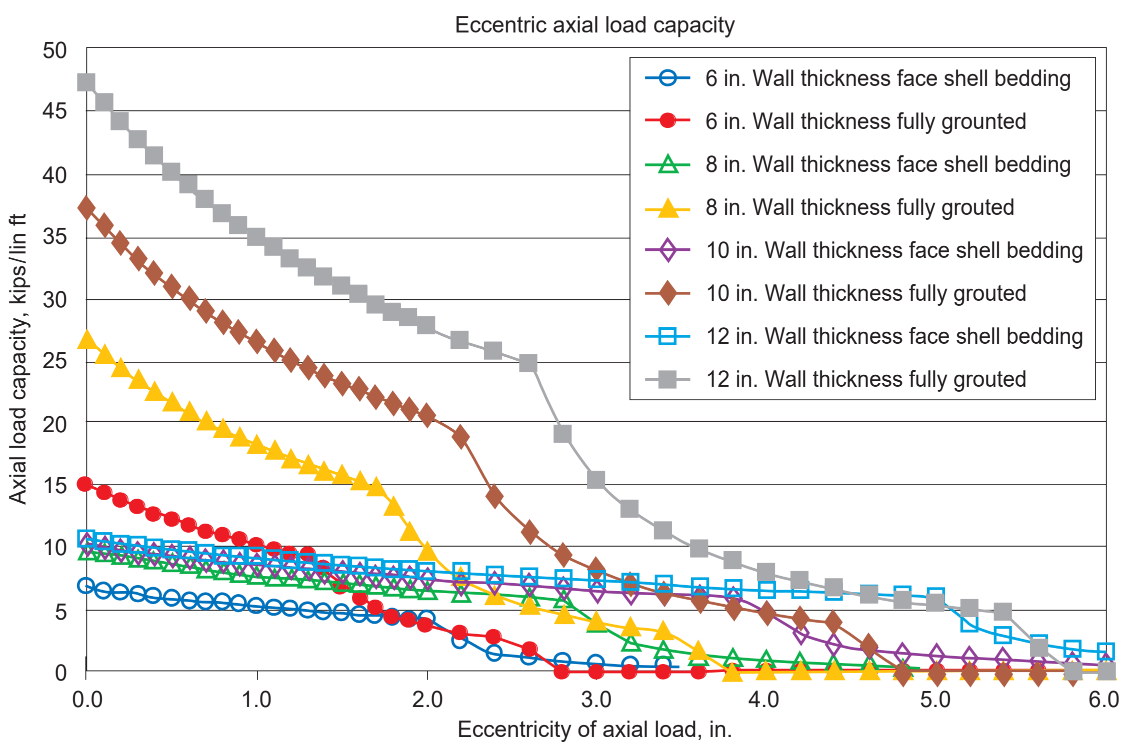


Fig. 3-9

Axial load capacity of unreinforced masonry walls with the following parameters: specified compressive strength of masonry f'_m = 1500 psi, height = 12 ft, Type S mortar made with masonry cement or air entrained portland cement-lime mortar. Where wind or earthquake loads can act simultaneously, axial load capacities shown here should be reduced.

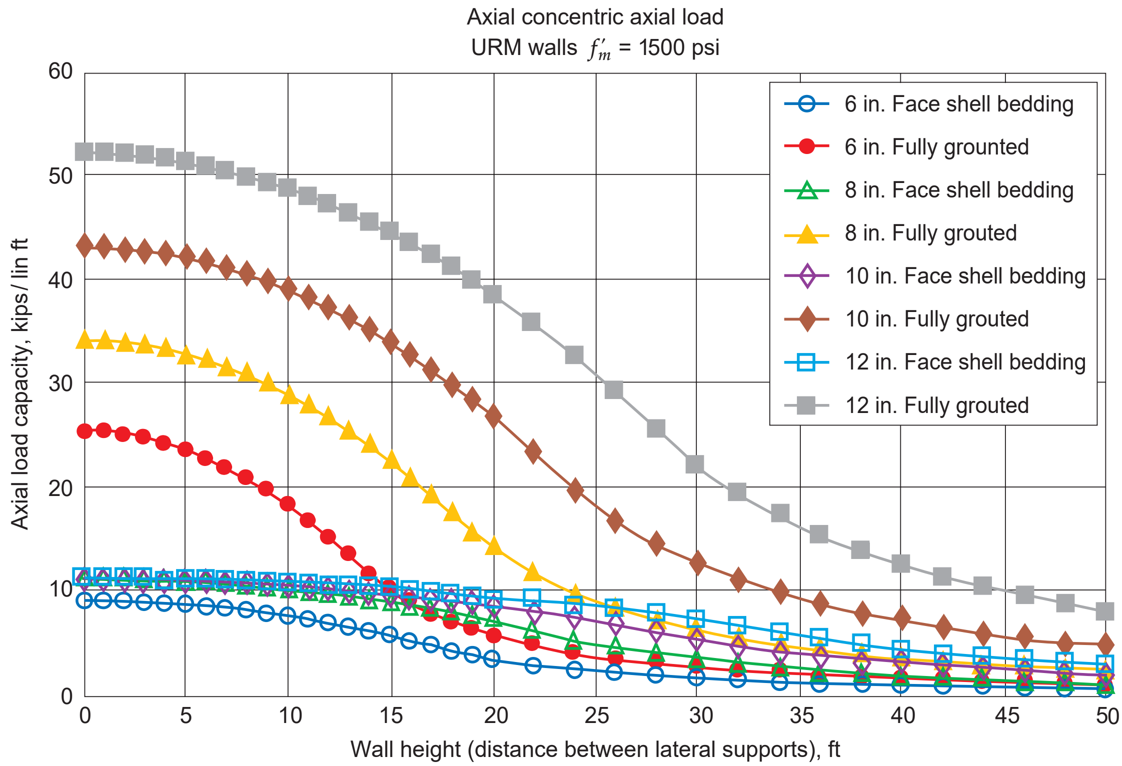


Fig. 3-10

Allowable concentric axial load on unreinforced masonry walls having specified compressive strength of masonry f'_m = 1500 psi.

increase its strength (up to a point). For example, in Fig. 3-11 an unreinforced masonry wall with no axial load resists a moment of approximately 135 ft-lb/ft. When the same wall is subjected to axial compression of 1500 lb, the moment capacity increases to about 440 ft-lb/ft, about threefold. Table 3-5 gives maximum wall heights for unreinforced and ungrouted concrete masonry walls subjected to both axial and wind loads for several sizes (thicknesses) of units.

Reinforcing bars increase the strength of concrete masonry walls. This can be seen by comparing a reinforced wall in Fig. 3-12 with a similar but unreinforced wall in Fig. 3-11. The reinforced wall has both higher moment and higher axial load capacity. The reinforced wall shown is lightly reinforced (#5 bars at 32 in.). Larger bars or closer spacings increase the capacity of the reinforced walls. Axial compression also increases the capacity of reinforced walls up to a point. In Fig. 3-12 the moment capacity with zero axial load is about 1070 ft-lb/ft. At an axial load of 1500 lb/ft, the moment capacity increases to 1400 ft-lb/ft.

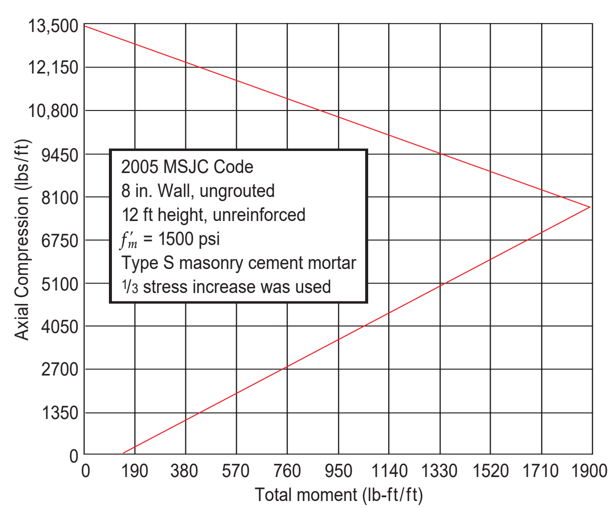


Fig. 3-11

Allowable stress interaction diagram of an unreinforced, ungrouted masonry wall. This represents the allowable moment that the wall can carry with axial load. Results are based on National Concrete Masonry Association software. Parameters: 8 in. wide concrete masonry units, specified compressive strength of masonry f'_m = 1500 psi, ungrouted, wall height h = 12 ft, Type S masonry cement mortar.

Table 3-5. Maximum Wall Heights for Unreinforced Hollow Unit Concrete Masonry Walls Subjected to Concentric Loads and Wind

Concentric axial load,		Nominal wall thickness t = 6 in. (152 mm)*						Nominal wall thickness t = 8 in. (200 mm)*					
		Wind load in psf (kN/m²)						Wind load in psf (kN/m²)					
		10	(479)	20	(958)	30	(1436)	10	(479)	20	(958)	30	(1436)
kip/ft	(kN/m)	Maximum wall height[1], ft (m)*											
0.00	0.00	7.86	(2.39)	5.56	(1.69)	4.54	(1.38)	10.39	(3.17)	7.35	(2.24)	6.00	(1.83)
0.25	(3.65)	9.69	(2.95)	6.85	(2.09)	5.59	(1.71)	12.37	(3.77)	8.75	(2.67)	7.14	(2.18)
0.50	(7.30)	11.23	(3.42)	7.94	(2.42)	6.48	(1.98)	14.07	(4.29)	9.95	(3.03)	8.12	(2.48)
0.75	(10.95)	12.58	(3.83)	8.89	(2.71)	7.26	(2.21)	15.59	(4.75)	11.02	(3.36)	9.00	(2.74)
1.00	(14.59)	13.80	(4.21)	9.76	(2.97)	7.97	(2.43)	16.97	(5.17)	12.00	(3.66)	9.80	(2.99)
1.25	(18.24)	14.92	(4.55)	10.55	(3.21)	8.61	(2.62)	18.25	(5.56)	12.90	(3.93)	10.54	(3.21)
1.50	(21.89)	15.96	(4.86)	11.28	(3.44)	9.21	(2.81)	19.44	(5.93)	13.75	(4.19)	11.22	(3.42)
1.75	(25.54)	16.94	(5.16)	11.98	(3.65)	9.78	(2.98)	20.57	(6.27)	14.54	(4.43)	11.87	(3.62)
2.00	(29.19)	17.86	(5.44)	12.63	(3.85)	10.31	(3.14)	21.63	(6.59)	15.30	(4.66)	12.49	(3.81)
2.25	(32.84)	18.74	(5.71)	13.25	(4.04)	10.82	(3.30)	22.65	(6.90)	16.02	(4.88)	13.08	(3.99)
2.50	(36.48)	19.58	(5.97)	13.84	(4.22)	11.30	(3.45)	23.62	(7.20)	16.70	(5.09)	13.64	(4.16)
2.75	(40.13)	20.38	(6.21)	14.41	(4.39)	11.77	(3.59)	24.56	(7.48)	17.36	(5.29)	14.18	(4.32)
3.00	(43.78)	21.16	(6.45)	14.96	(4.56)	12.21	(3.72)	25.46	(7.76)	18.00	(5.49)	14.70	(4.48)
3.25	(47.43)	21.90	(6.68)	15.49	(4.72)	12.65	(3.85)	26.32	(8.02)	18.61	(5.67)	15.20	(4.63)
3.50	(51.08)	22.62	(6.90)	16.00	(4.88)	13.06	(3.98)	27.17	(8.28)	19.21	(5.86)	15.68	(4.78)
3.75	(54.73)	23.32	(7.11)	16.49	(5.03)	13.47	(4.10)	27.98	(8.53)	19.79	(6.03)	16.16	(4.92)
4.00	(58.37)	24.00	(7.32)	16.97	(5.17)	13.86	(4.22)	28.77	(8.77)	20.35	(6.20)	16.61	(5.06)
4.25	(62.02)	24.66	(7.52)	17.44	(5.32)	14.24	(4.34)	29.55	(9.01)	20.89	(6.37)	17.06	(5.20)
4.50	(65.67)	25.31	(7.71)	17.90	(5.45)	14.61	(4.45)	30.30	(9.23)	21.42	(6.53)	17.49	(5.33)
4.75	(69.32)	25.94	(7.91)	18.34	(5.59)	14.97	(4.56)	31.03	(9.46)	21.94	(6.69)	17.92	(5.46)
5.00	(72.97)	26.55	(8.09)	18.77	(5.72)	15.33	(4.67)	31.75	(9.68)	22.45	(6.84)	18.33	(5.59)
5.25	(76.62)	27.15	(8.27)	19.20	(5.85)	15.67	(4.78)	32.45	(9.89)	22.95	(6.99)	18.73	(5.71)

*Actual wall thickness is less than the nominal dimension by the thickness of a mortar joint, usually ⅜ in. (9.5 mm).

[1] Based on an allowable flexural tensile stress of 20 psi (15 psi increased by ⅓ for wind).

(Table 3.5 continued on next page)

Table 3-5. Maximum Wall Heights for Unreinforced Hollow Unit Concrete Masonry Walls Subjected to Concentric Loads and Wind *(continued)*

Concentric axial load, kip/ft	(kN/m)	Nominal wall thickness t = 10 in. (250 mm)*						Nominal wall thickness t = 12 in. (300 mm)*					
		Wind load in psf (kN/m²)						Wind load in psf (kN/m²)					
		10	(479)	20	(958)	30	(1436)	10	(479)	20	(958)	30	(1436)
		Maximum wall height[1], ft (m)*											
0.00	0.00	12.12	(3.69)	8.57	(2.61)	7.00	(2.13)	13.64	(4.16)	9.65	(2.94)	7.88	(2.40)
0.25	(3.65)	14.42	(4.40)	10.20	(3.11)	8.33	(2.54)	16.24	(4.95)	11.48	(3.50)	9.38	(2.86)
0.50	(7.30)	16.41	(5.00)	11.60	(3.54)	9.47	(2.89)	18.47	(5.63)	13.06	(3.98)	10.67	(3.25)
0.75	(10.95)	18.17	(5.54)	12.85	(3.92)	10.49	(3.20)	20.46	(6.24)	14.47	(4.41)	11.82	(3.60)
1.00	(14.59)	19.79	(6.03)	13.99	(4.26)	11.42	(3.48)	22.28	(6.79)	15.75	(4.80)	12.86	(3.92)
1.25	(18.24)	21.28	(6.48)	15.04	(4.59)	12.28	(3.74)	23.96	(7.30)	16.94	(5.16)	13.83	(4.22)
1.50	(21.89)	22.67	(6.91)	16.03	(4.89)	13.09	(3.99)	25.52	(7.78)	18.05	(5.50)	14.74	(4.49)
1.75	(25.54)	23.98	(7.31)	16.96	(5.17)	13.84	(4.22)	27.00	(8.23)	19.09	(5.82)	15.59	(4.75)
2.00	(29.19)	25.22	(7.69)	17.83	(5.44)	14.56	(4.44)	28.40	(8.66)	20.08	(6.12)	16.40	(5.00)
2.25	(32.84)	26.41	(8.05)	18.67	(5.69)	15.25	(4.65)	29.73	(9.06)	21.03	(6.41)	17.17	(5.23)
2.50	(36.48)	27.54	(8.39)	19.47	(5.94)	15.90	(4.85)	31.01	(9.45)	21.93	(6.68)	17.90	(5.46)
2.75	(40.13)	28.63	(8.73)	20.24	(6.17)	16.53	(5.04)	32.24	(9.83)	22.80	(6.95)	18.61	(5.67)
3.00	(43.78)	29.68	(9.05)	20.99	(6.40)	17.13	(5.22)	33.42	(10.19)	23.63	(7.20)	19.29	(5.88)
3.25	(47.43)	30.69	(9.35)	21.70	(6.61)	17.72	(5.40)	34.56	(10.53)	24.44	(7.45)	19.95	(6.08)
3.50	(51.08)	31.67	(9.65)	22.40	(6.83)	18.29	(5.57)	35.66	(10.87)	25.22	(7.69)	20.59	(6.28)
3.75	(54.73)	32.62	(9.94)	23.07	(7.03)	18.84	(5.74)	36.74	(11.20)	25.98	(7.92)	21.21	(6.46)
4.00	(58.37)	33.55	(10.23)	23.72	(7.23)	19.37	(5.90)	37.78	(11.51)	26.71	(8.14)	21.81	(6.65)
4.25	(62.02)	34.45	(10.50)	24.36	(7.42)	19.89	(6.06)	38.79	(11.82)	27.43	(8.36)	22.39	(6.83)
4.50	(65.67)	35.32	(10.77)	24.98	(7.61)	20.39	(6.22)	39.78	(12.12)	28.13	(8.57)	22.96	(7.00)
4.75	(69.32)	36.18	(11.03)	25.58	(7.80)	20.89	(6.37)	40.74	(12.42)	28.81	(8.78)	23.52	(7.17)
5.00	(72.97)	37.02	(11.28)	26.17	(7.98)	21.37	(6.51)	41.68	(12.70)	29.47	(8.98)	24.06	(7.33)
5.25	(76.62)	37.83	(11.53)	26.75	(8.15)	21.84	(6.66)	42.60	(12.98)	30.12	(9.18)	24.60	(7.50)

*Actual wall thickness is less than the nominal dimension by the thickness of a mortar joint, usually ⅜ in. (9.5 mm).

[1] Based on an allowable flexural tensile stress of 20 psi (15 psi increased by ⅓ for wind).

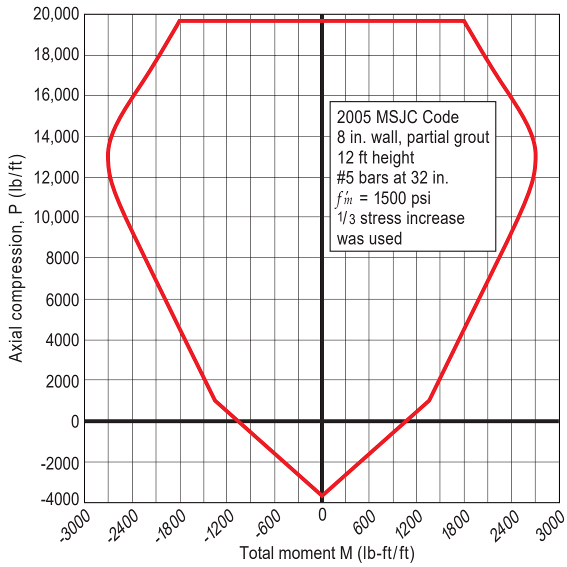


Fig. 3-12

Allowable stress interaction diagram, also called a moment diagram, of a reinforced masonry wall. This represents the allowable moment load that the wall can carry. Results are based on NCMA software. Parameter: fy = 60 ksi, f'_m = 1500 psi, A_s = 0.31 sq in., e = 3.813 in., h = 144 in. (12 ft).

The *IBC* permits the design of concrete masonry walls subject to combined axial and lateral loads to be based on strength design methods. As indicted in CMACN 1988, this approach leads to economical designs. In addition, the design of slender walls can be handled taking into account secondary effects due to lateral deflection of the wall. When using strength design, quality control in construction is essential to ensure proper installation of details shown in design drawings. Designers should also recognize the importance of details such as proper reinforcement anchorage and proper placement of mortar and grout, both at the joints and within the masonry unit cavities.

Shear Loads. Wind and earthquakes induce out-of-plane pressure as well as in-plane forces or shear loads on masonry walls. In combination with roof diaphragms, concrete masonry walls are used effectively to provide lateral stability for buildings under wind and earthquake loads. The *MSJC Code* permits the design of concrete masonry shear walls using allowable stress and strength design methods. Reinforcement can be used in mortar joints or grout-filled cavities to provide resistance to overturning forces in the plane of the wall. CMACN 1988 provides additional information on the design of concrete masonry shear walls, and Johal and Anderson 1988 contains information on the shear strength of masonry piers under cyclic loading.

Seismic Loads. Seismic loads are dynamic loads. They change quickly with time and do not last long. They can be thought of as a combination of lateral and shear loads acting on members that are axially loaded (self-weight of masonry building). In Chapter 4, important aspects of seismic design are discussed as they relate to masonry walls.

Cavity Walls. Cavity walls have different strength characteristics than single-wythe walls. Wind pressure is resisted by non-load-bearing cavity walls. Each wythe in a cavity wall helps resist wind by acting as a separate wall. If both wythes have the same thickness, they resist the wind equally, but they do not act as if they are fully bonded together. Cavity walls have less strength than single-wythe walls having the same total thickness. However, strength is often not a deciding factor and cavity walls have some distinct advantages: for example, they are good at keeping water out, and they provide good insulation.

Figs. 3-9 and 3-10 are illustrative examples for ungrouted hollow concrete masonry walls with face shell bedding based on the mortar bed widths (face shell thickness) given in Table 3-6. In the case of 10 in. and 12 in. (254 mm and 305 mm) wall thicknesses, the thinner (1.25 in., or 32 mm) thickness is used. Bending moments are computed for simple spans.

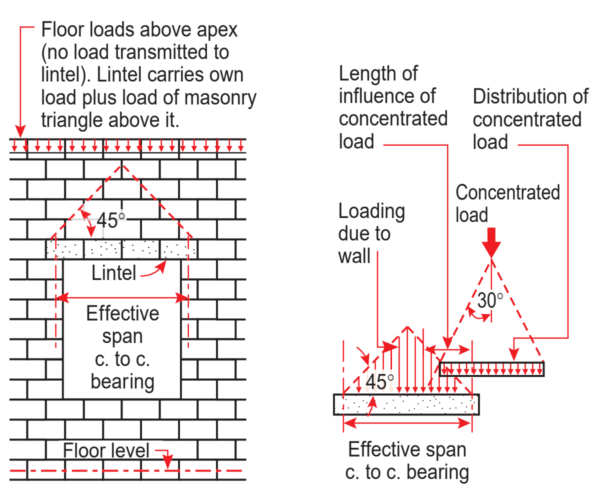
Figs. 3-11 and 3-12 are from NCMA software. For these interaction diagrams, the applied axial load and moment must fall within the contour in order to comply with the allowable stresses.

Table 3-6. Width of Face Shell in Hollow Concrete Masonry Units*

Nominal width of units, in. (mm)					
3 (76.2)	4 (102)	6 (152	8 (203)	10 (254)	12 (305)
Minimum face shell thickness, in. (mm)					
0.75 (19)	0.75 (19)	1 (25)	1.25 (32)	1.25 (32)† 1.375 (35)	1.25 (32)† 1.50 (38)

*Adapted from ASTM C90.
†This face shell thickness is permitted where allowable design loads are reduced. See ASTM C90 for specifics.

Lintels. Above each window or door opening in a wall, there should be a structural beam (lintel) to carry the wall loads, as shown in Fig. 3-13. Table 3-7 gives data for typical reinforced concrete masonry lintels, according to size of lintel and size and number of reinforcing bars. Deflection of lintels usually is not a problem. However, when lintels support unreinforced masonry or masonry designed by empirical means, the deflection under full dead and live load is limited to 1/600 of the clear span for spans up to 15 ft (4.57 m), and 0.3 in. (7.6 mm) for spans 15 ft (4.57 m) and over. Meeting these criteria often requires the use of a deeper lintel than needed for strength alone. Taking advantage of arching action can decrease the size of lintels significantly. Lintel design is discussed further in the next chapter and in TEK 17-1B 2001, TEK 17-2A 2000, and TMS MDG5 2007.



(a) Lintel loading with arching
(b) Influence of concentrated load

Fig. 3-13
Loads supported by lintels.

Table 3-7. Allowable Shear and Moment Capacities for Concrete Masonry Lintels (width x height)*

Steel size	No. of bars	V_{all}, lb	M_{all}, in.-lb	V_{all}, lb	M_{all}, in.-lb
Bottom cover, in. (mm)		**1.5 (3.8)**		**3.0 (76)**	
8 x 8 lintels					
No. 4	1	1730	20,460	1290	12,510
No. 5	1	1710	23,170	1270	13,930
No. 6	1	1690	25,220	1250	14,930
No. 4	2**	1730	25,460	1290	15,320
No. 5	2**	1710	28,140	1270	16,620
10 x 8 lintels					
No. 4	1	2190	23,810	1630	14,620
No. 5	1	2160	27,170	1600	16,430
No. 6	1	2140	29,760	1580	17,720
No. 4	2	2190	29,990	1630	18,140
No. 5	2	2160	33,430	1600	19,870
12 x 8 lintels					
No. 4	1	2640	25,400	1970	16,560
No. 5	1	2610	30,820	1940	18,710
No. 6	1	2580	33,930	1910	20,300
No. 4	2	2640	34,130	1970	20,740
No. 5	2	2610	38,300	1940	22,880
8 x 16 lintels					
No. 4	1	4090	61,110	3650	54,250
No. 5	1	4070	92,550	3630	80,860
No. 6	1	4060	109,740	3610	90,600
No. 4	2**	4090	107,750	3650	89,200
No. 5	2**	4070	123,960	3630	102,150

*Adapted from TEK 17-1B 2001.
Grade 60 reinforcement, f'_m = 1500 psi (10.3 MPa);
N = lb x 4.44822; N·m = in.-lb x 0.112985; No. 4 bar (M 13); No. 5 bar (M 16); No. 6 bar (M 19).
**For 8-in. (204-mm) lintels with two bars, low-lift grouting is recommended for adjacent jambs to ensure proper grout flow and consolidation.

Thermal Insulation

In selecting and sizing the heating and cooling equipment for a building, the designer must first determine the heating and cooling loads involved. These loads are made up of various exchanges of heat, including transfer of heat through exterior walls.

When the outdoor temperature is below the established indoor temperature, heat is lost from the building, and the heating system must replace it. Conversely, when the outdoor temperature is above the indoor temperature, heat is gained. In air-conditioned buildings this heat is absorbed by the cooling system. The upper part of Fig. 3-14 gives an example of heat flow through a multiwythe concrete masonry wall. The temperature gradient varies from 0ºF (17.8ºC) outside to 75ºF (23.9ºC) inside.

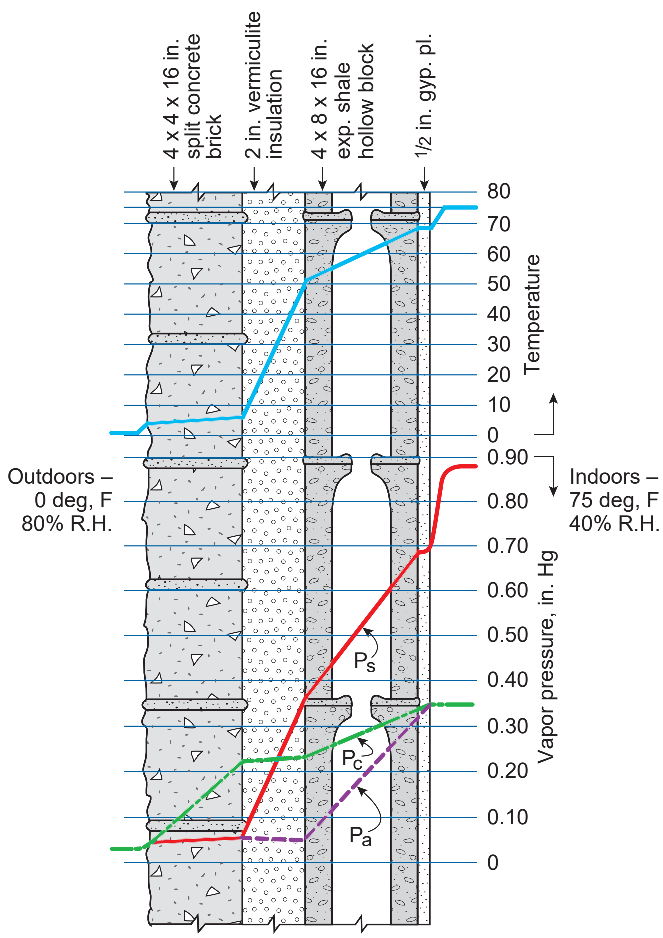


Fig. 3-14

Temperature and vapor pressure gradients for insulated concrete masonry cavity wall construction (*R* = 7.26, *U* = 0.14).

U and *R* Values Defined

Essential to the designer's calculations regarding the flow of heat through walls and other building components are *U* values, the coefficients or indices of total heat flow rate. They express the total amount of heat in British thermal units (Btu) that 1 sq ft (0.09 m^2) of wall (ceiling or floor) will transmit per hour for each degree Fahrenheit of temperature difference between the air on the warm and cool sides.

Another index of heat transfer is the *R* value, which is a measure of the resistance that a building section, material, and air space or surface film offers to the flow of heat. The *R* value is the reciprocal of a heat transfer coefficient such as *U* or f. The *R* value is for a stated thickness of a building section, and the unit of value for *R* is (°F · h · ft^2)/Btu, where h = hour. *R* values are particularly useful for estimating the effect of components of a section on the total heat flow because they can be directly added.

The overall heat transmission coefficient of a wall, the U value, includes the effect of the air film or surface conductance for the inside of the wall, f_i, as well as the effect of its outside air film, f_o. The *U* value is calculated by taking the reciprocal of this total: $1/f_i + 1/f_o$ + the sum of the *R* values for each component of the wall (see Valore 1980, ASHRAE 1990, and PCA EB083 1980). *U* values cannot be added or subtracted with meaningful results.

The *U* value for a wall section can be determined by test (ASTM C236, *Test Method for Steady-State Thermal Performance of Building Assemblies by Means of a Guarded Hot Box*), and many wall tests have been conducted for this purpose over the years. Actually, the rational method for estimating the *U* value by calculation was devised because of the innumerable types and combinations of materials going into modern building walls and the continuing development of new types. The method is based on the heat-flow resistance concept and principles related to the flow of electricity. Heat-flow resistance is analogous to electrical resistance. Thus, the flow of heat is directly proportional to the temperature difference and inversely proportional to the heat resistance.

Selecting the *U* Value

The hourly heat flow (Btu of heat loss or gain) through the exterior wall construction of a building can be determined by multiplying the *U* value of the wall section by the total net area in square feet (with areas of windows and doors deducted and dealt with separately), and then multiplying that value by the design temperature difference between the inside and the outside air. Since the surface area and temperature difference are generally established or fixed quantities, the *U* value alone remains subject to design adjustment.

In selecting the proper *U* value for a wall section, the designer should consider and weigh several factors. The relative importance of each will depend upon the type of building and its occupancy. For buildings intended for residential use—houses, apartments, dormitories, hotels—human comfort needs probably will govern. For commercial buildings devoted to manufacturing, process control requirements may be the primary factor in deciding the *U* value. In all cases, operational costs, that is, the cost of fuel or electric power, should be given careful consideration.

The requirements for building insulation have been undergoing a thorough change in recent times due to the emphasis on conservation of energy for winter heating and summer cooling. Since national standards continue to evolve, no attempt will be made here to quote insulation requirements of any specific regulatory agencies. The reader is referred to releases from such organizations as the local building department, the U.S. Department of Housing and Urban Development, and the American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc.

Typical Values for Concrete Masonry Walls

Concrete masonry walls offer insulation qualities combined with architectural appeal. Table 3-8 lists *R* values for single-wythe walls and Table 3-9 gives *R* values for

Table 3-8. Heat Resistance (*R*) Values of Single-Wythe Concrete Masonry Walls*

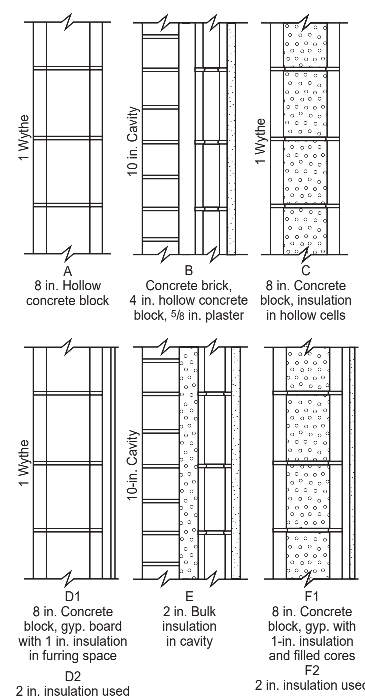
Nominal wall thickness, in.	Insulation in cells**	*R* value based on concrete unit weight				
		60 pcf	80 pcf	100 pcf	120 pcf	140 pcf
4	Filled	3.36	2.79	2.33	1.92	1.14
	Empty	2.07	1.68	1.40	1.17	0.77
6	Filled	5.59	4.59	3.72	2.95	1.59
	Empty	2.25	1.83	1.53	1.29	0.86
8	Filled	7.46	6.06	4.85	3.79	1.98
	Empty	2.30	2.12	1.75	1.46	0.98
10	Filled	9.35	7.45	5.92	4.59	2.35
	Empty	3.00	2.40	1.97	1.63	1.08
12	Filled	10.98	8.70	6.80	5.18	2.59
	Empty	3.29	2.62	2.14	1.81	1.16

* Adapted from TEK 6-11 2001. *R* values (defined in text) do *not* include the sums of the effect of air film or surface conductance on the inside of the walls ($1/f_i = 0.68$) and on the outside ($1/f_o = 0.17$).

** Loose-fill insulation such as perlite, vermiculite, or others of similar density

Table 3-9. Heat Transmission Values of Some Typical Concrete Masonry Walls*

Components	Heat resistance values, *R***							
	A	B	C	D1	D2	E	F1	F2
Surface film (outside)	0.17	0.17	0.17	0.17	0.17	0.17	0.17	0.17
8-in hollow concrete masonry at 100-pcf density (cores open)	1.75			1.75	1.75			
Cores filled with bulk insulation			4.85				4.85	4.85
Concrete brick at 140-pcf density		0.44				0.44		
2-in. air cavity		0.97						
4-in hollow concrete masonry at 100-pcf density		1.40				1.40		
2-in. bulk insulation in cavity						4.00		
Batt insulation between furring strips: 1 in.				3.70			3.70	
2 or 2¼ in.					7.00			7.00
½-in. gypsum board interior finish				0.45	0.45		0.45	0.45
⅝-in. plaster, lightweight aggregate		0.39				0.39		
Surface film (inside)	0.68	0.68	0.68	0.68	0.68	0.68	0.68	0.68
TOTAL resistance, *R*	2.60	4.05	5.70	6.75	10.05	7.08	9.85	13.15
U value, 1/*R*	0.384	0.247	0.175	0.148	0.100	0.141	0.102	0.076



* Adapted from TEK 6-11 2001. Ther overall heat transmission coefficients, called *U* values, are determined by the heat resistance values, *R*, as explained in the text.

** Key for wall design shown at right.

other common types of wall components. In Table 3-9 the *U* value for each complete assembly (bottom line) was computed after the *R* value of each component was tabulated and then added to give the total R value of each wall. In Table 3-10 the *U* values of 8-in. (203-mm) walls with various combinations of finish and insulation are given directly. See ESCSI 1972 for insulating values of other lightweight-aggregate concrete masonry walls, TEK 6-1A 1999 and TEK 6-2A 2005 for more data on *R* values of multi- and single-wythe walls, and TEK 6-11 2001 for more information on insulating concrete masonry walls, generally.

Table 3-10. Estimated *U* Values for 8-in. Hollow Concrete Masonry Walls*

Wall details	*U* value based on density of concrete used in block				
	60 pcf	80 pcf	100 pcf	120 pcf	140 pcf
No insulation	0.32	0.34	0.38	0.43	0.55
No insulation, ½-in. gypsum board on furring strips	0.21	0.23	0.25	0.27	0.31
No insulation, ½-in. foil-backed gypsum board on furring strips	0.15	0.15	0.16	0.17	0.19
Loose-fill insulation in cores	0.12	0.14	0.18	0.21	0.35
Loose fill-in cores, ½-in. gypsum board on furring	0.10	0.12	0.14	0.17	0.24
Loose fill-in cores, ½-in. foil-backed gypsum board, furring	0.08	0.10	0.11	0.12	0.16
1-in. rigid glass fiber, ½-in. gypsum board	0.14	0.14	0.15	0.15	0.17
1-in. polystyrene, ½-in. gypsum board	0.12	0.12	0.12	0.13	0.14
1-in. polyurethane, ½-in. gypsum board	0.10	0.10	0.11	0.11	0.12
Loose fill-in cores plus 1-in. rigid glass, ½-in. gypsum board	0.08	0.09	0.10	0.11	0.14
Loose fill-in cores plus 1-in. polystyrene, ½-in. gypsum board	0.07	0.08	0.09	0.10	0.12
Loose fill-in cores plus 1-in. polyurethane, ½-in. gypsum board	0.07	0.07	0.08	0.09	0.11
R-7 blanket insulation, ½-in. gypsum board, furring	0.09	0.10	0.10	0.10	0.11

* Adapted from TEK 67 1975. *U* values of other wall types and sizes are also given in reference.

It is important to select the correct wall as insulation against the weather, but this should not obscure some larger considerations affecting the total cost of heating and cooling a building. For example, heat flow through a single pane of glass in winter is 1.13 Btu per sq ft per deg F per hour (6.42 $W/m^2 \cdot °K$). This is six or seven times the heat flow through a lightweight concrete block wall with filled cores.

In general, the heat flow through the walls of a building is only a small part of the total heat flow. Heat losses through roofs, floors, and fenestration are other important considerations, as are losses due to infiltration, exhausts, fresh air intakes, and opening of doors (PCA EB083 1980).

Effect of Moisture Content

Heat transfer (conductivity) values increase in walls as the moisture content increases. The relationships found between the conductivity, density, and moisture content of concrete, mortar, or grout are shown in Fig. 3-15 (Brewer 1967). The heat transfer values for oven-dry weights of concrete are frequently used. However, in an occupied building the amount of moisture in the concrete or block may be termed "normally dry." This condition describes the equilibrium that the moisture content of concrete reaches after extended exposure to 78°F (26°C) air at 35% to 50% relative humidity. Note in Fig. 3-15 that conductivity in the normally dry condition is only slightly greater than in the oven-dry condition.

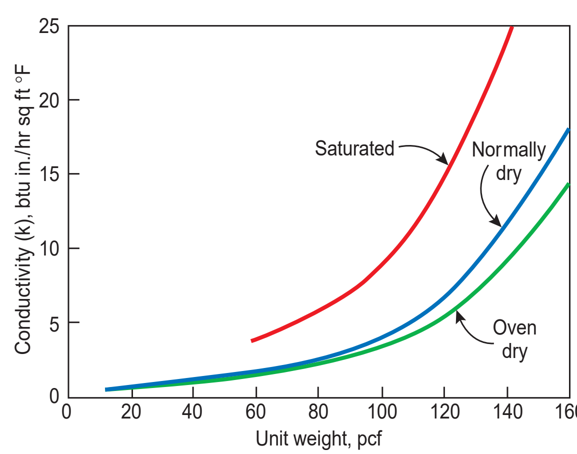


Fig. 3-15

Conductivity of concrete, mortar, or grout as affected by density and moisture. Aggregate type influences conductivity only as it affects the resulting unit weight and moisture content.

In the event concrete masonry becomes saturated with water, heat transfer will increase markedly. This condition could occur in a basement wall that has not been dampproofed. In walls above grade the condition might prevail for a short period of time after a heavy, driving rain.

Avoid applying a sealer to the cold side of a wall. Moisture will travel towards that side, and if its surface is sealed, the wall could approach saturation there, thus losing much of its insulating value. This illustrates the importance of using exterior paints that "breathe," as discussed in Chapter 7.

Heat Gain

The same heat transfer coefficients are used in both heating and cooling design calculations, except slight differences are made in the heat losses of the wall surfaces themselves. In addition, the calculation of cooling load may make use of temperature differentials that account for the effects of solar radiation and exterior surface reflectance, as well as the mass or weight of the building parts.

Heat gain from solar radiation is affected by the orientation of the building and the reflectivity of the exterior surfaces. Light-colored surfaces will reflect the sun's rays much more effectively than dark-colored surfaces. This explains the wider use of white or light-shaded paints and finishes for wall surfaces in the southern regions of the United States.

Steady State Versus Dynamic Thermal Response

When calculating heat transfer, a distinction should be made between masonry and nonmasonry construction because of the difference in heat storage capacity. Heavy construction such as concrete masonry does not respond to temperature fluctuations as rapidly as lightweight construction, even though the *U* values may be identical. Due to a "fly-wheel effect" the net transfer of heat through a concrete masonry wall section for a certain time period might actually be less. This cyclic phenomenon is termed "dynamic thermal response."

The practice in calculating heat transfer as outlined previously is based on a "steady-state" temperature differential, or a constant difference between extreme outdoor and indoor air temperatures. The size of heating or cooling equipment is calculated on this basis, but higher *U* values are permitted in buildings with heavy walls, floors, and roofs because they act as heat reservoirs. This is important because the actual temperature differential between indoors and outdoors is not constant—it fluctuates with the time of day.

The steady-state technique has been the accepted method of design for many years, even though the theory and basic mathematics of cyclic temperature heat losses have been known for more than a century and a half. Prior to the widespread availability and use of computers, the complexity and expense of the calculations prevented engineers from using the sophisticated approach.

To analyze the effect of daily temperature changes, a computer program for dynamic thermal response was developed by the National Institute of Standards and Technology (Peavy, Powell and Burch 1973). The computer program was verified with a structure built of 8-in.-solid (203-mm) lightweight concrete masonry walls with a 4-in.-thick (102-mm) concrete roof. After the experimental building was subjected to an outside cyclic temperature variation of 60ºF (33.3ºC), it was confirmed that the heat flow rates calculated by the steady-state method ranged from 32% to 69% higher than the rates calculated with the dynamic thermal response program.

The NBS computer program was used in a PCA study to compare heat losses of walls having equal U values (Catani and Goodwin 1976). Fig. 3-16 depicts the winter heat losses of three types of walls subject to typical outdoor temperature changes. The times at which peak loads occur are different, and there is a significant difference in the peak rate of heat loss, the value traditionally used to size heating equipment.

Fig. 3-17 shows summer heat gain curves for two types of walls with equal U value. It illustrates the well known fact that during a hot day a masonry building is cooler than a lightweight building. The relative air-conditioning loads can be visualized for the two types of walls.

For a detailed discussion of the principles of thermal mass design, application examples, and performance data for a variety of wall systems, see NCSCCMI 1994; Fiorato and Cruz 1980; Fiorato 1980; Van Geem and Fiorato 1983; Van Geem and Larson 1985; and Van Geem 1987.

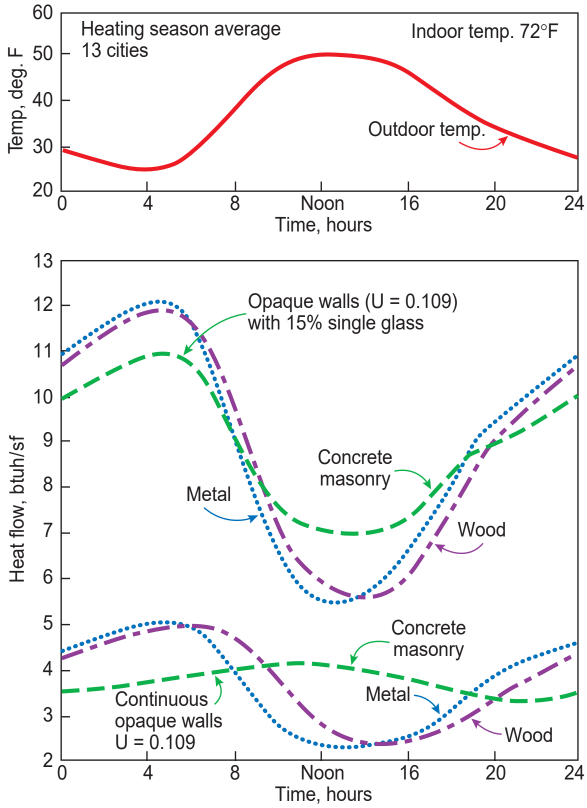


Fig. 3-16

Heat loss through masonry and nonmasonry walls, *U* values being equal.

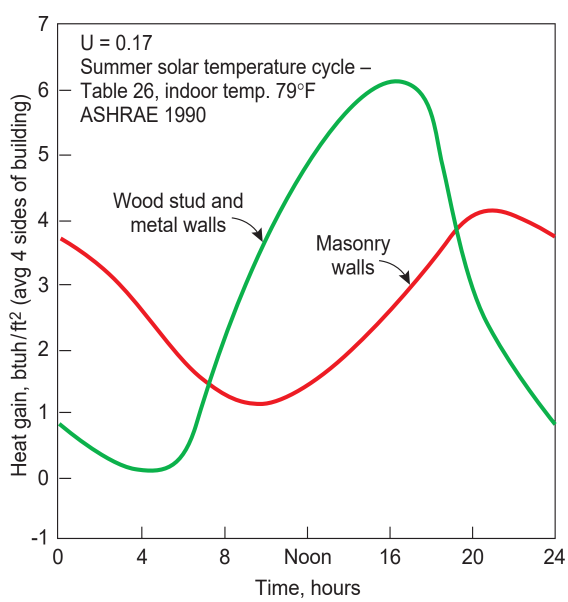


Fig. 3-17

Heat gain through masonry and nonmasonry walls, U values being equal.

Control of Water Vapor Condensation

When warm, humid air is chilled to a certain point, as by a cold surface, condensation takes place (Fig. 3-18). To prevent condensation or sweating on the interior or room-side surface of a wall, the overall resistance to heat transmission of the wall must be such that the surface temperature will not fall below the dew (condensation) point of the room air. Dew points for various room temperatures and relative humidity are listed in Table 3-11. It shows, for example, that with a room temperature of 70ºF (21ºC) and a relative humidity of 40%, the wall surface temperature should not fall below 45ºF (7.2ºC) if sweating is to be avoided.

Normally, sweating of the interior surfaces of building walls is not a problem when proper attention is given to the insulating quality of the walls and the relative humidity is controlled within reasonable limits. Water vapor condensation that occurs on uninsulated basement walls below grade during humid periods of the summer or during clothes laundering activity may require mechanical dehumidification or ventilation for its control.

The control of condensation within wall spaces and wall materials is more complex because it can occur whether the wall has an overall high or low resistance to heat flow. Water vapor is a gas in the air and will diffuse through building construction materials at rates that depend upon the water vapor permeability of the materials and the existing vapor pressure differential. The passage of water vapor through a material is not harmful in itself. It becomes of consequence only when, at some point along the water vapor flow path, a temperature level drops below the dew point and condensation occurs.

Fig. 3-18

Beads of water on the outside of this glass of ice water are caused by condensation of water vapor in the air as it comes in contact with the cold surface. (IMG24889)

Table 3-11. Dew Point Temperatures

Dry bulb or room temperature, deg. F	Dew point, deg. F, based on relative humidity									
	10%	20%	30%	40%	50%	60%	70%	80%	90%	100%
40	–9	5	13	19	24	28	31	34	37	40
45	–5	9	17	23	28	32	36	39	42	45
50	–1	13	21	27	32	37	41	44	47	50
55	3	17	25	31	37	41	45	49	52	55
60	6	20	29	36	41	46	50	54	57	60
65	10	24	33	40	46	51	55	58	62	65
70	13	28	37	45	51	56	60	63	67	70
75	17	31	42	49	55	50	65	68	72	75
80	20	36	46	54	60	54	69	73	77	80
85	23	40	50	58	65	70	74	78	82	85
90	27	44	55	62	69	74	79	82	86	90

Excessive accumulation of condensed water vapor in concrete masonry walls may lead to efflorescence or temporary formation of frost within the wall. In most concrete masonry buildings freezing does not constitute a problem due to the daily fluctuations in temperatures. Frost thaws and the moisture is released through the outer wythe as vapor—if the outer surface of the wall is not sealed—or through weepholes as condensate.

The risk of damage from frost buildup in walls is greatest during extended periods of very low outdoor temperatures and moderate or high indoor relative humidity that exceeds about 50%. However, when outdoor temperatures are very low, high indoor relative humidity is rare, except in laundries, bathing areas, etc. The maximum humidity that can be continuously maintained in a room is limited by the dew point of the wall or window or any sensitive zones on them.

To minimize condensation, and yet provide for human health and comfort, some agencies recommend that the maximum relative humidity maintained indoors should be approximately as follows (Olin, Schmidt and Lewis 1983):

Table 3-12. Recommended Indoor Relative Humidity

Outdoor temperature, °F (°C)	Indoor relative humidity, percent
0 (–17.8)	25
10 (–12.2)	30
20 (–6.7)	35
30 (–1.1)	40

An example of vapor pressure gradients appears in the lower part of Fig. 3-14 for a steady-state condition in which moisture and heat are migrating to the outdoors. The vapor pressure is expressed in inches of mercury (Hg). Gradient P_s assumes saturated indoor air (100% relative humidity), and gradient P_c assumes continuous vapor flow for the actual humidity, but neglects the possibility of condensation. Condensation would occur at the point where gradients P_s and P_c intersect. Since that point is in the granular vermiculite fill, where resistance to vapor flow is very low, the condensation would probably take place on the inside of the outer wall wythe. Then, since the temperature there is about 5°F (15°C), frost would develop. Gradient P_a shows actual vapor pressure gradient (ASHRAE 1990 and PCA EB083 1980).

Generally, when the designer is confronted with building service conditions conducive to water vapor condensation, a vapor retarder on or as close as possible to the warm surface of the wall is provided. The vapor retarder is a material—such as plastic film, asphalt-treated paper, and aluminum or copper foil—that will transmit little or no water vapor. Thus, the vapor retarder will reduce to a minimum the entrance of water vapor into the wall. Then, the reduced amounts of water vapor penetrating the vapor retarder (if any) will pass through the outer layers of the wall by diffusion. Of course, any outer surface treatment such as paint must be of a type that will "breathe."

For a vapor retarder to be fully effective, it must be applied as a leakproof, continuous layer. Openings such as those required for electrical outlet boxes must be given close attention, and avenues for vapor leakage through or around window and door frames must be stopped.

Acoustics

Noise is unwanted sound, and what is considered noise depends upon the individual and the level of tolerance. People value their privacy and do not care to hear the movements of their neighbors.

Acoustics as a science and technology is well established. The subject is complex, but if a few simple concepts are learned, the architect, engineer, and builder can do a great deal to assess and solve acoustical problems. Good acoustical design in residences and offices can be achieved with absorptive surfaces and relatively heavy wall and floor construction. Concrete masonry is an excellent sound barrier because of its density. An extended discussion of acoustics in buildings is presented in PCA IS159 1982.

Elements of Sound

The two most important parameters used for the study of acoustics are frequency and decibels—or, loosely speaking, tone and loudness. The tone of a sound depends on the number of vibrations per second, or the frequency. One vibration per second, or one cycle per second (1 cps), is called a hertz, which is abbreviated as Hz. On the piano, middle C has a frequency of 262 Hz. The lowest of the 88 piano keys has a frequency of 27 Hz, and the highest a frequency of 4186 Hz. This is essentially the range of tones used in the study of building acoustics.

The pressure of sound is measured by the decibel (db). Each increase of 20 db indicates a tenfold pressure increase. However, the human ear mechanism automatically reduces its sensitivity as the pressure increases. As an example, an increase of 10 db is a threefold increase in pressure but the loudness sensation to the ear is only doubled. Since the human ear has a greater range of sensitivity to intensity in the middle range of frequencies, loudness is determined by the pressure level in decibels at a frequency of 1000 cps (1000 Hz).

A better conception of the decibel as a unit of measure of sound intensity may be obtained from Table 3-13:

Table 3-13. Decibel Level of Common Sounds

Decibels	Sound
140	Jet at takeoff 80 ft (24.38 m) from tail
130	Threshold of discomfort
120	Thunder
110	Car horn at 3 ft (0.91 m)
100	Wood saw at 3 ft (0.91 m)
90	Noise inside a city bus
80	Noisy office or vacuum cleaner
70	Jet landing – at 3300 ft (1006 m)
60	Average office
50	Average conversation
40	Quiet radio
30	Quiet conversation
20	Whisper at 4 ft (1.22 m)
10	Normal breathing
0	Threshold of audibility

Criteria for Acoustic Ratings

Building codes regulate the amount of noise that must be stopped by walls, floors, and ceilings. Typical sound loss values are in the range of 40 db to 55 db for airborne and impact sounds.

There are three principal types of ratings, as shown in Table 3-14. Each type may be identified at any individual frequency or by class. Sound absorption coefficient (SAC) and noise reduction coefficient (NRC) values are in sabins, which are units measuring energy absorption and not sound or loudness. All other ratings are in decibels. The ratings have one thing in common: *the larger the number, the better the sound insulating quality of the wall or floor.*

Table 3-14. Acoustic Ratings

Type of rating	Rating by individual frequencies	Rating by class
Sound absorption (airborne)	SAC	NRC
Sound transmission loss (airborne)	STL	STC
Impact noise isolation or Impact sound isolation	ISPL	INR IIC

"Sound absorption" refers to the amount of airborne sound energy (sabins) absorbed by the wall surface adjacent to the sound. "Sound transmission loss" is the total amount of airborne sound (decibels) lost as it travels from one side of a wall or floor to the other. "Impact noise isolation" and "impact sound isolation" refer to the number of decibels lost through a floor from standardized impacts on top of the floor (or floor covering). ISPL, INR, and IIC ratings (see Table 3-14) are not used for walls. The ratings are governed by ASTM C423, C634, E90, E336, E413, E492, and E597.

Sound Absorption

Fig. 3-19 shows data for 8-in. (203-mm) lightweight concrete masonry walls tested in two different laboratories. Note how the absorption varies with the frequency. The sound absorption coefficient (SAC) is the amount of sound energy absorbed compared to a perfectly absorptive surface, such as an open window. Translated into decibels, SAC at 0.9 equals only 10 db; at 0.7, 5 db; at 0.5, 3 db; and at 0.3, 1.5 db. This is true regardless of the sound level. As a practical matter, it is difficult to lose much more than about 5 db of sound by absorption (reduce the loudness by 33%).

The noise reduction coefficient (NRC) is found by averaging the SAC values at frequencies of 250, 500, 1000, and 2000 Hz. In Fig. 3-20, Wall (a) has an NRC value of 0.46 (about 3 db).

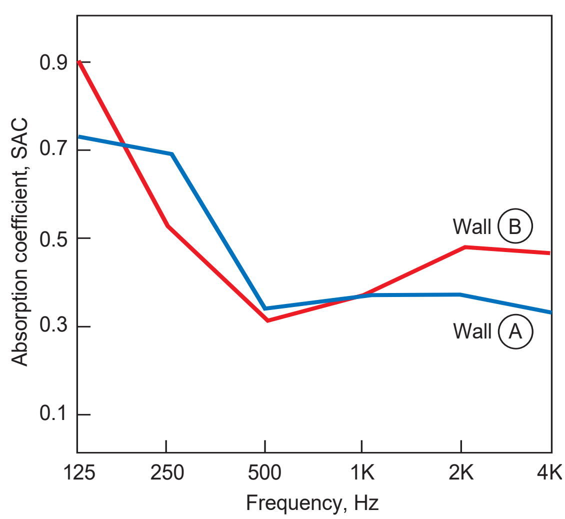
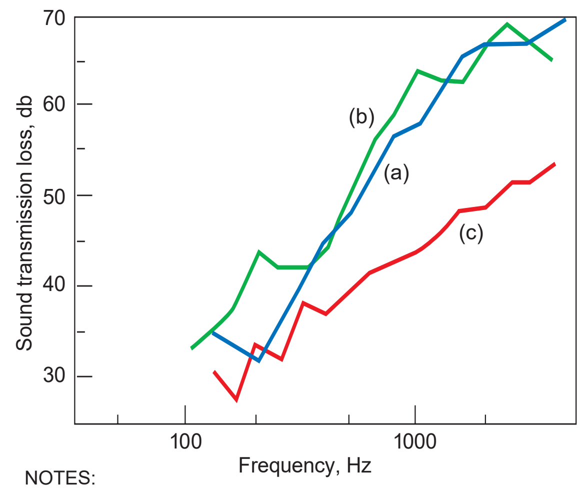


Fig. 3-19

Sound absorption test data for two 8-in. concrete masonry walls made with shale aggregate.



NOTES:

Wall (a) is 8-in. hollow heavyweight concrete masonry, one side painted and the other side furred, plus 1/2-in. gypsum wallboard. Weight is 45.6 psf and STC is 49.

Wall (b) is 6-in. hollow lightweight concrete masonry, one side painted and the other side 1/2-in. gypsum board on resilient channel furring. Weight is approximately 26 psf and STC is 53.

Wall (c) is same as *(b)* but without finish. Weight is about 23 psf and STC is 44.

Fig. 3-20

Sound transmission loss test data for several concrete masonry walls.

Typical NRC values are given in Table 3-15. However, a concrete block with uniformly fine texture, as pictured on the left in Fig. 1-31, may have an NRC value as high as 0.68 (5 db). In contrast, glass, plaster, and other smooth surfaces have NRC values of less than 0.05 (less than one-sixth of a decibel). Also note in Table 3-15 that painted concrete masonry has a reduced NRC value.

Table 3-15. Approximate Noise Reduction Coefficients*

Material		Surface texture	Approximate NRC
Lightweight aggregate block, unpainted		Coarse Medium Fine	9.40 0.45 0.50
Heavy aggregate block, unpainted		Coarse Medium Fine	0.26 0.27 0.28
Deduct from above for painting			
Paint	**Application**	**For 1 coat**	**For 2 coats**
All	Spray	10%	20%
Oil	Brush	20%	55%
Latex	Brush	30%	55%
Cement	Brush	60%	90%

* Adapted from TEK 13-2 1997.

Sound Transmission Loss

If walls have sealed surface pores on at least one side, the sound transmission loss (STL) is related to the weight of the wall. When the pores are sealed, the wall tends to transmit sound by acting as a diaphragm, literally stopping sound from passing through it. Because of this, a heavier wall reduces the transmission of sound more than a light wall, following what is known as "mass law." It holds true for homogeneous partitions that are nonporous and have uniform physical properties throughout the entire wall panel.

Table 3-16 shows STC values for various types of concrete masonry walls. An example of STL test data for several concrete masonry walls is given in Fig. 3-20. Additional STC values—up to 59 and 63—were obtained for concrete masonry and cast concrete walls, respectively, and the results are reported in PCA IS159 1982 and PCA EB083 1980. A standard method for determining the STC rating for masonry walls is published by The Masonry Society (TMS 0302 2007).

All stated values for sound transmission loss through a wall are meaningless if the wall panel has an opening. Large (such as a window opening) or small (such as an opening for a water pipe or electrical conduit), an opening can seriously alter the sound reduction capability of a wall. If maximum sound reduction is desired, any opening should be carefully avoided. For example, placing electrical outlet boxes back to back through a concrete masonry wall will provide an opening or flanking path through which sound can travel. Just as undesirable are any openings around doors, pipes, and air ducts. Another flanking path is provided by a partition that extends only to a suspended ceiling, rather than to the floor or roof above. Calking is necessary where walls abut and between walls and ceilings.

The sound level in a room is known as the masking sound or background noise; it swallows up lesser sounds transmitted through walls and floors. This is because the decibel levels of separate sounds are not directly additive. Table 3-17 shows how sound transmission loss through a wall panel affects noise conditions. The values are based on an assumed background noise level that corresponds to average conditions in most residences. Background noise levels in almost all offices and most institutions are higher.

Table 3-16. Data from Sound Transmission Loss Tests (ASTM E90) of Concrete Masonry Walls*

Wall description	Test No.**	Wall weight, psf	STC
Unpainted walls:			
8-in., hollow lightweight-aggregate units, fully grouted, No. 5 vertical bars at approx. 40 in. oc	1023-1-71	73	48
8-in., hollow lightweight-aggregate units	1144-2-71	43	49
8-in., composite wall – 4-in. brick, 4-in. lightweight hollow units	1023-4-71	58	51
8-in. dense-aggregate hollow units	1144-3-71	53	52
10-in. cavity wall – 4 in. brick, 4-in. lightweight hollow units	1023-6-71	56	54
Walls painted on both sides with 2 coats of latex paint:			
4-in. hollow lightweight-aggregate units	1379-5-72	22	43
4-in. hollow dense-aggregate units	1379-3-72	29	44
6-in. hollow lightweight-aggregate units	933-2-70	28	46
6-in. hollow dense-aggregate units	1379-1-72	39	48
8-in. hollow lightweight-aggregate units, fully grouted, No. 5 vertical bars at approx. 40 in. oc	1023-2-71	73	55
Walls plastered with ½-in. gypsum plaster on both sides:†			
8-in. composite wall – 4-in. brick, 4-in. lightweight hollow units	1023-10-71	61	53
8-in. hollow lightweight-aggregate units, fully grouted, No. 5 vertical bars at approx. 40 in. oc	1023-9-71	79	56
10-in cavity wall – 4-in. brick, 4-in. lightweight hollow units	1023-8-71	59	57
Walls covered with ½-in. gypsum board on resilient channels:†			
4-in. hollow lightweight-aggregate units			
4-in. hollow dense-aggregate units	1379-4-72	26	47
8-in. composite wall – 4-in. brick, 4-in. lightweight hollow units	1379-2-72	32	48
8-in. hollow lightweight-aggregate units	1023-5-71	60	56
10-in. cavity wall – 4-in. brick, 4-in. lightweight hollow units	933-1-70	40	56
8-in. hollow lightweight-aggregate units, fully grouted, No. 5 vertical bars at approx. 40 in. oc	1023-7-71	58	59
	1023-3-71	77	60

* Adapted from Table 2, TEK 4-1 1971.
** Kodaras Acoustical Laboratories, Elmhurst, NY
† Surface treatment on block side only of composite and cavity walls.

Table 3-17. Relationship Between Sound Transmission Loss Through a Wall and Hearing Conditions on Quiet Side*

Transmission loss, db	Hearing condition	Rating
30 or less	Normal speech can be understood quite easily and distinctly through the wall.	Poor
30 to 35	Loud speech can be understood fairly well. Normal speech can be heard but not easily understood	Fair
35 to 40	Loud speech can be heard but is not easily intellligible. Normal speech can be heard only faintly, if at all.	Good
40 to 45	Loud speech can be faintly heard but not understood. Normal speech is inaudible.	Very good – recommended for dividing walls between apartments.
45 or more	Very loud sounds such as loud singing, brass musical instruments, or a radio at full volume can be heard only faintly or not at all.	Excellent – recommended for band rooms, music practice rooms, radio and sound studios.

* This table is based on the assumption that a noise corresponding to 30 db is continuously present on the listening side.

Impact Sound Isolation

Impact sound ratings were adopted to combat annoying sounds of footsteps and objects dropping on floors above. For an effective sound barrier, a floor should have an impact sound isolation (IIC) rating of at least 40 db.

Although test data for floors made with concrete masonry are meager, other types of concrete floors have been tested many times. For example, following are the IIC ratings of several bare concrete floors:

Table 3-18. Impact Sound Isolation Ratings of Concrete Floors

Floor description	IIC (decibels)
4-in.-thick (102-mm) solid slab, 53 psf (2538 Pa)	25
6-in.-thick (152-mm) hollow prestressed slab, 43 psf (2059 Pa)	23
8-in.-thick (203-mm) hollow slab, 45-60 psf (2155-2873 Pa)	26
10-in.-thick (254-mm) solid slab, 121 psf (5793 Pa)	29

It can be expected that concrete masonry will perform slightly better than concrete. In either case the sound isolation of the bare floor is marginal, but floor coverings and ceiling treatments are immensely helpful, as shown in Table 3-19. Floor or ceiling treatments that add at least 20 db to the IIC rating will solve the acoustical problem of impact noises on concrete floors.

Table 3-19. Acoustic Rating Improvements for Concrete Floors with Various Treatments

Treatment	IIC (impact) improvement, db
Carpet, pad, and acoustic ceiling	58
Carpet and pad	48
Acoustic ceiling	27
½-in. T&G wood parquet	25
Cork tile and furred ceiling	21
Plaster or gypsum board ceiling	8
Vinyl tile	4
2-in. concrete topping	0

Other Acoustical Considerations

Noise-producing equipment should be kept as far as possible from occupied areas, especially bedrooms. Flexible connectors should be used to couple mechanical equipment to pipes, ducts, and electric power. Also, pipes and ducts should not be firmly connected to parts of the building that can serve as sounding boards. Instead, they should be supported by resilient connections to solid supports. Pipes and ducts that pass through walls and floors should be isolated from the construction by gaskets.

If a noise-producing sound must be located close to a work or sleeping area, sound barriers and sound absorbers around the source should be considered. In many instances quieter appliances and other equipment are the best solution. Manufacturers have become aware of the need, and many "sound-rated" devices are now available, frequently at little additional cost.

When a single wall is used as a sound barrier, it is sometimes desirable to provide a resilient connection between the wall and the building frame. A 5-db to 7-db improvement can result. Double walls perform better than single walls when of equal weight. Increased separation and sound-absorbing material in the cavity add to the performance of cavity walls. The sound transmission loss of a cavity wall is frequently about 8 db better than a solid wall of equal weight and, if the two wythes are of unequal weight, as much as 4 db more can be added to the STC rating.

Selective absorption that matches the frequency of an unwanted sound is obtained by slotting the face shells of concrete masonry units, Fig. 3-21 and Fig. 3-22.

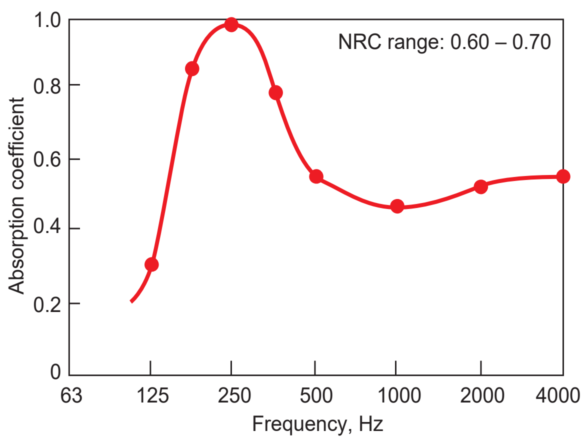


Fig. 3-21

Sound absorption test data for concrete "sound block."

Fig. 3-22

Slotted concrete block improve the acoustics. (IMG24891)

Highway and Railway Sound Barriers

Those who live or work along heavy traffic routes are well aware of traffic noise, typified in Table 3-20. Concrete masonry sound barrier walls (Fig. 3-23) are helpful in reducing noise levels, while providing a measure of privacy. Studies have shown that a 15-db sound reduction can readily be achieved by a concrete masonry wall (TRB 1973). The level of sound reduction depends on the relative distances of the wall to the highway (or rail line) and to the listener, as well as the height of the wall above the line of sight to the vehicle. See TEK 13-3A 1999 and TEK 14-15B 2004 for more details on sound barrier walls.

Table 3-20. Typical Noise Levels of Transportation Vehicles

Type of traffic	Noise level, db, based on distance from vehicle		
	50 ft	200 ft	800 ft
Passenger car, 50-60 mph	70	58	46
Truck, max, highway speed	88	76	64
Diesel train, 30-50 mph	97	85	73

Fig. 3-23

Traffic noise from expressways can be effectively shielded by a concrete masonry wall. Photo used with permission of International Masonry Institute. ©IMI (IMG24892)

Fire Resistance

Fire safety is a major element of building codes. Fire-related code provisions address both life-safety and property protection concerns by requiring building components and assemblies to meet a specified level of fire resistance. In simple terms, fire resistance can be defined as that property of a material or an assembly to withstand fire, or to give protection from fire (Fig. 3-24).

Fig. 3-24

Fire resistance is but one of the many positive qualities of concrete masonry, protecting occupants and property. The stable shown here remained intact after wildfires passed through the area. Non-combustible materials for walls as well as roof, and design features like no roof overhangs, prevented fire damage to the building. (IMG24893)

As building components, walls can have a dual function in their performance against fire. When they are constructed solely to prevent the spread of fire to another compartment or building, they are said to possess barrier fire resistance. This type of fire resistance would pertain to fire-rated, non-load-bearing walls. When walls are only required to perform structurally (exterior load-bearing walls sufficiently distant from a property line) for a specified fire rating period, they are said to possess structural fire resistance. It naturally follows that there are situations where walls must possess both barrier and structural fire resistance. Typically, the structural fire resistance of a concrete masonry wall will exceed the fire resistance that the wall can achieve as a barrier. Therefore, a concrete masonry wall will normally continue to carry a load, even though its established fire resistance rating period has been exceeded.

Whether walls are required to perform structurally, or as a barrier, or both, concrete masonry is an excellent choice. With its design flexibility, architects can adapt concrete masonry to a variety of prescribed fire resistance requirements for walls. Filling of core spaces, selecting different aggregates to change the unit weight, as well as using different block sizes are all ways of accomplishing this.

Concrete masonry walls also display excellent durability. Accordingly, only one test specimen is needed when conducting the ASTM E119 standard fire test. (This is explained in greater detail later.) Still another good quality of concrete masonry—it doesn't burn. Therefore, concrete masonry gives off no smoke or toxic fumes during a fire.

How Fire Endurance is Determined

Fire endurance can be defined as a measure of the elapsed time during which a material or assembly continues to exhibit fire resistance under specified conditions of test and performance. Fire endurance periods of building components are typically based on physical tests conducted according to ASTM E119, Test Methods for Fire Tests of Building Construction and Materials. E119 provisions require test specimens be subjected to a standard fire that follows the time temperature relationship shown in Fig. 3-25.

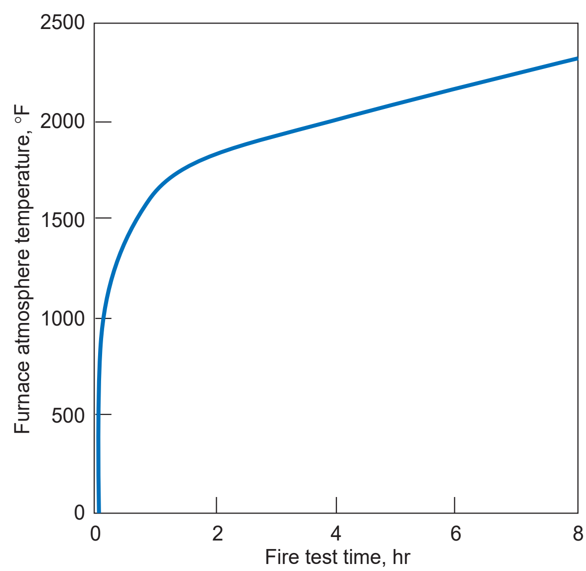


Fig. 3-25

ASTM Standard E119 time-temperature curve for fire tests.

Under the E119 standard, the fire endurance of a wall assembly is determined by the time required to reach the first of any of the following test end points:

1. The ignition of cotton waste due to the passage of flame or hot gases through cracks or fissures.

2. A single-point temperature rise of 325°F (163°C), or an average of 250°F (121°C) above ambient temperature on the unexposed surface of the wall. This is known as the heat-transmission end point.

3. An inability to carry the applied design load, or structural collapse of the wall. This is known as the structural end point.

Items 1 and 2 are associated with a wall's ability to perform as a barrier; the third item provides a criterion for structural evaluation.

Upon completion of the fire resistance portion of the fire endurance test, the wall assembly must also be subjected to the impact, erosion, and cooling effects of a standard hose stream test (Fig. 3-26). The duration of the water application on the fire-exposed side of the wall is based on the duration of the specimen's fire rating period. Any projection of water that passes through the wall's unexposed surface during the test constitutes an unsuccessful performance and terminates the test. It should be noted that the hose stream test is not intended to duplicate the scenario of water from a firefighter's hose striking a wall in an actual fire. Rather, it is intended to evaluate the test specimen's resistance to thermal shock. By design, the purpose of the hose stream test is to examine the specimen's ability as a fire barrier, and to take a conservative approach in guarding against the structural collapse of a wall under real fire conditions.

Table 3-21 summarizes the ASTM E119 end-point criteria and test conditions for wall assemblies.

Fig. 3-26

Following fire testing, concrete masonry walls are removed from the furnace and immediately subjected to hose stream tests applied to the incandescent face of the wall. This is intended to evaluate the test specimen's resistance to thermal shock. (IMG24894)

Introduction to Analytical Methods for Calculating Fire Endurance

The three U.S. model building codes (BOCA 1996; SBCCI 1997; and ICBO 1997) have traditionally required standardized fire testing to satisfy fire-resistance rating requirements for walls and other building components. Today, however, analytical methods for calculating fire endurance are recognized and accepted in the codes. This has been made possible due to the wealth of test data compiled from ASTM E119 tests through the years. The advantage of using analytical methods is the significant cost savings realized compared to the practice of conducting full-scale fire tests. Methods for calculating fire resistance are found in documents *Requirements for Determining Fire Resistance of Concrete and Masonry Construction Assemblies* (ACI 216/TMS 0216 2007) and Chapter 17 of the *International Building Code* (ICC IBC 2006).

Table 3-21. Applicable End-Point Criteria and Test Conditions for Concrete Masonry Members and Assemblies (Based on ASTM E119 Standard Fire Tests)

Member		End point			
		250°F average temperature rise or 325°F point temp. rise on unexposed surface	Flame impingement through cracks or fissures sufficient to ignite cotton waste	Carry applied load	Hose stream test
Walls	Bearing	Yes	Yes	Yes	Yes*
	Nonbearing	Yes	Yes	No load applied	Yes*

* Hose stream tests apply only to those walls required to have a one-hour rating or greater.

To analytically calculate the fire endurance of a wall, one must understand the end-point criteria of the standard testing procedure that governs its fire rating. The terminating point, or end-point condition, of an ASTM E119 test can occur as any one of the four criteria described previously (including the hose stream test). When concrete masonry walls are tested, the heat transmission end-point is nearly always reached prior to the passage of flame or gases, or structural failure. Thus, heat transmission is the controlling factor in establishing the fire resistance rating period assigned to the wall.

Concrete masonry also performs well in the hose stream portion of the test because of its exceptional durability. This durability permits the same test specimen that is subjected to the burn portion of the test to be used in the hose stream test immediately afterward. Other building assemblies, such as those using wood or steel studs and gypsum wallboard, are routinely tested by subjecting a duplicate test specimen to the hose stream test after being fire tested for only one-half of the fire endurance period of the original test specimen. This doesn't seem equitable, but nevertheless, it is permitted under the ASTM E119 test standard.

Factors Influencing Fire Endurance (Heat Transmission)

For concrete masonry units, equivalent thickness of the block (defined below) and unit weight are the primary factors that influence fire endurance. Moisture content does affect the material's thermal conductivity, but this is described in another section.

As indicated above, the fire endurance of concrete masonry walls will most often be determined by the heat-transmission end point. Since this parameter is a function of the temperature distribution through the wall, the fire endurance can be predicted analytically if the type of aggregate and equivalent thickness of the masonry units are known.

Effect of Aggregate on Unit Weight and Fire Endurance

As unit weight, which is determined by aggregate type, is reduced, the resistance to heat transmission increases, thereby increasing the fire endurance. Examination of Table 3-22 confirms that a concrete masonry wall built with lighter-weight aggregate units provides greater fire endurance than one constructed of normal-weight aggregate units. This is reflected by the requirement of a lesser thickness of lighter-weight aggregate block to achieve the same fire endurance rating as a normal-weight aggregate unit.

Structural lightweight concretes use aggregates such as expanded shale, clay, and slate and have unit weights ranging from 100 pcf (1600 kg/m^3) to about 120 pcf (2400 kg/m^3). Normal-weight concretes have unit weights ranging from 135 pcf to 150 pcf (2160 kg/m^3 to 2400 kg/m^3). Normal-weight concretes use siliceous aggregates obtained from natural sand and gravel or carbonate aggregates such as limestone.

Equivalent Thickness

Referring again to Table 3-22, the other critical parameter affecting the fire endurance of concrete masonry walls is the equivalent thickness. This factor is determined from the wall's actual thickness and the geometry of the concrete masonry unit. Hollow or solid concrete masonry units are available in nominal thick-

Table 3-22. Minimum Equivalent Thickness in Inches of Load-Bearing or Non-Load-Bearing Concrete Masonry Walls*

	Fire resistance rating, hours														
Type of aggregate	½	¾	1	1¼	1½	1¾	2	2¼	2½	2¾	3	3¼	3½	3¾	4
Pumice or expanded slag	1.5	1.9	2.1	2.5	2.7	3.0	3.2	3.4	3.6	3.8	4.0	4.2	4.4	4.5	4.7
Expanded shale, clay, or slate	1.8	2.2	2.6	2.9	3.3	3.4	3.6	3.8	4.0	4.2	4.4	4.6	4.8	4.9	5.1
Limestone, cinders, or unexpanded slag	1.9	2.3	2.7	3.1	3.4	3.7	4.0	4.3	4.5	4.8	5.0	5.2	5.5	5.7	5.9
Calcareous or siliceous gravel	2.0	2.4	2.8	3.2	3.6	3.9	4.2	4.5	4.8	5.0	5.3	5.5	5.8	6.0	6.2

* Values between those shown in the table can be determined by direct interpolation.
Where combustible members are framed into the wall, the thickness of solid material between the end of each member and the opposite face of the wall, or between members set in from opposite sides, shall not be less than 93% of the thickness shown in the table.

Minimum required equivalent thickness corresponding to the hourly fire-resistance rating for units with a combination of aggregate shall be determined by linear interpolation based on the percent by volume of each aggregate used in manufacture. Adapted from 2006 International Building Code.

nesses of 4, 6, 8, 10, and 12 in. (102, 152, 203, 254, and 305 mm) with varying percentages of solid area. The equivalent thickness of a block can be calculated using the following equation:

T_{eq} = % solid x actual thickness (Eq. 1)

For example, the equivalent thickness of a 50% solid, 8-in. (203-mm) nominal block would be calculated as:
0.50 x 7.625 = 3.8 in. (97 mm).
The percent solid any given masonry unit can be obtained from the manufacturer. If 100% solid, flat-sided masonry units are used, the equivalent thickness is the actual thickness.

Blended Aggregate Block

When it is necessary to determine the equivalent thickness of blended aggregate block, the *International Building Code* permits interpolation of Table 3-22 values in proportion to the percentage volume occupied by each of the block's component aggregates. The required equivalent thickness of a blended concrete masonry unit for a wall is determined as follows:

For calcareous or siliceous gravel (gravel) blended with pumice or expanded slag (slag):

T_{eq} required =
$(T_{eq\ gravel} \times V_{gravel}) + (T_{eq\ slag} \times V_{slag})$ (Eq. 2)

For calcareous or siliceous gravel (gravel) blended with expanded clay, shale, or slate (clay):

T_{eq} required =
$(T_{eq\ gravel} \times V_{gravel}) + (T_{eq\ clay} \times V_{clay})$ (Eq. 3)

For calcareous or siliceous gravel (gravel) blended with both categories of aggregates (slag and clay):

T_{eq} required =
$(T_{eq\ gravel} \times V_{gravel}) + (T_{eq\ slag} \times V_{slag}) + (T_{eq\ clay} \times V_{clay})$
(Eq. 4)

where,

$T_{eq\ slag}$, $T_{eq\ clay}$, and $T_{eq\ gravel}$ = specified equivalent thickness values as given in Table 3-22.

V_{slag}, V_{clay}, and V_{gravel} = the ratio of the volume of individual categorized aggregate to the total volume of aggregate for aggregates indicated in Table 3-22.

The following example demonstrates the use of the formula:

Given: Concrete masonry units are composed of 15% pumice, 30% expanded shale, and 55% calcareous aggregate.

Determine the required equivalent thickness of the units needed to provide a 2-hour fire-rated wall.

From Table 3-22 and blending formula (Eq. 4),

T_{eq} required =
3.2 (0.15) + 3.6 (0.30) + 4.2 (0.55) = 3.9 in. (99 mm)

The result indicates that the equivalent thickness of concrete masonry units composed of aggregates blended to the above proportions must be at least 3.9 in. (99 mm) if the wall is to provide a fire-resistance rating of 2 hours.

Effect of Fill

Completely filling the core spaces of hollow concrete masonry units with grout or loose-fill materials increases fire endurance such that the hollow units will perform as 100% solid units. Loose-fill materials include: sand, pea gravel, crushed stone, or slag meeting ASTM C33 requirements; pumice, scoria, expanded shale, expanded clay, expanded slate, expanded slag, expanded fly ash, or cinders meeting ASTM C331 requirements; perlite meeting ASTM C549 requirements; and vermiculite meeting ASTM C516 requirements (ICC IBC 2006). This is due to the increase in resistance to heat transmission provided by the block's fill material. Additional information on this subject is addressed in the *IBC* in Section 721.3.1, Equivalent Thickness. If grouting or filling of cores is only done intermittently along the length of the wall, the equivalent thickness—and thus the fire endurance of the wall—should be based on that of the hollow unfilled masonry units.

Multiwythe Walls

When multiwythe walls are constructed of concrete masonry, the fire endurance of the composite wall is greater than the summation of the individual fire endurance periods of its component layers. An equation that can be used to estimate the fire endurance of multiwythe walls based on the heat-transmission end point is:

$$R = (R_1^{0.59} + R_2^{0.59} + \ldots + R_n^{0.59} + A_1 + A_2 + \ldots + A_n)^{1.7} \quad \text{(Eq. 5)}$$

where,

R = total fire endurance rating in hours

$R_1, R_2, \ldots R_n$ = fire endurance in hours of each individual wythe

$A_1, A_2, \ldots, A_n$ = 0.30, factor for each 1 through n continuous ½-in. (12.7 mm) or greater airspaces between wythes.

When using the above equation, it is important to remember that this is just an estimation. Eq. 5 is not applicable in all cases because the exponent 1.7 and its reciprocal 0.59 are average values that vary from material to material.

The *IBC* requires that the fire ratings of walls of nonsymmetrical construction be based on the lesser of the two ratings obtained from tests conducted on each side of the wall, except when an exterior wall has a horizontal separation greater than 5 ft (1.52 m) from an interior lot line. When this situation is present, the fire rating is established using the interior side of the wall as the fire-exposed surface.

To apply the multiwythe equation (Eq. 5) to composite concrete masonry walls, "R" values should be obtained from Table 3-22. Values for other materials, such as concrete and brick masonry, are published in other industry sources (PCA SR267 1994).

Finish Materials Applied to Concrete Masonry

The *International Building Code* (*IBC*) contains guidelines for estimating the additional fire endurance provided by plaster and gypsum wallboard finishes applied to the fire-exposed and/or non-fire-exposed sides of concrete masonry walls.

Where plaster or gypsum wallboard is applied to the non-fire-exposed side of the wall, the fire resistance contribution of the finish material is determined as follows: Based on the type of aggregate used in the concrete masonry, and the type and thickness of the finish material, a multiplying factor from Table 3-23 is applied to the actual thickness of the finish material to obtain an adjusted thickness. This adjusted thickness is then added to the equivalent thickness of the concrete masonry to get an adjusted equivalent thickness. Then, Table 3-22 can be used to determine the fire resistance of the composite wall.

Where plaster or gypsum wallboard is applied to the fire-exposed side of the wall, the corresponding time assigned to the finish material shown in Table 3-24 is added directly to the fire resistance rating of the concrete masonry wall as determined from Table 3-22. Where finish materials are applied to both sides of the wall, the fire resistance contribution of the material on the non-fire-exposed side of the wall is determined first as described above. This adjusted value is then added directly to the appropriate Table 3-24 value to account for the fire resistance contribution of the material on the fire-exposed side of the wall. The net effect is the fire resistance of the entire assembly.

As is the case with nonsymmetrical multiwythe wall assemblies, calculations to determine the fire resistance of walls having finish materials on one side, or finishes of different types and thicknesses on each side, must be performed twice. In performing the calculations, the above procedure is used with the assumption that either side may be the fire-exposed side. The lesser of the two calculated values then establishes the fire resistance rating.

As noted above, for exterior walls having a horizontal separation of more than 5 ft (1.52 m) from a lot line or imaginary line between two buildings on the same lot, the *IBC* requires the fire to be assumed to occur on the interior side of the wall.

Table 3-23. Multiplying Factor for Finishes on Non-Fire Exposed Side of Wall

Type of finish applied to wall	Type of aggregate used in concrete masonry			
	Siliceous or calcareous gravel	Limestone, cinders, or unexpanded slag	Expanded shale, clay or slate	Pumice, or expanded slag
Portland cement-sand plaster	1.00	0.75*	0.75*	0.50*
Gypsum-sand plaster or gypsum wallboard	1.25	1.00	1.00	1.00
Gypsum-vermiculite or perlite plaster	1.75	1.50	1.50	1.25

* For portland cement-sand plaster ⅝ in. or less in thickness and applied directly to the concrete masonry on the non-fire exposed side of the wall, the multiplying factor shall be 1.00.

Table 3-24. Time Assigned to Finish Materials on Fire-Exposed Side of Wall

Finish description	Time, min
Gypsum wallboard	
⅜ in.	10
½ in.	15
⅝ in.	20
2 layers of ⅜ in.	25
1 layer ⅜ in., 1 layer ½ in.	35
2 layers ½ in.	40
Type X gypsum wallboard	
½ in.	25
⅝ in.	40
Portland cement-sand plaster applied directly to concrete masonry	*
Portland cement-sand plaster on metal lath	
¾ in.	20
⅞ in	25
1 in.	30
Gypsum-sand plaster on ⅜ in. gypsum lath	
½ in.	35
⅝ in.	40
¾ in.	50
Gypsum-sand plaster on metal lath	
¾ in.	50
⅞ in.	60
1 in.	80

* The actual thickness of portland cement-sand plaster, provided it is ⅝ in. or less in thickness, may be included in determining the equivalent thickness of the masonry for use in Table 3-22.

Protection of Structural Steel Columns

Concrete masonry units are used to provide fire protection for structural steel columns. An empirical equation—based on a limiting condition of the column's steel core temperature reaching 1000°F (538°C)—is available for predicting the fire endurance of box type concrete masonry-protected steel columns. The calculation method and equation are not provided in this text, but a comprehensive discussion of this subject, including examples, can be found in TEK 7-6 2003.

Closing Comments

The intent of this section on fire resistance is only for background information purposes. While the information contained herein accurately reflects the content of the building code currently in effect, the reader is advised to consult the latest edition and abide by its provisions if any discrepancies are noted.

For additional information on the fire resistance of concrete masonry see Menzel 1934 and Zwiers 1989.

Design and Layout of Concrete Masonry Walls

CHAPTER 4

The design of a concrete masonry wall depends on its required appearance, economy, strength and structural integrity, insulation, and acoustics. The layout of the wall involves other important considerations, such as the internal arrangement of components, modular planning, and provisions for shrinkage cracking control and weather resistance. All deserve careful planning if the wall is to successfully serve its intended purpose.

Fig. 4.1

Concrete masonry units can be arranged to create a dominating pattern. (IMG15885)

Types of Walls

Concrete masonry walls may be classified as solid, hollow, cavity, composite, veneered, reinforced, or grouted. These classifications sometimes overlap, but the basic terminology and bonding directions remain the same, as shown in Fig. 4-2.

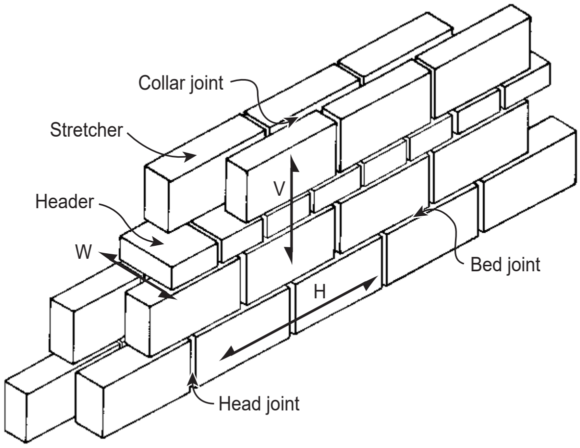


Fig. 4.2

Basic terms and bonding directions.

Solid Masonry Walls

Solid masonry walls (Fig. 4-3) are built of solid masonry units (ASTM C90 or C129) with all joints completely filled with mortar or grout. Solid masonry units are defined as having a net area of at least 75% of the total cross section (cells are less than 25%). Facing units are usually brick or other solid architectural units that are laid with full head and bed joints. Backup units consist of solid masonry units laid with full head and bed joints.

If units with flanged ends are used, the end cavity must be filled with grout. Spaces between units are filled with mortar.

Structural bond between wythes is ensured by unit metal ties, continuous metal ties, grout, or masonry

Moisture management is an important consideration in the design and construction of masonry walls. Key components for diverting water to the outside face include flashing membranes (left) and wicks or weep holes (right). See Figs. 4-55 and 4-60 for more information. (IMG24964, IMG24965)

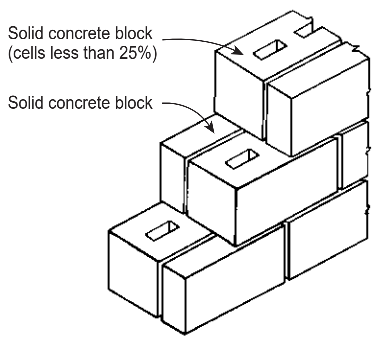


Fig. 4.3

Solid masonry wall.

headers. Though masonry headers have a long history of use, the other methods are now preferred and the Masonry Standards Joint Committee does not encourage the use of headers.

Headers usually consist of facing units laid transversely and extending 3 in. to 4 in. (76 mm to 102 mm) into the backing. If the wall does not have headers extending completely through it, headers from the opposite side overlap 3 in. to 4 in. (76 mm to 102 mm). The allowable vertical or horizontal distance between adjacent headers varies from 24 in. to 36 in. (610 mm to 914 mm), depending on the local code. Fig. 4-3 shows a solid wall in which the courses of each wythe overlap to create headers. Typical codes require that not less than 4% of the area of each wall face be composed of headers.

Although common in past decades, 100% solid masonry units are rarely used today. Due to this obsolescence, ASTM withdrew its C145 standard in 1990.

Hollow Masonry Walls

These walls (Fig. 4-4) are built of hollow masonry units (ASTM C90 or C129) or combined hollow and solid units laid in face-shell mortar bedding.

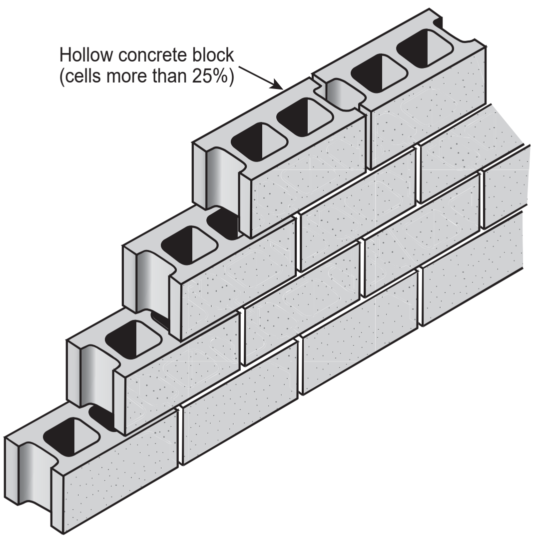


Fig. 4-4

Hollow masonry wall.

Hollow masonry walls may be built in any required thickness with single or multiple wythes. Multiwythe hollow masonry walls usually consist of two wythes—facing and backup—and may also be classified as composite walls. Bond between wythes is ensured by unit metal ties, continuous metal ties, or grout (and much less frequently now, masonry headers). All collar joints should be filled with mortar.

Cavity Walls

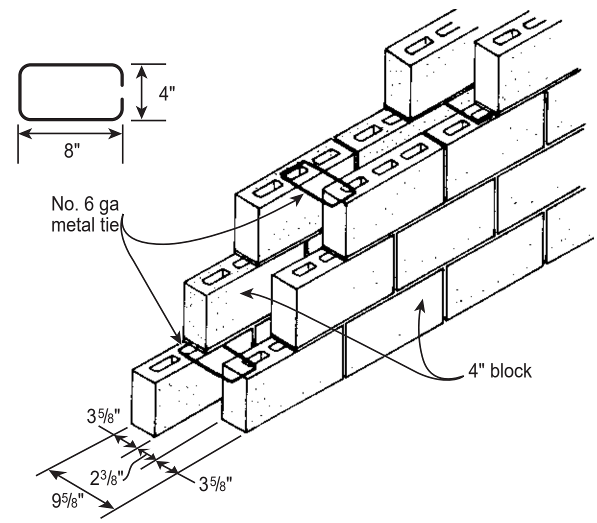
A cavity wall (Fig. 4-5) is a multiwythe wall with noncomposite action, allowing each wythe to independently accept and react to stress relative to its stiffness. A cavity wall consists of two walls separated by a continuous air space 2 in. (51 mm) or more wide (with or without insulation) and tied together by rigid metal ties embedded in the mortar joints of both walls. Cavities more than 4½ in. (114 mm) wide must have ties designed to support the load without pullout or buckling to allow compatible lateral deflection between wythes.

The facing wythe of a cavity wall usually consists of solid or hollow masonry units 3½ in. to 4 in. (89 mm to 102 mm) thick. The backing may be a single or multiwythe solid or hollow masonry wall. The thickness of the backing may be equal to or greater than that of the facing, depending on such structural requirements as wall height and the loads to be carried. Usually a cavity wall is designed so that all the vertical loads are carried by the backing; the outer wall serves as a weather-protective facing. Since they are tied together, both walls act to resist wind, although not necessarily equally.

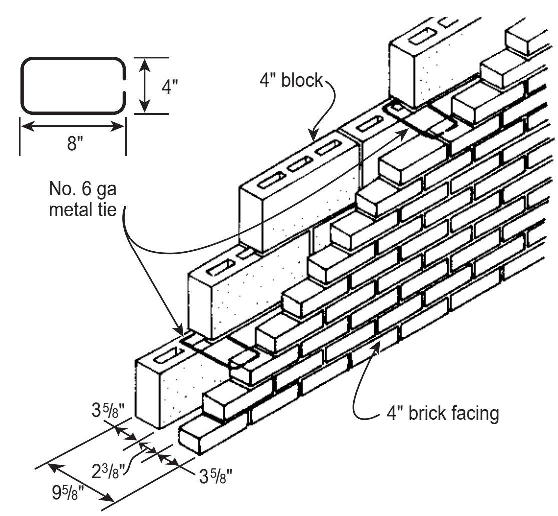
In areas of severe weather exposure, the cavity wall offers three main advantages:

1. It increases the insulating value of the wall and permits use of insulation within the wall.
2. It prohibits the passage of water or moisture across the wall.
3. It prevents the formation of condensation on interior surfaces; therefore, gypsum plaster may be applied directly to the masonry without furring, or the interior surface may be used as the finished wall without plastering.

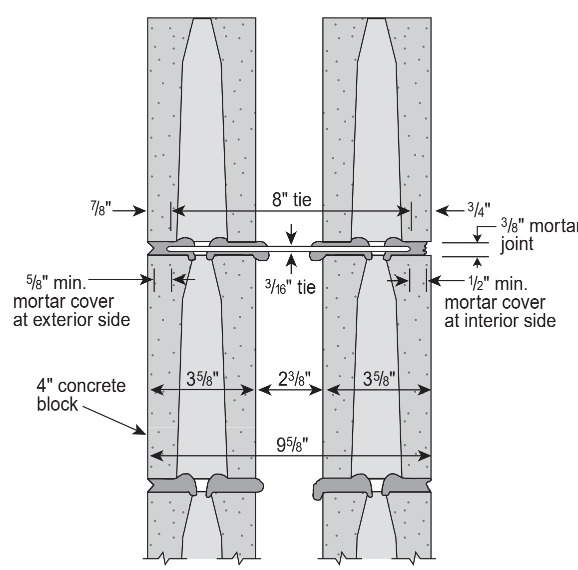
Insulation placed within the cavity may consist of mats, rigid boards, or non-water-absorbent fill material. Mats or rigid boards may be glass fiber,



(a) 10-in. wall of 4-in. block



(b) 10-in. wall of block and 4-in. brick



(c) Detailing of metal tie in 10-in. wall

Fig. 4.5

Cavity walls. Also see Figs. 4-6 and 4-11.

foamed glass, or foamed plastics. A vapor retarder or dampproofing is required on the cavity face of the inner wall unless waterproofed insulation is used or rigid insulating boards are held at least 1 in. (25 mm) away from the exterior wall.

Many fill materials absorb and adsorb water that penetrates into the cavity causing the masonry wall to remain more moist than other walls without fill materials. Increased levels of moisture in a wall can lead to frost damage, efflorescence, and a reduced *R* value.

Cavity walls with insulation should use adjustable ties (Fig. 4-6b). Truss-type ties crossing both wythes should be avoided to prevent damage to insulation boards during construction. Additional information on wall ties for non-composite action walls is contained in the section titled "Unit Metal Ties" in this chapter.

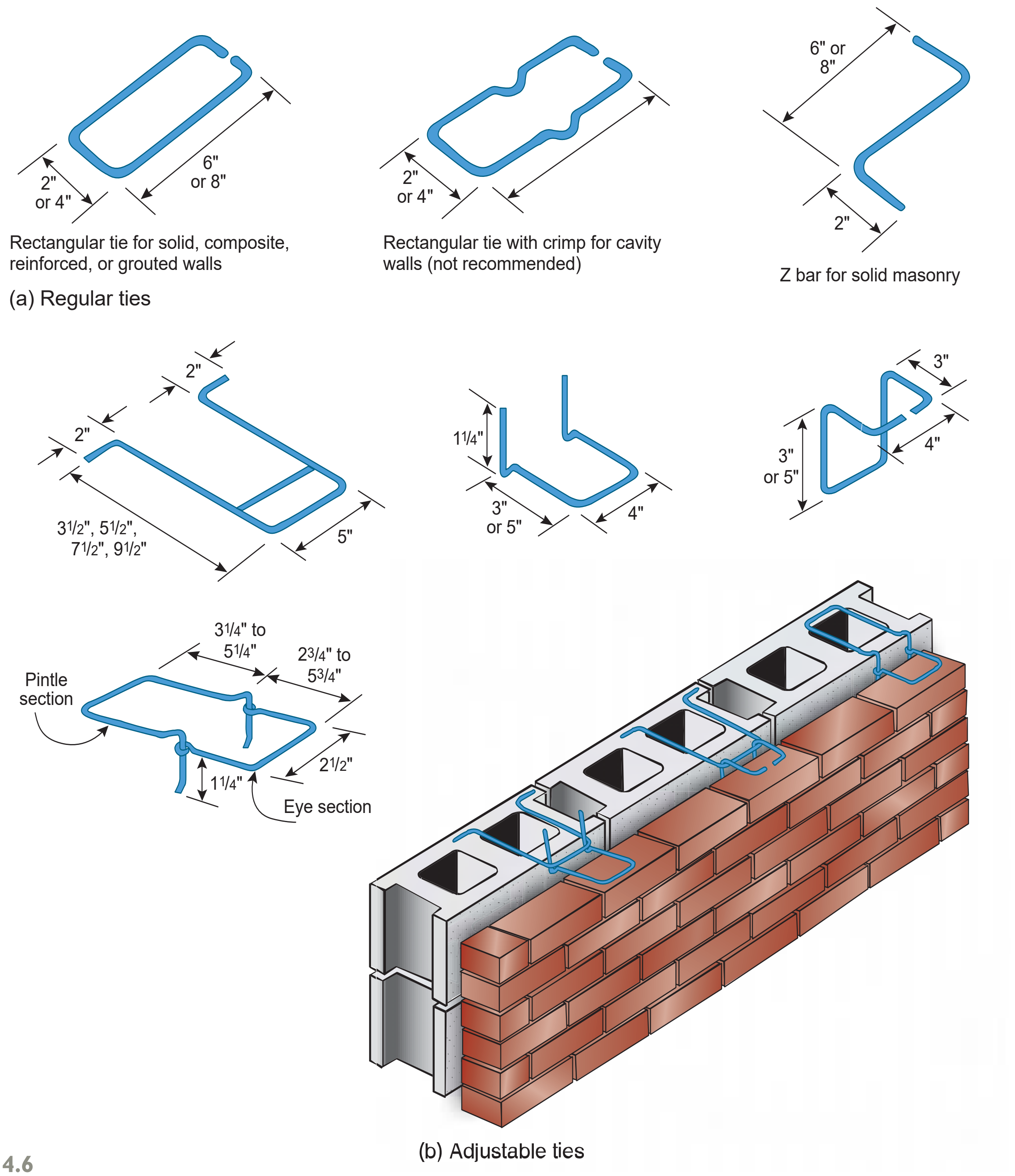


Fig. 4.6

Unit metal ties.

Composite Action Walls

A composite action wall (Fig. 4-7) is a multiwythe wall designed to act as a single member in response to loads. Stress is transferred and shared by the wythes through the mortar- or grout-filled collar joint and metal ties. Although not the preferred practice, headers may be placed across the filled or unfilled collar joint (Fig. 4-7b) in lieu of metal ties to provide shear transfer. Composite action walls constructed with headers are not as ductile as those built with metal tied wythes.

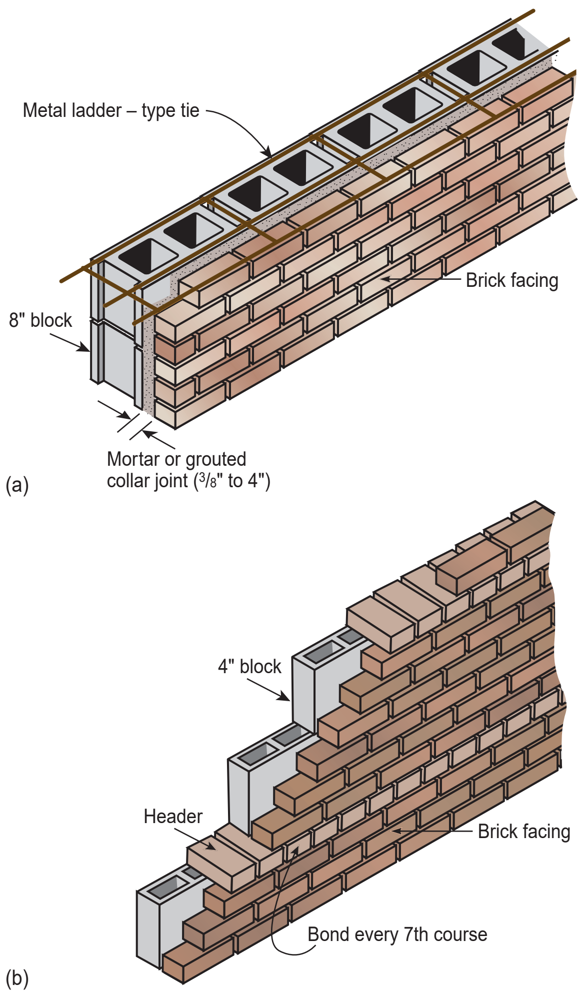


Fig. 4.7

Multiwythe composite action masonry walls. (a) Composite action block and brick wall with metal ties. (b) Composite action block and brick wall with headers. Header construction is not preferred as it does not provide as much ductility as metal tied wythes.

Anticipated shear bond stresses between wythes and collar joints, or within headers, should not exceed 5 psi (0.03 MPa) for mortared collar joints, 10 psi (0.07 MPa) for grouted collar joints, or the square root of the compressive strength of the header for header construction.

Most types of ties can be used except for Z ties, which should not be used with hollow units. At least one tie for every 2⅔ sq ft (0.25 m^2) or 4½ sq ft (0.42 m^2) of wall is required for a wire size of W1.7 (MW11) or W2.8 (MW18), respectively. Regular ties should be spaced no more than 36 in. (914 mm) horizontally and 24 in. (610 mm) vertically.

A note about headers. Header construction is not preferred because it does not provide the same degree of ductility as metal ties. Differential movement may cause the headers to crack. However, when used, header-bonded wythes of solid masonry should have the headers uniformly distributed, and with a cross-sectional area of at least 4% of the wall surface area. The distance between headers should not exceed 24 in. (610 mm). For hollow masonry, the maximum vertical distance is 34 in. (864 mm). Headers should be embedded at least 3 in. (76 mm) into each wythe.

More information on composite-action wall design can be found in the *MSJC Code,* the *MSJC Specification,* and the *Commentaries* to these documents (MSJC 2005).

Veneered Walls

It is common practice in residential construction to use masonry veneer as a non-load-bearing siding or facing material over a wood frame, as detailed in Appendix A (Fig. A-43). Designed to carry its own weight only, the veneer in this type of application is anchored but not bonded to the backing. In commercial work, the veneer may contain architectural units bonded with joint reinforcement to a concrete masonry backup wall that is load-bearing. If the collar joint is less than 2 in. (51 mm) wide, it is a veneered wall, not a cavity wall.

The purpose of the veneer is to provide a durable, attractive exterior finish that will reduce or prevent entrance of water or moisture into the building. An air space of at least 1 in. (25 mm)—preferably 2 in. (51 mm)—should be provided between the veneer and the backing to give additional protection against moisture penetration and heat loss. Flashing and weepholes are provided at the bottom of the air space to expel water that may penetrate the veneer.

For residential construction, metal ties anchoring the veneer to the backing are usually 22-gage (0.8 mm) corrugated, galvanized steel strips ⅞ in. (22 mm) wide. The *MSJC Specification* requires one corrugated sheet-metal anchor for each 2.67 ft^2 (0.25 m^2) of wall area. To satisfy this requirement, building code requirements for spacing of such ties vary widely, but an average value would be 16 in. (406 mm) vertically and 32 in. (813 mm) horizontally. For commercial construction, unit ties—or preferably, adjustable ties—are used.

Veneer may also be anchored to the backing by grouting it to paperbacked, welded-wire fabric attached directly to the wood studding. The thickness of grout between the backing and the veneer should be at least 1 in. (25 mm). No sheathing is required, although it may be added for stiffness, and the need for flashing and weepholes at the base of the wall is eliminated. This type of construction is commonly called reinforced masonry veneer. Other types of veneered walls are illustrated in Figs. 4-8a, b, and c.

Fig. 4-8a

A reinforced concrete masonry wall veneered with brick. The collar joint is not filled with mortar. (IMG24954)

Masonry Veneer Over Metal Stud Walls

Over the last 20 years, an exterior masonry wall system using metal studs (Fig. 4-8c) appeared on the building scene. It has been widely used, but it has not always performed successfully (Heslip 1983).

The system is an adaptation of conventional masonry veneer over wood studs, which has been used successfully for one- and two-family dwellings for decades.

Fig. 4-8b

A concrete masonry wall veneered with architectural concrete masonry units. (IMG24173)

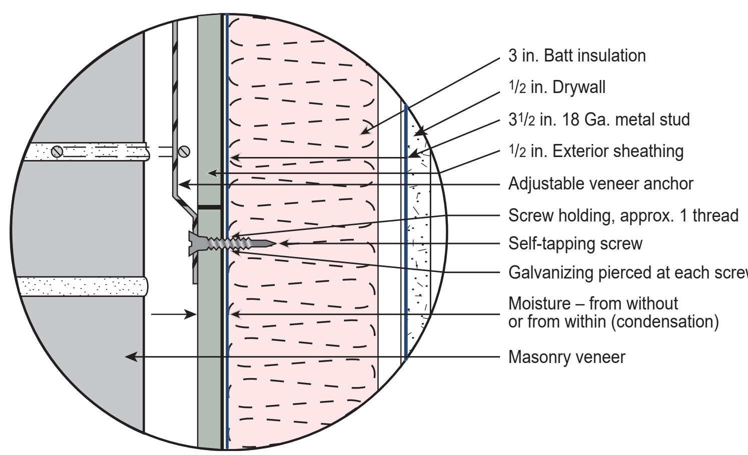


Fig. 4-8c

In a typical masonry veneer over metal stud wall system, the backup support system is light metal framing sheathed with a water-repellent gypsum board facing outside and regular drywall inside. An air space separates the masonry veneer from the support system. Metal anchors or ties attach the veneer to metal studs, which are light-gage C-shaped members screw-attached to U-shaped metal channels running horizontally at top and bottom. Sheathing is attached by driving self-tapping screws through the sheathing into the stud flange. Veneer anchors are screw-attached through the sheathing into the stud flange. The anchors span the air space and are embedded in the mortar joints of the veneer.

Generally, the masonry veneers are 4 in. (102 mm) thick and carry no vertical loads from the structure; lateral loads, such as wind, are transferred to the backup system by metal ties anchored in the mortar joints of the veneer.

The metal stud, masonry veneer system has several design considerations. One issue is the difference in stiffness of the masonry veneer as compared to the metal stud backup. The stiff veneer will typically crack under design wind loads. The flexible metal studs contribute adequate backup support and prescriptive tie spacing requirements are intended to limit crack width and ensure stability of the veneer.

While the issue of relative stiffness still bothers some engineers, many now accept allowable deflection values for the metal stud backup that reflect the behavior of masonry—in the range of L/600 to L/720 for brick (BIA 28B 1987). The National Concrete Masonry Association recommends that concrete masonry veneers over metal studs be designed to limit deflection of veneer to L/600 (TEK 10-1A 2005). This will limit the maximum crack width to about 0.020 in. (0.5 mm). For cracks of this size, water-repellent coatings have been found to resist water penetration effectively (TEK 10-3 2003).

Concern has also been raised regarding corrosion. By looking at the drawing of a typical masonry veneer over metal stud system in Fig. 4-8c, it can be seen that all that holds the masonry anchor to the metal stud is a turn or two of the threads of a commonly used self-tapping screw.

There is concern for the likelihood of moisture entering the wall and corroding the screw threads of this anchor system. Unlike the question of relative stiffness of the wall components, this is more a judgment call based on experience.

It can be anticipated that some wind-driven rain will penetrate 4 in. (102 mm) of masonry. In many climates the probability of condensation in the area of the screw threads of the anchor system is high. Whether from without or within, moisture around the pierced galvanized metal stud at the screw location can cause major problems if corrosion occurs.

Good design and construction practices should be followed to minimize water entry into walls, thereby minimizing corrosion. Techniques include well-tooled and filled mortar joints, provision for draining (flashing, weep holes), and good sealant joints. In addition, steel should be protected with galvanizing, proper embedment and cover, or a combination of galvanizing and embedment/cover (Grimm 1985).

To avoid some of the corrosion or durability issues arising from the compatibility of masonry veneers over metal stud backup, the use of conventional masonry cavity wall or masonry composite wall is suggested. These walls contain less metal, so there is less material available for corrosion.

Reinforced Masonry Walls

Though traditional unreinforced masonry is strong, reinforced masonry walls (Fig. 4-9) are even stronger, allowing for the construction of taller, thinner walls. The versatility of the technique allows masonry structures to be built in every location, even high-wind and seismic zones. It is most common in single-story and low-rise construction like warehouses and commercial buildings, but reinforced masonry is also suited to high-rise construction. Wall strength is increased by embedding steel reinforcement in grouted vertical and horizontal cavities. This permits the use of higher design stresses and an increase in the distance between lateral supports. Single or multiple wythes may be used.

Single-wythe walls consist of hollow masonry units laid with face-shell mortar bedding. The cores in the block are aligned to form continuous, unobstructed

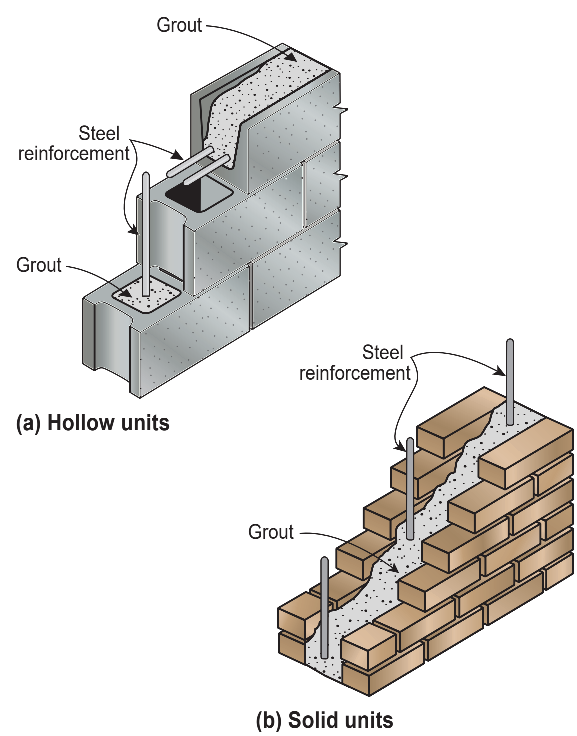


Fig. 4-9

Reinforced walls.

vertical spaces for the reinforcement to be placed and grouted. Two-core block are preferred to three-core block (and have largely replaced them) because of the ease in placing reinforcement and grout.

Multiwythe walls usually consist of two wythes of hollow or solid units. The wythes are erected with a ¾ in. to 6 in. wide (19 mm to 152 mm) continuous air space (collar joint) between them. Exterior walls may consist of a solid facing and a backing of hollow units, while interior walls may consist of two wythes of hollow units. Reinforcement is placed in the space between the wythes and grouted solid. Depending on site conditions, grouting may be performed intermittently as the wall is erected (low-lift grouting) or completely after erection to a full story-height (high-lift grouting).

Units used in three-wythe construction are usually solid and erected by the low-lift grouting method. The two outer wythes are erected first; reinforcement is placed in the collar joint between the wythes; and grout is poured into the collar joint. The units of the middle wythe are then “floated” (embedded) into the grout so that ¾ in. (19 mm) of grout surrounds the sides and ends of each unit.

In high-lift multiwythe grouted construction the grout space is not less than 2 in. or 3 in. (51 mm or 76 mm) wide, depending on the code. Wythes are tied with No. 9 rectangular ties that are 4 in. (102 mm) wide and 2 in. (51 mm) narrower than the nominal wall thickness. Spacing of ties is usually 16 in. (406 mm) horizontally and 16 in. (406 mm) vertically for a running bond pattern or 12 in. (305 mm) vertically for a stacked bond pattern. Codes restrict or do not permit the use of kinked or crimped ties in these walls.

Usually vertical and horizontal reinforcement in either multiwythe or single-wythe walls consists of No. 3 (M #10) steel bars. However, building codes permit the use of prefabricated-type continuous joint reinforcement for all or part of the horizontal steel.

Special units (Fig. 4-10) have been developed for use in single-wythe reinforced masonry construction. The most common unit is the open-end block shown in Fig. 4-10a. The advantage of this unit is that it can easily be placed around vertical steel rather than threaded down over the rods. A special H-shaped unit (Fig. 1-28c) also is made for reinforced grouted masonry. It can easily be placed between tall reinforcing bars. The low webs in special bond-beam units (Fig. 4-10b and c) not only permit grout to flow both horizontally and vertically, but also facilitate placement of horizontal steel. Some bond-beam units are manufactured with a closed bottom for use in lintel construction; some have depressions in the cross webs to maintain the appropriate steel spacing; and some may have an open end (Fig. 4-10b). To permit easy removal of part of the face shell for cleanout openings at the wall base, some units are scored.

Units used in reinforced concrete masonry sometimes have higher compressive strength than normal load-bearing units; the compressive strength generally ranges from 3000 psi to 5000 psi (20.7 MPa to 34.5 MPa) on the net cross-sectional area. Normally, block

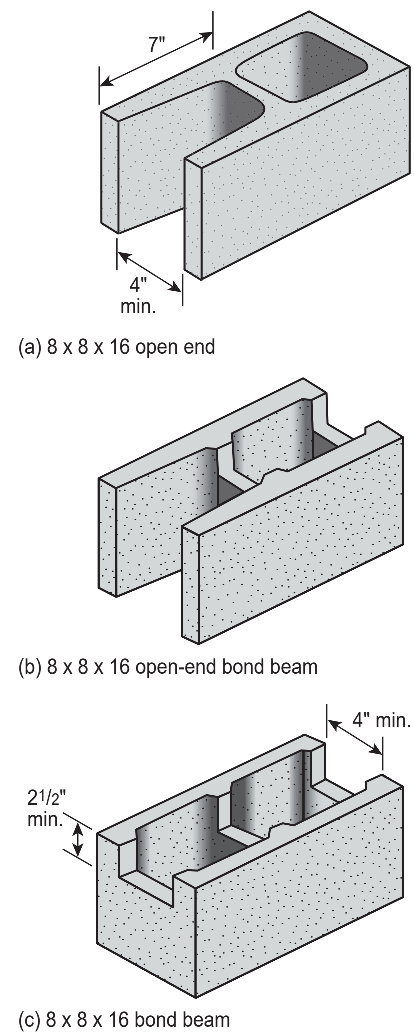


Figure 4.10

Special units for reinforced walls. Single cell (Fig. 3-5a) and double open-end units (Fig. 1-28c) are also available.

producers only stock units with strengths conforming to ASTM specifications. Consult local producers for specific available units.

See TEK 14-4A 2002 and TEK 14-7A 2004 for more information on reinforced concrete masonry and TEK 3-2A 2005 and TEK 9-4A 2005 for more information on grout and grouting for reinforced masonry.

Grouted Masonry Walls

Grouted masonry walls are similar to reinforced masonry walls but do not contain reinforcement. Grout is sometimes used in load-bearing wall construction to give added strength to hollow walls by filling a portion or all of the cores. It is also used in filling bond beams and, occasionally, the collar joint of a two-wythe wall.

For more information on grouting of masonry walls, see Kosmatka 1997, TEK 3-2A 2005, TEK 9-4A 2005, and "Building Reinforced Walls" in Chapter 6.

Bonding of Plain Masonry

All of the concrete block or brick in a masonry wall must be bonded (held together) to form a continuous mass. Although several methods may be used, bonding is treated as follows in each of the three directions shown previously in Fig. 4-2:

1. *Horizontally (H).* The mortar in the bed joint exerts a shearing bond on the top and bottom of the stretchers, which overlap to transfer loads and stresses across the head joints. Current codes (*MSJC 2005*, *IBC 2006*) require units to be laid in running bond in order to provide continuity across head joints. Running bond is defined as placement of masonry units such that head joints in successive courses are horizontally offset at least one-quarter of the unit length. If units are laid in a stack bond pattern or offset less than one-quarter of the unit length, horizontal reinforcement is required. Reinforcement may be the equivalent of a No. 9 gage wire for each 4-in. (102-mm) width of masonry unit at a vertical spacing of 16 in. (406 mm), or an equivalent amount placed in bond beams spaced not more than 48 in. (1219 mm) on center.
2. *Vertically in the plane of the wall (V).* Current codes neglect the ability of unreinforced masonry to resist direct tension, such as tension due to uplift from wind loads.
3. *Horizontally across the width (thickness) of a two-wythe wall (W).* The tensile bond of mortar in a collar joint is not credited; custom and codes require more positive measures such as metal ties. Masonry unit headers also serve this purpose but are much less common now than in the past.

While current design procedures neglect the tensile strength of unreinforced masonry, they do consider the flexural tensile strength of masonry. Criteria include consideration of whether: the direction of stress is parallel or perpendicular to bed joints; masonry is laid in running bond or stack bond; units are hollow or solid; and hollow units are grouted or ungrouted. Mortar type and composition also affect allowable stress values.

Unit Metal Ties

Unit metal ties consist of corrosion-resistant wire embedded in the horizontal mortar joints and engaging all wythes. The applicable specification for wire ties and anchors is ASTM A82. They are usually made of galvanized steel, but they may be made of stainless steel. In cavity walls, building codes generally require that metal ties be made with a W1.7 (MW11) or W2.8 (MW18) wire size.

Some unit metal ties used with cavity walls used to have a crimp (often called a "drip") located in the center of the tie, as shown in Fig. 4-6a. Its function was to cause any water that found its way into the cavity to drip off at the crimp before reaching the inner wythe. According to a National Bureau of Standards test report (see Fishburn 1943), the tensile or compressive strength of a 3⁄16-in.-diameter (4.8-mm) straight tie in a cavity wall exceeds 1200 lb (544 kg) when the mortar has a cube strength of 1330 psi (9.2 MPa). A crimp in the tie reduces the strength about 50%. The use of cavity wall ties with drips has been eliminated because of their reduced load capacity. To maintain the drip feature in straight ties without affecting tie strength, a plastic disk may be installed. Adjustable ties may also induce a drip.

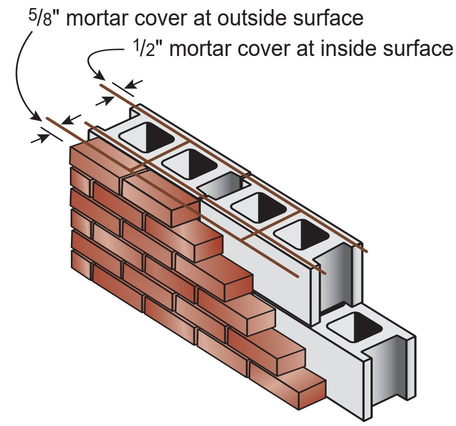
Fig. 4-6a shows a few commercial tie sizes. Ties used with solid masonry are sometimes bent into a "Z" shape with 2-in.-long (51-mm) legs at 90°. Codes do not allow the Z-shaped ties to be used in hollow masonry construction.

Unit metal ties are usually bent to a rectangular shape 4 in. (102 mm) wide. Tie length is such that the ends are embedded in the face-shell mortar beds at the outside faces of the wall (see Fig. 4-5).

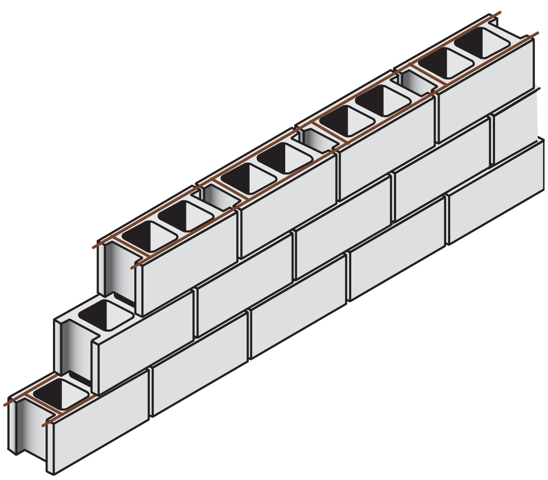
In cases where commercial tie sizes will not fit properly in the outer face-shell mortar beds, a mortar bed base is provided by strips of metal lath or fiberglass/polypropylene mesh laid in the joints receiving the ties;

otherwise ties are placed over the head joints or over the webs. A cover of mortar at least ⅝ in. (16 mm) thick is required at any face exposed to the weather (Fig. 4-5c).

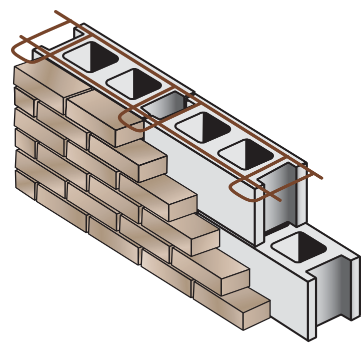
Unit metal ties also may be of the adjustable type, as shown in Figs. 4-6b and 4-11f and g. These ties simplify the construction of multiwythe walls by allowing the mason to erect the wythes independently, instead of simultaneously, as with ordinary ties. They also permit adjustment for differences in level between courses. The eye or loop section of the adjustable tie is installed in the first wythe erected—preferably at a head joint or cross web in hollow masonry—with the eyelets or loop close to the face of the wythe. The pintle section, which is always installed in the second wythe, is inserted either up or down.



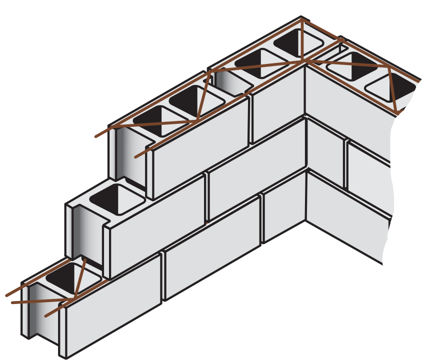
(c) Ladder tie for multiwythe wall



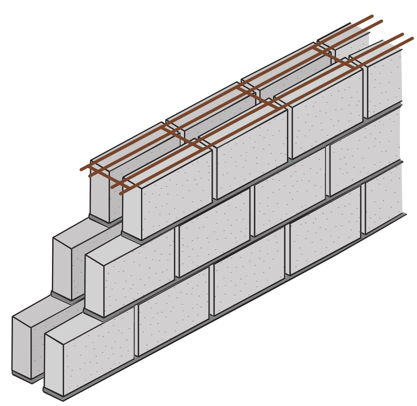
(a) Ladder type joint reinforcement for single-wythe wall



(d) Tab tie for multiwythe wall



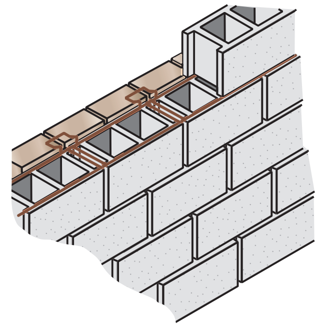
(b) Truss type joint reinforcement for single-wythe wall



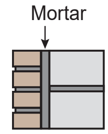
(e) Double ladder tie for multiwythe wall

Fig. 4-11

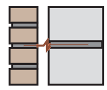
Continuous metal ties of joint reinforcement. *(Figures 4-11 f – j on next page.)*



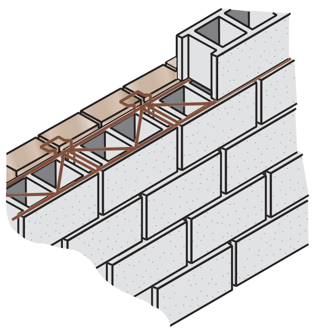
(f) Adjustable ladder tie



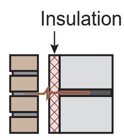
Cross section of adjustable tie for composite action wall



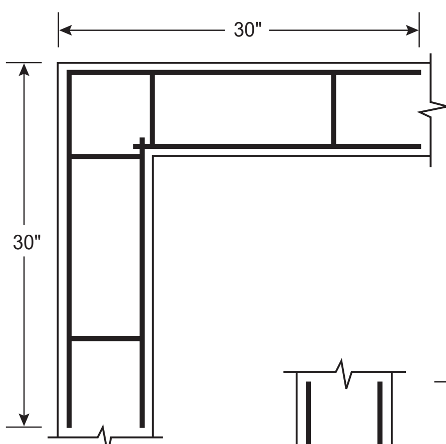
Cross section of adjustable tie for cavity wall (non-composite action)



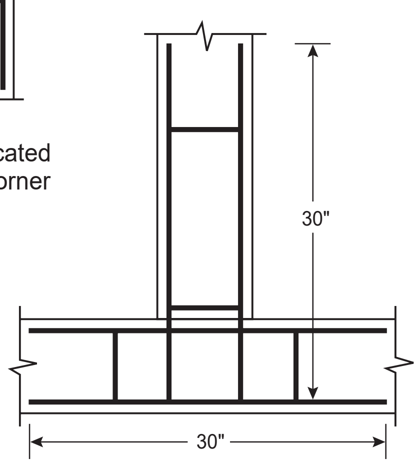
(g) Adjustable truss tie



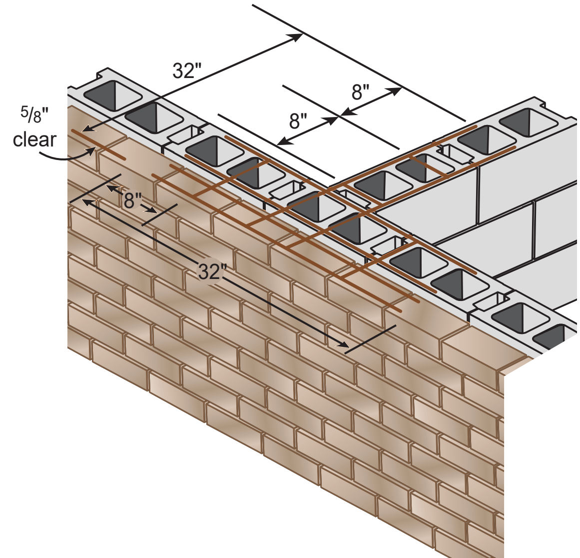
Cross section of adjustable tie for cavity wall with rigid insulation



(h) Prefabricated ladder corner



(i) Prefabricated ladder T



(j) Prefabricated ladder T

Adjustable ties for noncomposite action walls must be provided for each 1.77 sq ft (0.16 m^2) of wall surface and must be spaced not more than 16 in. (406 mm) horizontally or vertically. The maximum allowable misalignment of bed joints from one wythe to another cannot exceed 1¼ in. (32 mm) for adjustable ties. No more than 1⁄16 in. (1.6 mm) clearance is allowed between connecting parts (eye and pintle), and the pintle must have at least two legs of wire size W2.8 (MW18). For noncomposite action walls, the above requirements apply to cavities of 4½ in. (114 mm) or less in width (see MSJC 2005). While it is possible to apply unit metal tie sizes and spacing requirements for composite action walls to non-composite walls, it is more common to use adjustable metal ties.

When used with veneered construction, adjustable ties must be provided for each 2.67 sq ft (0.25 m^2) of wall area and must be spaced not more than 32 in. (813 mm) horizontally and 18 in. (457 mm) vertically. Additional ties must be provided around all openings larger than 16 in. (406 mm) in either direction; other requirements apply (see MSJC 2005).

Metal ties may cause thermal bridges in walls. A thermal bridge allows heat to "short circuit" the insulation in a wall, resulting in increased heat loss through a wall and local cold spots on or in a wall. For a detailed discussion of thermal bridges in wall construction, see TEK 6-13A 1996. For more information on the proper choices and uses of masonry ties, see Ribar 1995, Catani 1995, and MSJC 2005.

Continuous Metal Ties

Continuous metal ties are also called prefabricated joint reinforcement, mesh, or more commonly, joint reinforcement. Joint reinforcement normally consists of two or more parallel longitudinal wires to which cross wires are welded (Fig. 4-11). Joint reinforcement may be used for the following reasons:

1. To act as structural steel reinforcement to increase masonry's resistance to flexural, shear, and tensile stresses (TEK 12-2B 2005).
2. To act as longitudinal reinforcement for the control of cracking due to drying shrinkage and temperature changes (discussed later in this chapter).
3. To bond adjacent masonry wythes together in composite, faced, cavity, and veneer wall constructions.

Vertical spacing of joint reinforcement should not exceed 24 in. (610 mm). Maximum horizontal spacing of each tie location (spanning across the two wythes) is 36 in. (914 mm).

Joint reinforcement and ties must be corrosion resistant. Diagonal or perpendicular cross wires in joint reinforcement are welded to the longitudinal wires, usually at 16-in. (406-mm) spacing. The longitudinals are fabricated from deformed wire to obtain a better bond with the mortar. For multiwythe walls, manufacturers have developed continuous rectangular-tie assemblies (also called tab ties) that have rectangular ties welded at fixed intervals to longitudinal wires as shown in Fig. 4-11d.

Joint reinforcement is available in any width—usually 2 in. (51 mm) narrower than the nominal wall width—and in commercial lengths of 10 ft to 12 ft (3.05 m to 3.66 m). The longitudinal and cross wires of joint reinforcement generally have a minimum wire size of W1.1 (11 gage) (MW7) and a maximum wire size of one-half the mortar joint thickness. The two most common sizes used are W1.7 (9 gage) (MW11) and extra-heavy W2.8 (3⁄16-in. wire) (MW17). A mortar cover of at least 5⁄8 in. (16 mm) is required at any joint face exposed to the weather (see Fig. 4-5c).

For crack control, joint reinforcement made with 9-gage wire and spaced 16 in. (406 mm) on center vertically generally is adequate. But, the use of joint reinforcement in a wall is no guarantee against cracks. Joint reinforcement does not prevent cracking—it simply controls the size and spacing of cracks. Cracks may occur prior to the joint reinforcement developing any stress.

Also, as with unit metal ties, joint reinforcement may cause thermal bridges (TEK 6-13A 1996). For more information on the proper choices and uses of joint reinforcement, see Catani 1995 and MSJC 2005.

Masonry Headers

Masonry headers consist of stretcher units laid transversely to overlap units of the adjacent wythes or specially shaped header units. Usually they are placed in continuous courses. See the earlier section on "Composite Action Walls" and the *MSJC Code* (MSJC 2005) for header spacing requirements.

Headers have certain disadvantages compared to metal ties. When headers are used in a bonded multiwythe masonry wall having backup units of concrete masonry and a brick facing, care must be taken to maintain bond between the headers and the mortar. Immediately following the laying of the header course, heavy backup units are set on the headers, temporarily loading the headers off center (see Fig. 4-12). The mortar below the headers needs sufficient time to stiffen—otherwise, the headers may settle unevenly; this could cause a fine crack to develop at the external face between the headers and the facing underneath.

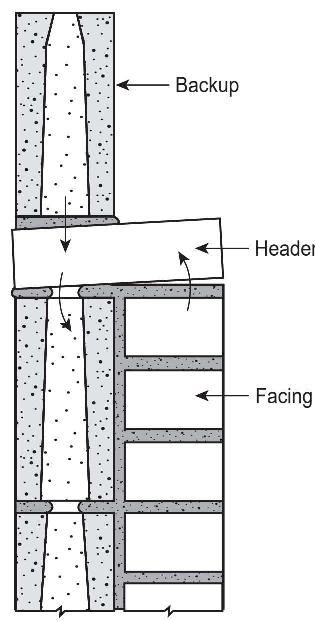


Figure 4-12

Mortar bond can be imparied by the use of masonry headers.

Furthermore, backup and facing units may have different thermal and shrinkage characteristics, and consequently different volume changes. Excessive vertical shrinkage of the concrete masonry facing (compared to the backup) may load the headers eccentrically, adding to the potential for rupture of the bond between the headers and the mortar at the external face.

The primary advantage of metal ties over masonry headers is their flexibility. Metal ties can accommodate the differential movements between adjacent wythes, thus relieving stresses and preventing cracking. Metal ties are recommended when resistance to rain penetration is important, or where wide differences exist between the physical characteristics of facing and backup materials.

Wall Patterns

Exposed concrete masonry is an attractive finished wall material for both exteriors and interiors of homes, churches, schools, and public and commercial buildings. One reason for the popularity of concrete masonry is the broad choice of sizes, shapes, textures, and colors. A variety of architectural effects may be obtained by: (1) varying the pattern in which units are laid, and (2) applying different treatments to the mortar joints.

For example, if a long, low look is desired, 2-in.-high (51-mm) units 16 in. (406 mm) long will accentuate the horizontal lines (Fig. 4-13). The opposite effect can be achieved by using other sized units evenly placed one atop the other to emphasize the vertical lines (stacked-bond pattern). Concrete block can also be laid in staggered (running bond), diagonal, and random patterns to produce almost any result the designer desires. Masonry overlapped at least one-fourth the unit's length is considered running bond by the *MSJC Code* (MSJC 2005).

Figure 4-13

Though seldom used in this orientation, diagonally-placed units create another visual effect. (IMG14583)

Customized architectural concrete masonry units have enjoyed extensive popularity, not only for use as individual profiles (Fig. 4-14), but to overshadow the mortar pattern (Figs. 4-1 and 4-15). The designer can use his ingenuity to create any number of patterns and, by using block with a visible third dimension, an infinite diversity of effects.

Fig. 4-14

Plain concrete masonry units in a simple stacked bond make a pleasing and unobtrusive backdrop for garden settings. (IMG24955)

Fig. 4-15

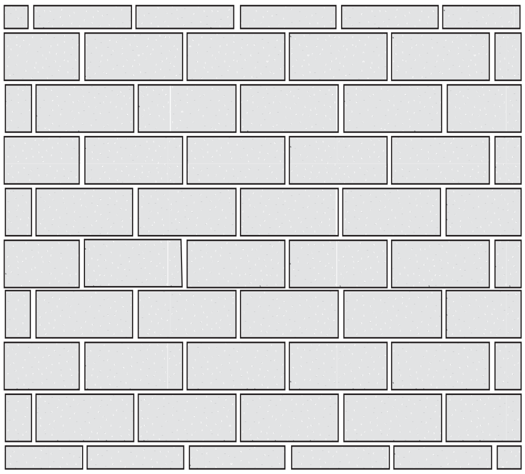
Split-faced, scored concrete masonry units create a rhythmic pattern that overshadows the joint pattern, resulting in an interesting texture. (IMG15910)

In some wall treatments all the joints are accentuated by deep tooling; in others only the horizontal joints are emphasized. In the latter treatment the vertical joints are tooled, refilled with mortar, and then rubbed flush (after the mortar has partially hardened) to give the joints a texture similar to that of the concrete masonry units. This treatment makes the horizontal joints stand out in relief. It is well suited to walls where strong horizontal lines are desired. If an especially massive effect is sought, every second or third horizontal or vertical joint can be accented by having all other joints, both horizontal or vertical, refilled with mortar (after tooling) and rubbed flush.

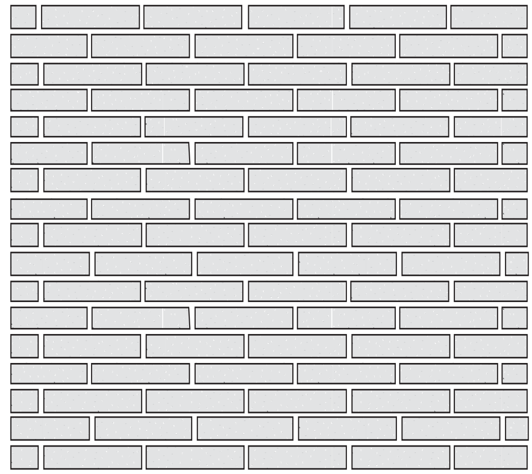
Numerous wall bond patterns are illustrated in Fig. 4-16. Variations of these patterns may be created by projecting or depressing the faces of some units from

Fig. 4-16

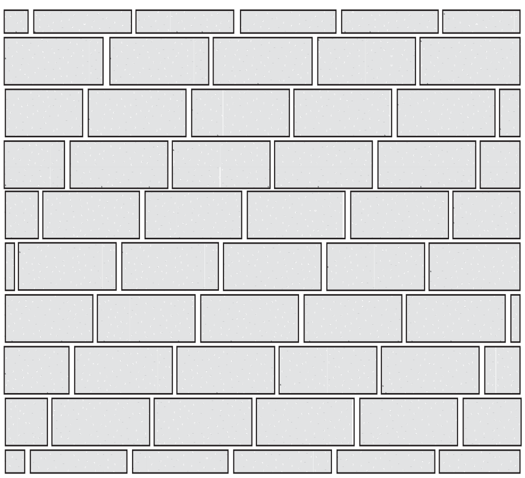
Forty-two patterns for concrete masonry walls. Some of the patterns illustrated require units of a size or shape that may not be produced in all areas. *Consult local producers for specific available units.*



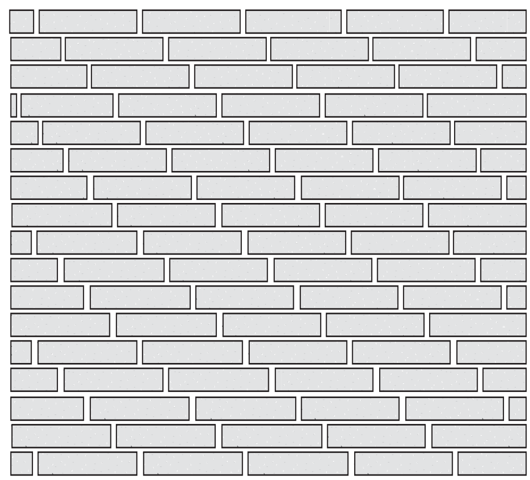
(a) Running bond, 8 x 16 in.



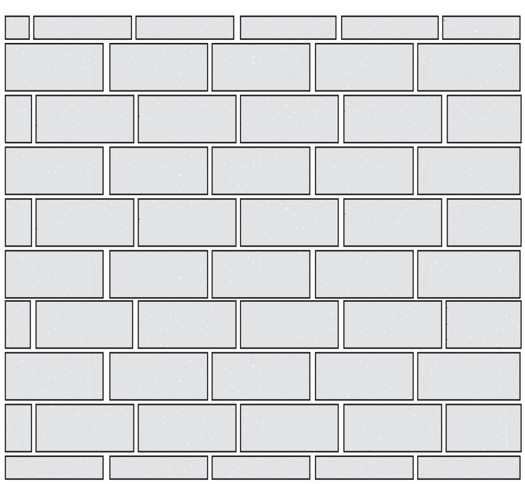
(d) Running bond, 4 x 16 in.



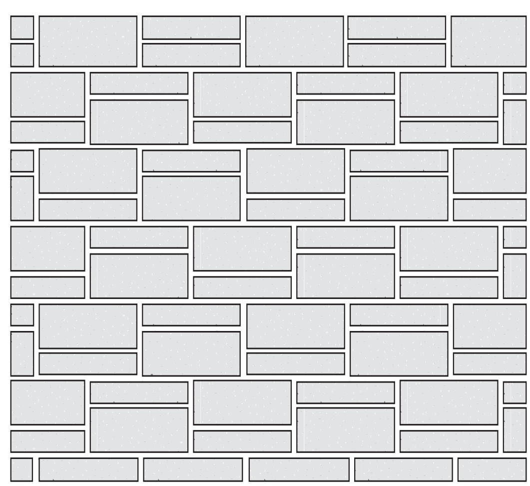
(b) Offset bond, 8 x 16 in.



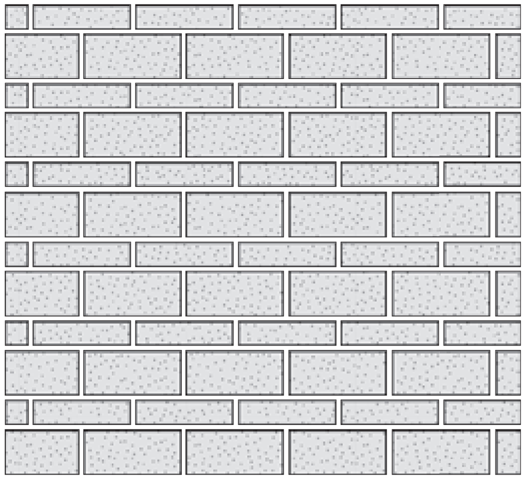
(e) Offset bond, 4 x 16 in.



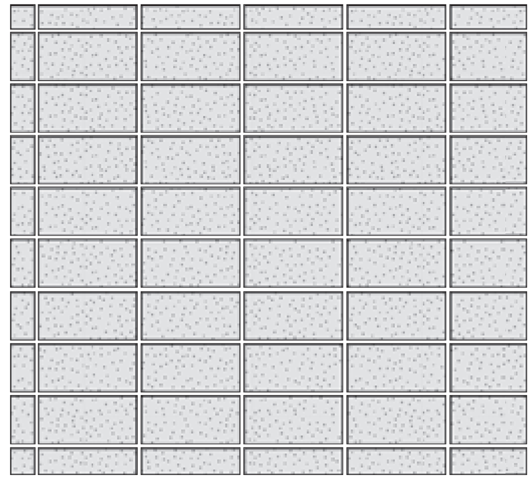
(c) Offset bond, 8 x 16 in.



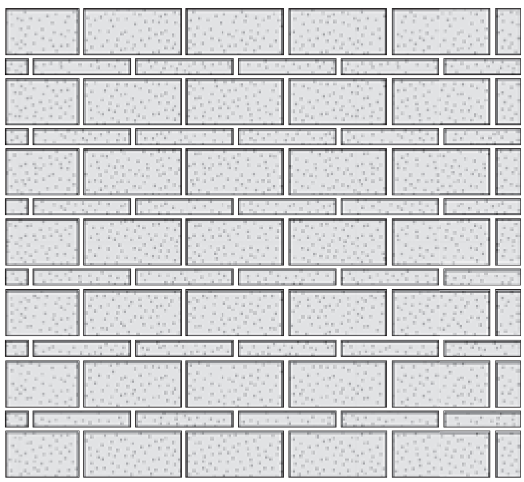
(f) Coursed ashlar, 4 x 16, 8 x 16 in.



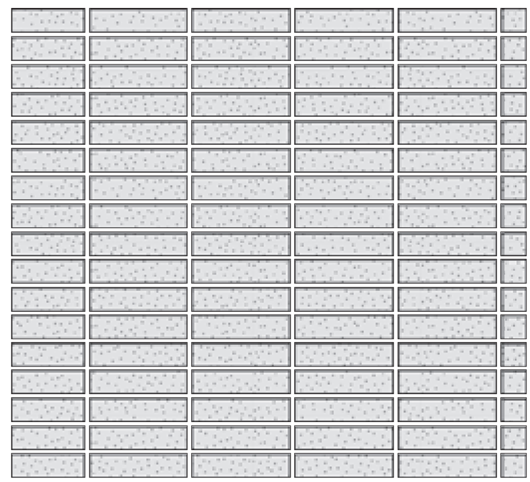
(g) Coursed ashlar, 4x16, 8x16 in.



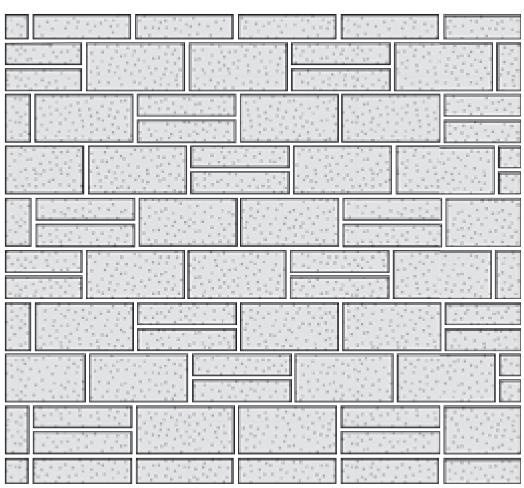
(j) Horizontal stacking, 8x16 in.



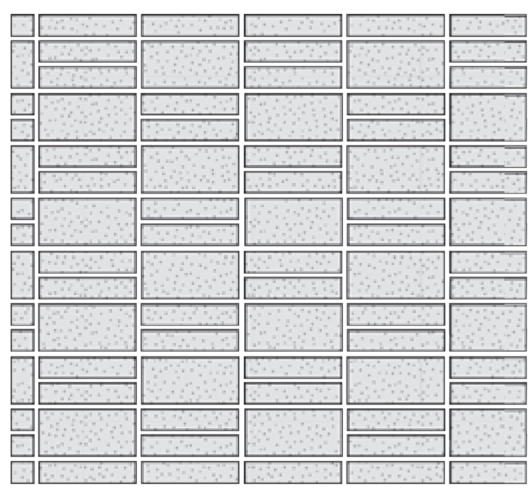
(h) Coursed ashlar, 8x16 in. brick size



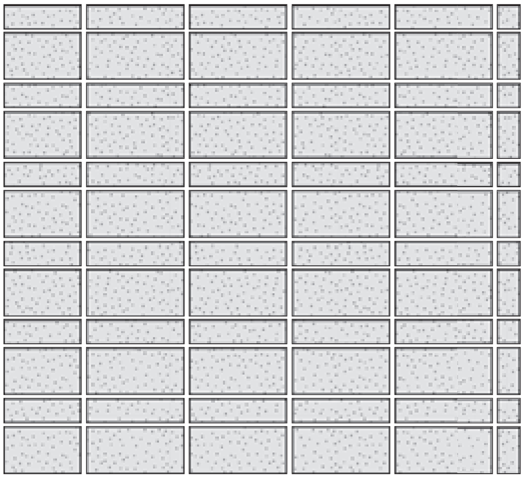
(k) Horizontal stacking, 4x16 in.

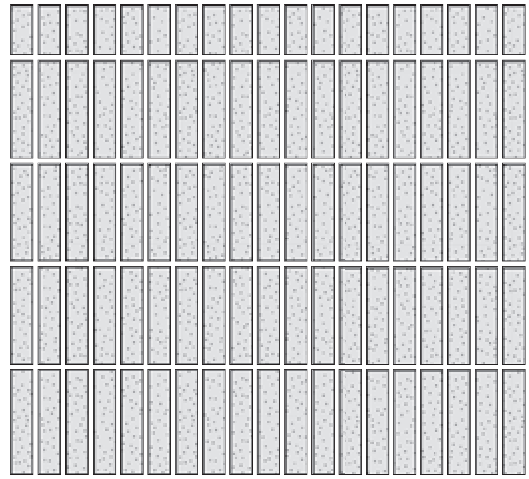


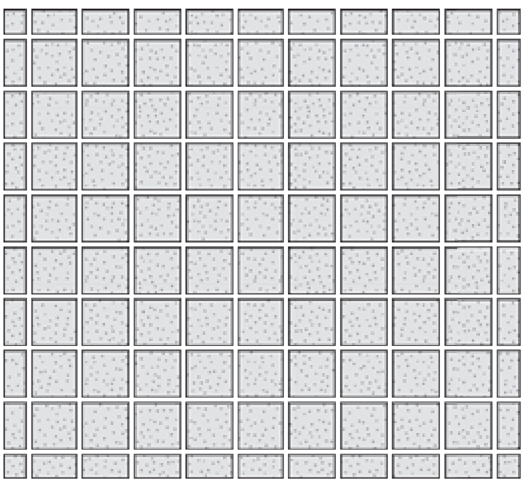
(i) Coursed ashlar, 4x16, 8x16 in.

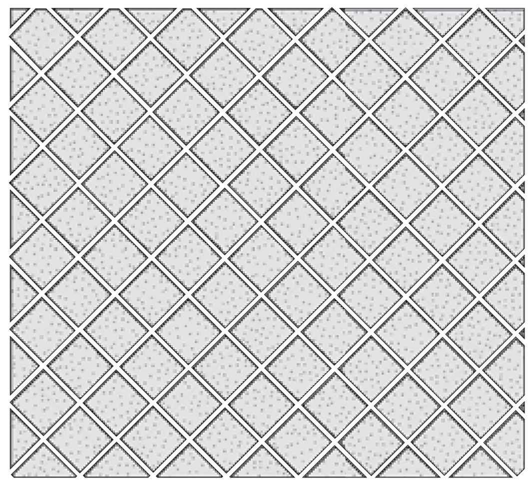


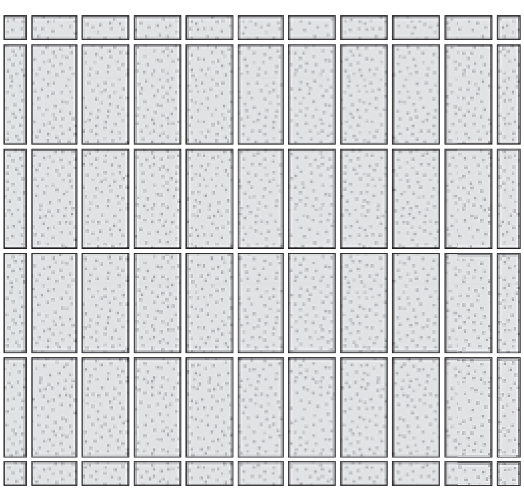
(l) Horizontal stacking, 4x16, 8x16 in.

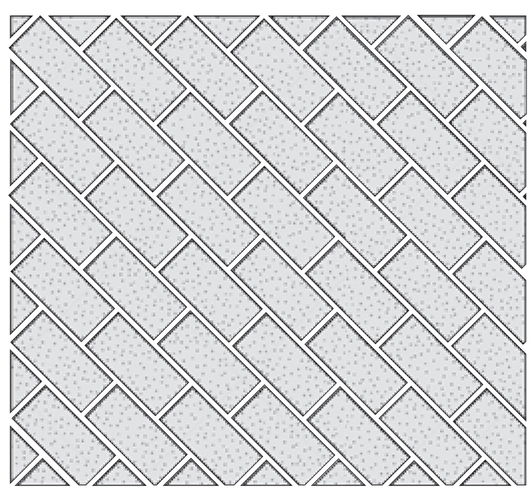

(m) Horizontal stacking, 4x16, 8x16 in.

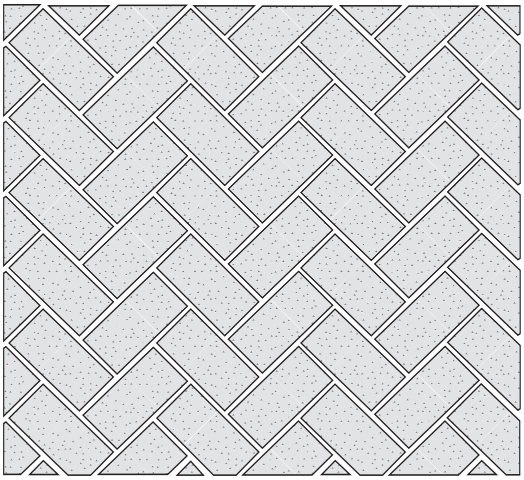

(p) Vertical stacking, 4x16 in.


(n) Square stacking, 8x8 in.

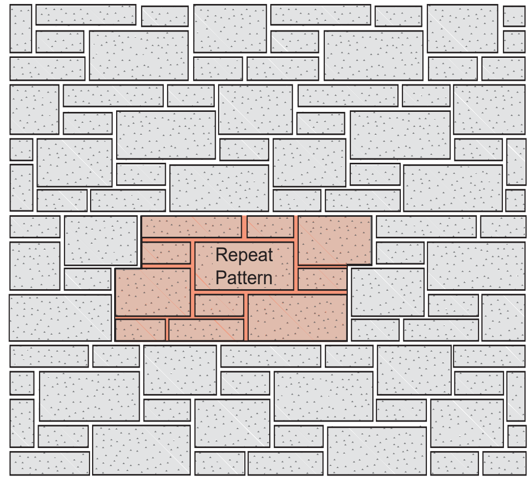

(q) Diagonal stacking, 8x8 in.


(o) Vertical stacking, 8x16 in.

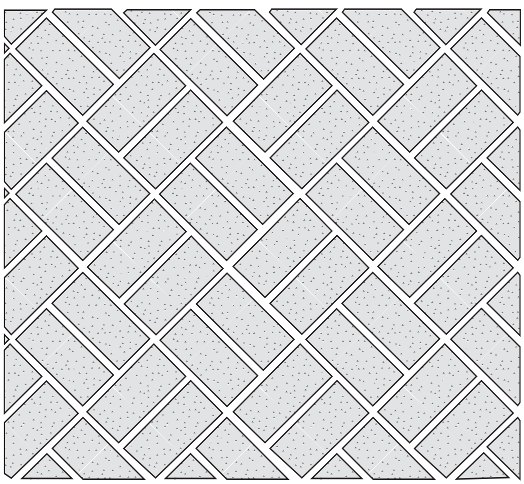

(r) Diagonal bond, 8x16 in.



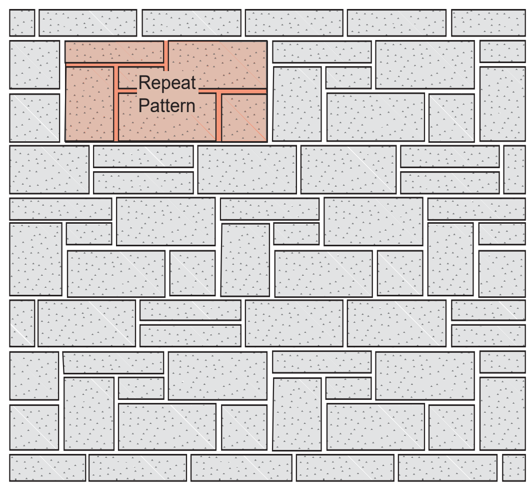
(s) Diagonal basketweave, 8x16 in.



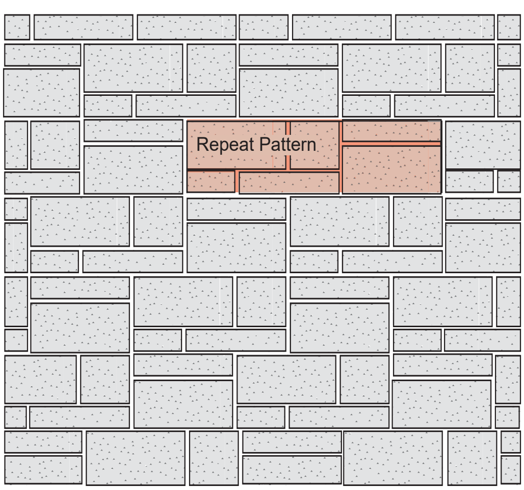
(v) Patterned ashlar, 4x8, 4x12, 4x16, 8x12, 8x16 in.



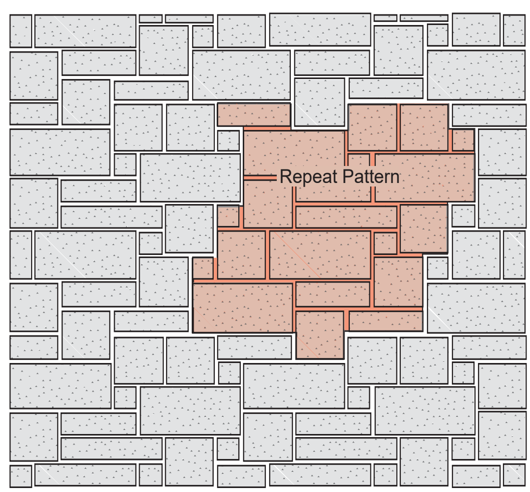
(t) Diagonal basketweave, 8x16 in.



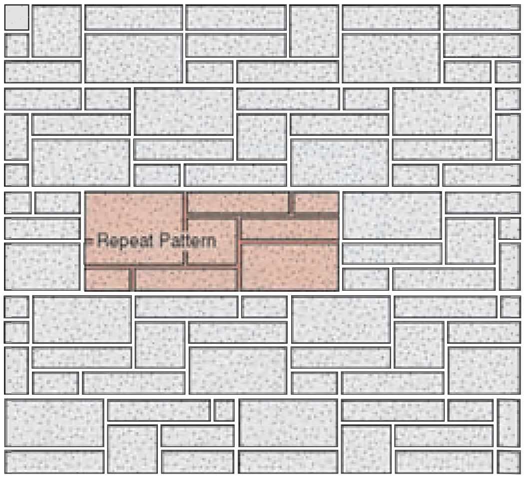
(w) Patterned ashlar, 4x8, 4x16, 8x8, 8x12, 8x16 in.



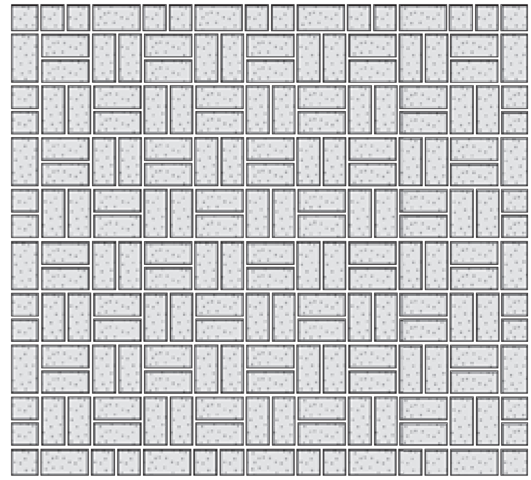
(u) Patterned ashlar, 4x8, 4x16, 8x8, 8x16 in

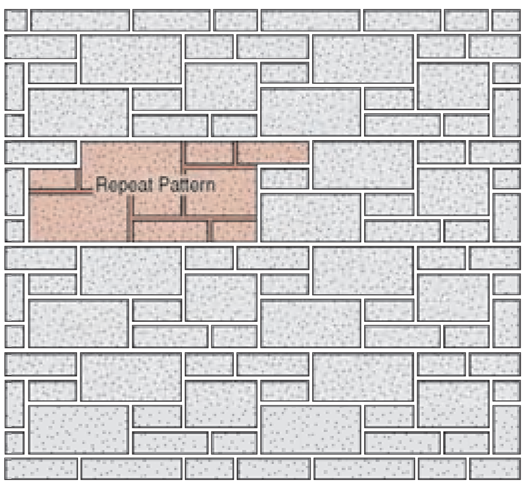


(x) Patterned ashlar, 4x4, 4x12, 4x16, 8x8, 8x16 in.

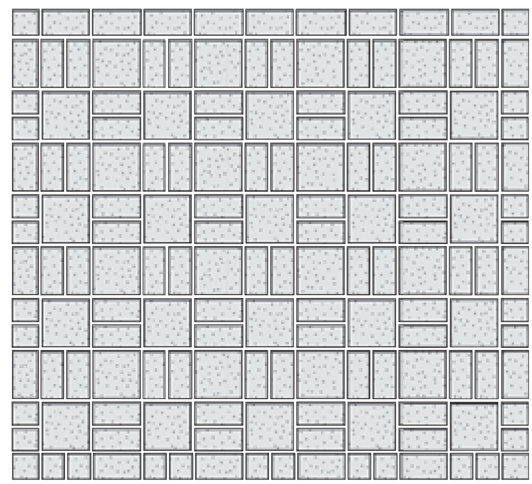


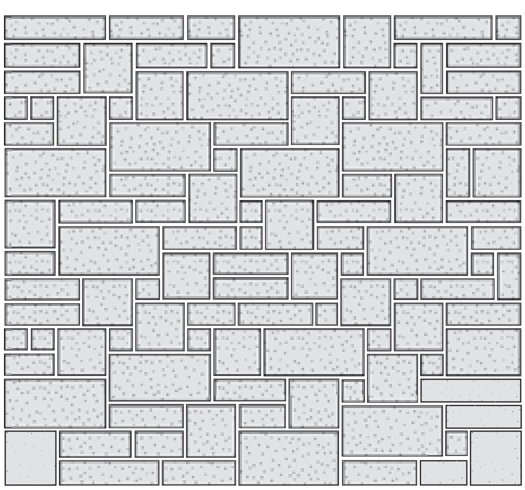
(y) Patterned ashlar, 4x8, 4x16, 8x8, 8x16 in.

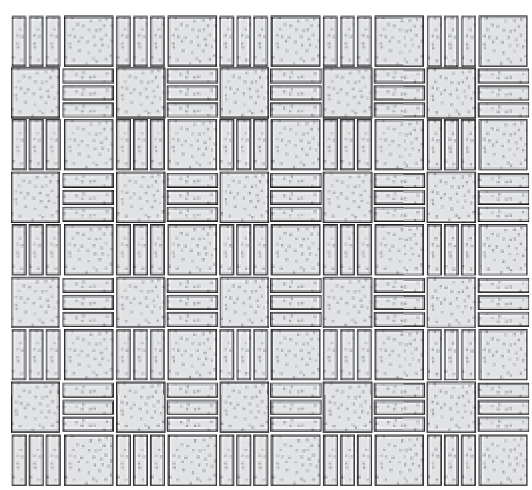

(bb) Basketweave, 4x8 in.

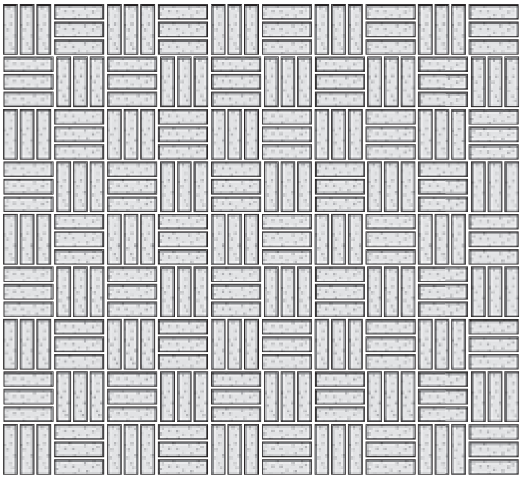


(z) Patterned ashlar, 4x8, 4x12, 8x12, 8x16 in.

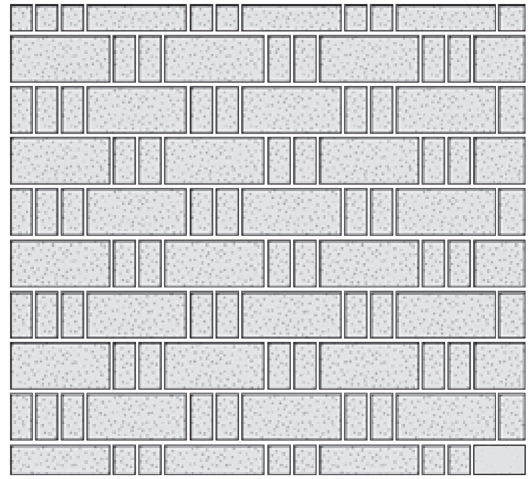

(cc) Basketweave, 4x8, 8x8 in.


(aa) Random ashlar, 4x4, 4x8, 4x12, 8x8, 8x16 in.

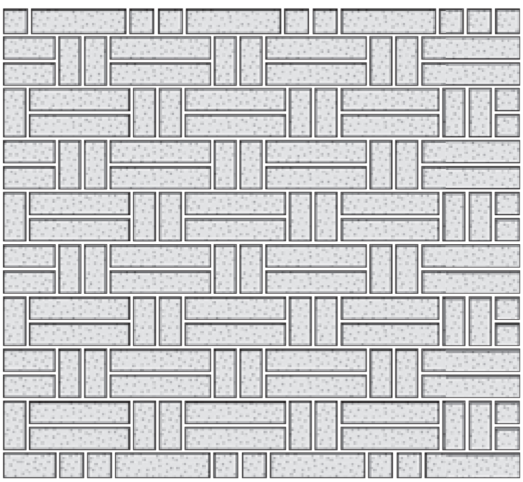

(dd) Basketweave, 8x8 in. brick size



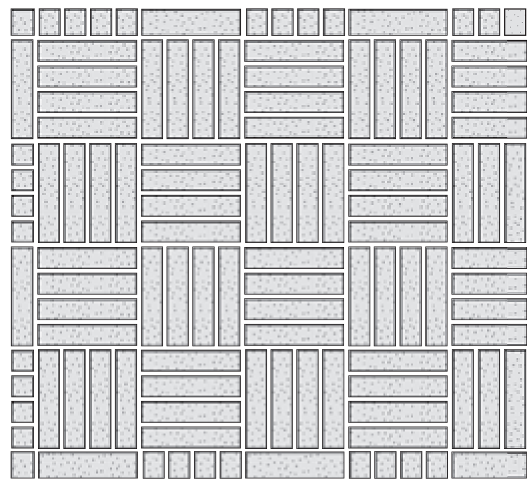
(ee) Basketweave, brick size



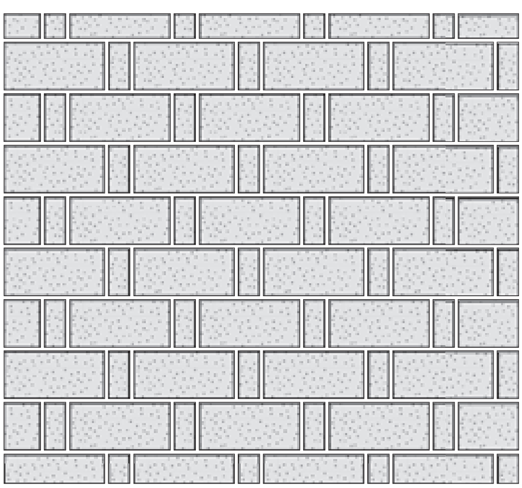
(hh) Basketweave, 4x8, 8x16 in.



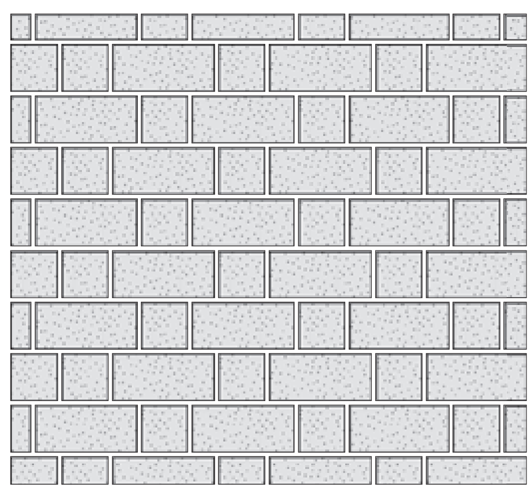
(ff) Basketweave, 4x8, 4x16 in.



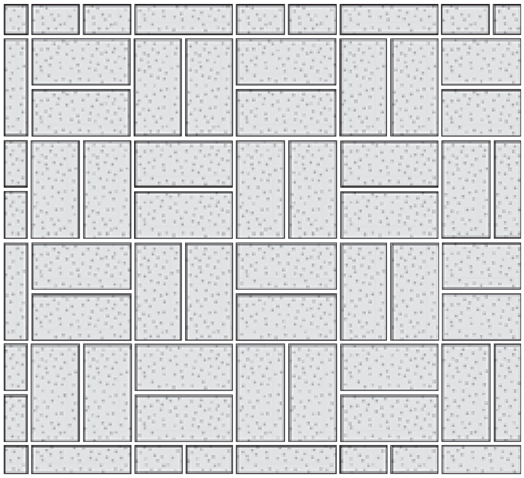
(ii) Basketweave, 4x16 in.

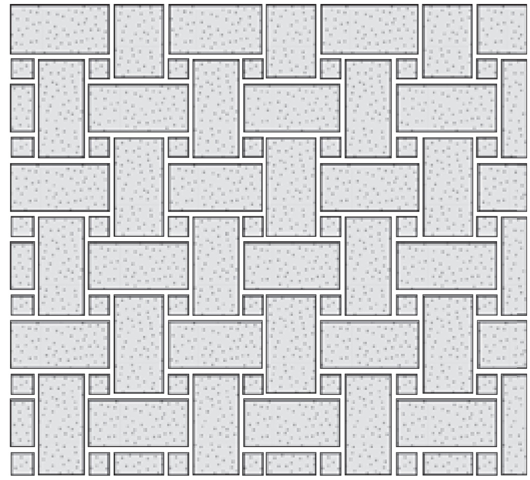


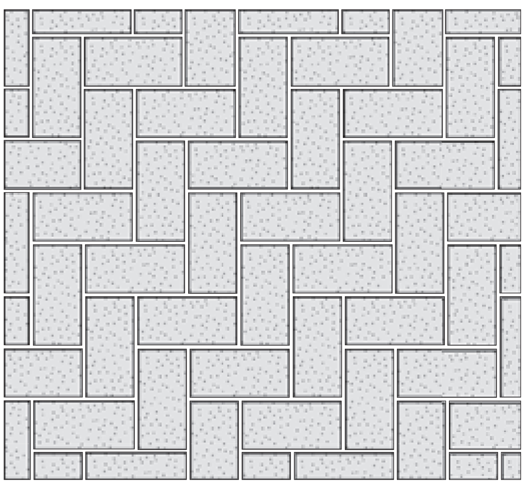
(gg) Basketweave, 4x8, 8x16 in.

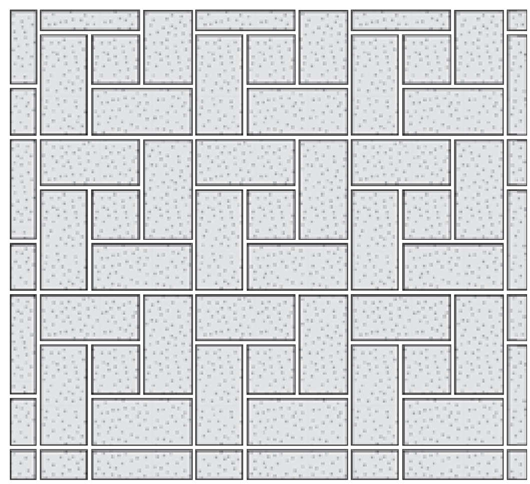


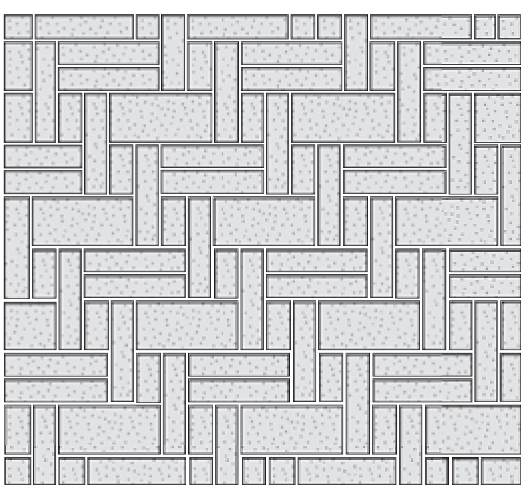
(jj) Basketweave, 8x8, 8x16 in.

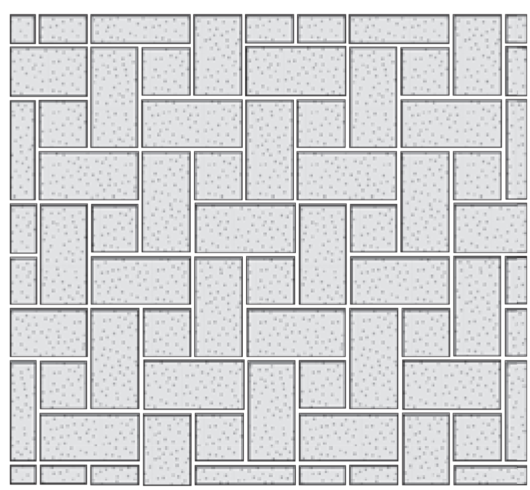

(kk) Basketweave, 8x16 in.


(nn) Basketweave, 4x4, 8x16 in.


(ll) Basketweave, 8x16 in.


(oo) Basketweave, 8x8, 8x16 in.


(mm) Basketweave, 4x8, 4x16, 8x16 in.


(pp) Basketweave, 8x8, 8x16 in.

the overall surface of the wall—or by substituting screen block, split block, or customized architectural units with three-dimensional faces, as discussed in Chapter 1.

Jointing and Control of Cracking

Building materials are subject to movement. Movement of concrete masonry walls is caused by: (1) changes in temperature of the masonry, (2) changes in moisture content of the masonry, (3) contraction of the masonry due to carbonation, and (4) movements of other parts of the structure.

When concrete masonry units are bonded together by mortar to form a wall, any restraint that will prevent the wall from expanding or contracting freely will set up stresses within the wall. Restraint against expansion generally results in low stresses in relation to the strength of the materials and rarely causes damage to concrete masonry walls. Moreover, expansion of walls is offset by shrinkage from carbonation and drying of the units. Expansion joints are not necessary in concrete masonry walls, except where required for design reasons due to the length or configuration of the building (PCA EB086 1982). The clay brick wythe of a multiwythe wall does require expansion joints.

On the other hand, when contraction of concrete masonry units is restrained, tensile stresses gradually build up within the wall. If these stresses exceed the tensile strength of the unit, the bond strength between the mortar and the unit, or the shearing strength of the horizontal mortar joints, cracks will occur to relieve the stresses (Fig. 4-17). Cracks usually disfigure a wall and cannot be easily concealed. Also, they affect the lateral stability of adjacent wall sections and must be repaired for a weather-tight seal. Cracking can be controlled, however, as will be discussed later.

Concrete and clay masonry materials exhibit different engineering characteristics. Each has its own moisture, thermal, elastic, and plastic flow (creep) properties that must be recognized and taken into account in design, or the masonry wall may not give satisfactory performance.

For more information on control of wall movements with concrete masonry, see TEK 10-2B 2005; Shideler 1955; Kuenning and Carlson 1956; Carlson 1956; Toennies and Shideler 1963; Shideler 1963; and Carlson 1953.

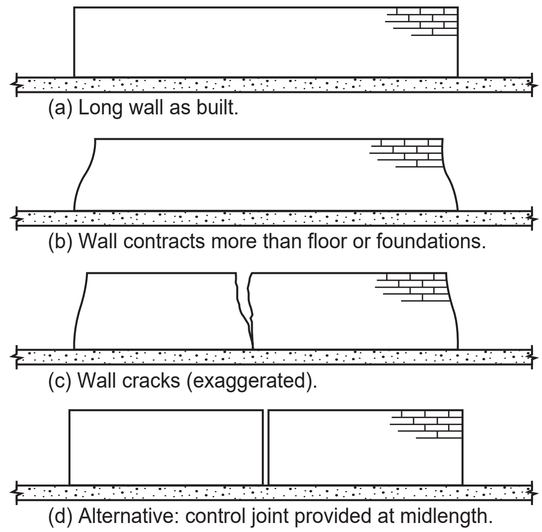


Fig. 4-17

Cracking of long wall by contraction (exaggerated).

Shrinkage Due to Moisture Loss

Building materials, except for the metals, tend to expand with increases in moisture content and contract with drying. For some materials these movements are reversible, for others they are not—or they are only partially reversible.

Clay and shale products, such as clay brick, expand upon contact with water or humid air, and this expansion is not reversible by drying at normal atmospheric temperatures. Clay brick has a coefficient of moisture expansion of about 0.03%.

Concrete masonry units such as concrete block expand with a moisture gain and contract with a moisture loss. Of greater immediate concern is the initial drying shrinkage of these units. Many factors affect the volume change of concrete masonry. The drying shrinkage of concrete block is primarily affected by the type of aggregate used, the method of curing and storage during manufacture, and the bond pattern of the units in the wall. Standard units made with normal sand and gravel aggregate generally have less shrinkage than units produced with various lightweight aggregates. The difference between the moisture content of the masonry units during construction and after the building is occupied will determine the amount of shrinkage in the wall. Values for drying shrinkage of concrete masonry can vary from as low as 0.01% to as high as 0.1%. Also see the *MSJC Code* (MSJC 2005).

High-pressure steam curing (autoclaving) of concrete masonry units will reduce shrinkage to approximately one-half the shrinkage of low-pressure (atmospheric) steam-cured units. In pumice units, however, the reduction in shrinkage will be approximately one-third. Few autoclaved units are produced today.

Proper drying of the units before they are laid in the wall will reduce the potential shrinkage of the wall. The degree of dryness will vary according to locality and use. Ideally, the units should be laid with a moisture content corresponding to or preferably slightly below the average annual relative humidity of the outside air for the locality or for the ambient atmospheric condition to which they will be exposed.

As noted in Chapter 1, moisture requirements for concrete masonry units have been removed from ASTM standards. To compensate for that change, control joint spacing guidelines have become slightly more conservative.

In construction practice, two methods are used to accommodate concrete masonry shrinkage: (1) minimizing the amount of stress buildup by means of discontinuities in the length of the wall (control joints), and (2) minimizing the width of cracks that might form by means of suitable restraints (joint reinforcement or bond beams). The presence of high-strength-wire joint reinforcement does not eliminate shrinkage, but it does distribute the shrinkage stresses and helps control the width of drying shrinkage cracks. These two methods can be used separately or together, as will be explained.

Thermal Movements

Theoretically, thermal expansion and contraction movements are reversible if a unit or member is unrestrained. Thermal movements occur both horizontally and vertically. The coefficients for thermal movement can be determined from measurement of length change of prisms in laboratory tests. The generally accepted coefficient for clay masonry is 0.04% per 100°F (55.6°C) [or 0.072% per 100°C].

Concrete masonry also undergoes thermal expansion and contraction. The coefficient is 0.045% per 100°F (55.6°C) [or 0.081% per 100°C] for concrete masonry. However, concrete masonry units may actually shrink while undergoing a temperature increase because of water loss.

Elastic Deformation

For stresses permitted in brick masonry, the relationship between deformation of the structural elements and their stress is approximately linear. The reduction in length of axially loaded masonry elements due to design loads is seldom critical in itself; however, because this dimensional change is in addition to those caused by other factors, it must be considered.

Elastic deformations for concrete masonry are similar to those found in brick masonry. They are important and must be considered in the design to assure the proper performance of the masonry construction.

Plastic Flow (Creep)

When continuously stressed, some materials gradually yield in the direction of the stress application. This is referred to as creep or plastic flow. In clay masonry construction, the clay units themselves are not subject to flow, although the mortar joints are. The joints, however, seldom comprise more than 15% to 27% of the volume in compression. A design value of 0.7×10^{-7} per psi (0.1×10^{-4} per MPa) is required by the *MSJC Code* for clay masonry plus mortar.

Creep in concrete masonry is much larger than in clay brick construction. For high-strength concrete masonry units, the design value for creep will be somewhat lower than the value for conventional cast-in-place concrete. The ultimate magnitude of creep of plain concrete masonry should be taken as 2.5×10^{-7} per psi (0.36×10^{-4} per MPa) according to the *MSJC Code*. Creep is not only a function of stress and time, but is also affected by the physical properties of the concrete and the conditions of exposure.

Composite Walls

As pointed out previously, a composite action wall (Fig. 4-7) is a multiwythe wall designed to act as a single member in response to loads. This combination of clay and concrete masonry units is popular. However, clay and concrete masonry respond in different ways to moisture, temperature, elastic deformation, and plastic flow; the movement in concrete block is greater and generally opposite to that in clay units, thus creating stress in the wall.

Tensile stresses within a wall can cause cracking when they exceed the tensile strength of the masonry. But, the designer can control these stresses and minimize the incidence of cracking by the use of bondbreakers, flexible anchorage, and control joints.

Differential Movement

A building is a dynamic structure, and its successful performance will depend on the designer's (and builder's) understanding of how all the separate parts interact. The performance of the walls, for example, is dependent on the materials of construction. All of these must be taken into account and a realistic assessment made of their relative effects in service.

In the case of cavity walls, any restraint of the differential movement between the exterior and interior wythes could lead to problems. For example, stresses and strains in the masonry system could cause lateral deflection (bowing or increased curvature) of the walls. Some type of metal ties connecting the two wythes should be used to accommodate differential movement.

Bond Prevention

Masonry walls are usually supported by concrete foundations. If the walls are of clay brick and the bottom course is fastened to the foundation wall with strong mortar—but with no provision for the opposing dimensional movement of the two materials—the result will inevitably be cracking at the foundation corners. In other instances, shrinkage cracks that sometimes originate in the foundation wall can extend up into the masonry wall.

These problems can be minimized by use of a bondbreaker between the foundation and the masonry wall. This could be a layer of building paper or smooth flashing material placed under the bottom course of brick in buildings where it is not necessary to anchor the walls to the foundation, as in Fig. 4-18a. The detail shown in Fig. 4-18b is suggested for grouted masonry walls.

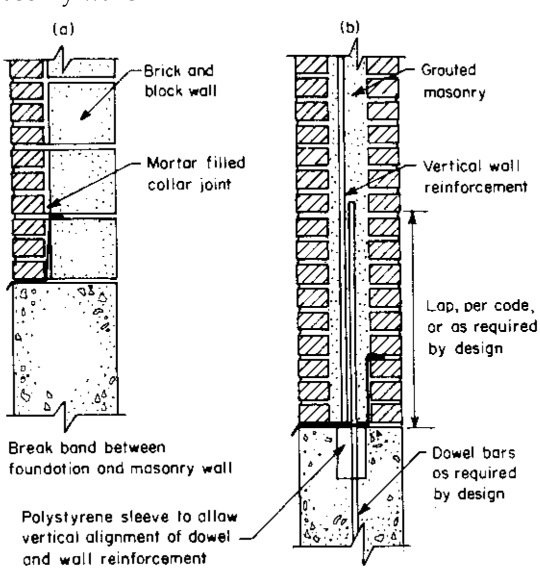


Fig. 4-18

Unbonded and bonded anchorage of masonry wall to foundation.

Flexible Anchorage

Masonry walls tied rigidly to the structural frame for lateral support often crack because of differential movements between the two components. These movements can be controlled by flexible anchors that will resist tension and compression but not shear. This flexibility will permit the wall and the structural frame to move independently of each other, within certain limits.

Types of Control Joints

Control joints, also called contraction or movement joints, are continuous, vertical weakened sections built into the wall (Fig. 4-19). If stresses or wall movements are sufficient to crack the wall, the cracks should occur at the control joints and thus be inconspicuous.

Fig. 4-19

Control (contraction) joint. The prefabricated joint filler fits into special grooves in the block as shown here. The joint will be filled with a sealant on the outside face of the wall to accommodate movement. See also Fig. 4-23. (IMG24957)

A control joint must permit ready movement of the wall in a longitudinal direction and be sealed against vision, sound, and weather. In addition, it may be required to stabilize the wall laterally across the joint.

There are a number of types of control joints for use in concrete masonry walls, but the most preferred types are the Michigan, the tongue-and-groove, and the premolded gasket. Fig. 4-20 shows the so-called Michigan type of control joint. It uses conventional flanged masonry units. A strip of building paper is curled into the end core covering the end of the block on one side of the joint; as the block on the other side of the joint is laid, the core is filled with mortar. The filling bonds to one block but the paper prevents bond to the block on the other side of the control joint. Thus, the control

Fig. 4-20

Michigan-type control joint. Mortar in the joint will be raked out prior to application of a sealant. (IMG4012)

Fig. 4-22

Tongue-and-groove units for control joints are made in full- and half-length sizes. (IMG13631)

joint permits longitudinal movement of the wall, while the mortar plug transmits transverse loads.

Figs. 4-21 and 4-22 show the tongue-and-groove type of control joint. These special units are manufactured in sets consisting of full- and half-length units. The tongue of one special unit fits into the groove of another special unit, or into the open end of a regular flanged stretcher. The units are laid in mortar exactly the same as any other masonry units, including mortar in the head joint; this is done so the mason can maintain bond more easily. Also, part of the mortar is allowed to remain in the vertical joint to form a backing against which a sealant can be placed. The

Fig. 4-21

Special units for tongue-and-groove type of control joint. (IMG4010)

tongue-and-groove units provide excellent lateral stability for the wall.

Figs. 4-19 and 4-23 shows the premolded gasket type of control joint. It is made by installing a fairly stiff premolded rubber insert in the vertical joint.

Fig. 4-24 illustrates joint stabilizing anchors designed to allow movement at joints while maintaining wall alignment perpendicular to wall movement. These anchors are also adaptable for attaching concrete masonry walls to wood, steel, or concrete framing.

Typically these control joints are first laid up in mortar, the same as any other vertical mortar joint. However, if a control joint is to be exposed to view, or the weather, the mortar should be permitted to become quite stiff, and then a recess is raked out to a depth of ⅜ in.

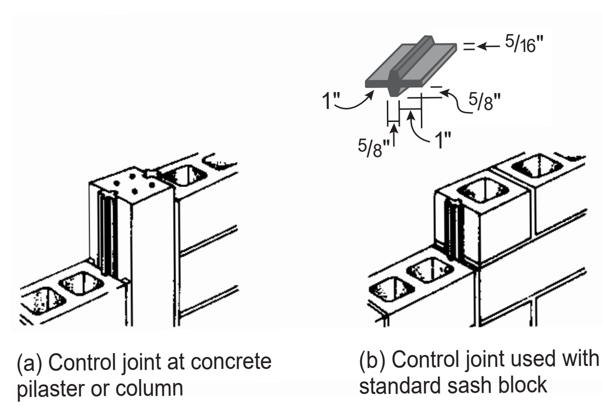


Fig. 4-23

Premolded control joint insert provides lateral support. See also Fig. 4-19.

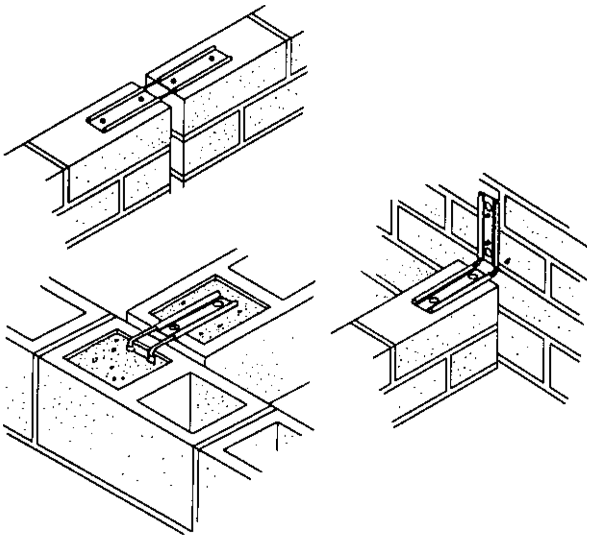


Fig. 4-24

Joint stabilizing anchors allowing shrinkage or expansion through the joint.

(10 mm) as shown in Fig. 4-25. The mortar remaining in the control joint forms a backing to confine an elastomeric joint sealant.

A preferable technique is to leave the mortar out entirely and use a joint-filler (backer rod) with an elastomeric sealant. Without the mortar, the joint can contract as well as expand. As a remedial technique when control joints are inadvertently left out of a wall, joints can be sawed—¼ in. (6.4 mm) minimum width—and then filled with backer rod and elastomeric sealant.

Fig. 4-25

Mortar at a control joint should be raked out to a depth of 3/8 in. (10 mm) prior to sealing. Either a pointing trowel (shown here) or a special wheeled rake may be used. (IMG4015)

Elastomeric sealants meeting ASTM C920 should be applied in accordance with ASTM C962. Some of the more successful elastomeric sealants for this purpose are the polysulfides, polyurethanes, and silicones. A nonsag, gun-applied sealant should be used in joints on vertical surfaces. Tooling is essential to force the sealant into the joint and to match the tooled mortar joints in the remainder of the wall (Fig. 4-26). Care must be taken to avoid smearing sealant onto the face of the wall.

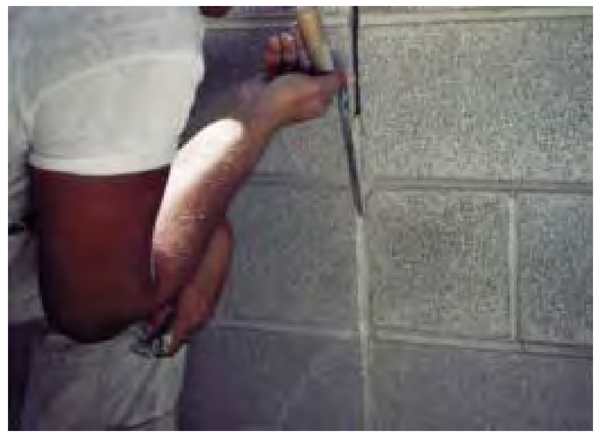


Fig. 4-26

Sealant being applied to a control joint. (IMG4016)

Location of Control Joints

No exact rules are available for the location of control joints. Each job must be planned individually to determine where joints can be placed without endangering the structural integrity or aesthetics of the structure. For walls without openings or other points of stress, control joints may be used effectively to control cracks by dividing a wall into a series of isolated panels. Two criteria for determining the location (spacing) of control joints are available: (1) an empirical method, and (2) an engineered crack control criteria.

The empirical method for determining control joint spacing for above grade exposed concrete masonry walls has developed over the years based on experience in various geographical conditions. Using this method, the distance between control joints should not exceed the smaller of 25 ft (7.62 m) or one and one-half times the wall height. As an example, consider a warehouse wall that is 20 ft (6.10 m) high and 100 ft (30.48 m) long. Multiplying the wall height by one and one-half would lead to a joint spacing of 30 ft (9.14 m), in excess of the 25-ft maximum allowed; therefore, the maximum joint spacing of 25 ft would govern.

This empirical method is based on walls that contain horizontal reinforcement having an equivalent area of steel of not less than 0.025 in.^{2}/ft (52.9 mm^2/m) of height to keep any unplanned cracks tightly closed. The control joint spacing may be adjusted up or down where local experience justifies, but no farther than 25 ft. A control joint should be located within 10 ft to 15 ft (3.05 m to 4.57 m) of a corner, and preferably one header or stretcher unit from the corner. Flexible ties should be installed at the corner to develop the load-carrying capacity of the wall, but allow for proper movement.

The engineered crack control criterion is relatively new and more involved than the empirical method. It is based on a Crack Control Coefficient (CCC) for the actual concrete masonry units used on the job. The CCC, which is an indicator of anticipated wall movement, is determined by summing up the combined effects of movement due to drying shrinkage, carbonation shrinkage, and contraction due to temperature changes. With the engineered crack control method, it is possible to limit crack width without the use of control joints by incorporating a predetermined amount of horizontal reinforcement. For detailed information on how to use these methods, see TEK 10-1A 2005 and TEK 10-2B 2005.

Control joints should also be located at the following points of weakness or high stress concentrations:

1. At all changes in wall height.
2. At all changes in wall thickness, such as those at pipe or duct chases and those adjacent to columns or pilasters (Figs. 4-27 and 4-28).
3. At (above) movement joints in foundations and floors.
4. At (below) movement joints in roofs and floors that bear on a wall.
5. At one side of door or window openings less than 6 ft (1.83 m) wide, and at both sides of openings over 6 ft wide. Control joints can be omitted if the proper amount of tensile reinforcement is placed above and below wall openings.
6. Adjacent to corners of walls or intersections within a distance of one-half the normal control joint spacing.

All large openings in walls should be recognized as natural and desirable joint locations. Although some adjustment in the established joint pattern may be required, it is effective to use the vertical sides of wall openings as part of the control joint layout. Under windows, the joints usually are in line with the sides of the openings. Above doors and windows, the joints must be offset to the end of the lintels. To permit movement, the bearing of at least one end of the lintel should be built to slide (Fig. 4-29). Plastic or bituminous sheets or other suitable material should be used for a slip plate.

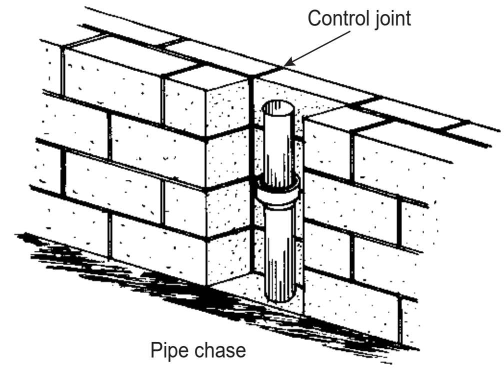


Fig. 4-27
A control joint should be located at a pipe chase or any other abrupt change in wall thickness.

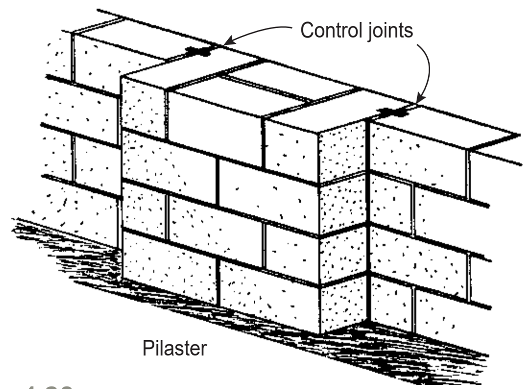


Fig. 4-28
A pilaster edge is a good location for a control joint.

Fig. 4-29
Sliding bearing for a lintel. (IMG4017)

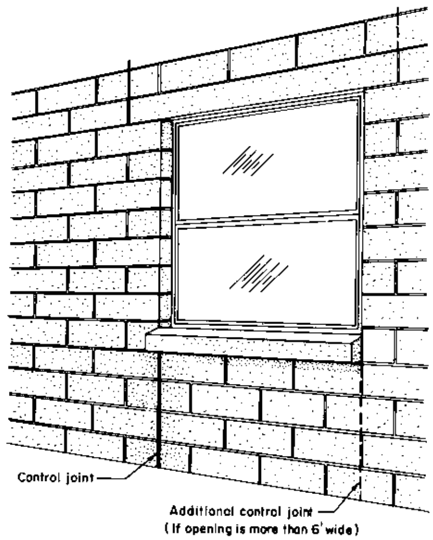


Fig. 4-30

Control joints should be located at window or door openings to avoid random cracking. (IMG24958)

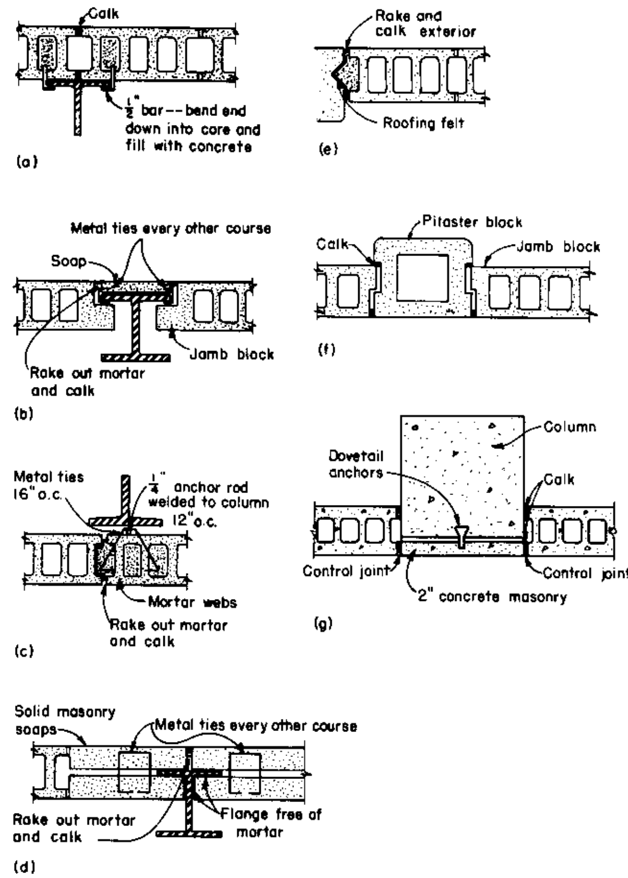


Fig. 4-32

Control joints at colums and pilasters. Joint stabilizing anchors in Fig. 4-24 are also used to attach walls to columns or pilasters while allowing in-plane movement.

Since openings less than 6 ft (1.83 m) wide require a control joint along one side only, and openings of more than 6 ft require joints along both sides (Fig. 4-30), a control joint between two windows should be avoided; it usually will not function properly (Fig. 4-31).

To avoid the occurrence of cracks due to differential movement between concrete masonry and structural framing members, such as columns and pilasters, a space should be allowed between the masonry and member to allow free movement. One or more control joints should be located at the column or pilaster (Fig. 4-32).

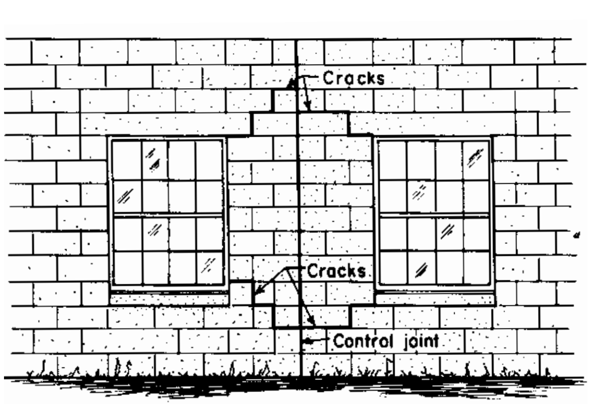


Fig. 4-31

Between windows is the wrong place for a control joint because cracks may seek a path of less restraint.

When a concrete masonry wall is reduced in thickness across the face of a column, a control joint should be placed along one or both sides of the column. Thin concrete masonry across the column face should be tied to the column by means of dovetail anchors (Fig. 4-32), or other suitable devices.

Where bond beams are provided only for crack control, control joints should extend through them. If there is a structural reason for a bond beam, a dummy groove or raked joint should be provided to control the location of the anticipated crack.

A concrete masonry or cast-in-place concrete foundation having both sides backfilled does not usually require control joints. However, long concrete masonry basement walls may require control joints, continuous metal ties (joint reinforcement), or reinforcing bars (see

TEK 3-11 2001; TEK 5-4B 2002; TEK 15-1B 2001; and TEK 15-3 1996).

Where concrete masonry units are used as backup for another material (facing) with masonry bond, the control joints should extend through the facing. Control joints need not extend through the facing when using flexible metal ties.

Control joints should extend through plaster applied directly to concrete masonry units. Plaster applied on lath that is furred out from the base requires control joints over previous joints in the concrete masonry and regular jointing rules for lath apply.

The design, detailing, and spacing of control joints should be by mutual agreement between the architect and the structural engineer. Both parties should consider: (1) availability of special concrete masonry units in the project area; (2) engineering aspects as to stress concentrations and requirements for concrete masonry; (3) experience with performance of masonry structures; and (4) aesthetics. Methods to control cracking include reducing the length of wall, and adjusting/decreasing joint reinforcement spacing requirements.

Joint Reinforcement

Although concrete masonry walls can be built essentially crack free, it is the infrequent crack for which joint reinforcement (Figs. 4-11 and 4-33) is provided. The function of joint reinforcement is not to eliminate cracking in concrete masonry walls, but merely to prevent the formation of conspicuous shrinkage cracks. It should be kept in mind that joint reinforcement does not become effective until the wall begins to crack. After cracking occurs the stresses are transferred to and redistributed by the steel. The result is evenly distributed, very fine cracks that are hardly visible to the naked eye.

Fig. 4-33

Joint reinforcement is placed in bed joints to control movements due to drying shrinkage and temperature changes. See also Figs. 4-11(a) and (b). (IMG24959)

The effectiveness of joint reinforcement depends on the type of mortar and the bond between the mortar and the longitudinal wires of the joint reinforcement. The better the bond strength at the mortar-reinforcement interface, the more efficient the reinforcement will be in arresting any cracking that develops.

After the joint reinforcement is placed on top of the bare masonry course, mortar is applied to cover the face shells and joint reinforcement. Minimum mortar cover from the exterior surface to the joint reinforcement should be ⅝ in. (16 mm); this mortar cover should be ½ in. (13 mm) on the interior surface as shown in Fig. 4-5c.

Prefabricated or job-fabricated corner and T-type joint reinforcement should be used around corners and to anchor abutting walls and partitions (Fig. 4-11). Prefabricated corners and tees are considered superior to job-fabricated because they are more accurately formed, fully welded, and easier to install. A 6-in. (152-mm) lapping of side wires at splices is essential. Continuity of the reinforcement must occur so that tensile stress will be transmitted.

The vertical spacing of joint reinforcement is dependent on the spacing of control joints. In addition, joint reinforcement should be located as follows:

1. In the first and second bed joints immediately above and below wall openings. The reinforcement should extend not less than 24 in. (610 mm) past either side of the opening, or to the end of the panel, whichever is less.

2. In the first two or three bed joints above floor level, below roof level, and near the top of the wall.

3. Joint reinforcement need not be located closer to a bond beam than 24 in. (610 mm). It should not extend through control joints unless specifically called for and detailed in the plans.

See TEK 10-1A 2005, TEK 10-2B 2005, TEK 10-3 2003, and TEK C10-2B 2005 for more details on crack control and control joints for concrete masonry walls.

Layout of Structural Features

Modular Planning

Modular planning is a method of coordinating the dimensions of various building components to simplify work and lower construction cost. Careful planning minimizes cutting and fitting of units on the job, operations that slow construction (Fig. 4-34). In a modular plan for concrete masonry construction, all horizontal dimensions are given in multiples of half the nominal length of a concrete block, usually 8 in. (203 mm). Vertical dimensions are given in multiples of the full nominal height of the block.

Tables 4-1 and 4-2 give modular lengths and heights for walls. If necessary, head and bed joints may have different thicknesses.

Fig. 4-34

Modular planning minimizes the cutting and fitting of block at the jobsite. (IMG24960)

Table 4-1. Length of Concrete Masonry Walls by Stretchers

No. of stretchers	Wall length,* ft, in.	Wall length,* mm, m	No. of stretchers	Wall length,* ft, in.	Wall length,* mm, m
1	1'4"	406 mm	8½	11'4"	3.45 m
1½	2'0"	610 mm	9	12'0"	3.66 m
2	2'8"	813 mm	9½	12'8"	3.86 m
2½	3'4"	1.02 m	10	13'4"	4.06 m
3	4'0"	1.22 m	10½	14'0"	4.27 m
3½	4'8"	1.42 m	11	14'8"	4.47 m
4	5'4"	1.63 m	11½	15'4"	4.67 m
4½	6'0"	1.83 m	12	16'0"	4.88 m
5	6'8"	2.03 m	12½	16'8"	5.08 m
5½	7'4"	2.24 m	13	17'4"	5.28 m
6	8'0"	2.44 m	13½	18'0"	5.49 m
6½	8'8"	2.64 m	14	8'8"	5.69 m
7	9'4"	2.84 m	14½	19'4"	5.89 m
7½	10'0"	3.05 m	15	20'0"	6.10 m
8	10'8"	3.25 m	15½	26'8"	8.13 m

* Based on concrete blocks 15⅝ in. (397 mm) long and half units 7⅝ in. (194 mm) long, with ⅜-in. (10-mm) thick head joints. Actual lengths of finished walls are ⅜ in. (10 mm) less than the modular dimensions shown in this table.

Metrics and Masonry

As noted here, masonry is designed and built on modules. This reduces the need to cut units, either to accommodate openings for windows and doors, or to make the ends of walls line up. In the United States, masonry units are manufactured to U.S. Customary unit sizes. These can be "soft converted" to metric sizes, meaning that the unit dimensions are multiplied by conversion factors and the size is reported as the rounded value. For example, a nominal 8-in. unit converts to a 203-mm unit. If the item were manufactured according to metric units, the logical nominal size would be 200 mm.

Although most other countries in the world have changed over to the International System (SI) units of measure, the U.S. masonry industry has not done so due to the high cost to low benefit. Converting molds (retooling) to metric sizes would be extremely expensive. There would be at least some period of time if not an indefinite period where dual units would have to be stocked, leading to confusion and possible mix-ups on jobs. And since masonry products are seldom exported due to weight, there is no loss of market due to incompatible sizes. The masonry industry petitioned the United States Congress to indefinitely delay conversion of masonry products to metric sizes. At this time, the conversion issue seems to have disappeared.

Table 4-2. Height of Concrete Masonry Walls by Courses

No. of courses	Wall height, ft, in. (mm, m)					
	⅜-in. (10-mm) bed joint		7/16-in. (11-mm) bed joint		½-in. (13-mm) bed joint	
	8-in. (10-mm) block	4-in. (200-mm) block	8-in. (10-mm) block	4-in. (200-mm) block	8-in. (10-mm) block	4-in. (200-mm) block
1	8" (203 mm)	4" (102 mm)	8 1/16" (205 mm)	4⅕" (103 mm)	8⅛" (206 mm)	4'⅛" (105 mm)
2	1'4" (406 mm)	8" (203 mm)	1'4⅛" (410 mm)	8⅛" (206 mm)	1'4½" (413 mm)	8'¼" (210 mm)
3	2'0" (610 mm)	1'0" (305 mm)	2'0 3/16" (614 mm)	1'0 3/16" (310 mm)	2'0⅜" (619 mm)	1'0⅜" (314 mm)
4	2'8" (813 mm)	1'4" (405 mm)	2'8¼" (819 mm)	1'4¼" (413 mm)	2'8½" (826 mm)	1'4½" (419 mm)
5	3'4" (1.02 m)	1'8" (508 mm)	3'4 5/16" (1.02 m)	1'8 5/16" (516 mm)	3'4⅝" (1.03 m)	1'8⅝" (524 mm)
6	4'0" (1.22 m)	2'0" (610 mm)	4'0⅜" (1.23 m)	2'0⅜" (619 mm)	4'0¾" (1.24 m)	2'0¾" (629 mm)
7	4'8" (1.42 m)	2'4" (711 mm)	4'8 7/16" (1.43 m)	2'4 7/16" (722 mm)	4'8⅞" (1.44 m)	2'4⅞" (733 mm)
8	5'4" (1.63 m)	2'8" (813 mm)	5'4½" (1.64 m)	2'8½" (826 mm)	5'5" (1.65)	2'9" (838 mm)
9	6'0" (1.83 m)	3'0" (914 mm)	6'0 9/16" (1.84 m)	3'0 9/16" (929 mm)	6'1⅛" (1.86 m)	3'1⅛" (943 mm)
10	6'8" (2.03 m)	3'4" (1.02 m)	6'8⅝" (2.05 m)	3'4⅝" (1.03 m)	6'9¼" (2.06 m)	3'5¼" (1.05 m)
15	10'0" (3.05 m)	5'0" (1.52 m)	10'0 15/16" (3.07 m)	5'0 15/16" (1.55 m)	10'1⅞" (3.10 m)	5'1⅞" (1.57 m)
20	13'4" (4.06 m)	6'8" (2.03 m)	13'5¼" (4.10 m)	6'9¼" (2.06 m)	13'6½" (4.13 m)	6'10½" (2.10 m)
25	16'8" (5.08 m)	8'4" (2.54 m)	16'9 9/16" (5.12 m)	8'5 9/16" (2.58 m)	16'11⅛" (5.16 m)	8'7⅛" (2.62 m)
30	20'0" (6.10 m)	10'0" (3.05 m)	20'1⅞" (6.14 m)	10'1⅞" (3.10 m)	20'3¾" (6.19 m)	10'3¾" (3.14 m)
35	23'4" (7.11 m)	11'8" (3.56 m)	23'6 3/16" (7.17 m)	11'10⅞" (3.61 m)	23'8⅜" (7.22 m)	12'0⅜" (3.67 m)
40	26'8" (8.13 m)	13'4" (4.06 m)	26'10½" (8.19 m)	13'6½" (4.13 m)	27'1" (8.26 m)	13'9" (4.19 m)
45	30'0" (9.14 m)	15'0" (4.57 m)	30'2 13/16" (9.22 m)	15'2 13/16" (4.64 m)	30'5⅝" (9.29 m)	15'5⅝" (4.71 m)
50	33'4" (10.16 m)	16'8" (5.08 m)	33'7⅛" (10.24 m)	16'11⅛" (5.16 m)	33'10¼" (10.32 m)	17'2¼" (5.24 m)

Door and Window Openings

The example of modular planning given in Fig. 4-35 shows the widths of door and window openings as well as wall lengths in multiples of 8 in. (203 mm). Since the concrete block is produced with dimensions ⅜ in. (10 mm) less than its nominal or modular length of 16 in. (406 mm), the actual dimensions of the finished door and window openings are ⅜ in. (10 mm) greater than their modular dimensions given on the plan. The actual dimension of the finished wall is ⅜ in. (10 mm)

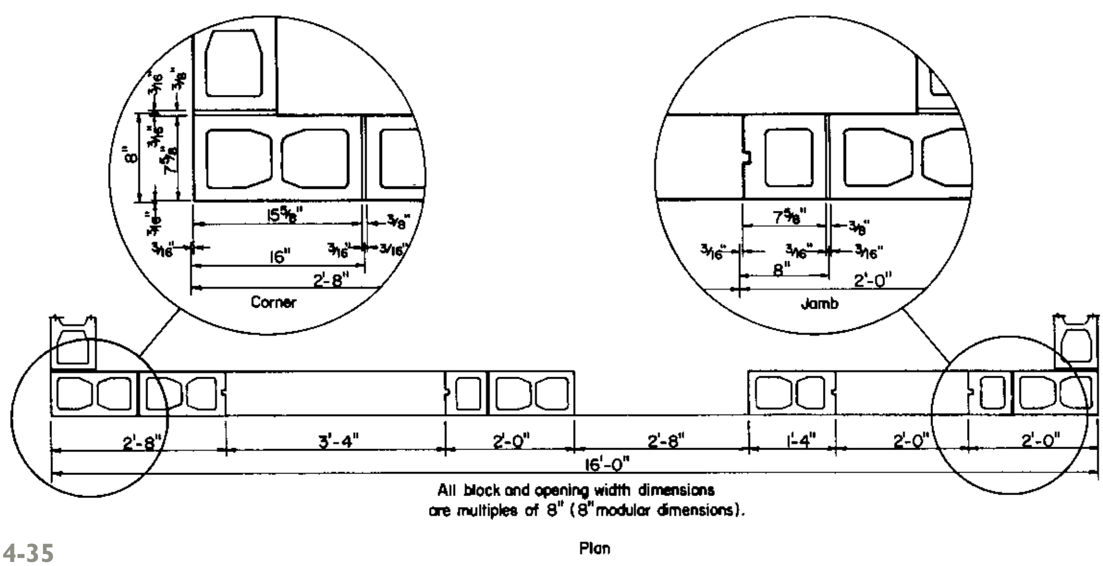


Fig. 4-35

Modular planning of a wall.

less than its modular dimension on the plan. However the concrete foundation is built to the full modular dimension and the mason starts the corner masonry unit 3⁄16 in. (4.8 mm) in from the end.

Modular design for concrete masonry requires that window and door frames also be modular sizes, as shown in Figs. 4-36 and 4-37. The shaded portion of Fig. 4-36 indicates the cutting of units required had nonmodular openings and nonmodular wall length been used.

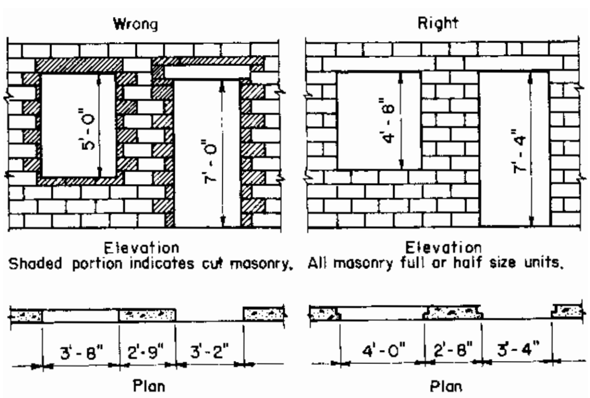


Fig. 4-36

Examples of wrong and right planning of concrete masonry wall openings based on 8x8x16-in. block.

Corners

An important consideration in modular planning is the method to be used for constructing corners. Eight-inch-thick (203-mm) walls do not pose a problem in this regard, but thicker or thinner walls require some attention so that the 4-in. or 8-in. (100-mm or 203-mm) module is preserved. Figs. 4-39 through 4-43 show some suggested details for handling corner layouts for walls of various thicknesses.

Fig. 4-38

Concrete units create clean, crisp corners on masonry structures. (IMG24961)

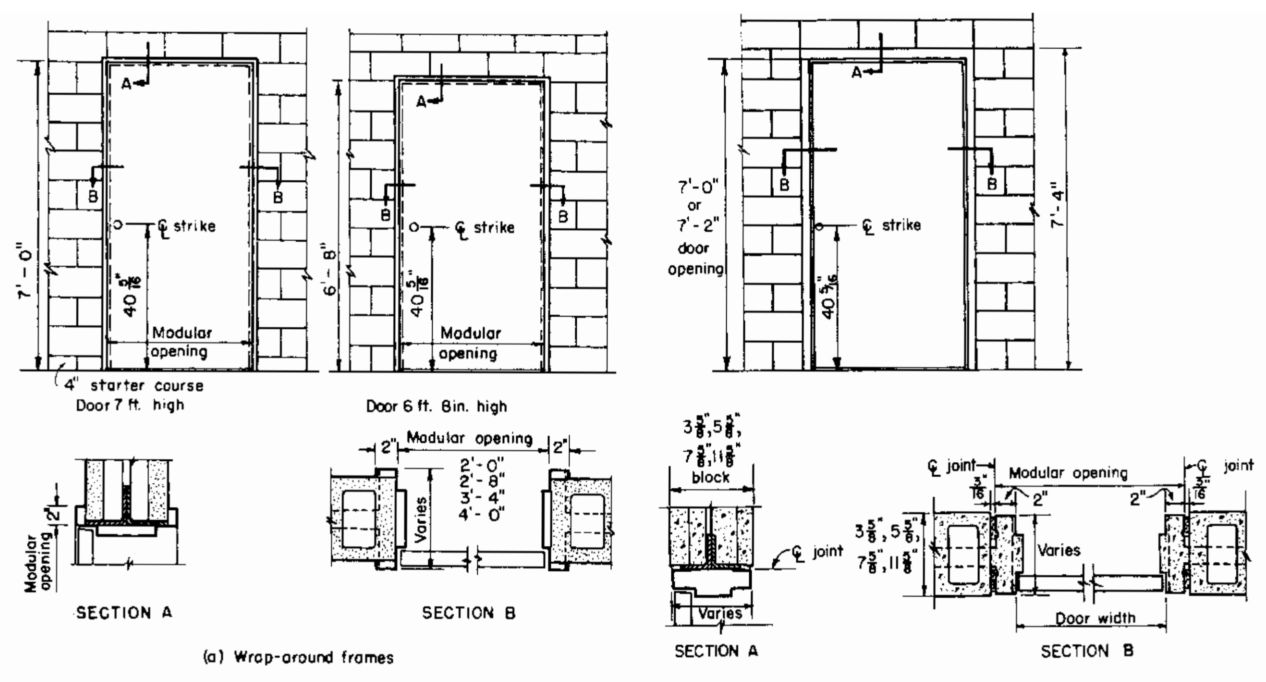


Fig. 4-37

Modular-sized door openings.

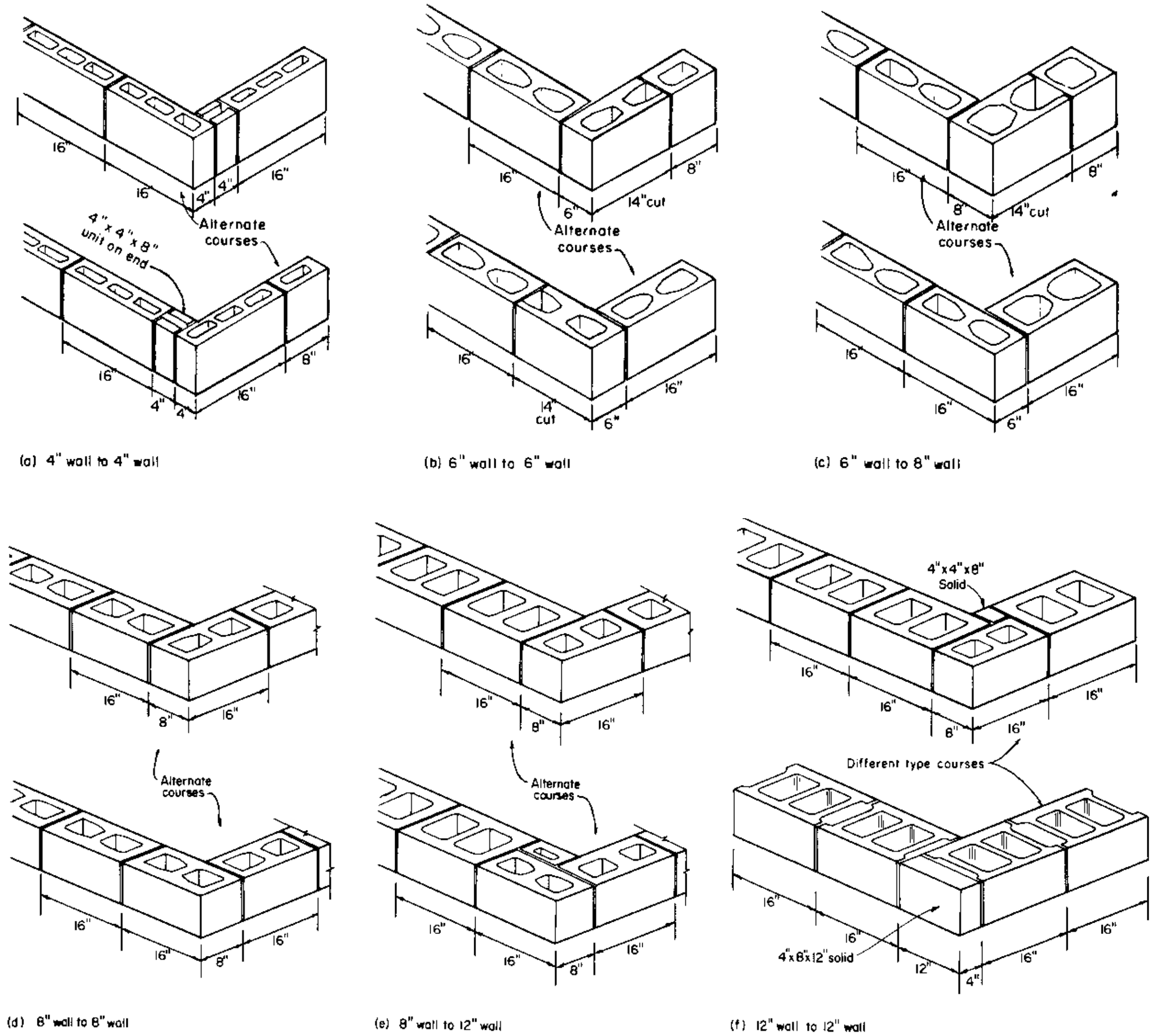
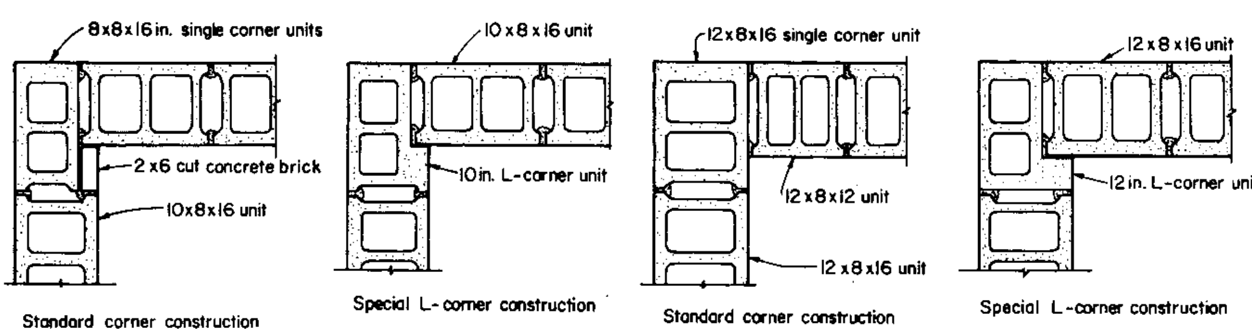


Fig. 4-39

Standard corner layouts for walls 4, 6, 8, and 12 in. thick.



(a) 10" wall to 10" wall

(b) 12" wall to 12" wall

Fig. 4-40

Corner layouts comparing standard and special L units for 10- and 12-in. walls.

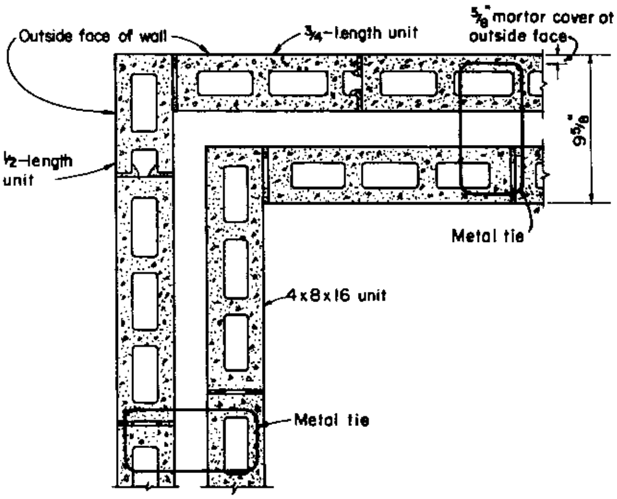


Fig. 4-41

Corner layout for 10-in. cavity wall.

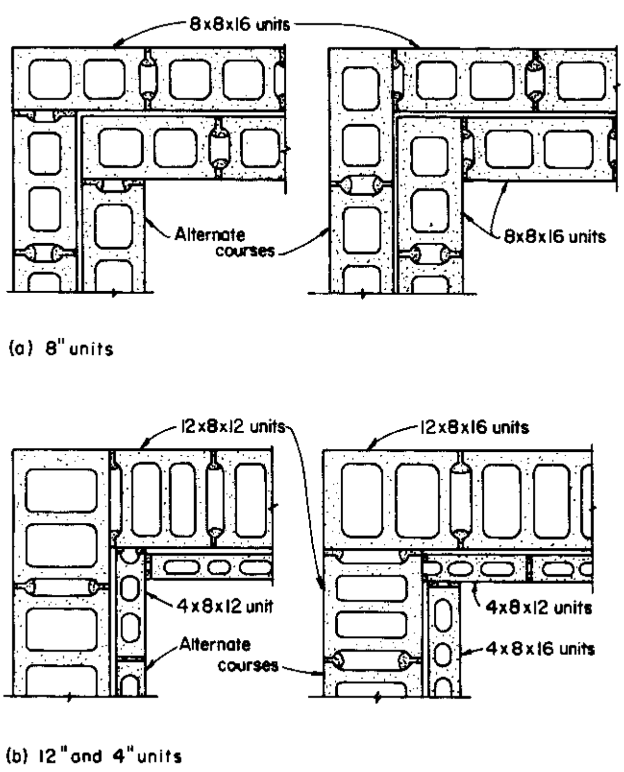


Fig. 4-42

Corner layouts for 16-in. walls.

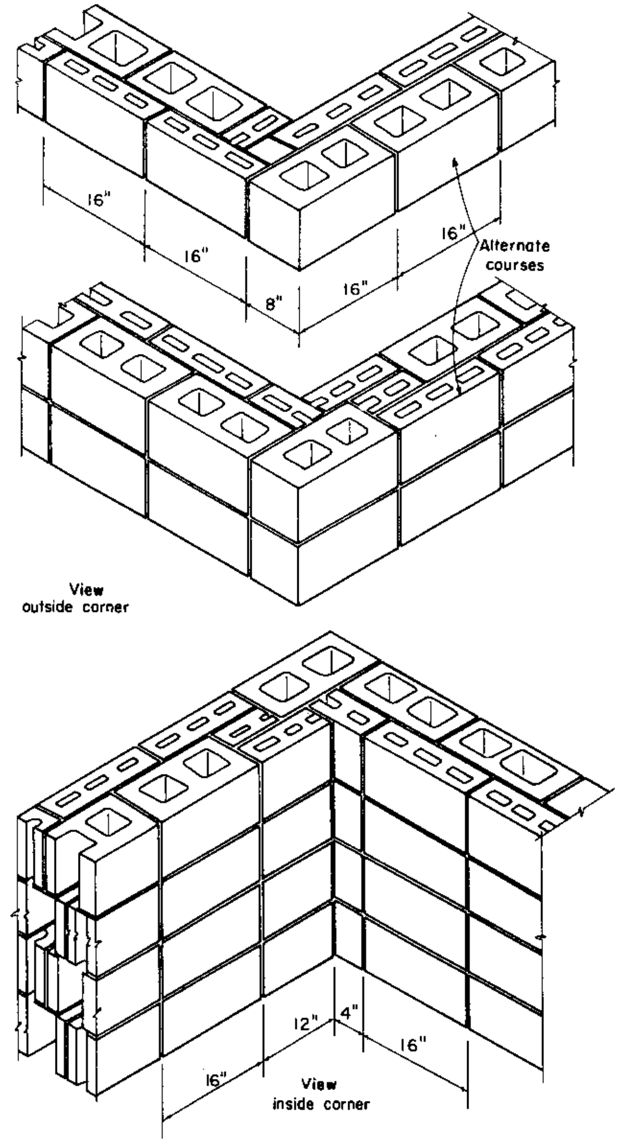


Fig. 4-43

Corner layout for a 12-in. wall with stacked bond pattern.

Intersections

Connection of intersecting walls needs to be planned unless the method is predetermined by the local building code. If there is a choice, two questions must be studied: (1) will the wall require lateral support, and (2) where will the control joints be located? Several conditions are illustrated in Fig. 4-44.

Intersecting, load-bearing block walls that depend upon one another for continuity and lateral support, as at point A in Fig. 4-44, should be securely anchored to

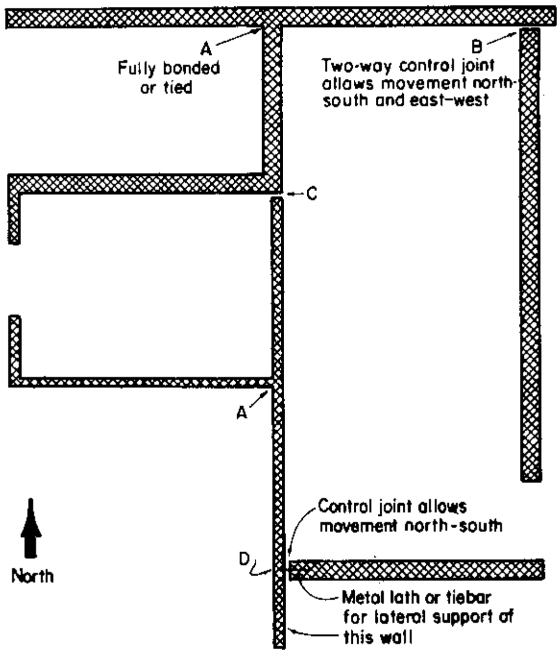


Fig. 4-44

Jointing at intersecting walls.

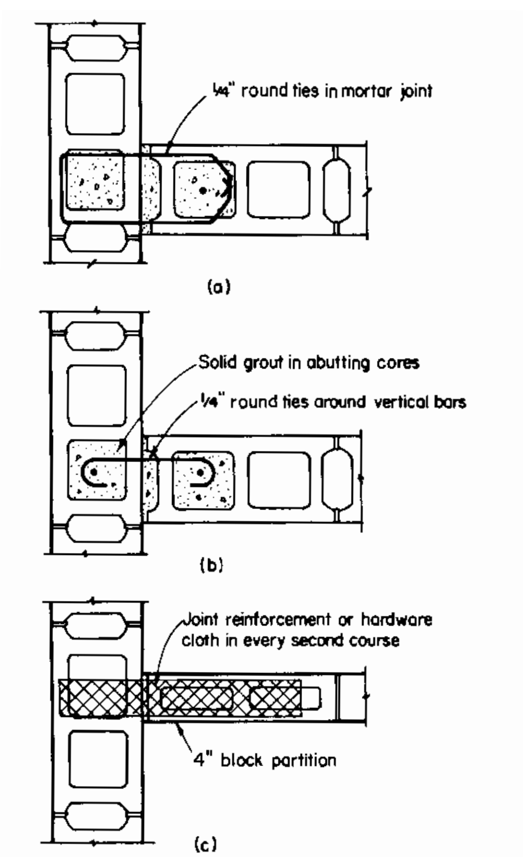


Fig. 4-45

Rigid connections for intersecting walls.

resist all forces that might tend to separate them. Such walls should be connected with true masonry bond so that half of the units of each wall are embedded in the other wall. Alternate connections are shown in Fig. 4-45. Another method is to use the detail of Fig. 4-46a, except that the elastomeric joint sealant is replaced with a regular mortar joint, as in Fig. 4-47.

At points B or C in Fig. 4-44, a full control joint is assumed to be necessary to allow movement in two directions. The joint would be sealed with a joint-filler

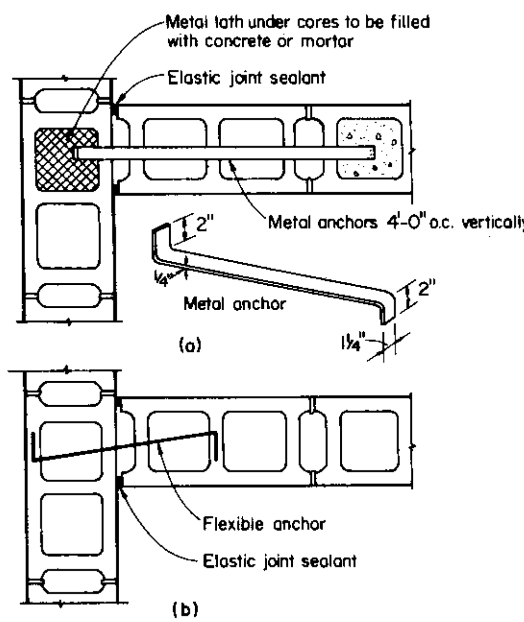


Fig. 4-46

Flexible connections for intersecting walls.

Fig. 4-47

Steel tiebar provides lateral support to wall at back in photo. (IMG4019) (backer rod) and elastomeric sealant, contain no mortar, and have no block across it.

At point D in Fig 4-44, the wall running north-south will try to move transversely to the other. In addition, it requires lateral support—a steel tiebar as shown in Fig. 4-46a. The appropriate cores are filled with mortar after pieces of metal lath are placed under the cores to support the filling. The ends of the tiebar are embedded in this mortar filling. The result is a hinged control joint that permits the wall to move slightly (at right angles to the abutting wall) and yet possess lateral support. The tiebars are spaced not more than 4 ft (1.22 m) apart vertically.

In another method for point D in Fig. 4-44, a control joint is placed at the junction of the walls. Lateral support is provided by joint reinforcement, strips of metal lath, or ¼-in.-mesh (6.4-mm) galvanized hardware cloth placed across the joint between the two walls (Fig. 4-45c). When metal strips are used, they are placed in alternate courses in the wall, or not more than 18 in. (457 mm) on center. They are sufficiently flexible to permit lateral movement of the abutted wall. If one wall is constructed first, the hardware cloth is built into it and later tied into the mortar joints of the second wall (Fig. 4-48).

Fig. 4-48

Hardware cloth provides lateral support to wall at right in photo. (IMG4021)

Bond Beams

Bond beams are reinforced courses of block that bond and integrate a concrete masonry wall into a stronger unit. They increase the bending strength of the wall and are imperative in walls for resisting high wind, hurricane, and earthquake forces. In addition, they exert restraint against wall movement, and thus reduce the formation of cracks. They may even be used at vertical intervals instead of vertical reinforcing steel.

Bond beams are constructed with special concrete masonry units (Fig. 1-17 c through f). The units are filled with grout and reinforced with embedded steel bars (see Fig. 4-49). Bond beams are usually located at the top of walls to stiffen them. Since they have appreciable structural strength, they can be located to serve as lintels over doors and windows. When bond beams are located just above the floor, they act to distribute the wall weight (making the wall a deep beam), and thus help avoid wall cracks if the floor sags. Bond beams may also be located below a window sill. Examples of common bond-beam locations are shown in a number of figures in Appendix A.

Fig. 4-49

Construction of a bond beam for wall reinforcement. (IMG24962)

In load-bearing walls, bond beams are best placed in the top course immediately beneath the roof framing system. Where heads of openings occur within 2 ft

(610 mm) of the roof framing system or ceiling in multistory buildings, a bond beam at or immediately above the lintel can be considered the equivalent of a bond beam at the top of the wall or at ceiling height.

In non-load-bearing walls, bond beams may be placed in any one of the top three courses below the roof slab or deck. This permits the bond beam to serve three functions—as a structural tie, lintel, and crack control device.

Reinforcement of bond beams must satisfy structural requirements, but should not be less than two No. 4 (#13) steel bars in 8-in.-wide (203-mm) bond beams and two No. 5 (#16) steel bars in 10 in. and 12 in. wide (250 mm and 305 mm) bond beams. In some earthquake-prone areas building codes require a 16-in.-deep (406-mm) bond beam with two additional No. 4 (#13) bars located in the top of the beam. Bars should be bent around corners and lapped (Fig. 4-50) according to the local building code.

When the bond beams serve only as a means of crack control, they should be discontinuous at control joints. Where structural considerations require that bond beams be continuous across control joints, a dummy groove should be provided to control the location of any anticipated crack.

If the bond beams are used to replace joint reinforcement, their spacing should be as given in Table 4-3. Note that the area of steel required in the bond beams is greater than that required in the joint reinforcement. This is due not only to a lower reinforcing bar yield strength, but also to a loss of bond-beam effectiveness, which is assumed to be reduced one-third because of the wetting effect of grout on the wall and the accompanying increase in ultimate drying shrinkage of the wall.

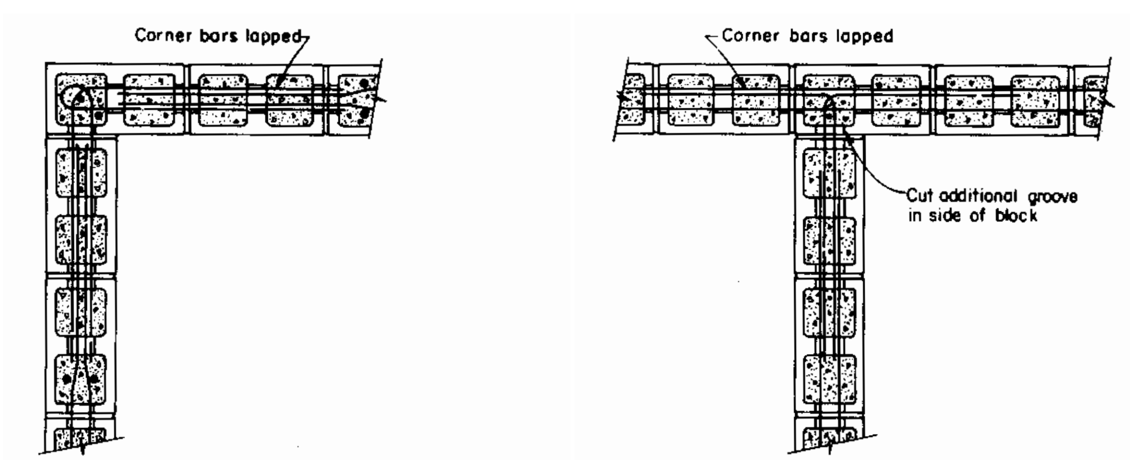


Fig. 4-50

Bond-beam corner details.

Table 4-3. Equivalent Spacing of Bond Beams and Joint Reinforcement*

Maximum spacing of joint reinforcement, in. (mm)**	Spacing based on bond-beam reinforcement, ft, in. (m)†		
	Two No. 4 (#13) bars	Two No. 5 (#16) bars	Two No. 6 (#19) bars
24 (600)	8'0" (2.44)	8'0" (2.44)	8'0" (2.44)
16 (400)	5'4" (1.63)	8'0" (2.44)	8'9" (2.44)
8 (200)	2'8" (0.81)	4'8" (1.42)	6'8" (2.03)

* Adapted from Table 3-3, US Army/US Air Force 1973.
** No. 9 gage wire with yield strength of 65,000 psi (448 MPa).
† Yield strength of 40,000 psi (276 MPa).

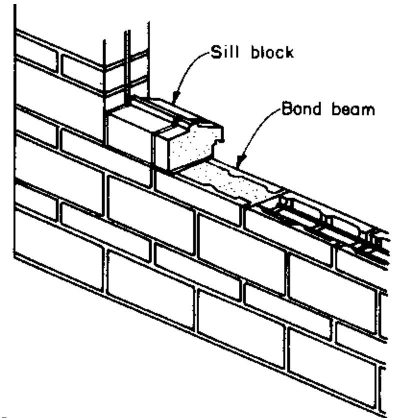


Fig. 4-51
Sill block of modular dimensions.

Lintels

Lintels are beams that span openings in walls; they support the weight of the wall and other loads above openings. Concrete masonry lintels may be made of special lintel masonry units (Fig. 1-17g), bond-beam masonry units, or standard units with depressed, cutout, or grooved webs. The units are laid end to end to form a channel for placement of reinforcing steel and grout. Concrete masonry lintels are easy to construct, do not require heavy hoisting equipment, and they match the bond pattern and surface texture of the surrounding masonry. Lintels may also be made of conventional precast concrete, steel angles, or concrete masonry members molded on special machines that produce surface textures similar to block.

Lintels should have a minimum bearing of 6 in. (152 mm) at each end. A rough rule of thumb is to provide 1 in. of bearing for every foot of clear span (83 mm of bearing per meter of clear span).

For more information on concrete masonry lintels and precast concrete lintels, see TEK 17-1B 2001 and TEK 17-2A 2000, respectively.

Sills

Some concrete masonry producers make sill units in a modular length of 7⅝ in. (194 mm), as shown in Fig. 4-51. They are mortared together to form a continuous sill. Because of the difficulty in ensuring a watertight mortar joint on top of the sill, the course below is constructed of solid units or a bond beam. Other sill units are shown in Fig. 1-17a.

Piers and Pilasters

Piers are isolated columns of masonry, while pilasters are columns or thickened wall sections built contiguous with and forming part of a masonry wall. Pilasters may project on one or both sides of the wall. If the projection is entirely on one side, the pilaster is generally referred to as a flush pilaster or as an interior or exterior pilaster.

Both piers and pilasters are used to support heavy, concentrated vertical roof or floor loads and to provide lateral support to the walls. They also offer an economic advantage by permitting construction of higher and thinner walls with plain concrete masonry; otherwise the walls would have to be reinforced or made thicker.

Piers and pilasters may be constructed of special concrete masonry units (Figs. 1-20 and 1-21) or units similar to those used in the wall, whether solid or hollow. Hollow units may be grouted and may or may not contain embedded reinforcement. In grouted piers and pilasters, all vertical joints are fully mortared. Pilaster units should be laid with mortar of the same quality as planned for the masonry between pilasters.

Fig. 4-52

A typical pilaster in a standard block wall. (IMG24963)

Some typical pilaster designs are shown in Figs. 4-53 and 4-54. Most of these layouts are adaptable to piers. Note that grouted piers and pilasters require ties embedded in the face-shell mortar bedding. These ties are necessary to hold the masonry units together while the fresh grout exerts fluid pressure, and to make the units work together. Tie diameter should not exceed half the joint thickness.

If grouted units are reinforced, they should contain ¼-in. (6.4-mm) ties with closed (lapped) ends. These ties should be in contact with the outside of the vertical reinforcing bars. For pilasters, such as those in Figs. 4-53 and 4-54, the ¼-in. (6.4-mm) ties are installed as the block work progresses.

Planning Weathertight Walls

The outside wythe of a cavity wall can be considered a rain screen—as are veneered and shingled walls that are backed up with a vented air space. Such walls are highly weather-resistant, even in driving rains. On the other hand, solid masonry construction is more vulnerable to leakage. In choosing this type of construction, the designer and builder should accept the possibility and consequences of some leakage, or else they should use great care in selecting materials and overseeing installation. While workmanship is the most important element (see PCA IS245 2001; PCA IS246 2001), it isn't fair to always hold the mason responsible for leaks due to poor workmanship. The owner, architect, and builder share the responsibility because they govern the type of design, materials, and workmanship desired.

The elements of watertight concrete masonry walls are discussed throughout this handbook. They include sound masonry units, proper mortar, and a high standard of construction. Additional information can be found in Dubovoy 1994, Melander and Ghosh 1992, PCA IS191 1991, PCA IS219 1991, PCA IS220 1992, TEK 19-2A 2004, and TEK 85 1977.

ASTM specifications for concrete brick and block do not specify water permeability, but they do note that protective coatings may be required to prevent water penetration.

Portland cement plaster (stucco) will generally suffice to make a hollow concrete masonry wall weathertight. Acrylic paints and other coatings may also do this, but they may have to be reapplied every few years. Additional information on plaster, paints, and other coatings is given in Chapter 7.

Table 4-4. Flashing Locations and Functions

Location	Function
Under coping	Prevents water penetrating joints in coping stone from entering masonry below
Over window and door heads	Collects and discharges water penetrating from masonry above
Under window sills	Collects and discharges water penetrating sill joints and window jambs
Over foundation	Collects and discharges water penetrating masonry above and prevents upward water migration to first course above foundation
Over bond beams	Collects and discharges water from masonry above
Over penetrations	Collects and discharges water from wherever the masonry cavity is interrupted

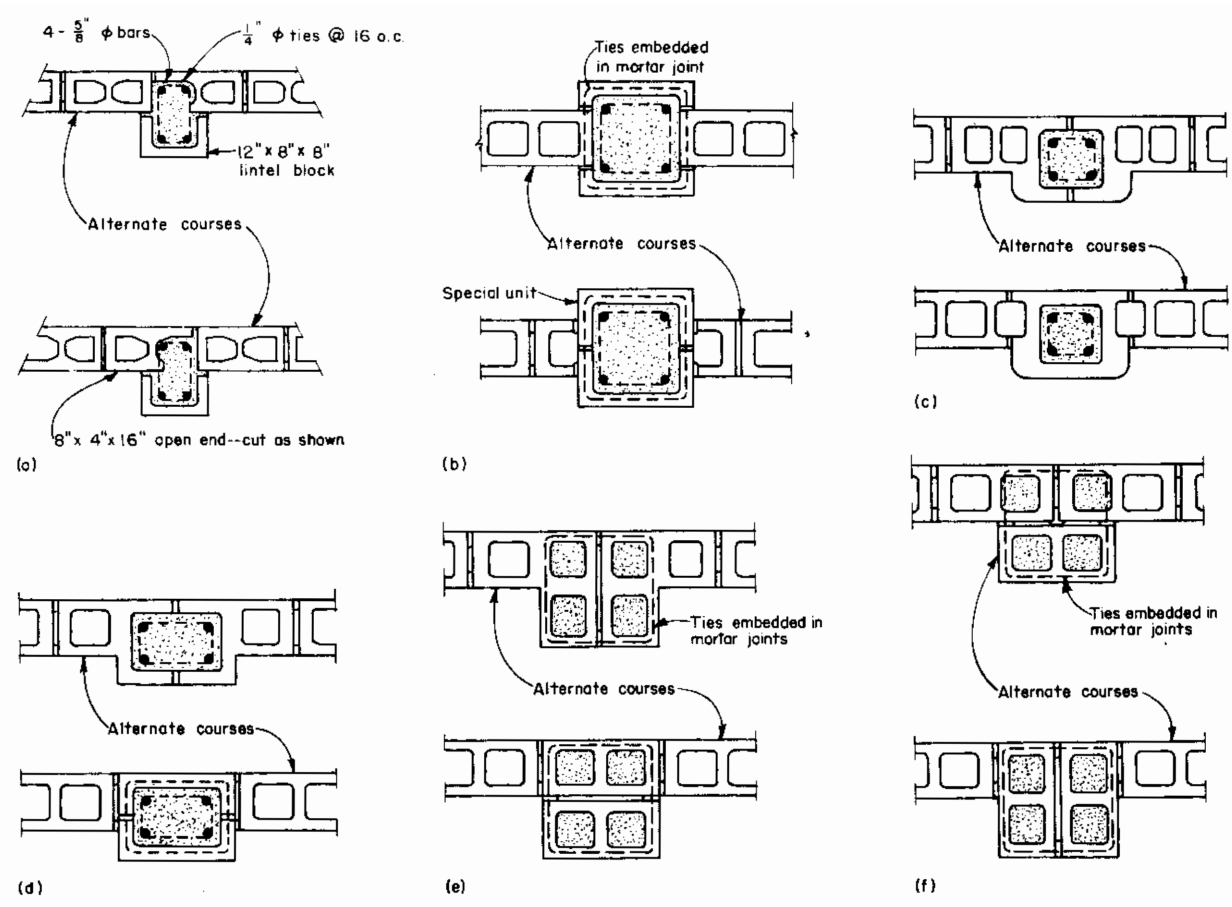


Fig. 4-53

Pilaster layouts.

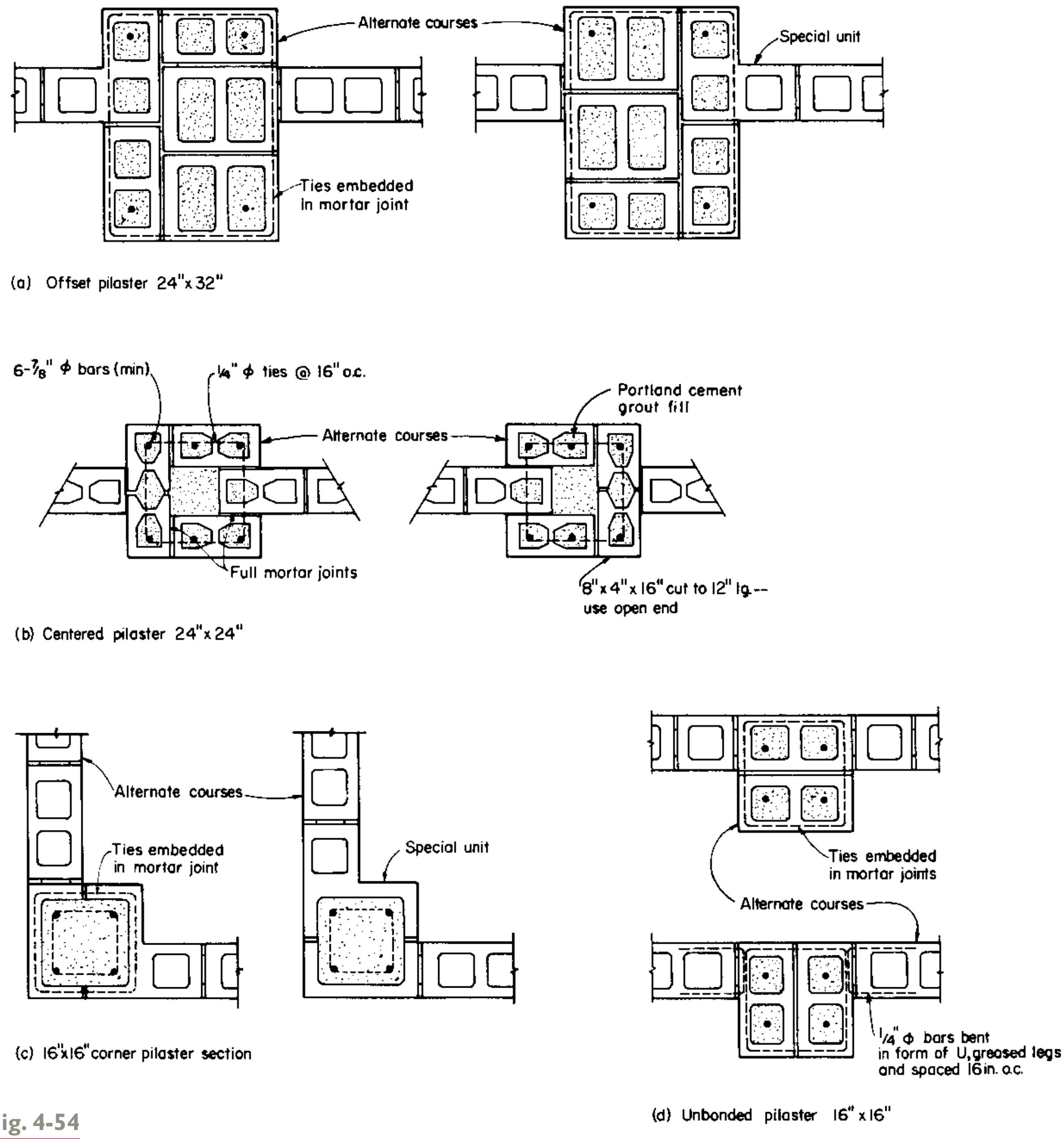


Fig. 4-54

Other pilaster layouts.

Fig. 4-55

Applying flashing at the base of a concrete masonry wall where it meets the footing. The flashing should extend beyond the face of the wall. (IMG24964)

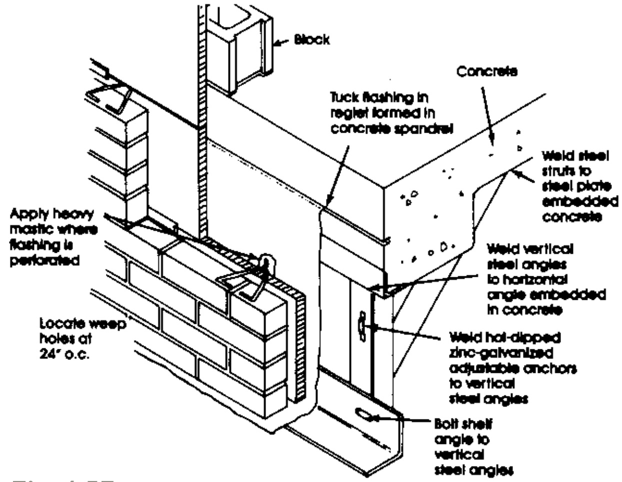


Fig. 4-57

Flashing in brick spandrel supported on steel shelf angle suspended from concrete frame. For this detail and others on flashing for brick spandrel on steel frame, see Laska 1990.

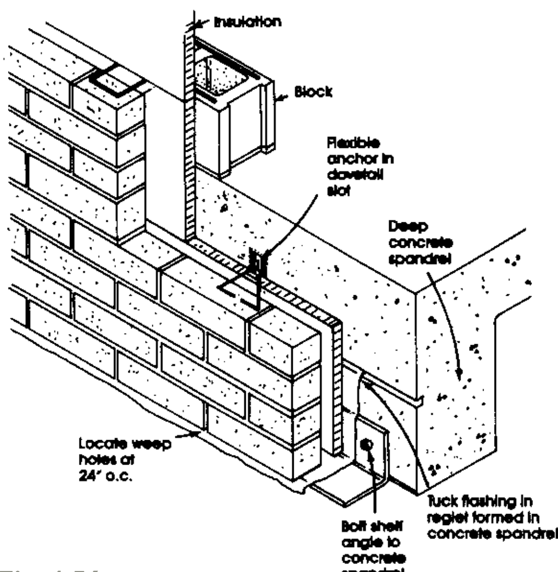


Fig. 4-56

Flashing in brick spandrel supported on steel shelf angle attached to concrete frame. See Laska 1990.

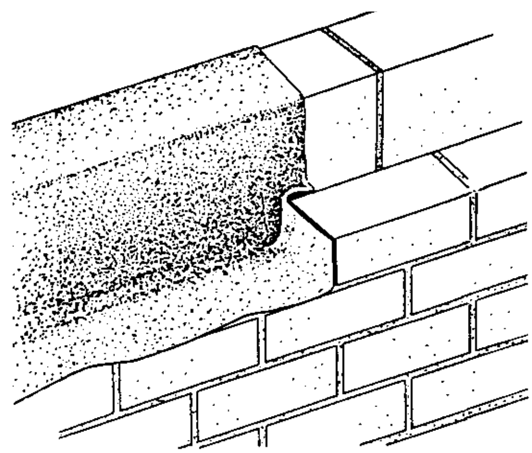


Fig. 4-58

End dam where flashing stops or is not continuous, as at openings in a wall. The flashing shold be turned up into the head joint to form a dam that forces water to flow toward the nearest weephole.

Leaky walls are not confined to any one type of masonry construction. Leaks can occur in walls built of the best materials. The percentage of those that leak is small, but receive a disproportionate amount of attention.

Flashing

Flashing is a sheet material placed at strategic locations in masonry walls to intercept the flow of moisture and direct it to the exterior. It is difficult to completely prevent rainwater from entering walls at locations such as parapets, copings, sills, projections, recesses, and roof intersections, unless proper flashing is installed. In areas subjected to severe driving rains, or where experience has shown that water penetration is to be expected, flashing and weepholes should be provided. Flashing also prevents upward movement of water by absorption; thus flashing should interrupt moisture from the ground. Flashing locations are briefly summarized in Table 4-4 and are discussed more thoroughly below. Design details and examples of flashing and weepholes are shown in Figs. 4-55 through 4-60, in Appendix A, and in Beall 2004 and TEK 19-5A 2004. Specific details for flashing of parapet walls are discussed in Ribar 1991.

Flashing of masonry is simplified if the designer and installer realize that all masonry imbibes water and retains this moisture until it transpires to the atmosphere through evaporation. Also, under adverse rain exposure, masonry walls may allow water penetration. Water penetration is tolerable only when the penetrating water is intentionally directed away from the building interior by through-the-wall flashing that diverts the water to the exterior. Flashing should be provided in all masonry and should extend beyond the face of the wall.

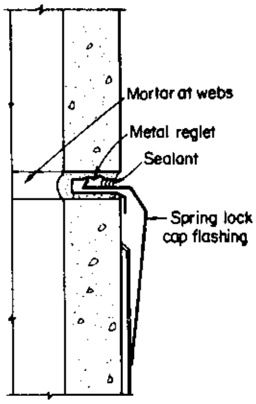


Fig. 4-59

Metal reglet used for flashing at parapets.

Flashing should be continuous or made continuous by lapping and bonding the lap joints. Flashing design and installation should always consider end dams at their terminus. An end dam is formed by turning the ends of the flashing upward, thus fabricating a three-sided reservoir so water is allowed to exit through weepholes (Fig. 4-58).

Any moisture that enters a cavity wall above ground level will gradually travel downward. To divert this water to the exterior of the building, continuous flashing and weepholes are installed at the bottom of a cavity (Fig. A-2, Appendix A).

Where there is a basement and the floor consists of wood joists, the flashing may be located above the bottom of the joists (Fig. A-25, Appendix A). If metal flashing is used, it may be extended at least 2 in. (51 mm) past the inside face of the wall and bend downward at an angle to serve as a termite shield. In past practice, if the flashing was not required to serve as a termite shield, it may have been stopped ½ in. (13 mm) from the outside faces of the wythes; however, current experience is that all flashing should be carried to the face of the wall. In concrete slab-on-ground construction, the flashing extending into the interior wythe may be above the top level of the slab (Fig. A-2, Appendix A).

Flashing should be installed over all windows, doors and other wall openings not completely protected by overhanging projections. Although flashing may not be required under monolithic sills, it is advisable where sill block are used. Both ends of the sill flashing should be extended beyond the jamb line and turned up at least 1 in. (25 mm) into the wall to create an end dam (Fig. 4-58). Where the underside of the sill does not slope away from the wall, or where no drip is provided, the flashing should be extended and bent down to form a drip. Otherwise, water running down windows and over sills will continue down the face of the building and probably cause unsightly stains.

In structural frame buildings the inner wythe of a cavity wall is constructed flush with and anchored to the beams and columns, while the outer wythe is supported by a steel shelf angle attached to a spandrel beam at each floor level (Fig. A-14b, Appendix A). Flashing normally is necessary even when galvanized or stainless steel shelf angles are used. Flashing should be placed on the shelf angle and extended at least 8 in. (203 mm) up and over the beam or anchored into a reglet in the beam.

One detail used for flashing at parapets is shown in Fig. 4-59. Others appear in Figs. A-18, A-20, and A-22 in Appendix A.

Suitable flashing materials must be: (1) impervious to moisture penetration; (2) resistant to corrosion caused by exposure either to the atmosphere or to alkalies present in mortar; (3) sufficiently tough to resist puncture, abrasion, or other damage during installation; and (4) easily formed to the desired shape and capable of retaining this shape throughout the life of the structure. The choice of material is governed mainly by cost and suitability. Select flashing material carefully since repair and replacement costs will be much higher than the original cost.

Materials generally used for flashing are: cold-rolled copper; copper laminates, such as lead-coated copper; galvanized and stainless steels; plastics, such as polyvinyl chloride (PVC) and polyethylene; synthetic rubber compounds, such as ethylene propylene diene monomer (EPDM); bituminous fabrics; and self-adhering, rubberized asphalt membranes. Copper, a durable and easily workable material, has an excellent performance record but is more costly than most other flashing materials. It is available in special preformed shapes. It does not react with fresh mortar unless chlorides are present. When copper is exposed to weather, rainwater runoff may stain or discolor the masonry surfaces below. Where this staining or discoloration is objectionable, coated copper or another flashing material should be used.

Stainless steel is very durable, nonstaining, highly resistant to corrosion, and workable. Stainless steel flashing is available in several gages and finishes. Although it will not stain adjacent areas and resists rough handling, it can be difficult to solder and form.

Bituminous fabrics are less costly but also less durable than copper or stainless steel flashing. Care must be exercised during their installation in order to avoid tears and punctures.

Flashing made of plastic materials is also available. However, not all plastics are suitable for use in contact with mortar and thus it is necessary to rely on the past performance of a particular material before selecting it for use in a concrete masonry wall.

Combination flashing consists of materials combined to utilize the best properties of each effectively. Examples of combination flashing are plastic- or asphalt-coated metals, steel- or fiberglass-reinforced bituminous fabrics, copper-plated stainless steel, multilayered mylar, and fiberglass.

Self-adhering flashing is increasingly popular. These self-sealing, self-healing, flexible, rubberized-asphalt materials are designed for application to masonry, concrete, steel, gypsum, or wood. They are easy to form and join, do not require a separate lap adhesive, but may require a surface conditioner for proper adhesion to dusty, dirty surfaces. To provide a watertight seal, a termination bar should be applied at the top of the flashing when used with steel and wood stud construction. This type of flashing should not be applied at temperatures below 25°F (4°C), and since it degrades in UV light, it should not be left exposed to long periods of sunlight. A metal drip edge is required because the flashing must be stopped ½-in. (13 mm) short of the wall face to prevent deterioration from UV light (see TEK 19-4A 2003).

Flashing will reduce the flexural strength of a wall by reducing its continuity in bending resistance and shear. This is not an important factor for houses and small buildings. However, for buildings with tall or thin walls it must be taken into account by the structural designer.

Fig. 4-60

A rope wick protrudes from a masonry block wall, acting as a weep to provide drainage. Other interesting aspects of this wall include that it is made with two types of architectural concrete units, one having a rounded profile, the other having decorative aggregates and a ground (polished) face. The joints are movement joints as they are filled with sealant and not mortar. (IMG24965)

Weepholes

Weepholes are an inseparable companion to flashing. Weepholes should be provided immediately above all flashing or other waterstops, except where flashing is located under copings, to drain away any accumulated water (Fig. A-2, Appendix A) The holes are usually located in the head joints of the outer wythe and spaced about 2 ft (610 mm) apart, or preferably installed at multiples of the length of the concrete masonry units. Under adverse weather conditions it may be necessary to install weepholes at the base of the first course at all cell (core) locations in the masonry units. In no case should weepholes be located below grade. They should also be kept small to exclude rodents.

Weepholes are formed by: (1) omitting mortar from part or all of a joint, (2) inserting short lengths of greased or oiled rods, tubing, or hose into the mortar and extracting them when the mortar is ready for tooling, (3) inserting short lengths of cotton sash cord (rope wicks) into the joints and leaving them in place permanently, or (4) using proprietary plastic or metal vents. The inserts should extend into the cavity for several inches to provide a drainage channel through any mortar droppings that might have accumulated. It is a good practice to fill the cavity with pea gravel to a level just above the weepholes or cell vents. The gravel acts as a "French drain" and also prevents mortar droppings from accidentally filling the cavity at the weepholes. Also, there are a number of proprietary mortar collection devices available that may be installed at regular intervals in the cavity to prevent mortar from clogging weepholes.

Whenever possible, the cavity side of weepholes should be covered with copper or plastic insect screen cloth to prevent the entry of insects. Material such as fibrous glass or stainless steel wool may also be placed into open weepholes. Sometimes absorbent inorganic material is inserted into the holes to act as wicks, drawing moisture out of the cavity. This is especially recommended over lintel or spandrel flashing to prevent the likelihood of staining the wall below. Cotton sash cord (rope wicks) may serve as dams during heavy water penetration but they are excellent for wicking and removing small quantities of water at the base of the cavity or core (Fig. 4-60). Weepholes filled with inorganic materials should be spaced not more than 16 in. on centers.

With proper design and installation, weepholes also function as vents to discharge moisture as vapor. When cell vents are used in the bottom of a wall and small holes are used at the top of the cavity, the void is vented, allowing quick removal of moisture from the wall. Cell vents may be used at both the top and bottom of walls; this technique is becoming more popular, especially in colder climates.

See Beall 1991; Beall 2003; TEK 19-2A 2004; TEK 19-5A 2004; TEK 19-4A 2003 for more details on weepholes.

Safeguards Against Hurricanes and Earthquakes

In terms of effect of loads on masonry structures, high winds and earthquakes exhibit similarities and differences. Hurricanes and earthquakes exert extreme lateral loads on structures, requiring careful attention to lateral load-resisting systems and connections at intersections of walls and roof or floor diaphragms. In areas at risk of hurricanes and earthquakes, masonry is reinforced to provide for lifesafety. For a discussion of the performance of masonry structures in a recent major earthquake and hurricane, see Klingner 1994 and Samblanet 1996, respectively.

High winds can also exert significant uplift pressures on roofs. Indeed, past investigation of hurricane damage to masonry structures has identified loss of the roof diaphragm as a leading cause of the collapse of masonry walls. As a result, in such areas, roof trusses should be tied to bond beams with hurricane clips or steel anchors. The designer needs to establish that design wind uplift forces will be adequately resisted by the weight of masonry connected to the roof or by vertical reinforcing steel connected to the foundation.

The *MSJC Code* and *IBC* address wind loads in several design methods. In allowable stress, load combinations are used. In strength design, load combinations are used and the result is modified by a strength reduction factor, ϕ. In empirical design, if masonry is part of the lateral force-resisting system, it can only be used where basic wind speeds are not greater than 110 mph (177 km/hr). For other interior and exterior elements that are not part of the force-resisting system, empirical design of masonry is allowed when the exposure will not exceed certain prescribed limitations for building height and wind speed.

The *Standard Building Code* (SBCCI SC 1997), which had been adopted extensively in the southeastern United States, also contained provisions for resistance to high wind forces that are prevalent on the Atlantic and Gulf coasts. The SBC referenced SSTD-10, *Standard for Hurricane Resistant Residential Construction* (SBCCI SSTD-10 1997), which covered prescriptive provisions for residential masonry construction in areas where the fastest mile wind speeds are 90 mph (145 km/hr) or greater.

Building code provisions for seismic design have changed significantly in recent years. These changes include modifications to how seismic loads are determined. Currently, the *IBC* requires that a designer establish the Seismic Design Category (SDC) for a structure. This an involved process which includes consideration of regional seismic activity, site-specific soil characteristics, building use (related to the societal impact of the loss of the structure in an earthquake), and the building's design response to ground motion. Seismic Design Category designations from A (minimum) to F (highest) determine seismic design loads and prescriptive design criteria for key structural elements. Particular attention is required in the design of the lateral force-resisting system to resist seismic loads. In addition to engineered design, the *IBC* and *MSJC* require prescriptive reinforcement for masonry shear walls and additional prescriptive anchorage of elements in higher SDC applications. Chapter 14 of TMS MDG5 2007 and TEK 14-12B 2005 contain additional information on seismic design of concrete masonry.

All-Weather Concrete Masonry Construction

CHAPTER 5

The key to successful and satisfactory construction of concrete masonry in any weather—hot or cold—lies in advance planning and satisfactory preparation. All-weather construction involves some changes in procedures and additional equipment and supplies. The need for these must be anticipated if construction is to be continuous and profitable.

Both hot and cold weather significantly influence the entire masonry construction industry. Hot-weather problems are often encountered but not recognized, resulting in some sacrifice of quality or increase in construction costs. On the other hand, greater extension of the construction season into the winter months in recent years has resulted in better utilization of manpower and encouraged innovative construction techniques.

An important part of planning for all-weather construction is accurate weather-forecasting. Builders can plan their construction on the basis of their own weather experience plus information available from the weather bureau. Weather factors important to concrete masonry construction include temperature, wind, rain, snow, humidity, and sun or cloudiness. Combinations of these factors affect construction workers and materials much more seriously than any single factor.

For example, wind and temperature together create a greater impact or chill factor than temperature alone. The cooling effect of a 20-mph (32-km/hr) wind at 20°F (-7°C) is the same as that of still air at 10 below zero (-23°C). Furthermore, a combination of high temperature, low relative humidity, and high wind can cause the early drying of mortar much more rapidly than can any one of these elements alone.

Although "normal," "cold," and "hot" are relative terms for masonry construction, normal is generally considered to be any temperature between 40°F and 90°F (4°C and 32°C). Building codes and specifications vary somewhat in this respect. In any case, it is important to remember that some problems may be experienced even within this so-called normal temperature range; for example, problems associated with hot weather may occur even when the temperature is below 90°F (32°C).

With modifications in design and construction procedures, concrete masonry construction can be completed satisfactorily despite the weather. In many cases, concrete masonry construction during hot weather may cost little, if any, more than the same construction during normal temperatures. The added cost of masonry construction due to cold weather often amounts to less than 1.5%. As the departure from normal becomes greater, the measures necessary to overcome the effects of temperature become more important and more costly.

Hot-Weather Construction

Hot weather poses some special problems for concrete masonry construction. These arise, in general, from higher temperatures of materials and equipment and more rapid evaporation of the water required for cement hydration and curing. Other factors contributing to the problems include wind velocity, relative humidity, and sunshine.

The *MSJC Specification* (MSJC 2005) defines hot weather construction as any time the ambient temperature exceeds 100°F (37.8°C), or 90°F (32.2°C) with a wind velocity greater than 8 mph (12.9 km/hr). See Table 5-1.

Above: Heated enclosures can extend masonry construction into colder weather — see Fig. 5-7. (IMG12504) Right: Retempering mortar is a common practice, especially during hot weather — see Fig. 2-16. (IMG13630)

Table 5-1. Cold Weather Construction Requirements*

Ambient temperature	**Cold weather procedures for work in progress**
Above 40°F (4.4°C)	No special requirements.
Below 40°F (4.4°C)	Do not lay glass unit masonry.
32°F to 40°F (0 to 4.4°C)	Heat sand or mixing water to produce mortar temperature between 40°F and 120°F (4.4°C and 48.9°C) at the time of mixing. Heat materials for grout only if they are below 32°F (0°C).
25°F to 32°F (-3.9°C to 0°C)	Heat sand or mixing water to produce mortar temperature between 40°F and 120°F (4.4°C and 48.9°C) at the time of mixing. Keep mortar above freezing until used in masonry. Heat materials to produce grout temperature between 70°F and 120°F (21.1°C and 48.9°C) at the time of mixing. Keep grout temperature above 70°F (21.1°C) at the time of placement.
20°F to 25°F (-6.7°C to -3.9°C)	In addition to requirements for 25°F to 32°F (-3.9°C to 0°C), heat masonry surfaces under construction to 40°F (4.4°C) and use wind breaks or enclosures when the wind velocity exceeds 15 mph (24 km/h). Heat masonry to a minimum of 40°F (4.4°C) prior to grouting.
20°F (-6.7°C) and below	In addition to all of the above requirements, provide an enclosure and auxiliary heat to keep air temperature above 32°F (0°C) within the enclosure.
Ambient temperature (minimum for grouted; mean daily for ungrouted)	**Cold weather procedures for newly completed masonry**
Above 40°F (4.4°C)	No special requirements.
25°F to 40°F (-3.9°C to 4.4°C)	Cover newly constructed masonry with a weather-resistive membrane for 24 hours after being completed.
20°F to 25°F (-6.7°C to -3.9°C)	Cover newly constructed masonry with weather-resistive insulating blankets (or equal protection) for 24 hours after being completed. Extend the time period to 48 hours for grouted masonry, unless the only cement used in the grout is ASTM C150 Type III.
20°F (-6.7°C) and below	Keep newly constructed masonry above 32°F (0°C) for at least 24 hours after being completed. Use heated enclosures, electric heating blankets, infrared lamps, or other acceptable methods. Extend the time period to 48 hours for grouted masonry, unless the only cement used in the grout is ASTM C150 Type III.

* Adapted from guide specifications of the International Masonry Industry All-Weather Council (IMIAWC 1993) and MSJC 2005. For more specific details, see MSJC 2005.

Fig. 5-1

Slump block facing used in an arid region where hot-weather construction procedures are regularly practiced. (IMG24174)

Masonry Performance at High Temperatures

As the temperature of mortar increases, there are several accompanying changes in its physical properties:

1. Workability is lessened; that is, for a given workability, more water is required.
2. A given amount of air-entraining agent will yield less entrained air.
3. Initial and final set will occur earlier, while evaporation will generally be faster.
4. Depending on the surface characteristics, temperature, and moisture content of the concrete masonry units, their absorption of moisture from the mortar will be faster.

As a result of these changes mortar will rapidly lose water needed for hydration. Despite its higher initial water content, mortar will be somewhat more difficult to place, and the time available for its use will be shorter.

Early surface drying of mortar joints is particularly harmful. Evaporation removes moisture more rapidly from the outer surface of mortar joints, but the interior retains moisture longer and so develops greater strength. A difference in strength across the thickness of a wall reduces its buckling strength. Also, weak mortar on the surface reduces the strength of a wall exposed to wind and other horizontal forces. For these reasons, during hot weather construction mortar beds should not be spread more than 4 ft (1.22 m) ahead of the masonry being placed, and masonry units should be placed within one minute of spreading the mortar.

Selection and Storage of Materials

During hot weather there is a temptation to reduce the amount of cementitious material in the mortar mixture in order to lessen the heat of hydration released at early ages. Actually, the better solution is to increase the amount of cementitious material. This will accelerate rather than retard the mortar's early-strength gain, and thus secure the maximum possible hydration before water is lost by evaporation.

Mortar materials stored in the sun can become hot enough to significantly affect the temperature of the mortar mixture itself. Covering or shading materials from the sun can be helpful. For example, sand delivered to jobsites normally contains free moisture ranging from 4% to 8%, which is sufficient to ensure that a covered or shaded stockpile of sand remains reasonably cool. If the moisture content drops much below this level, the stockpile should be sprinkled to increase evaporative cooling.

In hot weather the main objective is to see that all of the materials of concrete masonry are placed without having acquired excess heat. Heat should be minimized in concrete masonry units by storing them in a cool place, and the mortar mixture should be relatively cool. The most effective way of cooling mortar is to use cool water during mixing. Immediately after mortar has been mixed, it begins to rise in temperature and must be protected from further heat gain during construction.

Other Construction Practices

Attention should be given to cooling metal equipment with which the masonry materials, particularly mortar, come into contact. Relatively cool mortar can gain heat rapidly when transported in a metal wheelbarrow or other container that has been exposed for hours to the sun's rays. Metal mortarboards can become quite hot and wooden mortarboards can become very absorptive in hot weather. Flushing them with cool water immediately before use, or working under sunshades can lessen such difficulties.

Since wind and low relative humidity cause increased evaporation, the use of wind screens and fog (water) sprays can effectively reduce the severe effects of hot, dry, windy weather. Also, covering walls immediately after construction will effectively slow the rate of moisture loss from masonry. Damp-curing is very effective, particularly in development of tensile bond. If the wall will be subjected to flexure, consideration should be given to damp-curing.

In areas where high ambient air temperatures are common, masonry construction is sometimes rescheduled to avoid hot, midday periods. Construction late in the day, at night, or during the early morning hours can avoid many hot-weather problems.

For more information on hot-weather masonry construction, see PCA IS243 2003.

Cold-Weather Construction

The *MSJC Specification* (MSJC 2005) considers cold weather construction to exist when the ambient temperature, or the temperature of masonry units, falls below 40°F (4.4°C).

Below that temperature the productivity and workmanship of masons and the performance of masonry materials and the completed structure may be lowered.

During cold weather, masons are concerned not only with their normal construction tasks but also with personal comfort, additional materials preparation and handling, and the protection of the structure. As temperatures continue to drop, these extra activities consume more time.

Masonry Performance at Low Temperatures

Immediately after concrete masonry units are laid during cold weather, several factors come into play. The absorptive masonry units tend to withdraw water from mortar, but mortar, having the property of retentivity, tends to retain water. The surrounding air may chill masonry as well as withdraw water through evaporation. Also, if the masonry units are cold when laid, they will drain heat from the mortar. Any combination of these factors can influence strength development.

As the ambient temperature falls below normal, mortar ingredients become colder and the heat-generating reaction between portland cement and water (hydration) is substantially reduced. Hydration and strength development virtually stop at temperatures below freezing. However, construction may proceed at temperatures below freezing if the mortar ingredients are heated. As the ambient temperature decreases further, the masonry units also should be heated, and the structure should be maintained above freezing for several hours after completion of a wall.

Mortar mixed with cold but unfrozen materials possesses plastic properties quite different than at normal temperatures. The water requirements for a given consistency decrease as the temperature falls, more air is entrained with a given amount of air-entraining agent, and initial and final set are delayed. Also, with lower temperature the early strength gain of mortar is less, although final strength may be as high or higher than that of mortar used and cured at normal temperatures.

Heated mortar materials produce mortars with performance characteristics identical to those in the normal-temperature range, and thus heating is desirable for cold-weather masonry construction. Mortars mixed at a particular temperature and subjected to a lower ambient temperature lose heat until they reach the ambient temperature. If the ambient temperature is below freezing when the mortar temperature reaches 32°F (0°C), the mortar temperature remains constant until all water in the mortar is frozen. Afterward, the mortar temperature continues to drop until it reaches the ambient temperature.

The rate at which mortar freezes is influenced by the air temperature and wind, the temperature and properties of masonry units, and the temperature of mortar. When fresh mortar freezes, its performance characteristics are affected by many factors—for example, water content, age at freezing, and strength development prior to freezing. Frozen mortar takes on all the outward appearances of hardened mortar, as evidenced by its ability to support loads as well as its ability to bond to surfaces.

Mortar possessing a high water content expands when it freezes and the higher the water content, the greater the expansion. The expansive forces will not be disruptive if moisture in the freezing mortar is below 6%. Therefore, during cold-weather construction every effort should be made to achieve mortar with a low water content. Dry masonry units and protective coverings should be used.

Mortar that is allowed to freeze gains very little strength and some permanent damage is certain to occur. If the mortar has been frozen just once at an early age, it may be restored to nearly normal strength by providing favorable curing conditions. However, such mortar will be neither as resistant to weathering nor as watertight as mortar that had never been frozen.

Selection of Materials

Cold-weather concrete masonry construction generally requires only a few changes in the mortar mixture. Concrete masonry units used during normal temperatures may be successfully used during cold weather. Under the prevailing recommendations for winter construction (Table 5-1), the masonry units will generally lower the moisture content of the mortar to below 6%; hence, any subsequent accidental freezing should not be disruptive.

At low temperatures, mortar performance can be improved—and an early-strength gain obtained—by use of Type III high-early-strength portland cement (ASTM C 150; or ASTM C 1157 Type HE). Also, mortar made with lime in the dry, hydrated form is preferred to slaked quicklime or lime putty because it requires less water.

Admixtures often considered for use in mortar include antifreezes, accelerators, corrosion-inhibitors, air-entraining agents, and color pigments. Those used with proven success in cold weather are the accelerators and air-entraining agents.

Certain admixtures for mortar are misunderstood. So-called "antifreeze" admixtures accelerate strength gain rather than lower the freezing point. To significantly lower the freezing point of mortar, these compounds, as well as several types of alcohol, would have to be used in such great quantities that the compressive and bond strengths of masonry would be seriously lowered. Therefore, antifreeze compounds are not recommended for cold-weather masonry construction.

The primary reason for using accelerators is to increase rates of early-age-strength development, that is, to hasten the hydration of portland cement in mortar. Accelerators include calcium chloride, soluble carbonates, calcium nitrate, calcium nitrite, calcium formate, sodium thiocyanate, silicates and fluosilicates, calcium aluminate, and organic compounds such as triethanolamine.

The most commonly used accelerator in cast-in-place concrete is calcium chloride. However, its use in mortar is prohibited because of possible adverse side effects, such as increased shrinkage, efflorescence, and particularly corrosion of embedded metal. The *MSJC Specification* (MSJC 2005) requires that any admixture used in mortar contain not more than 0.2 % chloride ions. Where accelerators are desired for use in masonry, nonchloride, noncorrosive accelerators may be used.

The compounds in some proprietary admixtures have been modified to contain corrosion-inhibitors for winter construction of concrete containing embedded metal. Although reports have been published on the performance of corrosion-inhibiting compounds, their value for cold-weather concrete masonry construction has not been fully determined.

Air entrainment increases mortar workability and freeze-thaw durability. The addition of an air-entraining admixture at the mixer on a jobsite is not recommended due to the sensitivity of the admixture and the likelihood of poor control in monitoring air content. Cementitious materials with factory controlled amounts of air-entraining agent, such as masonry cement, mortar cement, air-entraining portland cement, or air-entraining lime, should be used if air-entrainment is desired.

Some pigments contain dispersing agents to speed the distribution of color throughout the mortar mixture. The dispersing agents may have a retarding effect on the hydration of portland cement, and this retardation is particularly undesirable in cold-weather masonry construction. In addition, the masonry may have a greater tendency to effloresce.

The use of any admixture in mortar must be approved by the project engineer.

Storage and Heating of Materials

At delivery time all masonry materials should be adequately protected for any exposure conditions at the construction site. During cold weather the safe storage of mortar materials can be accomplished by providing a shelter (Fig. 5-2). As discussed later in this chapter,

Fig. 5-2

A temporary shelter will protect not only the equipment and materials but also the mixing operation. (IMG15862) shelters may be erected by using scaffolding sections, enclosure covers, and lumber. With a properly erected shelter, mortar materials may be delivered, stored, protected from the elements, heated, and mixed within the shelter.

Regardless of the temperature, all masonry materials should be protected from the weather. Bagged materials and masonry units should be securely wrapped with canvas or polyethylene tarpaulins and stored above ground—for example, on pallets—to prevent moisture migration from the ground. Masonry sand should be covered to keep out rain, snow, and ice.

The most important consideration in heating materials is that sufficient heat be provided to assure cement hydration in mortar. After all materials are combined, the mortar temperature should be within the range of 40°F to 120°F (4.4°C to 49°C). If the air temperature is falling, a minimum mortar temperature of 70°F (21.1°C) is recommended. Mortar temperatures in excess of 120°F (49°C) are not recommended; they pose a personnel safety hazard and may cause excessively fast mortar hardening with a resultant loss of compressive and bond strength. Heating requirements for various air temperatures are given in Table 5-1 and in the *MSJC Specification* (MSJC 2005).

Water

When the weather turns cold, contractors heat the water for two reasons: (1) it is the easiest mortar material to heat; and (2) water can store the most heat, pound for pound, of any of the materials in mortar. Recommendations vary as to the highest temperature to which water should be heated. Some specifiers put a maximum temperature of 180°F (82°C) on the heated water because it poses a personnel safety hazard. Also, there is a possibility of flash set if exceedingly hot water comes into contact with cement. Combining sand and water in the mixer first, before adding the cement, will lower the temperature of the mixture and avoid this difficulty. With this precaution, and the use of aggregates that are cold enough, even boiling water may be used successfully, but with extreme caution. A common way to heat the water on site is to use a propane torch and a steel drum (Fig. 5-4).

Sand

When the air temperature is below 32°F (0°C), sand should be heated and all frozen lumps should be thawed. Generally, the temperature of the sand is raised to 45°F to 50°F (7°C to 10°C). However, if the need exists and facilities are available, there is no objection to raising the sand temperature much higher; 150°F (66°C) is a reasonable upper limit.

Fig. 5-3

Concrete masonry units covered with canvas or plastic tarpaulins to keep the block dry. (IMG12505)

Fig. 5-4

A propane torch is used to heat the water that will be used in mortar mixing. (IMG12507)

Sand should not be heated to a temperature that would cause decomposition or scorching. When siliceous sand is heated above 1000°F (538°C), scorching can occur. There is a practical method of limiting sand temperature—a touch of the hand. The stockpile must be mixed periodically to assure uniform heating.

A commonly used method of heating sand is to pile it over a metal pipe containing a fire (Fig. 5-5). Another method is to use steam circulated through coils or placing sand over electric heating coils. Steam heating systems are an economical source of heat for winter construction.

Fig. 5-5

A propane torch heats the sand pile that is used for mortar mixing. (IMG15858)

Masonry Units

Masonry units can be heated on pallets stored in a heated enclosure or stored in a heated area. If heated enclosures are used for construction, as discussed later, a supply of masonry units can be thawed on the scaffold (Fig. 5-6).

During very cold weather, frozen walls must be heated before grout is poured into cores or cavities. The air temperature in the bottom of the grout space should be raised to above 40°F (4.4°C) before grouting proceeds. Heated enclosures may be used for this purpose.

Construction of Temporary Enclosures

The advantages of uninterrupted construction activity during cold weather have persuaded many contractors to build temporary enclosures. Also, U.S. federal regulations require heated enclosures on government projects to maintain year-round construction.

Fig. 5-6

Masonry units are placed on a mason's scaffold for warming and protection. Plastic tarps over a frame enclose the scaffolding and the wall under construction. (IMG15758)

Providing temporary enclosures for concrete masonry construction has several objectives:

1. To achieve temperatures high enough to facilitate cement hydration in mortar and thus obtain the initial strength required for support of superimposed masonry.
2. To improve the comfort and efficiency of masons and the other crafts.
3. To protect materials.

Enclosure construction may use temporary, independent framework covered with sheet membranes, tarpaulins, or prefabricated panels (Figs. 5-6 and 5-7). Materials for enclosures include lumber, steel, canvas, building paper, and several plastics, such as fiberglass and polyethylene.

Since enclosures are normally built for temporary use, low-cost, lightweight, easily erected and dismantled, but tightly sealed, enclosure construction is the goal. The type of enclosure constructed depends on whether one or more crafts are to be protected, whether the enclosure is provided by the general contractor or the masonry subcontractor, and whether the building has single or multiple stories. Protection may be given to the walls only, the entire building, or just one floor at a time.

The most popular sheet membrane material is polyethylene film in thicknesses of 6 mils to 12 mils (150 mm to 300 mm); it is usually clear plastic to let in the light and heat of the sun. Polyethylene reinforced with fiber

Fig. 5-7

A heated enclosure for masonry construction has many benefits for the contractor, including an earlier completion date and retention of good workers. Masons can work straight through the cold-weather season in northern climates, instead of only 70% of the time. (IMG12504)

Fig. 5-8

When the weather suddenly turned cold, this scaffold was enclosed with polyethylene plastic sheeting. (IMG12508)

or wire mesh is widely used because it is more tear resistant. Fiberglass panels or reinforced polyethylene tarpaulins with grommets can be used again and again.

A common practice in concrete masonry construction is to enclose only the wall by attaching a protective cover to the outside of the mason's scaffold. In Fig. 5-8, when the inner wythes of the wall were laid, the enclosure was fashioned by suspending polyethylene tarpaulins from the building framework (permanent or temporary) several feet behind the mason. Prefabricated panels also could have been used on the framework. They are made with wood frames, plywood corner gussets, and stapled or nailed lattice battens to secure the membrane edges, as shown in Fig. 5-9.

The complete enclosure of a building is usually selected by the general contractor, rather than the masonry subcontractor, or is a requirement of the job specifications. For low-rise buildings, it offers the opportunity of protection for later crafts and for subsequent erection of interior concrete masonry partitions. Generally, low-rise enclosure is accomplished by erecting a temporary framework of timber with polyethylene or canvas cover.

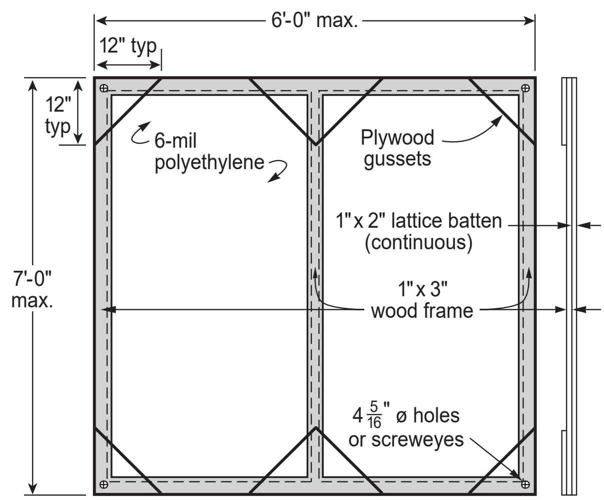


Fig. 5-9

A typical polyethylene enclosure panel.

Complete enclosure of a high-rise building begins with the first floor at ground level. Framework, walls, and the first floor can be built within this enclosure. The enclosure is then lifted for construction of subsequent floors. As the enclosure is lifted, openings in the newly erected walls are closed with temporary panels until the windows and doors are installed. Hence, the entire building may be heated.

Heating of Enclosures

The most economical and convenient source of heat for temporary enclosures will vary from area to area. Natural gas is often selected for its economy, but other heat sources such as electricity, steam, fuel oil, and bottled propane may be more readily available. Consideration should be given to the volume of air to be heated and the cost of bringing the source of heat to the jobsite.

Heat loss or gain is calculated in British thermal units. One Btu (1055 J) is equal to the amount of heat required to raise the temperature of 1 lb (0.45 kg) of water by 1°F (0.56°C). Natural gas rates are often expressed in therms. One therm is equal to 100,000 Btu. Electric rates are based on kilowatt-hours (1 kwh = 3415 Btu). Portable heaters are classified by Btu of heat output. They are manufactured in various sizes ranging up to several million Btu.

Table 5-2 gives the heat loss for a tight polyethylene enclosure. It does not include heat loss through flaps (masons coming and going), cracks, and loose-fitting film. Thus, the tabulated values should be increased 25% to 50% if they are used as a guide to the size of the heater required.

Table 5.2. Heat Loss of Polyethylene Film*

Wind, velocity, mph	Heat loss, Btu per sq. ft. per hour (w/m^2)		
	Per 1°F (0.5°C)	Per 20°F (11°C)	Per 50°F (28°C)
0 (0)	0.70 (2.21)	14 (44)	35 (110)
5 (8)	0.93 (2.93)	19 (60)	46 (145)
10 (16)	1.05 (3.31)	21 (66)	52 (164)
20 (32)	1.17 (3.69)	23 (73)	58 (183)
30 (48)	1.23 (3.88)	25 (79)	61 (192)
40 (64)	1.26 (3.97)	25 (79)	63 (199)

* Source: ASHRAE 1990.

For example, suppose a polyethylene enclosure is:

1. 10 ft (3.05 m) wide, 50 ft (15.24 m) long, and 15 ft (4.57 m) high,
2. a 30-mph (48-km/hr) wind is expected, and
3. the enclosure must be warmed 20°F (11.1°C).

Enclosures at grade have five cold sides. In high-rise construction, however, work might occur one floor at a time, resulting in six cold sides: an unheated floor, directly above the work area, one below, and four sides. Consider six cold sides for this example. As a practical matter, assume that plastic covers all six sides. The volume of the enclosure is 7500 cu ft (212 m^3) and the surface area is 2800 sq ft (260 m^2).

First the enclosure must be warmed 20°F (11.1°C). Knowing that 3600 Btu (3798 kJ) will heat 10,000 cu ft (283 m^3) of air 20°F (11.1°C), we need only 2700 Btu (2849 kJ) to warm the 7500-cu-ft enclosure 20°F. Then, assuming a 50% heat loss through loose flaps and cracks, and based on Table 5.2, the film will lose 25 Btu/sq ft/hr, so total heat loss is 1.5 x 25 Btu/hr x 2800 sq ft = 105,000 Btu/hr to maintain the temperature.

The total heat required the first hour would be 2,700 + 105,000 = 107,500 Btu (113 MJ). One or two heaters with at least this capacity should be provided. Introduce the heat gradually so that the 20°F (11.1°C) temperature rise is spread as uniformly as possible over the first hour. Then the heaters may be throttled down slightly to 105,000 Btu per hour to maintain the proper heat level. To get an idea of the cost of heating this enclosure with natural gas: 100,000 Btu (106 MJ) equals one therm, and the cost of natural gas in recent years has varied between 20 cents and 60 cents a therm.

In some cases the heating plant intended for the building may be used if a release is signed for the heating contractor. For a large building, the builder is typically required to supply temporary heat. Where only the wall under construction is enclosed, light portable heaters are appropriate (Fig. 5-10).

Although venting ductwork can be connected to some portable heaters, ideally a heater should be located outside while blowing hot air into the enclosure. Venting of fossil-fuel burning heaters is very important because

Fig. 5-10

An indirect-fired heater may be used to heat an enclosure. Combustion gases should be vented to the exterior. (IMG12275) they produce carbon dioxide. Venting such heaters assures a safe supply of fresh air to the workmen, thus maintaining their health and productivity.

It should be noted that excessively dry heat may cause rapid drying of the mortar. Thus, live steam is a good alternative heat source for enclosures, although it does have limitations—for example, ice may form on the enclosure.

Other Construction Practices

An important practice during cold-weather masonry construction is to have masonry units delivered dry and kept dry until they are laid in the wall. In addition, masonry units should be laid only on a sound, unfrozen surface and never on a snow- or ice-covered base or bed. Not only is there danger of movement when the base thaws, but there will be little or no bond developed. It is also good practice to heat the surface of an existing masonry course to the same temperature as the masonry units to be added. The heat should be sustained long enough to thaw the surface thoroughly.

During cold weather the mortar should be mixed in smaller quantities than usual to avoid excessive cooling before use. Metal mortarboards with built-in electrical heaters may be used if care is taken to avoid overheating or drying of the mortar. To avoid premature cooling of heated masonry units before they are laid in a wall, only those units that will be used immediately should be removed from the heat source.

Regardless of temperature, care should be taken to prevent concrete masonry units from getting wet before being laid in a wall. In cold weather, wetting of masonry units only adds to the problem of keeping masonry units free of moisture that can freeze on the surface. Wetting of units also increases shrinkage, and defeats the goal of drawing water from the mortar to reach a moisture content level below 6% (to prevent mortar expansion upon freezing).

Tooling time during cold weather is less critical than at normal temperatures, so the mason may lay more masonry units before tooling. In all instances, however, the joint should be tooled before mortar gets too hard. ***Caution:*** premature tooling at day's end will cause lighter joints.

Upon completion of each section or at the end of each workday, measures should be taken to protect new concrete masonry construction. During cold-weather, rapid drying out or early freezing of the mortar should be prevented. The tops of walls must be protected from rain or snow by plastic or canvas tarpaulins extending at least 2 ft (610 mm) down all sides of the construction.

During cold-weather construction, careful attention to quality control should be exercised. As shown in Fig. 5-11, masonry test prisms should be covered and stored in a curing box in a manner similar to the treatment given to concrete test cylinders. The temperature inside the box should be maintained between 60°F and 80°F (16°C and 27°C) as required by ASTM C 31, Standard Method of Making and Curing Concrete Test Specimens in the Field.

Safety precautions require added emphasis during cold-weather construction for several reasons: (1) Workers direct more of their attention to personal comfort and out-of-the-ordinary construction problems due to low temperatures. (2) Workers must overcome personal hazards, such as uncertain footing on ice and snow, and clumsiness due to bulky protective winter clothing. (3) Workers must take extra care with flammable building materials and heaters since the possibility of fire and asphyxiation is increased.

In addition, enclosures built for cold-weather protection should be securely guyed or braced if there is danger of snow and ice loads or wind forces. Snow and ice loads can contribute to overloading an unheated enclosure. Wind forces can make tarpaulins enclosing scaffolds act like sails. Also, the combination of wind forces and the dead weight of stacked masonry units can overload enclosure framework, unless it has been carefully sized and installed.

For additional information on cold-weather masonry construction, see IMIAWC 1993 and PCA IS248 2003.

Fig. 5-11

Concrete masonry test prisms are covered with polyethylene and cured in a heated box. (IMG15865)

Construction Techniques for Concrete Masonry

CHAPTER 6

Man has been building masonry structures for thousands of years, and the methods have been passed on from generation to generation by instruction and example. The techniques of concrete masonry construction are well known to architects, engineers, and builders. The recommendations and explanations given in this chapter reflect the current state-of-the-art.

Quantity Takeoffs

The first step in construction is to estimate the quantity of materials required. The tables on the next three pages may be used as guides for quantity takeoffs of concrete masonry materials.

For single-wythe walls, wall weights and material quantities are given in Table 6-1. Table 6-2 lists material quantities for composite walls bonded with metal ties or masonry headers. The mortar quantities include the customary allowance for waste that occurs during construction for a variety of reasons. For more information on estimating the quantity of mortar required for a masonry job, see "Estimating Mortar Quantities" in Chapter 2.

The breakdown of materials in 1 cu ft (0.03 m^3) of mortar is given in Table 6-3. Note that some of the sample mixes given fit the classification for two types of mortar. This is because mortar specifications permit

Table 6-1. Wall Weights and Material Quantities for Single-Wythe Concrete Masonry Construction*

Nominal wall thickness, in. (mm)	Nominal size (width x height x length) of concrete masonry units, in. (mm)	Average weight of 100-sq ft (10-m^2) wall area, lb (kg)**		Material quantities for 100-sq ft (10-m^2) wall area		Mortar for 100 units, cu ft (m^3)‡
		Units made with sand-gravel aggregate†	Units made with light-weight aggregate†	Number of units	Mortar, cu ft (m^3)	
4 (100)	4x4x16 (100x100x400)	4500 (2230)	3550 (1740)	225 (243)	16.2 (0.46)	7.2 (0.20)
6 (150)	6x4x16 (150x100x400)	5100 (2500)	3900 (1910)	225 (243)	16.2 (0.46)	7.2 (0.20)
8 (200)	8x4x16 (200x100x400)	6000 (2940)	4450 (2180)	225 (243)	16.2 (0.46)	7.2 (0.20)
4 (100)	4x8x16 (100x200x400)	4050 (1980)	3000 (1470)	112.5 (121.5)	10.1 (0.29)	9.0 (0.25)
6 (150)	6x8x16 (150x200x400)	4600 (2250)	3350 (1640)	112.5 (121.5)	10.1 (0.29)	9.0 (0.25)
8 (200)	8x8x16 (200x200x400)	5550 (2720)	3950 (1940)	112.5 (121.5)	10.1 (0.29)	9.0 (0.25)
12 (300)	12x8x16 (300x200x400)	7550 (3700)	5200 (2550)	112.5 (121.5)	10.1 (0.29)	9.0 (0.25)

* Based on ⅜-in. (10-mm) mortar joints.

** Actual weight of 100 sq ft of wall can be computed by the formula WN +145M where W is the actual weight of a single unit; N, the number of units in 100 sq ft of wall; and M, the mortar (cu ft) for 100 sq ft of wall.

† Based on Fig. 1-6, using a concrete density of 138 pcf for units made with sand-gravel aggregate and 87 pcf for lightweight-aggregate units, and the average weight of unit for two- and three-core block.

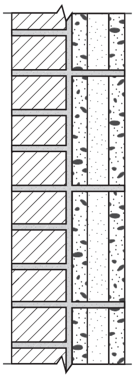
‡ With face-shell mortar bedding. Mortar quantities include allowance for waste.

Above: Placing block into position with the aid of a stringline – see Fig. 6-26. (IMG15841)
Right: Checking for plumb – see Figure 6-17. (IMG15851)

Table 6-2. Material Quantities (Concrete Block, Brick, and Mortar) for 100-sq ft (10-m²) Area of Composite Walls

Wall thickness	Wall section*	No. and size, in. (mm) of block	No. of brick	Mortar, cu ft (m³)**
		Stretchers		
8 (200)	A—metal ties	112.5—4x8x16 (122—100x200x400)	675 (729)	24.3 (0.69)
12 (300)	B—metal ties	112.5—8x8x16 (122—200x200x400)	675 (729)	24.3 (0.69)

* Key for type shown below.
** Mortar quantities based on ⅜-in. (10-mm) mortar joints with face-shell bedding for the block; mortar quantities include allowance for waste. All unit sizes are nominal. Note that the difference in wall thickness does not affect mortar quantities because only face-shell mortar bedding is used.



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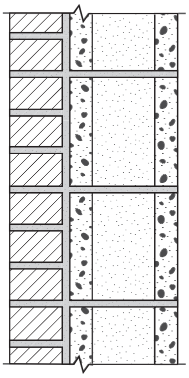


B

Table 6-3. Sample Quantities of Mortar Materials

Mortar type*	Mix proportions, parts by volume**				Material quantities, cu ft (m^3) for 1 cu ft (m^3) of mortar†				
	Portland cement	Masonry cement†	Hydrated lime	Sand	Portland cement	Masonry cement	Hydrated lime	Sand cu ft (m^3)	Mortar quantity cu ft (m^3)
M	1	1	—	6	1 bag	1 bag	—	6	6
M or S	1	—	¼	3	1 bag	—	¼ bag	3	3
N	1	—	1	6	1 bag	—	1 bag	6	6
N or O	—	1	—	3	—	1 bag	—	3	3

* See Chapter 2, "Specifications and Types."
** The proportions shown here fall within the range of mixes allowed in Table 2-1, Chapter 2.
† Type N.

Table 6-4. Volume of Grout in Two-Wythe Grouted Concrete Brick Walls*

Width of grout space, in. (mm)	Grout, cu yd (m^3) for 100-sq ft (10-m^2) wall area**	Wall area, sq ft (m^2), for 1 cu yd (m^3) of grout**
2.0 (50)	0.64 (0.53)	154 (18.7)
2.5 (63)	0.79 (0.66)	126 (15.3)
3.0 (75)	0.98 (0.80)	105 (12.8)
3.5 (88)	1.11 (0.92)	89 (10.8)
4.0 (100)	1.27 (1.05)	79 (9.6)
4.5 (113)	1.43 (1.19)	70 (8.5)
5.0 (125)	1.59 (1.32)	63 (7.7)
5.5 (138)	1.75 (1.45)	57 (6.9)
6.0 (150)	1.91 (1.59)	53 (6.4)
6.5 (163)	2.06 (1.71)	49 (6.0)
7.0 (175)	2.22 (1.84)	45 (5.5)

* Adapted from *MIA 1975*.
** A 3% allowance has been included for waste and job conditions.

Table 6-5. Volume of Grout in Grouted Concrete Block Walls*

Wall thickness, in. (mm)	Spacing of grouted cores, in. (mm)	Grout, cu yd (m^3), for 100-sq ft (10-m^2) wall area**	Wall area, sq ft (m^2), for 1 cu yd (m^3) of grout**
6 (150)	All cores grouted	0.79 (0.66)	126 (15.3)
	16 (400)	0.40 (0.33)	250 (30.4)
	24 (600)	0.28 (0.23)	357 (43.4)
	32 (800)	0.22 (0.18)	450 (54.7)
	40 (1000)	0.19 (0.16)	526 (63.9)
	48 (1200)	0.17 (0.14)	588 (71.4)
8 (200)	All cores grouted	1.26 (1.05)	79 (9.6)
	16 (400)	0.74 (0.61)	135 (16.4)
	24 (600)	0.58 (0.48)	173 (21.0)
	32 (800)	0.49 (0.41)	204 (24.8)
	40 (1000)	0.44 (0.37)	228 (27.7)
	48 (1200)	0.39 (0.32)	257 (31.2)
12 (300)	All cores grouted	1.99 (1.65)	50 (6.1)
	16 (400)	1.18 (0.98)	85 (10.3)
	24 (600)	0.91 (0.76)	110 (13.4)
	32 (800)	0.76 (0.63)	132 (16.0)
	40 (1000)	0.70 (0.58)	143 (17.4)
	48 (1200)	0.64 (0.53)	156 (19.0)

* Adapted from *MIA 1975*.
** A 3% allowance has been included for waste and job conditions. All quantities include grout for intermediate and top bond beams in addition to grout for cores.

Fig. 6-1

Tooling the mortar joints of a split-block concrete masonry wall. The fractured faces of these units produce walls with a rugged appearance. (IMG14600)

a range in the amounts of lime and sand used for any type of mortar. For all practical purposes, the limits of the range of proportions for the various types of mortar coincide.

Tables 6-4 and 6-5 give grout quantities for grouted walls of concrete brick and concrete block, respectively. These tables are also useful for estimating grout in reinforced concrete masonry.

Construction Procedures

Keeping Units Dry

When delivered to the job, concrete masonry units should be stockpiled on pallets or other supports free from contact with the ground and covered with canvas or polyethylene tarpaulins. This keeps the units at equilibrium with the ambient humidity, making them suitable for construction. During construction, the tops of concrete masonry walls should be covered with canvas or polyethylene tarpaulins to prevent rain or snow from entering cores in the block. See Chapter 5 for hot- and cold-weather construction practices, including coverings and enclosures.

Concrete masonry units should never be wetted immediately before or during placement, a practice customary with some other masonry materials. As discussed in Chapter 4, when moist concrete masonry units are placed in a wall, they will shrink when the units dry out. If this shrinkage is restrained, as it usually is, stresses develop that may cause cracks in the wall. Hence, it is important that the units be kept dry, or in equilibrium with the ambient humidity and temperature.

Sometimes it may be advisable to dry concrete masonry units below the moisture content usually specified for the locality; for example, where walls will be exposed to relatively high temperatures and low humidity in interiors of heated buildings. In such cases it is advisable to use units that have been dried to approximately the average relative humidity to which the finished construction will be exposed in service.

Damp concrete masonry units can be stacked to facilitate drying and then artificially dried by blowing heated air through the cores and spaces between the stacked units. An inexpensive and efficient drying method consists of a combination oil- or gas-burning heater and fan. This method of drying works equally well indoors or outdoors and can readily be used in the block plant or at the jobsite.

Mortaring Joints

Two types of mortar bedding are used with concrete masonry: full mortar bedding and face-shell mortar bedding (Fig. 6-2). With full mortar bedding, the unit webs as well as face shells are bedded in mortar. Full bedding is used for laying the first course of block on a footing or foundation wall, as well as for laying solid units such as concrete brick and solid block. Full mortar bedding is also commonly used when building concrete masonry columns, piers, and pilasters that will carry heavy loads. Where some vertical cores are to be solidly grouted, such as in reinforced masonry, the webs around each grouted core should be fully mortared. *For all other concrete masonry work with hollow units, it is common practice to use only face-shell bedding (Fig. 6-3).*

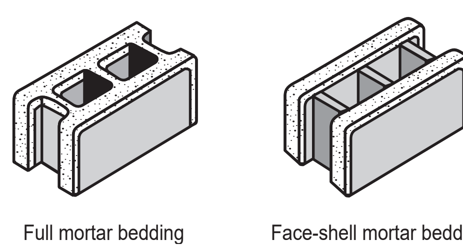


Fig. 6-2

Types of mortar bedding: full (left) and face shell. Normally, only face-shell mortar bedding is used to lay concrete block.

Block

All concrete block should be laid with the thicker part of the face shell up. This provides a larger mortar-bedding area for the bed (horizontal) joints and makes the block easier to lift.

In the past, a mechanical mortar spreader was sometimes used to speed production, especially on long, straight walls. Unfortunately, that equipment is no longer available.

For head (vertical) joints, mortar is applied only on the face-shell ends of block. Some masons butter (mortar) the vertical ends of the previously placed block; others set the block on one end and butter the other end before laying the block. Time can be saved by placing three or four block on end and buttering all vertical edges in one operation (Fig. 6-4). Some masons butter both the block already laid and the next block to be laid (Fig. 6-5); this practice ensures well-filled head joints.

Fig. 6-3

In face-shell mortar bedding, the webs do not receive mortar. (IMG8093)

Fig. 6-4

A mason spreads mortar on the bed joint for three block at a time and then butters the head joints so all three units can be placed in rapid sequence. This is convenient because three block plus mortar joints equals 4 ft (1.22 m), the length of a mason's level. (IMG8082)

Fig. 6-5

A well-filled head joint results from mortaring both block. (IMG15834)

Regardless of the method used to apply mortar to the vertical edges, each block is lifted over its final position in the wall and pushed downward into the mortar bed and sideways against the previously laid block so that mortar oozes out of the head and bed joints on both sides of the face shell (Fig. 6-6). This indicates the joints are well filled.

Fig. 6-6

Each block is pushed downwards and sideways so that mortar oozes out of the head and bed joints. (IMG13629)

Caution: Mortar should not be spread too far ahead of the actual laying of units—otherwise, it may stiffen and lose its plasticity, resulting in poor bond. In hot, dry weather it may be necessary to spread only enough mortar for a few block as they are laid (see Table 5-1 for hot weather requirements).

As each block is laid, excess mortar extruding from the joints is cut off with the trowel and thrown back onto the mortarboard for reuse. Some masons apply this extruded mortar to the vertical face shells of the block just laid. If there has been a delay such that the extruded mortar stiffens on the block before it is cut off, the extruded mortar should be reworked on the mortarboard before reuse. Mortar droppings picked up from the scaffold or floor should never be reused.

Brick

For concrete brick, as well as clay brick, mortar should be spread uniformly thick for the bed joints and furrowed only slightly, if at all (Fig. 6-7). Many specifications and some building codes prohibit furrowing on bed joints. The weight of the brick and the courses above help compact the mortar and ensure watertight bed joints.

Fig. 6-7

For laying brick, the mason spreads mortar uniformly on the bed joints. (IMG17002)

In brick construction, special care should be taken in filling head joints because they are more vulnerable to water penetration than bed joints. If head joints are not completely filled with mortar, voids and channels may permit water (especially wind-driven rain) to penetrate to the inside of the wall. Plenty of mortar should be troweled onto the end of the brick to be placed so that when the brick is shoved into place, mortar will ooze out at the top and around the sides of the head joint, indicating the joint is completely filled (Fig. 6-8). Dabs of mortar spotted on both corners of the brick do not completely fill the head joints, and "slushing"—attempting to fill the joints from above after the brick is placed—cannot be relied on to fill all voids left in the head joints.

Fig. 6-8

Brick is pressed into place so that mortar oozes out of the head and bed joints. (IMG17003)

Laying Up a Wall

First Course

On jobs where more than one mason is working, the footing or slab foundation must be level so that each mason can start his section of wall on a common plane and the bed joints will be uniformly straight when the sections are connected. If the foundation is badly out of level, the entire first course should be laid before masons begin work on other courses, or a level plane should be established with a transit or engineer's level.

After the corners are located, masons often string out the masonry units for the first course without mortar in order to check the wall layout (Fig. 6-9). A chalk line is sometimes used to mark the foundation and help align the block accurately.

Fig. 6-9

To check the layout, the mason may string out the block without mortar. (IMG8080)

Before any units are laid, the top surface of the concrete foundation should be cleaned. Laitance should be removed and aggregate exposed by sandblasting, chipping, or scarifying if necessary to ensure a good bond between masonry and the foundation. Then, a full mortar bed is spread and furrowed with a trowel to ensure plenty of mortar along the bottom edges of the block for the first course (Fig. 6-10). If the wall is to be grouted, the mortar bedding for the first course should not fill the area under the block cores that are to be grouted; the reason for this is that grout should come into direct contact with the foundation.

Fig. 6-11

The corner block is laid first and carefully positioned, then each subsequent block is pushed downward into the mortar bed and sideways against the previous block. (IMG8083)

Fig. 6-10

A full bed of mortar is necessary for laying the first course of block. (IMG8081)

The corner block should be laid first and carefully positioned (Fig. 6-11). After three or four block have been laid, the mason's level is used as a straightedge to assure correct alignment of the block (Fig. 6-12). These units are then carefully checked with the level and brought to proper grade (Fig. 6-13) and made plumb (Fig. 6-14) by tapping with the trowel handle. The entire first course of a concrete masonry wall should be laid with great care, making sure each unit is properly aligned, leveled, and plumbed. This will assist the mason in laying succeeding courses. Any error at this stage—that is, the first course—means continuing difficulty in laying up a straight, true wall.

Fig. 6-12

After corners are laid with great care, the mason's level is used as a straightedge to assure correct alignment of the block. (IMG16337)

Fig. 6-13

Block are leveled by tapping with the trowel handle. (IMG15853)

Fig. 6-14

Tapping with the trowel handle also is used to plumb the block (make it vertically straight). (IMG15850)

Corners

Corner construction precedes laying of units between the corners. The corners of a wall normally are built up higher—four or five courses higher—than the course being laid at the center of the wall. As each course is laid at a corner, it is checked with a level for alignment (Fig. 6-15), for level (Fig. 6-16), and for plumb (Fig. 6-17). In addition, each block is carefully checked with a level or straightedge to make certain that the faces of all the units are in the same plane (Fig. 6-18).

Fig. 6-15

When laying up corners, the mason checks the face of each course for alignment. (IMG15847)

Fig. 6-16

Checking a corner block for level. (IMG15852)

Fig. 6-17

Checking a corner for plumb. (IMG15851)

Fig. 6-18

Checking the faces of block with a level to make certain all are in the same plane. (IMG17004)

Other precautions are necessary at corners to ensure true, straight walls. An accurate method of finding the top of the masonry for each course is provided by use of a simple story pole made from a wood strip with markings 8 in. (203 mm) apart. Alternately, masons can use commercially available metal story poles or common tape measures (Fig. 6-19). Also, since each course is typically staggered one-half unit, the mason can easily check the horizontal spacing of the units by placing his level diagonally across their corners (Fig. 6-20).

Fig. 6-19

Using a tape measure to check the spacing of courses. (IMG15849)

Fig. 6-20

Diagonal check of the horizontal spacing or stagger of units. (IMG16333)

Between Corners

After the corners at each end of a wall have been laid up, a mason's line (string line) is stretched tightly from corner to corner for each course; the top outside edge of each block is laid to this line (Fig. 6-21). The line is moved up as each course is laid. Different devices can be used to fasten the line or to prevent sag between corners, such as:

1. a corner block (Fig. 6-22) held in place at the corner by tension on the line,
2. a line pin (Fig. 6-23) driven into a mortar joint that has set,
3. a line twig (Fig. 6-24) held by a brick and used to eliminate line sag, or
4. a line stretcher (Fig. 6-25) fitted over the top of the wall at any convenient place.

Fig. 6-21

With string line in place, the mason lays block between corners for the third course. Masons have individual ways of gripping the block. (IMG15846)

Fig. 6-22

Corner block used to attach string line. (IMG15848)

Fig. 6-23

Line pin driven into a hardened mortar joint. (IMG24198)

The manner of handling and gripping a masonry unit is important, and the most practical way for each individual is determined through practice. Generally, the mason tips a block slightly towards himself so that he can see the upper edge of the course below and thus place the lower edge of the block directly over it (Fig. 6-26). By rolling the block slightly to a vertical position and shoving it against the previously laid unit, the mason can lay the block to the line with minimum adjustment. This speeds the work and reduces the possibility of breaking mortar bond by not moving the unit excessively after it has been pressed into the mortar. Light tapping with the trowel handle should be the only adjustment necessary to level and align the unit to the mason's line (Fig. 6-27). The use of the mason's level between corners is limited to checking the face of each unit to keep it aligned in a true plane with the face of the wall.

Fig. 6-24

A line twig held in place by a brick eliminates sag in mason's line. (IMG15845)

Fig. 6-26

Tipping the block slightly allows the mason to see the upper edge of the course below so he can place the lower edge of the block directly over the course below. (IMG15841)

Fig. 6-25

A line stretcher fits over the top of the wall at any convenient spot. (IMG15843)

Fig. 6-27

Light tapping with the trowel handle brings the block into position with the string line. (IMG15840)

When steel joint reinforcement is required, it is laid on top of the block and mortar is troweled over it (Fig. 6-28).

Caution: All adjustments to a unit's final position must be made while the mortar is soft or plastic. Any adjustments made after the mortar has stiffened or even partially set will reduce the mortar bond and may cause cracks between the masonry unit and the mortar. This could allow penetration of water. Any unit disturbed after the mortar has stiffened should be removed and relaid with fresh mortar. Realignment of a unit should not be attempted after a higher course has been laid.

Care must be taken to keep the wall surface clean during construction. In removing excess mortar that has oozed from joints, the mason should avoid smearing soft mortar onto the face of the unit, especially if a wall is to be left exposed or will be painted. Numerous embedded mortar smears will detract from the neat appearance of a finished wall. They can never be completely removed, and paint cannot be depended upon to hide them.

Mortar droppings that do stick to the wall should be almost dry before they are removed with a trowel (Fig. 6-29). Then, when dry and hard, most of the remaining mortar can be removed by rubbing with a small piece of concrete masonry (Fig. 6-30) and by brushing (Fig. 6-31).

Fig. 6-28

Joint reinforcement placed in the wall is troweled over with mortar before the next course is placed. (IMG15839)

Fig. 6-29

When almost dry, mortar droppings can be cut off a wall with a trowel to prevent smears. (IMG24177)

Fig. 6-30

Most of the dry mortar remaining on the wall can be rubbed off with a small piece of concrete masonry. (IMG13635)

Fig. 6-31

Brushing—the final step in mortar removal. (IMG15837)

Closure Unit

Before the closure unit is laid in a course of masonry, the length of the opening should be checked in order to avoid joints that are too tight or too wide. If necessary, the closure unit should be accurately measured, sawed (hopefully never), and dressed for a proper fit in the opening.

When installing the closure unit, the mason butters all edges of the opening and all four vertical edges of the closure unit (Fig. 6-32). Then he carefully lowers the unit into place. If any of the mortar falls off, leaving an open joint, the mason should remove the closure unit, apply fresh mortar, and repeat the operation. The mortar joints should then be dressed with the point of the mason's trowel (Fig. 6-33). Closure unit locations should be staggered throughout the height of the wall.

Fig. 6-33

Mortar joints in the closure block are dressed with the point of the trowel. (IMG15832)

Building Composite Walls

In composite action concrete masonry walls, the inner wythe laid is parged (backplastered) with mortar not less than ⅜ in. (10 mm) thick before the adjacent wythe is laid (Fig. 6-34). This provides composite action of the two wythes and helps prevent water penetration through the wall. Before parging, however, mortar protruding from the joints of the first-laid wythe should be cut flush while the mortar is still soft (Fig. 6-35); otherwise, parging over the hardened mortar may break the bond in the mortar joints, resulting in a leaky wall. A plasterer's trowel is more efficient than a brick trowel for parging.

Fig. 6-34

The first wythe of a composite wall is parged with mortar before the adjacent wythe is laid. (IMG4003)

Fig. 6-32

All edges of the opening for the closure block are buttered and the block is carefully lowered into place. (IMG15834)

Fig. 6-35

If the wall is to be parged, extruded mortar from joints should be cut off flush before the mortar hardens. The joints should be left untooled. (IMG24178)

The preferred practice is to place and parge the inner wythe before laying the facing wythe. Parging of facing units is usually discouraged. But if the facing is laid first, a mason's level should be used during parging to support the facing and prevent it from tilting and breaking bond in the mortar joints (Fig. 6-36). With a light facing wythe, however, it is best to lay up the block backing first so that the parging can be applied on the more substantial wythe (Fig. 6-37).

Concrete block can also be used as a backup for facings of natural stone or architectural concrete masonry units. (Fig. 6-38). Because the bed joints in the stone and the block do not line up, corrugated metal strips embedded in the joints can be used to tie the two wythes together.

Fig. 6-36

A level is often used during parging to brace the facing. (IMG16341)

Fig. 6-37

The block backup is the more substantial wythe on which to apply parging. (IMG17041)

Fig. 6-38

Concrete block used as backup for a composite wall covered with architectural concrete masonry units. (IMG24173)

Building Cavity Walls

Cavity walls generally consist of two single-wythe walls separated by a continuous air space 2 in. to 4 in. (50 mm to 102 mm) wide, but connected by rigid metal ties embedded in the mortar joints (Figs. 6-39 and 6-40). The ties should have sufficient mortar cover, as shown in Fig. 4-5c.

During construction of the wythes, the cavity must be kept free of mortar droppings that could form a bridge for moisture to pass across the cavity to the interior wythe. A simple method of maintaining a clear cavity is to catch mortar droppings on a board laid across a tier of ties. When the masonry reaches the next level for installation of ties, the board is raised, cleaned, and

Fig. 6-39

A cavity wall in which the two wythes are held together with unit ties. Note that this cavity also contains insulation board. (IMG15868)

Fig. 6-40

A cavity wall with continuous joint reinforcement, which serves the same purpose as unit ties. (IMG15902)

repositioned (Fig. 6-41). An alternate method of keeping mortar droppings away from weep holes, and thereby maintaining open drainage, is plastic mortar netting (Fig. 6-42).

As an alternative, mortar droppings in the cavity may be avoided by spreading the mortar bed so that it remains back about ½ in. (13 mm) from the edge of the cavity. When the next layer of masonry units are laid, the mortar spreads to the edge of the unit without squeezing out into the cavity. Still another method commonly used is to spread the mortar and then draw the trowel over the mortar in an upward and outward direction away from the cavity, thus forming a beveled mortar bed. When the units are laid on this beveled bed, the mortar spreads only to the cavity edge. In

Fig. 6-41

To keep the cavity clean, a wood strip is laid across the ties in the cavity and lifted to remove mortar droppings after several courses are placed. (IMG18227)

Fig. 6-42

Plastic netting products, like the bright green material at the lower right of the photo, are placed between masonry wythes to catch mortar droppings and prevent clogged weep holes. Photo shows brick veneer, CMU back-up, seismic ties, and flashing material. (IMG24193)

addition, the clean-out opening concept, discussed later in this chapter under "High-Lift Grouting," is also used.

Any mortar fins occurring on the inner faces of the cavity should be troweled flat. This not only prevents the mortar from falling into the cavity but also provides a smooth surface to facilitate placement of insulating materials, if required.

Weepholes are required at the bottom of cavity walls to drain away moisture that may penetrate the wall and run down the inner face of the outer wythe. Weepholes should be located at the bottom of about every second or third head joint in the bottom course of the outside wythe. Cotton sashcord, permanently encased in mortar, makes a good weephole (Fig. 6-43). Flashing (Fig. 6-44) is required in the bottom portion of the cavity wall to direct any water to the weepholes.

During installation of flashing in cavity walls, care must be taken to avoid tearing or puncturing the flashing material, thus destroying its effectiveness. Through-the-wall flashing can be laid over a thin bed of mortar, and then another thin layer of mortar placed on top of the flashing to act as bedding for the next masonry course. If a shelf angle is involved, adhere the flashing to the shelf angle with an adhesive, and then a full bed of mortar can be placed before setting the next masonry course. The seams of the flashing should be thoroughly bonded to ensure continuity of the flashing and prevent penetration of water. Most sheet metal flashing can be soldered, but it requires lockslip joints

Fig. 6-43

Cotton sashcord, permanently encased in mortar, makes a good weephole. (IMG17007)

Fig. 6-44

Flashing is required in cavity walls to direct water to weepholes. (IMG8105)

at intervals to permit thermal expansion and contraction. Plastic flashing, generally joined by heat or appropriate adhesives, does not require expansion seams because it is usually elastic enough to take a certain amount of stretching. Additional information on flashing and weephole construction is given at the end of Chapter 4, in Appendix A, and in Beall 2004; TEK 19-5A 2004; Beall 1991; Ribar 1991; and TEK 19-4A 2003.

The cavity-side face of the interior wythe can also be parged to provide an effective barrier to water penetration. Refer to the earlier section on "Building Composite Walls" and to PCA PA043 1992 for more information on parging.

Fig. 6-45

Reinforced concrete masonry walls are used to safeguard against high winds, hurricanes, and earthquakes. (IMG15830)

Building Reinforced Walls

For reinforced masonry wall construction (Fig. 6-45), the procedures used in laying masonry units, placing reinforcing bars, and pouring grout vary with the size of the job, the equipment available, and the preferences of the contractor. Therefore, this section covers only the general requirements of common practice.

Reinforcing Bars

In 1995, the American Society for Testing and Materials (ASTM) began the process of revising the metric bar sizes in the ASTM specifications for reinforcing bars. The aim of the proposed revisions was soft metrification of the inch-pound bar sizes in the specifications. In 1996, the revisions were approved by ASTM. The "soft metric conversion" of the inch-pound bar sizes is shown in Table 6-6. Soft metric conversion means describing the nominal dimensions of inch-pound reinforcing bars in metric units, but not physically changing the bar sizes.

Several rebar-producing mills announced in early 1997 they were beginning to phase in the production of soft metric bars. Within a few years, the shift to exclusive production of soft metric reinforcing bars was essentially achieved. Virtually all reinforcing bars currently produced and used in the U.S. are soft metric. The steel mills' initiative of soft metric conversion enables the industry to furnish the same reinforcing bars to inch-pound construction projects as to metric construction projects, and eliminates the need for the steel mills and fabricators to maintain a dual invertory. Today, U.S.-

Table 6-6. Comparison of Inch-Pound and Metric Bar Sizes*

Inch-pound bar size designations**	Nominal diameter, in. (mm)	Metric bar size designations†
#3	0.375 (9.5)	#10
#4	0.500 (12.7)	#13
#5	0.625 (15.9)	#16
#6	0.750 (19.1)	#19
#7	0.875 (22.2)	#22
#8	1.000 (25.4)	#25
#9‡	1.128 (28.7)‡	#29‡
#10	1.270 (32.3)	#32
#11	1.410 (35.8)	#36
#14	1.693 (43.0)	#43
#18	2.257 (57.3)	#57

* Adapted from NIBS 1996.
** Adapted from ASTM A615, A616, A617, and A706.
† Adapted from ASTM A615M, A616M, A617M, and A706M.
‡ Maximum size reinforcement allowed in masonry (MSJC 2005).

produced reinforcing bars furnished to any construction project most likely will be soft metric.

Throughout the *Concrete Masonry Handbook,* the new metric rebar designations are given in parentheses following the "old" designations. Readers should refer to Table 6-6 if the metric and inch-pound bar size designations cause confusion. Note that only two bars share the same size designation (#10); but the #10 inch-pound bar has a diameter that is more than three times that of the #10 metric bar.

Procedures Before Grouting

Solid or hollow concrete masonry units should be laid so that their alignment forms an unobstructed, continuous series of vertical cores within the wall framework. Spaces in which reinforcement will be placed should be at least 2 in. (51 mm) wide. No grout space should be less than ¾ in. (19 mm) or more than 6 in. (152 mm) wide; if the grout space is wider than 6 in. (152 mm), the wall section should be designed as a reinforced concrete member.

Two-core, plain-end units are preferable to three-core units because the larger cores allow easier placement of reinforcing bars and grout. Also, two-core units are more easily aligned to form continuous, vertical spaces. When A-shaped, open-end masonry units (Fig. 4-9) are used, they are arranged so the closed ends are not abutting.

The mortar bed under the first course of block should not fill the core area to be grouted because the grout must come into direct contact with the foundation. All head and bed joints should be filled solidly with mortar for the full thickness of the face shell. With plain-end units, however, it is not necessary to fill the head joint across the full unit width. Also, when a wall is to be grouted intermittently—that is, for reinforcement spaced at 16, 24, 32, or 48 in. (406, 610, 813, or 1219 mm) on center—the webs at the edges of those cores destined to contain grout are mortared. When the wall is to be solidly grouted, none of the cross webs need be mortared since it is desirable for the grout to flow laterally and form the bed joints at all web openings.

Mortar protrusions that cause bridging and could restrict the flow of grout require an excessive amount of vibration or puddling to assure complete filling of the grout space. Hence, care is necessary that mortar projecting more than ⅜ in. (10 mm) into the grout space be removed, and that excess mortar not extrude and fall into the grout space. The mason can prevent mortar from extruding into the grout space by placing the mortar no closer than ¼ in. to ½ in. (6.4 mm to 13 mm) from the edge of the grout space and troweling the mortar bed upward and outward, away from the edge, thus forming a bevel. Mortar droppings in the collar joint or grout spaces of multiwythe walls can be caught and removed by using a wood strip as described in the preceding section on cavity wall construction.

Vertical reinforcement may be installed before or after the masonry units are laid. When the reinforcing bars are placed before the units, the use of two-core, open-end, A- or H-shaped units (Figs. 4-10a, b and 1-29c) becomes desirable in order to thread the units around the reinforcing steel. When the bars are placed after the units are laid, adequate positioning devices are required to prevent displacement during grouting. Both vertical and horizontal reinforcement should be accurately positioned and rigidly secured at intervals by wire ties or spacing devices (Fig. 6-46). The distance between reinforcement and the masonry unit must not be less than ¼ in. (6.4 mm) for fine grout or ½ in. (13 mm) for coarse grout.

Horizontal reinforcement is placed as the wall rises. The reinforcing bars are positioned in bond-beam, lintel, or channel units, which are then solidly grouted (Figs. 6-47 and 6-48). Where the wall itself is not to be solidly grouted and cored bond-beam units are used, the grout may be contained over open cores by placing a grout barrier, such as metal lath, in the horizontal bed joint before the mortar bed is spread for the bond-beam units. Paper or wood should not be used as a grout barrier because of fire resistance requirements.

Fig. 6-48

Horizontal reinforcing bars positioned in a bond beam that will be solidly grouted. (IMG24196)

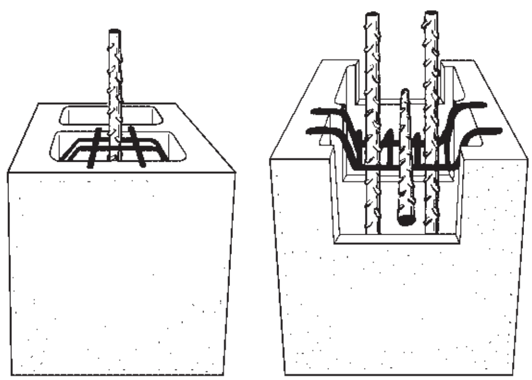


Fig. 6-46

Reinforcing bar spacers.

To ensure solid grouting of bond beams, it may be necessary to fill those portions of the bond beams between the vertically grouted cores as the bond-beam courses are laid, especially if the spacing of vertically grouted cores is greater than 4 ft (1.22 m). Otherwise, grout may not flow far enough horizontally from the cores being grouted to completely fill the bond beams.

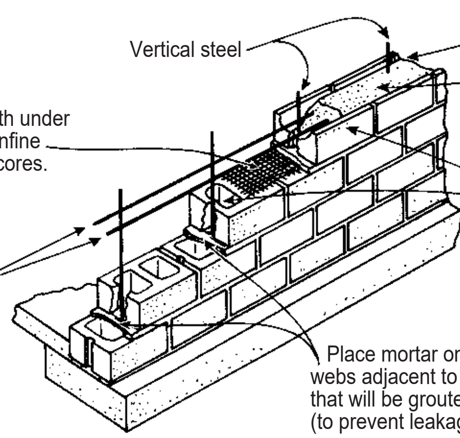


Fig. 6-47

Low-lift grouting of a typical single-wythe reinforced concrete masonry wall.

A concrete masonry wall should be grouted as soon as possible to reduce shrinkage cracking of the joints. However, placing grout before the mortar has been allowed to cure and gain sufficient strength may cause shifting or blowout of the masonry units during grouting operations. Therefore, to fill the cavity in two-wythe masonry or in large cavities of masonry sections made up of two or more units and containing vertical joints—such as pilaster sections (Figs. 6-49 and 6-50)—grout should be poured only after the mortar in the entire height of the masonry has been cured a minimum of 3 days during normal weather or 5 days during cold weather. The hydrostatic or fluid pressure exerted by freshly placed grout on the masonry shell may be ignored when filling hollow-core masonry units; thus, it is necessary to cure mortar in hollow-unit masonry walls for only 24 hours before grouting.

Fig. 6-49

In this pilaster, a set of four reinforcing bars is connected with ties held in place with soft iron wire. (IMG24199)

Fig. 6-50

Large cavities in masonry sections made up of two or more units and containing vertical joints, such as this wall, require sufficient time for the mortar joints to cure before grouting. (IMG15829)

Low-Lift Grouting

A "lift" is a layer of grout pumped or poured in a single continuous operation. A "pour" is considered to be the entire height of grouting completed in one day; it may be composed of a number of successively placed grout lifts.

Of the two grouting procedures in general use—low- and high-lift grouting—low-lift grouting is the simplest and most common. This procedure requires no special concrete masonry units or equipment.

In low-lift grouting of a single-wythe wall, the wall is built to a height not exceeding 5 ft (1.52 m) before grout is pumped or poured into the cores. This operation is repeated by alternately laying units and grouting at successive heights not exceeding 5 ft (1.52 m) each. In high-lift grouting, the wall is built to full story-height before grouting the cores or cavities.

Typical reinforced, single-wythe, hollow-masonry construction using low-lift grouting is shown in Fig. 6-47. Vertical cores to be filled should have an unobstructed alignment. Refer to Table 2-10 for minimum grout space dimensions.

The vertical reinforcing bars may be relatively short in low-lift grouting because they need only extend above the top of the lift a moderate distance for overlap with the reinforcing bars in the next lift. The minimum lap splice length required for bars in tension or compression is determined by an equation contained in both the allowable stress and strength design chapters of the *MSJC Code* (MSJC 2005), but may not be less than 12 in. (305 mm).

As an alternative, vertical steel may extend to full-wall-height for one-story construction or to ceiling height (plus overlap for splicing) for multistory construction. However, since the longer lengths of steel require the use of open-end units, some masonry contractors prefer to lap the steel just above each 5-ft (1.52-m) lift.

Grout is moved from the mixer to the point of deposit in the grout spaces as rapidly as practical (Figs. 6-51, 6-52, and 6-53). Pumping or other placing methods that prevent segregation of the mixture and limit grout

Fig. 6-51

Grout from a hopper is placed into a wall by gravity using a vertical hose. (IMG15828)

Fig. 6-52

While helping to handle the grout hose, a worker controls the pump shutoff with a button in his right hand. (IMG15827)

Fig. 6-53

Note that grouting for smaller jobs may also be performed with a 5-gallon bucket. (IMG15826)

splatter are used. On small projects, grout is poured with buckets having spouts or funnels to confine the grout and prevent splashing onto the face or top surface of the masonry. Grouting should be done from the inside face of the wall if the outside will be exposed. Dried grout can deface the exposed surface of a wall and be detrimental to the mortar bond of the next masonry course. On most projects, grout pumps are recommended to save time and money.

Whenever work is stopped for one hour or longer, a horizontal construction joint should be made by stopping the grout pour about 1 in. (25 mm) below the top of the masonry unit to form a key with the next grout lift (Fig. 6-54).

During placement, grout should be rodded—usually with a 1x2-in. (25x51-mm) wooden stick—or mechanically vibrated to ensure complete filling of the grout space and solid embedment of the reinforcement. It takes very little effort to consolidate the grout properly because of its fluid consistency. When high absorption masonry units are used, it may be necessary to rerod or revibrate the grout 15 to 20 minutes after placement;

Fig. 6-54

Grouting is stopped about 1 in. (25 mm) below the top of the block to form a key with the next lift. (IMG17008)

this will overcome any separations of the grout from the reinforcing steel and eliminate voids caused by settlement of the grout and absorption of water from the grout into the surrounding masonry. Over-vibration, however, must be carefully avoided at this stage. More hazardous than during initial consolidation, over-vibration at this stage could cause blowouts, broken ties, cracked masonry units, or segregation of the grout.

In low-lift grouting of masonry with two or more wythes, the exterior wythe is laid up a maximum of 18 in. (457 mm) above the interior wythe. After the interior wythe is laid, the cavity between the wythes is grouted in lifts not to exceed six times the width of the grout space, with a maximum of 8 in. (203 mm). A minimum mortar curing period is not necessary before grouting. Grout is poured into the grout space to within 1 in. (25 mm) of the top of the interior wythe and then consolidated.

Where there are more than two wythes, the middle wythe (usually of brick size) may be built by "floating" the units into the grout space—that is, pushing the units down into the grout so that a ¾-in. (19-mm) depth of grout surrounds the sides and ends of each unit. No units or pieces of a unit less than 10 cu in. (160 cm^3) in size should be embedded in the grout by floating. (It should be noted that some professionals consider "floating" uneconomical because the brick will usually be more expensive than the volume of grout displaced.

High-Lift Grouting

With this procedure, grouting is delayed until the wall has been laid up to full-story-height. When certain conditions are met—masonry has cured for at least 4 hours, the grout slump is 10 in. to 11 in. (250 mm to 275 mm), and there are no intermediate bond beams—grout can be placed in lifts up to 12.67 ft (3.86 m). High-lift grouting is intended for use on wall construction where reinforcement, openings, and masonry unit arrangements permit the free flow of grout and allow the use of mechanical vibration to properly consolidate the grout in all cores and horizontal grout spaces. The vertical cores should have an unobstructed alignment with a minimum dimension of 3 in. (76 mm) and a minimum area of 9 sq in. (58 cm^2) for a 12-ft (3.66-m) pour of coarse grout (see Table 2-10 for other requirements). In two-wythe masonry, the minimum dimension of the grout space (cavity) between wythes is 2 in. or 3 in. (51 mm or 76 mm), depending on the governing code and pour height (Table 2-10); the maximum is 6 in. (152 mm).

Vertical bulkheads extending the full height of the wall should be provided at about 26 ft (7.92 m) intervals to control the flow of the grout horizontally. In a hollow-unit masonry wall, such barriers are made by placing mortar on cross webs and blocking the bond-beam units with masonry bats (pieces of broken brick) set in mortar. In a multiwythe wall, the barriers are laid into the grout spaces as the wall is erected. In addition to confining grout to a manageable area, these barriers may be used as stiffeners or points at which to locate wall bracing.

Proper preparation of the grout spaces is an important feature of high-lift grouting. Before grouting, it is necessary to remove all mortar droppings and debris through cleanout openings. Not less than 3 in. (76 mm) in size, a cleanout opening should be located at the bottom of every core in hollow-unit reinforced masonry containing dowels or vertical reinforcement, and in at least every other core that is grouted but has no vertical bars. Cleanouts should be provided in solidly grouted masonry at a maximum spacing of 32 in. (813 mm) on center. In a two-wythe masonry wall, the cleanouts may be provided at the bottom of the wall by omitting alternate units in the first course of one wythe. The governing building code or standard should be consulted to verify requirements for cleanout openings.

Cleanout openings in the face shells of units should be made before the units are laid. Special scored units that

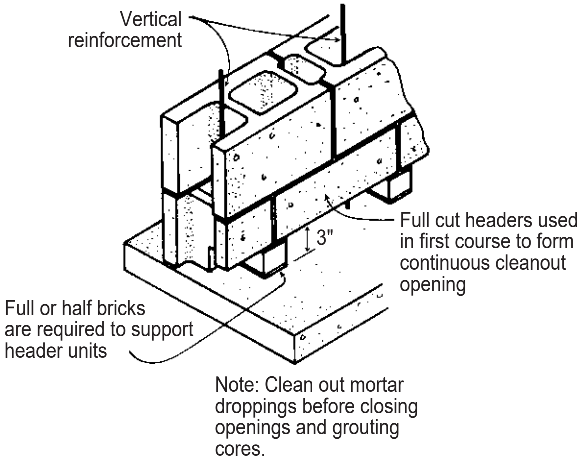


Fig. 6-55

Cleanout opening detail (alternate).

permit easy removal of part of a face shell are sometimes used. Also, an alternate cleanout design makes use of header units as shown in Fig. 6-55.

Good practice is to cover the bottom of a grout space with polyethylene sheeting or a 2-in. to 3-in. (51-mm to 76-mm) layer of sand to act as a bond-breaker for the mortar droppings. The grout space should be flushed at least twice a day (midday and quitting time) with a high-pressure stream of water. In a better procedure that keeps the masonry from being moistened unnecessarily, the mortar droppings and projections are dislodged with a long rod as the work progresses. After the masonry units are laid, the sand or polyethylene sheeting is removed, compressed air is used to blow any remaining mortar out of the grout space, and the space is checked for cleanliness and the reinforcement for position. A mirror is a good inspection tool for looking up into the grout space through a cleanout opening.

Before grouting, the cleanout openings are closed by inserting masonry units, replacing the face shells that were originally removed from the units, or by placing formwork over the openings to allow grouting right up to the wall face. Grouting need not be delayed until the face-shell plugs or cleanout closure units are cured, but they should be adequately braced to resist the grout pressure.

In high-lift grouting, intermediate horizontal construction joints are usually not permitted. Once the grouting of a wall section is started, one pour of grout to the top of the wall, in 5-ft (1.52-m) maximum lifts, should be planned for a workday. Should a blowout, equipment breakdown, or any other emergency stop the grouting operation, a construction joint may be used if approved by the inspector. The alternatives are to wash out the fresh grout—or rebuild the wall.

For economical placement, a uniform 5-ft (1.52-m) lift of grout is generally pumped into place and immediately—not more than 10 minutes later—consolidated by vibration. Each succeeding lift of grout is pumped and consolidated after an appropriate lapse of time, generally 30 to 60 minutes, depending upon weather conditions and the masonry's absorption rate. This lapse of time allows for settlement shrinkage and absorption of excess grout water by the masonry units. The waiting period also reduces the hydrostatic pressure of the grout and thus the possibility of a blowout. In each lift, the top 12 in. to 18 in. (305 mm to 457 mm) of grout is revibrated before or during placement of the succeeding lift.

In multiwythe wall construction, the total length of wall that can be grouted in one pour is limited. This length is determined by the number of sections (bounded by vertical bulkheads) that can be grouted while still maintaining the one-hour maximum interval between successive lifts in any section.

The maximum height of pour is limited by the requirements listed in Table 2-10 and by practical considerations, such as segregation of grout, the effect of dry grout deposits left on masonry units and reinforcing steel, and the ability to consolidate the grout effectively. The height of pour may be governed by story height. Thus, an 8-in. (203-mm), single-wythe wall may have a 20-ft (6.10-m) pour height. When the grout pour height exceeds 8 ft (2.44 m), building codes sometimes require special inspection of the work.

Extreme care should be used to prevent grout from staining masonry walls that will be exposed to view, especially in architectural uses of concrete masonry. If grout does contact the face of the masonry, it should be removed immediately by washing. Also, soon after the wall has been fully grouted, all exposed faces showing grout scum or stains (percolated through the masonry and joints) should be washed down thoroughly with a high-pressure water stream. If necessary, further cleaning may be done after curing and before final acceptance by the architect.

The time- and money-saving advantages of high-lift grouting on large projects are obvious. The vertical steel can be placed after the wall is erected to full-story height, and even on a job of moderate size, the grout can be supplied by a ready-mix producer and pumped in a continuous operation. The main disadvantages of high-lift grouting may be the need for a grout pump, or other means of pouring grout rapidly, and the requirement for cleanout openings at the base of the wall.

See TEK 9-4A 2005 and TEK 3-2A 2005 for more information on grout and grouting for reinforced masonry walls.

Tooling Mortar Joints

The weathertightness of joints and the neat appearance of concrete masonry walls are dependent to a great extent on proper tooling. Tooling is the compressing and shaping of the mortar face of a joint with a special tool that is slightly larger than the joint. (Fig. 6-56). After a wall section has been laid and the mortar has become thumbprint-hard, joints are usually considered ready for tooling. Thumbprint-hard may be defined as that condition when a clear thumbprint can be impressed into the mortar joint without cement paste adhering to the thumb.

Sometimes units are laid almost up to quitting time, and the last units are tooled too early. Early tooling brings more paste to the surface, and the joints will be lighter in color. If some joints will be tooled early, then all joints should be tooled early so that all the mortar surfaces are more uniform than mortar tooled at varying time periods after placement. During hardening, mortar has a tendency to shrink slightly and pull away from the edges of the masonry units. Proper use of a jointing tool restores the intimate contact between the mortar and the units and helps to make joints weathertight. Proper tooling also produces uniform joints with sharp, clean lines.

Fig. 6-56

Tooling a horizontal concave-type joint. (IMG14600)

Horizontal (bed) joints should be tooled before vertical (head) joints. A jointer for tooling horizontal joints should be at least 22 in. (559 mm) long, preferably longer, and upturned on at least one end to prevent gouging (Fig. 6-56). A jointer for vertical joints is smaller and S-shaped (Fig. 6-57). Vertical joints should be struck upward to close the gap between extruded mortar and the unit. Plexiglas jointers are available to avoid staining white or light-colored mortar joints. After the joints have been tooled, any mortar burrs that are left should be trimmed off flush with the face of the wall by using a trowel or a plastic loop (Fig. 6-58). Finally, joints are dressed with a burlap bag, carpet, or brush (Fig. 6-59).

Fig. 6-57

Tooling a vertical joint. (IMG14599)

Fig. 6-58

Mortar burrs are trimmed off after the joints are tooled. For easier removal of burrs from a split-face wall, the mason uses a plastic loop instead of a trowel. (IMG14598)

Fig. 6-59

Dressing masonry with a brush after tooling. (IMG14602)

The principal types of mortar joints used in concrete masonry are shown in Fig. 6-60. The concave, vee, raked, and beaded types need special jointing tools, whereas the flush, struck, and weathered types are finished with a trowel. The extruded type (also called skintled or weeping) is made by using extra mortar that is squeezed out or extruded as the units are laid; it is not trimmed off, but left to harden. Extruded joints are not recommended for walls that will be exposed to heavy rains, high winds, freezing temperatures, or walls to be painted.

Vee joints are usually narrow in appearance and have sharp shadow lines. Concave joints (pictured in Fig. 6-56) have less pronounced shadows. Both types, when properly tooled, are very effective in resisting rain penetration. They are recommended for exterior weather-tight walls, as are weathered joints.

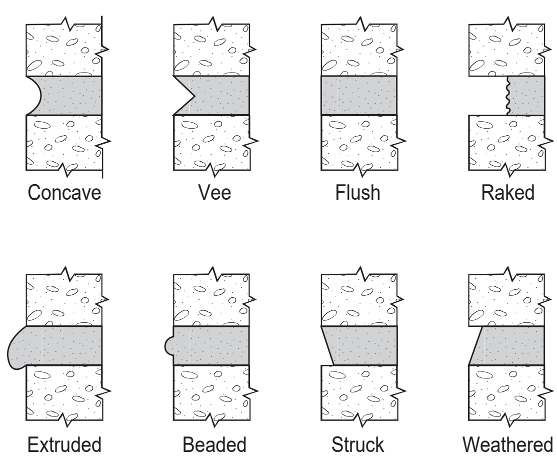


Fig. 6-60

Principal types of mortar joints.

Flush joints are simple to make because the excess mortar is simply trimmed off with a trowel (striking upward rather than downward) and the flush face rubbed with a carpet-covered wood float. In this type of joint the mortar is not compacted by tooling, and small hairline cracks produced when the mortar is pulled away from the units by the trimming action may permit infiltration of water into the wall. Flush joints are used in walls that will be plastered.

Raked joints (pictured in Fig. 6-61) are made with a special tool called a joint raker or a skate. The mortar is removed to a depth of not more than ½ in. (13 mm). Raked joints produce dark shadows that accent the masonry pattern. Since raked joints create ledges that hold rain, snow, or ice that may affect the watertightness of a wall, they are best suited to dry climates or interior use. It should also be noted that raked joints provide less corrosion protection for joint reinforcement. Without special consideration, very little mortar, only about ⅛ in. (3.2 mm), is left to protect the reinforcement from the weather. Reinforcement should have a minimum mortar cover of ⅝ in. (16 mm) for masonry exposed to weather or earth.

Fig. 6-61

Raked joints create stronger shadow lines and accentuate the outline of the block. (IMG17009)

Beaded joints are basically extruded joints that are tooled with a special bead-forming jointer. The beads protruding on the wall surface present strong shadow lines, but special care is required to obtain a straight line appearance.

The struck and weathered mortar joints are generally used to emphasize horizontal lines. Struck joints are easy to make with a trowel, especially if the mason works from the inside of the wall. However, their small ledges do not shed water readily, making them unsuitable for use in areas where heavy rains, driving winds, or freezing temperatures are common. On the other hand, weathered joints—one of the types recommended for weathertight walls—shed water easily but require careful finishing; they must be worked with a trowel from below.

The overall appearance of a masonry wall depends not only on the joint treatment but also on the color uniformity of the joints. Although mortar shade is influenced to some degree by the moisture condition of the units and by the atmospheric conditions, it depends mainly on the uniformity of the mortar mixture and the time of joint tooling. The amount of water used in mixing colored mortar greatly influences the shade and thus requires accurate control. Colored mortar is usually not retempered, since additional water may cause a significant lightening of the mortar. Any colored mortar that has become too stiff for use should be discarded. A darker color results if the mortar is tooled when relatively hard rather than reasonably plastic, but some masons consider mortar ready for tooling only when thumbprint-hard. Uniform time of tooling is important for obtaining uniformly colored joints.

Patching and Pointing

In spite of good workmanship, joint patching or pointing (the act of troweling additional mortar into a joint shortly after masonry units are laid) may sometimes be necessary. Mortar in a head joint may have fallen out while the units were being placed, a mortar crack may have formed while the units were being aligned, or units may have been dislodged by other construction activity. Furthermore, there may not have been enough mortar in a joint to fill the space left by a broken corner or edge. Sufficient additional mortar should be forced into such spots to completely fill the joints.

Preferably, patching or pointing is done while the mortar in the joint is still fresh and plastic. If the back of the face shell can be reached when forcing additional mortar into the joint, the mason provides a backstop, such as the handle of a hammer. Any depressions and holes made by nails or line pins should be filled with fresh mortar before tooling.

When patching must be done after the mortar has hardened, the joint is chiseled out to a depth of about ½ in. (13 mm), thoroughly wetted, and tuckpointed with fresh mortar. The replacement of hardened mortar by fresh mortar in cutout or defective joints is usually called "tuckpointing" (see Chapter 9). The term "pointing" usually refers to the repair of fresh joints.

Termite Protection

Termites can squeeze through openings as small as 1⁄32 in. (0.8 mm), and their shelter tubes have been found in the cavities of concrete masonry. Therefore, concrete masonry requires that special precautions be taken in construction that needs protection against these wood-eating insects.

Masonry foundations, piers, and basement walls should be treated with a chemical such as aldrin, dieldrin, or chlordane. The chemical—at least 2 gal (7.6 L) for each 10 lin ft (3.05 lin m)—is injected or buried below the surface of the ground along the wall or the base.

In addition, all masonry foundation walls and piers should be properly flashed and capped with cast-in-place concrete. The cap should be at least 4 in. (102 mm) thick and reinforced with two No. 3 (#10) bars. The cap should extend the full width of the wall and across the voids in veneered or cavity walls. The top of the cap should be at least 8 in. (203 mm) above grade. Solid masonry units are not acceptable as a substitute for cast-in-place concrete capping for termite protection.

Bracing of Walls

Freshly constructed masonry walls are at risk of being blown over by wind. Such losses can be prevented by observing good construction practices. Most building codes, the U.S. Occupational Safety and Health Administration (OSHA), and the American Society of Concrete Contractors (ASCC) require that new walls be braced for wind (Fig. 6-62).

Section 1926.700(a) of the OSHA Construction Safety and Health Regulations adopts, by reference, Article 12.5 of the American National Standard Safety Requirements for Concrete Construction and Masonry Work (ANSI A10.9), which states: "Masonry walls shall be temporarily shored and braced until the designed lateral strength is reached, to prevent collapse due to wind or other forces."

Fig. 6-62

Newly laid concrete masonry walls should be braced against wind because of their low strength when freestanding. (IMG15821)

The ASCC Safety Manual (ASCC 1996) requires that all masonry walls over 8 ft (2.44 m) in height be adequately braced unless the wall is supported by other means. Other safety requirements in the Manual include the establishment of a limited access zone whenever a masonry wall is to be constructed. See ASCC 1996 and CMWB 2001 for further details.

Concrete masonry walls usually are not designed to be freestanding. Wind pressure can create four times as much bending stress in a new freestanding wall as in a finished wall of a building. This stress occurs at the bottom of the wall where flashing or lack of bond decreases the wall strength to resist tensile wind forces, and fresh mortar in a wall is weak.

Bracing should be provided if the height of the unsupported wall exceeds that given in Table 6-7. Where bracing is used, the heights shown are the safe heights above the bracing. For example, to withstand wind gusts of 20 mph (32 km/h), the freestanding height (without bracing) of a 10-in.- (254-mm-) thick wall made with normal weight units should not exceed 22.0 ft (6.71 m). If wind speeds exceed the 20-mph (32-km/h) limit during the initial period (see footnote 3 in table), work on the wall must stop and the restricted zone on both sides of the wall must be evacuated. For a definition of this restricted area, see reference CMWB 2001. Table 6-7 is based on the assumption that the mortar has no tensile strength and wall stability is accomplished from its self weight only, that is, the walls are freestanding, nonreinforced, ungrouted concrete masonry.

Table 6-7. Maximum Unbraced Height of Ungrouted Hollow Concrete Masonry Walls During the Initial Period, ft (m)*

Nominal wall thickness, in. (mm)	Density of masonry units, g, lb/ft³ (kg/m³)			
	Lightweight units	Medium weight units**		Normal weight units
	$95 \le g \le 105$ ($1522 \le g \le 1682$)	$105 \le g \le 115$ ($1682 \le g \le 1842$)	$115 \le g \le 125$ ($1842 \le g \le 2002$)	$125 \le g$ ($2002 \le g$)
4 (102)	8.0 (2.44)	8.0 (2.44)	8.0 (2.44)	8.0 (2.44)
6 (152)	8.0 (2.44)	8.0 (2.44)	8.0 (2.44)	8.1 (2.47)
8 (203)	10.8 (3.29)	12.0 (3.66)	13.1 (3.99)	14.2 (4.33)
10 (254)	17.0 (5.18)	18.8 (5.73)	20.0 (6.10)	22.0 (6.71)
12 (305)	23.2 (7.07)	25.7 (7.84)	28.1 (8.56)	30.6 (9.33)

* Adapted from CMWB 2001. Assumptions in table are: Initial period = as masonry is being laid, up to maximum of one working day; wind speed limit of 20 mph (32 kph); up to 8 ft (2.44 m) above grade, evacuation not necessary until wind speed reaches 35 mph (56 kph) and above. Also see NCMA TEK 3-4B 2000.

** For medium weight units, use the $105 \le g \le 115$ category unless it is known that units are 115 lb/ft³ or more.

Quality of Construction

Sometime before, during, and after construction, questions are asked about the quality of construction. This is investigated by quality control and quality assurance personnel. "Quality control" is the contractor's or manufacturer's effort to achieve a specified result. "Quality assurance" is the owner's effort to require a level of quality and determine its acceptability. Several factors are involved:

1. The knowledge and attitude of those in charge determine how much quality is wanted and/or will be achieved.
2. The assignment of responsibility for quality construction depends upon the type of job.
3. The requirements for satisfactory quality in construction are well established but require familiarity.

The quality assurance program assures the owner that the building is constructed in accordance with the applicable standards and specifications. Quality assurance addresses: (1) the responsibilities of those involved with the project, (2) materials control, (3) inspection, (4) laboratory and field testing, (5) documentation of conditions or materials meeting or not meeting the specifications, (6) lines of communication, and (7) reporting. The contractor's or producer's quality control program is the production tool, or the actual construction, testing, and inspection, performed to demonstrate specification compliance.

For the owner and his quality assurance representative, the key to success—a quality concrete masonry structure—is a quality conscious masonry contractor. The local masonry association can usually suggest a contractor or answer questions concerning contractors. Another good practice is to check the contractor's references and previous work.

In the field, the roles of the quality control and quality assurance inspectors are much greater than simply overseeing a few tests and inspecting the completed structure. They must become very familiar with the job specifications and drawings. As this can be a lengthy process, it is a great advantage to have the engineer or architect or their authorized representatives on the jobsite.

The quality control inspector must also thoroughly understand the *MSJC Specification* (MSJC 2005). Reflecting the experience of the entire industry, each paragraph and sentence in the *MSJC Specification* is packed with significance. Reference specifications are equally important, and copies should be readily available to the inspector. Moreover, since a competent inspector must know or be able to quickly determine many things, it is suggested that inspectors become familiar with the entire *Concrete Masonry Handbook.* One of its purposes is to explain and set forth recommended practices for quality construction.

Quality and safety of construction can usually be equated, particularly in engineered masonry construction. In this type of work, the importance of inspection is so great that allowable stresses should be reduced if there is no engineering or architectural supervision of the construction. ACI 121R (*Quality Assurance Systems for Concrete Construction*), the *MSJC Code*, the *MSJC Specification*, and *Commentaries* to these documents provide guidance and requirements for quality assurance and quality control (see MSJC 2005).

Fig. 6-63

Construction of a multi-family residence with engineered load-bearing concrete masonry. (IMG15682)

Sampling and Testing Masonry Units

Tests for compressive strength, absorption, weight, and dimensions are made on masonry units selected at the place of manufacture from lots ready for delivery. At least 10 days should be allowed for the completion of the tests. Tests for drying shrinkage, however, must be conducted long before delivery. The new shrinkage requirement is 0.065% or less.

Compression tests of masonry units require testing machines of large capacity. The equipment in most commercial testing laboratories has a maximum capacity of 300,000 lb (136,000 kg), which may be insufficient to test the ultimate strength of a single high-strength concrete masonry unit. Therefore, ASTM C140 permits a unit to be "sawed into segments" if a lower-capacity testing machine has to be used. For example, a two-core unit could be cut down to a one-core unit (see Holm 1972).

Making a Sample Panel

In concrete masonry work involving an architect or engineer, a sample wall panel is highly recommended. Built by the contractor at the start of the job, the sample panel is approved by the quality assurance representative. The architect or owner should also approve the overall appearance of the panel.

Typically 64 in. (1.63 m) long and 48 in (1.22 m) high, the sample panel should include the masonry reinforcement as well as show the workmanship, coursing, bonding, thickness, tooling of joints, range of unit texture and color, and mortar color—all as specified or selected. Of course, the finished work should match the sample panel.

The sample panel may or may not be a part of the building. If a part of the building, it should be located such that easy access to it for approval/rejection of future work can be established. If the sample panel is a separate panel and not part of the building, it should also be used for acceptance/rejection of such matters as cleaning of masonry and adequacy of surface treatments. The sample panel should not be removed until the owner accepts the building.

Testing Project Mortar

Before construction begins, 2-in. (51-mm) mortar test cubes may be prepared in the laboratory, in accordance with ASTM C270, to check the compatibility and compressive strength characteristics of the cementitious materials and sand to be used in the project mortar. These cube tests are made only if the mortar mixture has been specified by strength, not proportion. Because a much greater water content is used during construction, the strengths of any cubes made from mortar sampled at the project cannot be compared to the ASTM C270 strength specifications. However, periodic cube tests made from field mortar can be used to check the uniformity of batching operations. They will be even more useful if they are referenced to accurately measured batches.

ASTM C780 is useful for recommending specific masonry mortar field tests and for interpreting the test results. These test results provide a more reliable measure of uniformity of field batching than if periodic cube tests were made according to ASTM C270. A fast check of mortar proportions can be made using the mortar aggregate ratio test contained in an annex of ASTM C780. The relative proportions of sand to cement indicate if mortar was batched in accordance with the mix design. For more information on field testing of masonry mortar, see ASTM C780 and PCA IS242 1992.

Testing Masonry Prisms and Grout

Prism strength tests (Fig. 6-64), discussed in Chapter 3, may be required not only in advance of design but also as part of quality control in the field, especially on projects involving engineered concrete masonry. During construction, one test is usually required for every 5000 sq ft (465 m^2) of wall; each test includes three prisms and not less than three prisms are made per story. Some test values may fall below the specified prism strength; if so, this should be evaluated in light of the discussion in Chapter 3.

Fig. 6-64

Method of testing the compressive strength of a masonry prism. (IMG15880)

Separate field tests for compressive strength of grout, discussed in Chapter 2, may be another requirement for quality control. The *MSJC Specification* (MSJC 2005) requires grout to have a minimum compressive strength of 2000 psi (13.8 MPa) at 28 days when tested according to ASTM C1019, unless grout is specified according to ASTM C476 proportions.

Destructive Testing of Grouted Walls

Some quality control practices for grouted concrete masonry walls involve the use of destructive testing. This procedure requires the drilling of cores from the completed walls and submittal of these cores to visual inspection and physical tests. This practice not only causes damage to the walls but also is expensive, is not directly repeatable, and does not necessarily determine locations of imperfections.

Where grouted walls are to be cored, the cores should be taken at least 6 ft (1.83 m) from a corner and not under an opening in the wall. The governing code or specification should be checked for the size of core required, and at least two cores should be tested for each project. Codes that require core tests usually specify a minimum compressive strength of 750 psi (5.2 MPa) at 7 days and 1500 psi (10.3 MPa) at 28 days.

It should be noted that, while the cores are drilled laterally through the wall, they must be test-loaded along the core axis, that is, at right angles to the axis of the applied loads on the wall. Therefore, it is unlikely that the test result is a true measure of wall strength. A truer representation of the strength of a masonry wall in the direction of the anticipated applied loads is obtained by testing a sample prism cut from of the wall.

Generally, through-the-wall cores are taken to check their compressive strength. However, they may also be taken to check the shear bond strength between the masonry units and grout. The test determines the unit force required to shear the masonry face shells from the grout core for each face. Some building codes specify a minimum shear bond strength of 100 psi (0.69 MPa) at 28 days.

Nondestructive Testing of Grouted Walls

Without damage to the walls, two tests—ultrasonic and radiographic inspection—permit considerable wall area to be inspected for major variations or flaws.

The ultrasonic test measures the time sound waves take to pass through the thickness of a grouted wall. When the time interval indicating good grouting is known, the time measure can be used as a quality control tool. A relatively long time interval indicates the presence of flaws such as voids, cracks, or honeycomb. The moisture content of the wall affects the time interval, but does not interfere with identifying variations within the wall. Although ultrasonic inspection could cost more than drilling and testing cores, the more complete coverage available may well justify the increased cost.

In the radiographic test, a beam of either X-ray or cobalt 60 isotope radiation is passed through a grouted wall to expose a photographic film on the reverse side. The film shows variations in wall density as gradations of black and white, and thus the sensitivity of the procedure depends to a large extent on the type of wall constructed. Since radiation is involved, a hazard does exist with this method of inspection.

Dry-Stacked, Surface Bonded Masonry

As an alternative to conventional concrete masonry wall construction, masonry units are dry-stacked

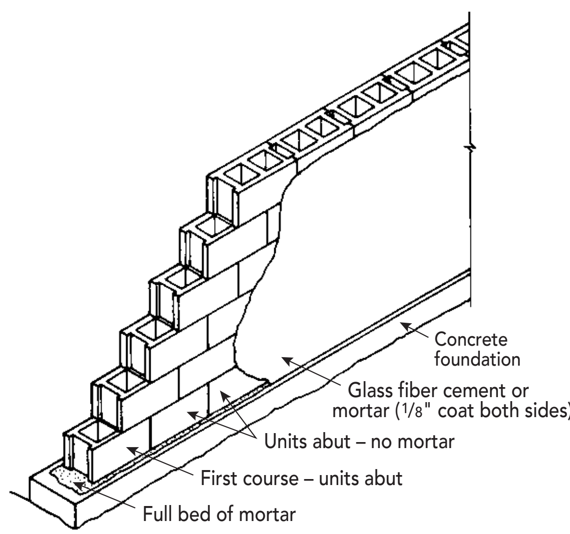


Fig. 6-65

Dry-stacked, surface-bonded masonry.

without mortar in the bed and head joints and a layer of glass-fiber reinforced cement paste or mortar is applied. The technique is referred to as dry-stacked, surface-bonded masonry (Fig. 6-65).

Manufacturers provide proprietary mixtures consisting of cement and alkali-resistant glass fibers; the mixtures also may contain fine aggregate. These formulations are standardized by product specification ASTM C887. Guidance for construction practices is provided in ASTM C946.

Masonry walls are built using a full mortar bed under the first course of block laid on the foundation. Units in the first course abut each other without any mortar in the head joints. Subsequent courses of block are dry-stacked, again without benefit of mortar in the bed or head joints. Units are laid in a running bond pattern. Wedges or shims assist in maintaining level courses. Throughout the height of a wall, leveling courses bedded in mortar are laid when vertical differences exceed ½ in. (13 mm) in 10 ft (3.05 m) for a single course. Leveling courses are also installed at floor levels. After dry-stacking, the surface bonding mixture is combined with water, mixed, and hand- or machine-applied to both sides of the wall, providing a coating at least ⅛ in. (3.2 mm) thick. Spray or trowel finishes are attainable.

Applied Finishes for Concrete Masonry

CHAPTER 7

A wide variety of applied finishes are possible with concrete masonry construction. The finish to use in any particular case will be governed by the type of structure in which the walls will be used, the climatic conditions to which they will be exposed, and the architectural effects desired. Some popular finishes are described in this chapter.

Paints

The main purposes of painting concrete masonry walls are to add a fresh appearance and color and to alter the surface texture and pattern. Additional reasons are to reduce the passage of sound through a wall and, as discussed below, to bar the passage of moisture. The paint selected should not only achieve these goals but also attach itself tenaciously to the surface of the masonry, retain its appearance for a long time, and be economical.

Paints are pigmented coatings that form opaque films. Paint mixtures have minute solid particles of pigment suspended in a liquid referred to as a vehicle. The pigment provides color and hiding power (conceals the surface beneath). The vehicle includes two elements: (1) a solvent or thinner that supplies the desired consistency for application, and (2) a binder that bonds the pigment particles into a cohesive paint film during the drying and hardening process. Some paints dry and harden by evaporation of the solvent, some by oxidation, and others by chemical reaction and evaporation of the solvent. Over time, environmental regulations on volatile organic compounds have tightened, limiting the use of certain solvents. Local design professionals or building departments can provide guidance on what is available and what is commonly used in a particular region (TEK 8-1A 2004).

Some paints breathe, that is, they are permeable and allow passage of water vapor. Others are impermeable or nonbreathing. Impermeable paints should be applied to the side of a wall where moisture enters, while permeable paints should be applied to the side where moisture exits. If the surface from which moisture is attempting to leave is coated with an impermeable paint, blistering will occur and the paint will peel.

There are other technicalities that must be considered when selecting paint for a concrete masonry surface, such as: (1) whether or not the paint will be damaged by the probable presence of alkalies, and (2) whether or not the surface texture requires alteration before application of the paint.

Types Commonly Used

Many products have been used to paint concrete masonry walls, with varying degrees of success. The basic constituents and pertinent characteristics of paints now commonly used on concrete masonry walls are described below. Urethanes, polyesters, and epoxies are also used successfully.

Portland Cement Paints

Of the various types of paint used on concrete masonry construction, those with a portland cement base (Fig. 7-1) have the longest service record. U.S. Federal Specification TT-P-21 (USGSA 1951), which gives requirements for composition, provides for two types and two classes of portland cement paint: Type I,

Left: Portland cement-based plaster makes an attractive and durable finish for concrete masonry walls. (IMG24203) Right: A plasterer levels a plaster base coat with a darby. (IMG24206)

Fig. 7-1

A stippled, heavy cement-based coating on a concrete masonry screen wall. (IMG15889)

Fig. 7-2

The concrete masonry surface is uniformly dampened with a water spray just before application of a portland cement paint. A garden pressure sprayer with a fine-fog nozzle is recommended. (IMG25248)

which contains a minimum of 65% portland cement by weight, is for general use; Type II, with at least 80% portland cement by weight, is for maximum durability. Within each type, Class A contains no aggregate filler, and is for general use, while Class B contains 20% to 40% siliceous sand filler for use on open-textured surfaces.

A concrete masonry surface should be damp when a portland cement paint is applied (Fig. 7-2). Proper setting and curing require the presence of water, a favorable temperature, and sufficient time for hydration. If the paint is modified with latex, moist curing is not necessary because the latex retains sufficient moisture in the paint film for hydration.

Although portland cement paints may be formulated on the job, the best results in durability and uniformity of color are most often obtained by using products marketed in prepared form. Portland cement paints form hard, flat, porous films that readily permit passage of water vapor. These paints are not harmed by the presence of alkalies, and may be applied to freshly built concrete masonry surfaces, although the results will be better if painting is deferred at least three weeks.

Latex Paints

Latex paints are water-thinned—that is, they are based on aqueous emulsions of various resinous materials such as acrylic resin, polyvinyl acetate, and styrene butadiene. With an ever-increasing use of polymers, blends, and modifications of the base resins, the distinction between these materials has been blurred to the point where any such classification is somewhat meaningless. They all dry very rapidly by evaporation of water, followed by coalescence of the resin particles.

Careful surface preparation is required when latex paints are applied to concrete masonry surfaces because they do not adhere readily to chalked, dirty, or glossy surfaces. However, these paints have many advantages: (1) they are easy to apply and have little odor; (2) they are economical, nonflammable, breathing paints that are not damaged by alkalies; (3) they have excellent color retention; and (4) they are very durable in normal environments. Latex paints containing acrylic resin are more expensive than the other latex types, but field experience has shown them to give the best performance.

Oil-Based Paints and Oil-Alkyds

Oil-based paints contain drying oils as the binder and are nonbreathing. They are similar to conventional house paints. Easy to use, these paints are durable under some exposures, but they are not particularly hard or resistant to abrasion, chemicals, or strong solvents. They are also damaged by alkalies.

Oil-based paints are often modified with alkyd resins to improve resistance to alkalies, reduce drying time, and improve performance in other ways. When the substitution of resins for oil is high, they are referred to as varnish-based paints. The oil-alkyds, and even the varnish-based paints, may be susceptible to damage from alkalies. Oil-alkyds also are nonbreathing paints.

There are few instances where serious consideration should be given to an oil-based or oil-alkyd paint for use on concrete masonry.

Rubber-Based Paints

Formulated with a chlorinated natural rubber, or a styrene-butadiene resin, these paints form a nonbreathing film with alkali and acid resistance. They are useful not only for exterior masonry surfaces but also for interior surfaces that are wet, humid, or subject to frequent washing—swimming pools, wash and shower rooms, kitchens, and laundries. They also are used where alkali resistance is important and where requirements for resistance to the entrance of moisture are greater than can be supplied by latex paints. Rubber-based paints may be used as primers under less moisture-resistant paints.

Surface Preparation

Regardless of the type of paint selected for use on concrete masonry, its success or failure depends upon the adequacy of surface preparation. In most cases success is more assured if the surface has aged at least six months before painting; this is because of the dampness usually present in a new concrete masonry wall and the alkalinity of the surface. If the paint is not sensitive to either moisture or alkalies (such as a portland cement paint or latex paint), a long aging period is not necessary. Earlier use of oil- or alkyd-base paint, which may be subject to damage from alkalinity, is possible if the surface is neutralized by pretreatment with a 3% solution of phosphoric acid followed by a 2% solution of zinc chloride. However, this procedure is now rarely used because of the success of other paints not requiring pretreatment, such as portland cement and latex paints.

For paint to adhere, concrete masonry surfaces must be free of dirt, dust, grease, oil, and efflorescence. Dirt and dust may be removed by compressed air, brushing, scrubbing, or hosing. If a surface is extremely dirty, wet or dry sandblasting, waterblasting, or steam-cleaning may be used. Grease and oil may be removed by applying a 10% solution of caustic soda, trisodium phosphate, or detergents specially formulated for use on concrete. Efflorescence can be cleaned off by brushing or light sandblasting. After any of these treatments, the surface should be thoroughly flushed with clean water.

Fill coats, also called fillers or primer-sealers, are sometimes used to fill voids in open or coarse-textured concrete masonry surfaces. Applied by brush before the finish coat, the fill coat usually contains white portland cement and a fine siliceous sand. If acrylic latex or polyvinyl acetate latex is included in the mixture, moist curing is not required. It should be noted that fill coats impair sound absorption but improve the sound transmission loss of a concrete masonry wall.

For more information on preparation for surface coatings, see ASTM D4261 (Standard Practice for Surface Cleaning Concrete Unit Masonry for Coating) and “Cleaning Concrete Masonry Surfaces” in Chapter 9.

Paint Preparation and Application

Paint must be thoroughly stirred just prior to application. Power stirrers and automatic shakers are becoming more common, but they are not recommended for latex paints because of the possibility of foaming. Hand stirrers should have a broad, flat paddle.

Thinning of paint should only be done in accordance with the manufacturer's directions; excessive paint thinning will result in coatings of low durability. Color tinting should also be done carefully in accordance with the manufacturer's suggestions.

The paints commonly used on concrete masonry are applied by brush, roller, or spray as described below. Roller application and spraying are often used for large areas.

1. *Portland cement paints* are applied to damp surfaces with brushes having bristles no longer than 2 in. (51 mm) (Fig. 7-3). The paint should be scrubbed into the surface as shown in Fig. 7-4. An interval of at least 12 hours should be allowed between coats. After completion of the final coat, a 48-hour period of moist curing is necessary if the paint is not latex modified.

2. *Latex paints* may be applied to dry or damp surfaces by roller or spray, but preferably by a long-fiber, tapered nylon brush 4 to 6 in. (102 to 152 mm) wide (soaked in water for two hours before use). When the surface is moderately porous or extremely dry weather prevails, it is advisable to dampen the surface before painting. These paints dry throughout as soon as the water of emulsion has evaporated, usually in 30 to 60 minutes, and require no moist curing.

3. *Oil-based and oil-alkyd paints* should not be applied during damp or humid weather, or when the temperature is below 50°F (10°C). Pretreatment to neutralize the surface is recommended if the masonry is less than 6 months old (see "Surface Preparation"). Application of these paints is by brush, roller, or spray (usually by brush) to a dry surface. Each coat should be allowed to dry at least 24 hours, and preferably 48 hours, before application of succeeding coats.

4. *Rubber-based paints* are usually applied by brush to dry or slightly damp surfaces. Two or three coats are necessary to achieve adequate film thickness, and the first coat is usually thinned in accordance with the manufacturer's recommendations. A 48-hour delay is recommended between coats. Recoating should be performed with care; because of the strong solvents used in rubber-based paints, subsequent coats tend to lift or attack the previous coat.

Fig. 7-3

Typical brushes used in applying portland cement paint: *(left to right)* ordinary scrub brush, window brush, brush with detachable handle, and fender brush. (IMG16607)

Fig. 7-4

Portland cement paint is applied at the joints first. (IMG25249)

Caution: Most paints are flammable, and some have solvents that are highly flammable. Therefore, adequate ventilation during painting should be provided according to the manufacturers' recommendations.

Clear Coatings

In many areas, architects specify clear coatings or water repellents for concrete masonry structures. This is done to render the surface water-repellent, which protects the masonry from soiling and surface attack by airborne pollutants, and to facilitate cleaning. Further advantages are to prevent the surface from darkening when wet and to accentuate surface color. In some regions where weather exposure is not severe and air pollution is not a problem, clear coatings may not be necessary.

The two general types of water repellents are surface applied treatments and integral water repellents. Surface treatments are applied after the wall is built on the side of the wall that will be exposed to weather. Integral water repellents are added to masonry units during manufacturing and to the jobsite mortar to ensure compatibility and bond (TEK 19-1 2006).

The coating selected should be water-clear and capable of being absorbed into the surface. It should also be long-lasting and not subject to discoloration with time and exposure. Good service has been obtained with coatings based on a methyl methacrylate form of acrylic resin (Litvin 1968), silanes, siloxanes, and a number of other compounds. Brush or spray application of one or two coats of a relatively low-solid-content coating is usually satisfactory. Consult the coating manufacturer as to the life expectancy of the coating or sealer. Building owners should be prepared to reapply certain coatings or sealers every 5 to 10 years.

Stains

Decorative staining of concrete masonry walls can give good results if the proper stain is selected and applied correctly. However, there may be some drawbacks to staining. For example, color applied after concrete hardens is not as long-lasting as that incorporated into the concrete mixture during block manufacture. Also, the color effects or shades of a stain may vary.

Types

Several types of stains may be used on concrete masonry. They include:

1. *Oil stains*, which sometimes require aging of the wall for several months before application, or pretreatment of the surface to inhibit reaction between alkalies in the concrete masonry and the oil vehicle in the stain. Many stains suitable for wood also are suitable for concrete masonry.
2. *Metallic salt stains*, which are slightly acid solutions of salts that result in the deposit of colored metallic oxide or hydroxide in the surface pores of the concrete masonry. These deposits are not soluble in water.
3. *Organic dyes*, which contain aniline dyes.

Application

For best results, staining should be delayed 30 to 45 days or longer after the concrete masonry structure is built. The surface must be dry and clean—free of oil, grease, paint, and wax. Acid etching is usually not necessary or advisable because of the porosity of a concrete masonry surface. Two or more applications of a stain may be required to secure the depth of color desired.

Each coat of stain should thoroughly saturate the surface and be evenly applied by a constant number of passes of a brush, roller, or low-pressure spray. Care should be taken that the stain does not streak or overlap into a dried area. From four to five days should elapse between coats, depending upon the masonry surface, ambient conditions, and the stain used. It will often take three or four days for a stained surface to reach its final color.

Portland Cement Plaster

Portland cement plaster and portland cement stucco are the same finishing material. It can be applied to any concrete masonry surface. Although the term plaster denotes both interior and exterior use of the material, stucco is the term often associated with exterior use, and in some areas plaster denotes interior use only.

Portland cement plaster is a combination of portland cement, blended cement, masonry cement, or plastic (stucco) cement with sand, water, and perhaps a plasticizing agent such as lime. A color pigment may be used in the finish coat, and the use of white portland cement allows for the most efficient use of pigment. Plastic cement is a hydraulic cement specifically designed for use in portland cement-based plaster or stucco. It is marketed as a prepackaged product that is mixed at the jobsite with sand and water. The term "plastic" does not indicate the inclusion of organic compounds in the cement, but refers to the ability of the cement to impart a high degree of workability to the plaster. Plastic cement is widely used in the Southwestern United States for plastering applications. Plastic cement is manufactured to conform to ASTM C1328, Standard Specification for Plastic (Stucco) Cement.

Portland cement plaster has many of the desirable properties of concrete and, when properly applied, forms a hard, strong, durable, decorative finish. There is an almost unlimited variety of textures, colors, and patterns possible. The rougher textures help conceal slight color variations, lap joints, uneven dirt accumulation, and streaking.

Portland cement plaster finishes are primarily used for exterior walls, but they are also particularly well-suited for interior high-moisture locations such as kitchens, laundries, saunas, bathrooms, and various industrial facilities. The use of exterior plaster (stucco) involves considerations such as water penetration, corrosion of reinforcement and accessories, and stresses due to wider variations of temperature and humidity than normally present in interior applications.

Plaster should conform to ASTM C926, Standard Specification for Application of Portland Cement Based Plaster. Also, refer to ASTM Standard Specifications C631, C932, C933, C1032, C1063, C1328, and TEK 9-3A 2002. Furthermore, a full discussion of portland cement plastering can be found in PCA's *Portland Cement Plaster/Stucco Manual* (Melander, Farny and Isberner 2003).

Jointing for Crack Control

The proper design and selection of materials for a concrete masonry wall can substantially minimize or eliminate undesirable cracking of its portland cement plaster finish. Cracks can develop in this finish for many reasons: for example, shrinkage stresses; building movements; foundation settlement; restraint from lighting and plumbing fixtures, intersecting walls or ceilings, pilasters, and corners; weak sections in a wall due to construction joints; and cross-sectional changes, such as at openings.

It is difficult to anticipate or prevent cracks from all these possible causes, but they can be largely controlled by the proper use of joints. Control joints should be installed directly over any previous joints in the base (Fig. 7-5). For plaster bonded directly onto concrete masonry, additional joints are not usually needed.

Concrete masonry walls that use metal lath for the plaster base should be divided into square or rectangular panels not exceeding 144 sq ft (13.4 m^2) in size. Ceilings and curved or angular surfaces should be limited to 100 sq ft (9.3 m^2). A control joint should be placed at least every 10 ft to 12 ft (3.05 m to 3.66 m). Ideally, the panels formed by control joints should have a length to width ratio of 1 to 1 (square), but in no case should a panel length-to-width ratio exceed 2½. The metal reinforcement in the plaster should not extend across control joints, and the material used for control joints in exterior surfaces should be weathertight and corrosion-resistant. ASTM C1063, Specifica-

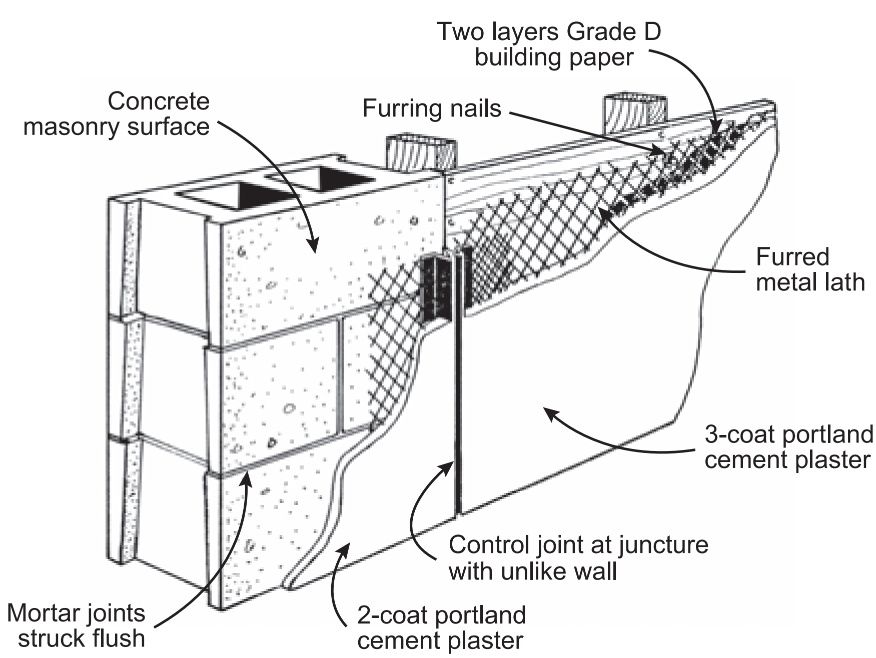


Fig. 7-5

Control joints should be placed between dissimilar walls.

tion for Installation of Lathing and Furring to Receive Interior and Exterior Portland Cement-Based Plaster, provides guidance on the minimum requirements for metal bases and accessories for plaster.

Mixes

Data for plaster mixes are given in Tables 7-1, 7-2, and 7-3. Note that lime should not be added when masonry cement or plastic cement is used. These cements already contain plasticizers and only sand and water need to be added, thus simplifying jobsite proportioning and mixing.

When proportioned in accordance with the requirements of Table 7-2, a good plastering mixture will be recognized by its workability, ease of troweling,

Table 7-1. Recommended Base-Coat Plaster Types for Specific Bases*

Plaster base	Recommended plaster mixes	
	First coat	Second coat
Concrete masonry**	CL M CM or MS P	CL M CM, MS, or M P
Metal reinforcement†	C CL CM or MS M CP P	C, CL, M, CM, or MS CL CM, M, or MS M CP or P P

* Adapted from ASTM C926.

** High-absorption bases such as concrete masonry should be moistened prior to scratch coat application.

† Metal reinforcement with paper backing may require dampening of paper prior to application of plaster.

Table 7-2. Base-Coat Plaster*

Plaster mix symbols	Parts by volume**						
	Cementitious materials					Volume of aggregate per sum of separate volumes of cementitious materials	
	Portland cement or blended cement	Plastic cement	Masonry cement N	Masonry cement M or S	Lime	1st coat	2nd coat†
C	1	—	—	—	0 – ¾	2½ – 4	3 – 5
CL	1	—	—	—	¾ – 1½	2½ – 4	3 – 5
M	—	—	1	—	—	2½ – 4	3 – 5
CM	1	—	1	—	—	2½ – 4	3 – 5
MS	—	—	—	1	—	2½ – 4	3 – 5
P	—	1	—	—	—	2½ – 4	3 – 5
CP	1	1	—	—	—	2½ – 4	3 – 5

* Adapted from ASTM C926.

** A range of sand contents allows for adjustment of each mix to optimize plaster properties using local materials. The workability of the plaster mix will govern the amounts of lime and sand. To determine the volume (in parts) of aggregate to use, add up the parts of cementitious materials and multiply by a number within the range shown in the last two columns above.

† Within the limits shown, the same or greater proportions of sand should be used in the second coat as in the first coat.

Table 7-3. Job-Mixed Finish-Coat Plaster*

Plaster mix symbols**	Proportion parts by volume					
	Cementitious materials					Volume of aggregate per sum of separate volumes of cementitious materials†
	Portland cement or blended cement	Plastic cement	Masonry cement N	Masonry cement M or S	Lime	
F	1	—	—	—	¾ – 1½	1½ – 3
FL	1	—	—	—	¾ – 2	1½ – 3
FM	—	—	1	—	—	1½ – 3
FCM	1	—	1	—	—	1½ – 3
FMS	—	—	—	1	—	1½ – 3
FP	—	1	—	—	—	1½ – 3

* Adapted from ASTM C926.

** For finish surfaces subject to abrasive action, specify mix F, FP, FCM, or FMS.

† To determine the volume (in parts) of aggregate to use, add up the parts of cementitious materials and multiply by the appropriate number shown in the last two columns above. Perlite may be substituted for sand to increase the fire resistance and insulating value of plaster, and decrease the weight by as much as 60%. Perlite plasters should incorporate fibers and should be used only over base coat plasters containing perlite aggregate. Perlite plaster should not be used in areas subject to impact or abrasion.

adhesion to bases, and ability to attach itself to surfaces without sagging. Batch-to-batch uniformity will help assure color uniformity and uniform suction for subsequent coats.

Consistent measuring and batching methods are important. All ingredients should be thoroughly mixed (preferably in a power mixer) with the amount of water needed to produce a plaster of workable consistency. Mixing time should be a minimum of 2 minutes after all materials are in the mixer, or until the mixture is uniform in color. Limit the size of a batch to that which can be used immediately, or in not more than 2½ hours. Remixing with the addition of water to restore plasticity is permissible within the same time limits, but this should be avoided when colored plasters are used. The additional water might affect color consistency.

Color pigments are often used in the finish coat, which is usually a factory-prepared stucco finish mixture. It should be noted that in some areas the term “stucco” refers only to the finish coat, while in most other regions it refers to the entire thickness. Factory-prepared finish mixtures assure greater uniformity of color than job-prepared mixtures; the manufacturer’s recommendations should be closely followed. If the finish coat is job-mixed, a truer color and a more pleasing appearance will be obtained when a white portland cement and a fine-graded, light-colored sand are used.

Natural or synthetic fibers are sometimes added to plaster mixtures to improve cracking resistance and pumpability. To avoid workability and mixing problems, fibers should not be used in excess of 2 lb per cu ft (32 kg/m^3) of cementitious material.

Surface Preparation

Concrete masonry provides an excellent base for portland cement plaster because of its rigidity and excellent bonding characteristics. Bond occurs both mechanically and chemically. Mechanically, bond results from keying; that is, interlocking of plaster with the open texture in the concrete masonry surface. Suction by the masonry also improves mechanical bond; that is, paste is drawn into the minute pores of the surface. Chemically, the similar materials adhere well to each other.

A new concrete masonry surface can be used as a plaster base with minimum consideration for surface preparation. For best results, the concrete masonry units should have an open texture and be laid with struck joints (Fig. 7-6). The surface should be free of oil, dirt, or other materials that might reduce bond; then prior to application of plaster, it should be uniformly dampened, but not saturated, with clean water using a fine-fog nozzle (Fig. 7-7).

An old concrete masonry surface should be carefully examined to establish its bonding characteristics. A surface having the desired texture and cleanliness will perform as well as a new masonry surface. If the masonry has been painted, sandblasting must be used to remove the paint and improve the bonding characteristics. Otherwise, furred metal lath must be anchored to the wall over a weather resistive barrier (WRB), typically a waterproof building paper or felt (Fig. 7-8).

Fig. 7-6

The natural rough texture of concrete block provides a good base for portland cement plaster and the metal accessory creates a strong corner with a clean line. (IMG24183)

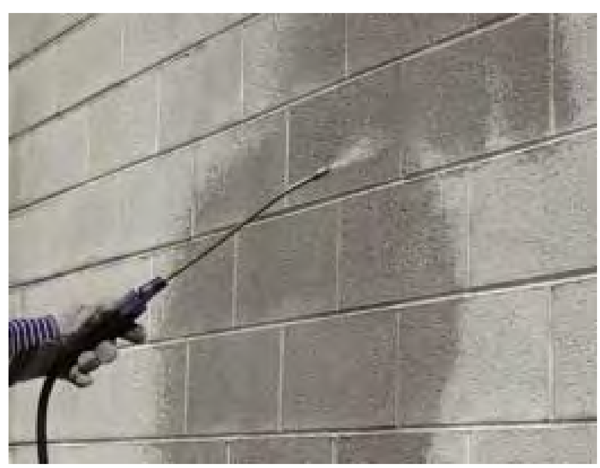


Fig. 7-7

A water spray is used to prepare the concrete block surface for its first coat of plaster. (IMG25250)

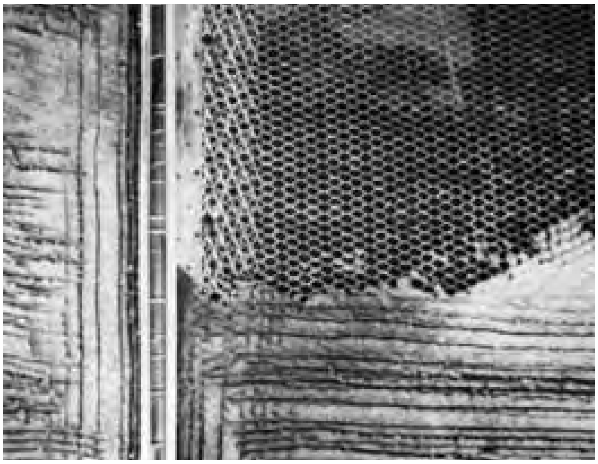


Fig. 7-8

Metal lath is applied over waterproof building paper or felt. Dimples in the expanded metal lath provide proper furring for embedment of the metal. (IMG12572)

The term "furring" applies to spacer elements used to maintain a gap between lath (or a finish such as wallboard) and the masonry. "Lath" is a material whose primary function is to serve as a plaster base. The most common types of lath are expanded metal lath, expanded stucco mesh, hexagonal wire mesh (stucco netting), stucco mesh, and welded-wire fabric.

The suitability of an unpainted concrete masonry surface as a plaster base can be tested by spraying it with clean water to see how quickly moisture is absorbed through suction. If water is readily absorbed, good suction is likely; if water droplets form and run down the surface, suction is probably inadequate. For low-suction surfaces, bond must be increased by applying a bonding agent or a dash-bond coat (containing 1 part portland cement, 1 to 2 parts sand, and sufficient water for a thick paint-like consistency). In lieu of a bonding agent or dash coat, bond may be provided by metal lath. Metal lath must be solidly anchored to the base, and paper is used behind the lath as it is in other lathed systems to isolate the substrate and plaster from one another.

Application

Plaster may be applied by hand or machine in two or three coats in accordance with the required thicknesses given in Table 7-4. Horizontal (overhead) applications seldom exceed two coats, and two coats are often used when plaster is applied directly to concrete masonry as shown in Fig. 7-9. Three coats are applied when furred

Table 7-4. Nominal Plaster Thickness for Three- and Two-Coat Work,* in. (mm)

Base	Vertical				Horizontal			
	1st Coat	2nd Coat	3rd Coat	Total	1st Coat	2nd Coat	3rd Coat	Total
Interior and Exterior								
Three-coat work**								
Metal plaster base	⅜ (9.5)	⅜ (9.5)	⅛ (3)	⅞ (22)	¼ (6)	¼ (6)	⅛ (3)	⅝ (16)
Solid plaster base								
Unit masonry†	¼ (6)	¼ (6)	⅛ (3)	⅝ (16)	use two-coat work			
Metal plaster base over solid base†	½ (12.5)	¼ (6)	⅛ (3)	⅞ (22)	½ (12.5)	¼ (6)	⅛ (3)	⅞ (22)
Two-coat work††								
Solid plaster base								
Unit masonry	⅜ (9.5)	⅛ (3)		½ (12.5)				⅜ (9.5) max‡

* Adapted from ASTM C926. Where a fire rating is required, plaster thickness should conform to the applicable building code or to an approved test assembly. Nominal thickness is exclusive of texture.

** The finish coat thickness may vary, provided that the total plaster thickness complies with this table and is sufficient to achieve the texture specified. For exposed-aggregate finishes, the second (brown) coat may become the "bedding" coat; it should be of sufficient thickness to receive and hold the aggregate specified.

† Dash or brush coats of plaster are not acceptable as one of the required coats. Where masonry and concrete surfaces vary in plane, plaster thickness required to produce level surfaces shall not be required to be uniform.

†† For two-coat work, only the first and finish coats for vertical surfaces and the total plaster thickness for horizontal surfaces are indicated. The use of two coats is common practice when plaster is applied directly to vertical concrete masonry, and horizontal application seldom exceeds two coats.

‡ On horizontal solid-base surfaces such as ceilings or soffits requiring more than ⅜-in. (10-mm) plaster thickness to obtain a level plane, metal reinforcement should be attached to the concrete and the thickness specified for three-coat work on metal reinforcement over solid base applies. Where ⅜-in. (10-mm) or less plaster thickness is required to level and decorate and there are no other requirements, a liquid bonding agent or dash-bond coat may be used.

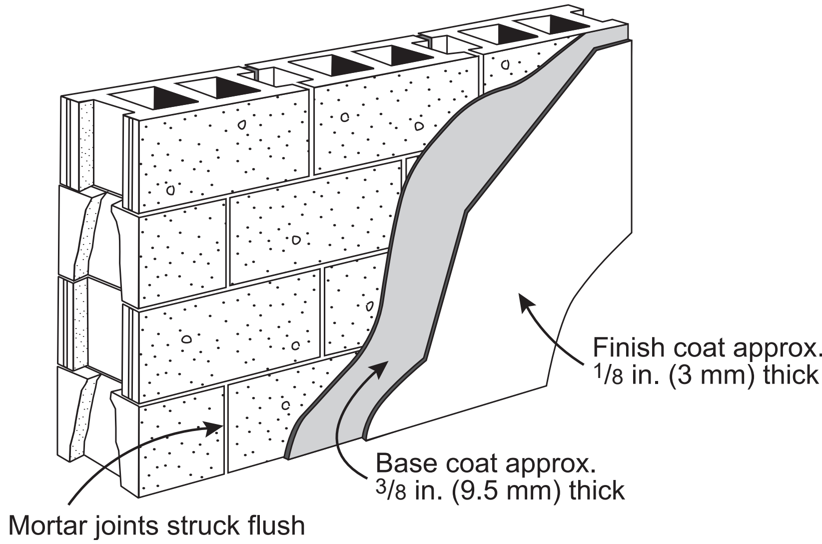


Fig. 7-9

metal lath is used as a plaster base. A sprayed color coat—the finish coat—requires two applications; the first to ensure complete coverage and the second to obtain the desired texture.

Hand application involves traditional plastering tools and practices proven successful over many years. Even for hand application, plaster is often mechanically mixed and may be pumped to workers to simplify placement of material (Figs. 7-10 and 7-11). As further evidence of the benefits of equipment in construction, machine application (Fig. 7-12) is now widely used because it offers many advantages: (1) pumping capability, (2) faster application, (3) elimination of lap and joint marks, (4) the possibility of deeper and darker colors, and (5) a more uniform texture.

Fig. 7-10

Fresh plaster is prepared in a mortar mixer and transferred to a pump hopper. (IMG24164)

Fig. 7-11

Fresh plaster is pumped to workers on scaffolds for placement on the wall, greatly improving material movement on the job. (IMG24165)

Fig. 7-12

Machine application of plaster. (IMG12569)

Machine application requires different procedures than those used for hand application. Basically, the mixture is sprayed from the machine nozzle against the prepared base or previous coat (Fig. 7-12). Nevertheless, if machines are to be used to best advantage, manufacturers' instructions should be carefully followed.

Proper consistency for machine-applied plaster is best determined by observing the plaster during application. If the plaster is too fluid to build up the proper thickness without sagging, the water content is too high; if plaster will not pump or is exceedingly difficult to strike off, the water content is too low. Use of a well-graded aggregate greatly improves the pumpability of plaster. To monitor consistency, specifications may require a slump test for plaster taken from the nozzle of the plastering hose.

Sufficient time, depending on the ambient temperature, should be provided between coats to allow the plaster to develop sufficient rigidity to resist cracking or other damage when the next coat is applied.

Curing

To obtain the best results from the cementitious materials in portland cement plaster, some moisture must be maintained in the plaster for the first few days after application. Moist curing, under present plastering practice, usually is applied only to the base coat and continued until application of the finish coat. Generally, fogging the surface with water at the start and again at the end of the work day will suffice. If the relative humidity is high (more than 70%), the frequency of moistening the surface may be reduced. If it is hot, dry, and windy, the plaster surface should be moistened and covered with a single sheet of polyethylene plastic (weighted or taped down) to prevent water loss through evaporation.

Immediately before the finish-coat application, the base coat should be uniformly moistened. This moisture, along with the water in the finish coat plaster, provides the total curing of the finish-coat plaster. No additional water should be applied to the finish-coat plaster until it has hardened. The addition of water to colored finish-coat plaster before hardening is a common cause of color variations.

An adequate temperature is important for satisfactory curing. As the temperature drops, hydration slows and practically stops at the freezing point. Therefore, portland cement plaster should not be applied to frozen surfaces, and of course frozen materials should not be used in the mixture. In cold weather it may be necessary to heat the mixing water and the work area. ASTM C926 recommends a heated enclosure to maintain the air temperature above 40°F (4.4°C) for 48 hours before plastering, while plastering, and for the duration of the curing period (at least 48 hours).

Ready-Mixed Plaster

Ready-mixed plaster, or extended life plaster, is made with the same ingredients as conventional plaster, except it contains a set-controlling admixture that keeps the plaster workable for 2½ to 72 hours, depending on the admixture dosage and brand. The plaster is usually mixed at a central location, such as a ready-mix concrete plant, or in a mobile truck-mixer. It is delivered to the jobsite in a trowel-ready condition, stored at the jobsite in protected plastic containers, and then transferred to the plasterer in smaller containers as needed.

The plaster is applied in the conventional manner. The primary advantages of ready-mixed plaster are its uniformity—the ingredients are accurately combined and mixed—and its relative ease of use. Also, since jobsite mixing is not needed, plaster ingredients need not be stored at the jobsite. Ready-mixed plaster is no longer common, although it can be useful on projects where mixing and storage space are limited. For more information, see the discussion on extended life mortar in Chapter 2.

Furred and Other Finishes

In addition to plaster, other finishes such as fiberboard, gypsum wallboard, and wood paneling are sometimes applied directly to concrete masonry wall surfaces and sometimes upon furring or insulation board as in exterior insulation and finish systems (EIFS).

Furring, which may be wood or metal, ensures a definite air space of ¾ in. (19 mm) or more between the masonry and the finish (Fig. 7-13). Furring may be necessary to:

1. Provide a suitably plumb, true, and properly spaced supporting construction for a wall finish.
2. Eliminate capillary moisture transfer in exterior or below-grade concrete masonry walls, thus minimizing the likelihood of condensation on interior wall surfaces.
3. Improve thermal insulation.
4. Improve sound insulation.

The furring strips are fastened to the concrete masonry with cut nails, helically threaded concrete nails, or powder-actuated fasteners (Fig. 7-14). Adhesives can be used to attach wallboard directly to wood furring, although a few nails may be required until the adhesive has set.

Wood furring is combustible even if enclosed by masonry and a fire-resistant finish. Building codes sometimes prohibit such combustible construction.

Gypsum wallboard finishes consist of one or more layers of factory-fabricated gypsum board having a noncombustible gypsum core with surfaces and edges of paper or other materials. *Gypsum products are not recommended where significant exposure to moisture is expected.* In such applications, portland cement plaster may be used, or, in many areas, glass-fiber, mesh-reinforced, concrete backer board is available and is recommended for moisture exposures.

Typical materials used to increase thermal resistance of furred finishes include: (1) flexible fiber insulation (batts and blankets), (2) loose-fill insulation, (3) rigid plastic insulation, and (4) reflective-foil insulation (foil is attached to the back surface of the rigid insulation). Mineral fiber blankets may be installed behind the wallboard not only to improve thermal insulation but also to decrease sound transmission. Resilient clips for lath attachment may also be used to decrease sound transmission.

Exterior Insulation and Finish Systems

Exterior insulation and finish systems (EIFS) sold in the United States evolved from systems developed and used successfully in Europe for over 30 years. Used extensively on residential and commercial buildings, EIF systems are well suited for use on concrete masonry walls (Fig. 7-15).

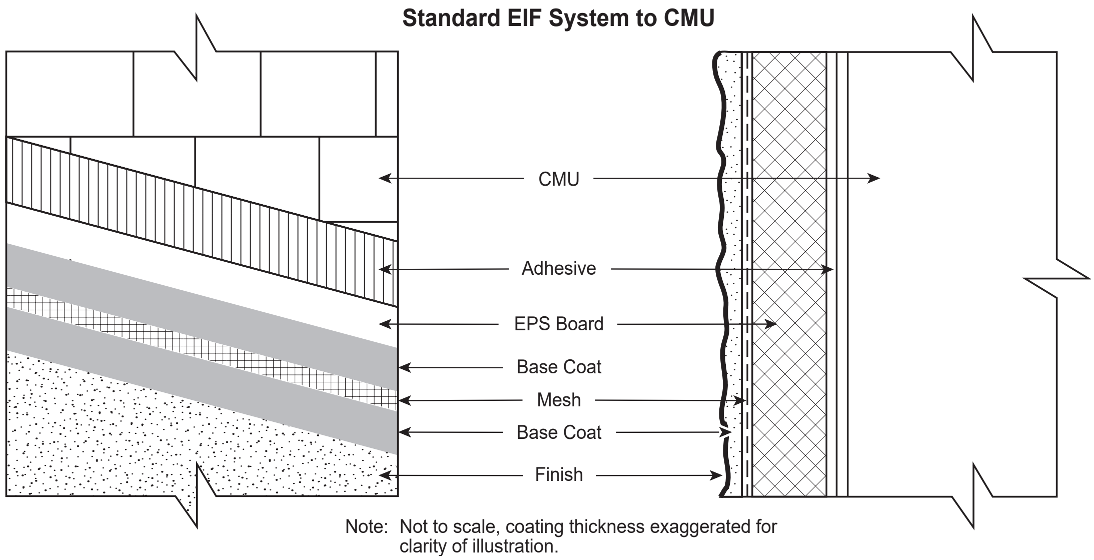
Fig. 7-13

Nailing wallboard to wood furring strip. (IMG24185)

Fig. 7-14

Wood furring strips are nailed to the mortar joints between the block. (IMG25247)

The basic make-up of EIF systems is similar across all manufacturers, though there is a wide range of specific component products. EIF systems are exterior cladding assemblies consisting of a wet-applied plaster-like cementitious lamina over rigid foam plastic insulation board. Expanded polystyrene (EPS) board is the insulation most often used, with polyisocyanurate and extruded polystyrene (XPS) board distant seconds. Board is fastened to the wall with adhesive, mechan-



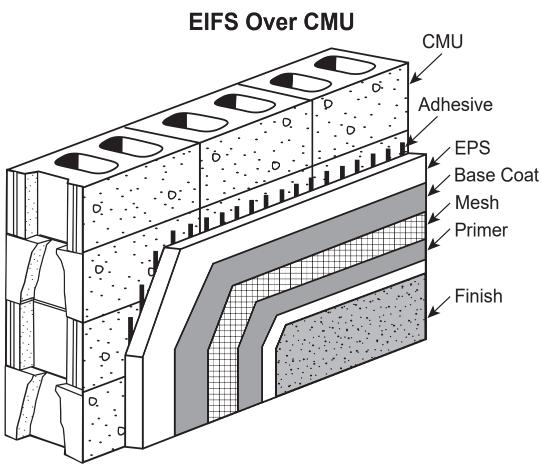


Fig. 7-15

Typical PB-type EIF system consists of (from outside in) an acrylic textured finish; a primer; a base coat with embedded fiberglass mesh; and EPS insulation board adhesively attached to the substrate. Drawing courtesy of ParexLahabra, Inc.

lation most often used, with polyisocyanurate and extruded polystyrene (XPS) board distant seconds. Board is fastened to the wall with adhesive, mechanical fasteners, or both. With a wide range of colors and textures available, the finishing options with EIF systems are about the same as those for conventional portland cement plaster.

The EIFS Industry Members Association (EIMA) classifies EIF systems as PB (polymer-based) or PM (polymer-modified). Informally, Class PB systems are sometimes referred to as thin coat or flexible finishes, while the Class PM systems are sometimes referred to as thick coat or hard coat finishes.

A typical PB system consists of EPS insulation bonded to the substrate with adhesive; fiberglass mesh embedded in a base coat; and a textured, colored finish coat. The base coat thickness is determined by the thickness required to embed and cover the fiberglass mesh, about 1⁄16 in. (1.6 mm) thick for a single layer of the typical standard impact resistive fiberglass mesh. When an additional layer of fiberglass mesh of greater weight is used to provide higher impact resistance, the base coat is accordingly thicker. The finish coats are polymer-based and are most often applied in the thickness of the maximum aggregate particle size in the finish. Textures are typically available in aggregate sizes from approximately 0.04 in. to 0.12 in. (1 mm to 3 mm). PB systems are lightweight and flexible. Typical substrates include concrete and concrete masonry, gypsum sheathing, glass mat gypsum sheathing, and wood necessary to remove the paint, apply a surface conditioner for adhesive, or attach the insulation board using mechanical fasteners. Any surface with poor bonding characteristics requires mechanical fastening.

A typical PM system has a base coat that is approximately ¼ in. (6.4 mm) thick. The base coat thickness is independent of the thickness or number of layers of fiberglass mesh. PM systems have traditionally been applied over extruded polystyrene (XPS) insulation board mechanically fastened to the wall, although they can consist of EPS with adhesive attachment to the wall. They require control joints similar to conventional portland cement stucco, whereas the PB systems do not. Finish coats are the same as for Class PB systems.

Some EIF systems share characteristics of both PB and PM systems. Their base coats are slightly thicker than what is required to embed the fiberglass mesh, but still thin and flexible enough not to require the control jointing used in PM systems that have base coats ¼ in. (6.4 mm) or greater in thickness.

All EIFS, including PB, require joints where there are joints in the underlying materials. Joints are also common at floor lines to accommodate floor deflection or dimensional changes in floor framing.

One of the main advantages claimed for EIF systems is that the insulation is placed where it is most effective—that is, on the building's exterior. PB systems tend to be more economical than PM systems because they use less expensive insulation and the base coats are thinner. However, for equivalent fiberglass mesh weights, PB systems offer lower impact resistance than PM systems.

Due to the rapid increase in the use of EIFS in the 1990s, some structures experienced moisture infiltration resulting from improper design or installation. In the decade since this issue arose, manufacturers have developed systems with drainage for moisture management. Such EIFS are installed with water-resistive barriers behind them and with provisions for drainage of incidental water from between the insulation board and water-resistive barrier. There are two forms of water-resistive barriers. One is a coating, usually supplied by the EIFS manufacturer, that can be applied to the substrate wall with the insulation board then adhered over it. The other, in sheet form, can be installed with the EIFS insulation board mechanically fastened over it. EIFS manufacturers provide various means for draining water from between the barrier and insulation board.

In the U.S., model building codes require water resistive barriers and drainage behind EIFS on wood-framed residential structures. In the early 1990s, when EIF systems were gaining popularity in the United States, their fire safety had been called into question. Since that time, however, the model building codes have addressed this potential problem by requiring stringent testing for flame spread and exposure to radiant heat and other requirements relating to installation of these systems. Complete criteria for the evaluation of EIFS, EIFS with drainage, and water-resistive barrier coatings have been adopted by the ICC Evaluation Service, Inc. subsidiary of the International Code Council (ICC).

There have been fewer problems with EIF systems that have used concrete masonry as the major supporting substrate (Piper 1988). Concrete masonry walls make a superior substrate for EIF systems because they are stable and not affected by moisture that may enter the wall.

Product manufacturers offer guidelines and educational programs for installation of EIF systems. For more information on EIFS and a listing of consensus standards on the systems, consult the organizations listed below. ASTM Committee E06.58 on Exterior Insulation and Finish Systems has developed a set of EIFS standards, and ANSI standards and a design guide are available from EIMA. The Association of the Wall and Ceiling Industry (AWCI) offers an educational program for applicators.

- ASTM www.astm.org
- Association of Wall and Ceiling Industries www.awci.org
- EIFS Industry Manufacturers Association www.eima.com
- International Code Council Evaluation Service www.icc-es.org.

Various Applications of Concrete Masonry

CHAPTER 8

The most common application of concrete masonry is for walls of buildings of all kinds. However, there are a number of other common applications, as described in this chapter.

Fireplaces and Chimneys

Fireplaces and chimneys are important elements in the design and construction of homes. The fireplace can be a central feature for family social life, and the chimney often is a dominant and interesting architectural feature on the home exterior, as well as a focal point of interior design (Fig. 8-1). Accordingly, fireplaces and chimneys should be aesthetically pleasing as well as functional.

Fig. 8-1

An attractive two-face fireplace constructed of ground and polished concrete masonry units laid in stack bond. Note the use of exposed concrete masonry for both interior and exterior walls. (IMG24187)

Various requirements for fireplaces and chimneys normally are set forth in local building codes, but they are usually for a single residential fireplace. In the event the chimney is multistory, extra wide or extra high, or there are multiple fireplaces and flues within the chimney, special design considerations are necessary. A fireplace can be located on one floor directly above one on the floor below, but each fireplace must have a separate flue. Fig. 8-2 shows a way to combine multilevel fireplaces into one chimney. Each flue takes off from the center of the smoke chamber.

The design and construction of an efficient, functional fireplace requires adherence to basic rules concerning fireplace location and the dimensions and placement of various component parts. The designer and builder should keep in mind the basic functions of a fireplace: (1) assure proper fuel combustion, (2) deliver smoke and other products of combustion up the chimney, (3) radiate the maximum amount of heat, (4) provide an attractive architectural feature, and (5) offer simple, firesafe construction.

Combustion and smoke delivery depend mainly upon the shape and dimensions of the combustion chamber, the proper location of the fireplace throat and the smoke shelf, and the ratio of the flue area to the area of the fireplace opening. The third objective, heat radiation, depends on the dimensions of the combustion chamber and proper slope and construction of angles and flue. Firesafety depends not only on the design of the fireplace and chimney but also on the ability of the masonry units to withstand high temperatures without warping, cracking, or deteriorating.

Above: Concrete masonry textures can simulate natural stone. (IMG24205) Right: Concrete masonry units are popular for landscaping applications — see Fig. 8-18. (IMG15711)

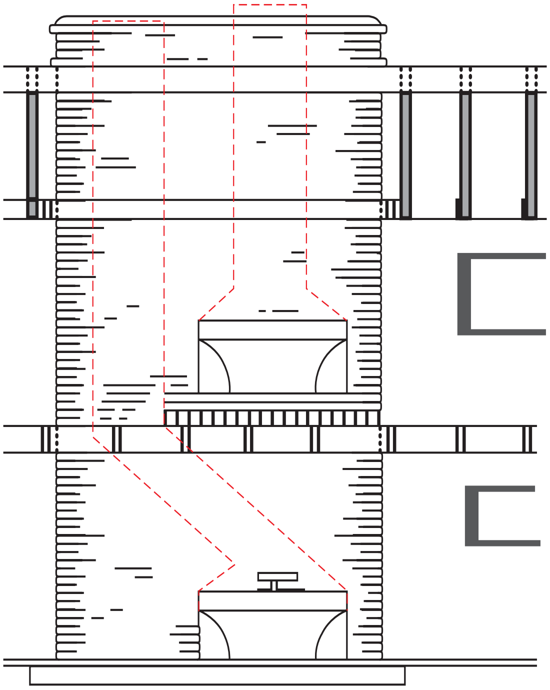


Fig. 8-2

Chimney with separate flues for fireplaces on two floors.

When properly designed, concrete masonry can also be used safely for chimneys for wood stove heating of residences. A dangerous error sometimes created by do-it-yourselfers is the omission of flue liners or stacks. Fireclay mortar instead of portland cement mortar should be used in firebrick masonry and between flue liners. Fireplace owners should also be aware that creosote, a byproduct of wood burning, can slowly attack concrete masonry.

Types of Fireplaces

There are several types of fireplaces being used today, and the basic principles involved in their design and construction are the same. These types and some standard sizes found to work satisfactorily under most conditions are given in Fig. 8-3 and Table 8-1.

The single-face fireplace (pictured at top in Fig. 8-1) is the oldest and most common variety, and most standard design information is based on this type. The multiface fireplace, used properly, is highly effective and attractive, but it may present certain problems with draft and opening size that usually must be solved on an individual basis. The two-face (opposite or see through) fireplace is not recommended by some governmental agencies. If used, this type of fireplace requires a fire screen of fire-resistant, tempered Pyrex glass to be placed on one side to prevent fire from blowing out into the room.

Barbecues (or outdoor fireplaces) can discharge into a chimney attached to the house with a separate flue or, if desired, can be located separately from the house with its own chimney. Inexpensive, serviceable barbecues can be built of concrete masonry with minimum labor and time. The site selected should be sheltered from the wind, conveniently located between play and work areas, and afford adequate entertaining space. Details of a simple barbecue are shown in Fig. 8-4 and those of a more elaborate one in Fig. 8-5.

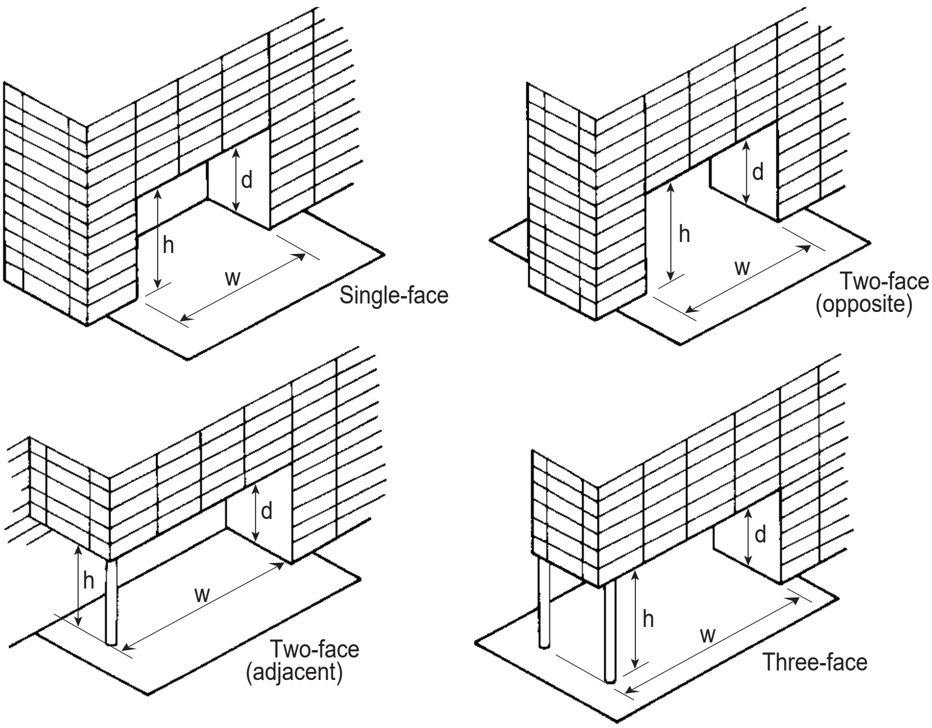


Fig. 8-3

Fireplace types with one to three faces.

Table 8-1. Fireplace Types and Standard Sizes*

Type**	Width (w), in. (mm)	Height (h), in. (mm)	Depth (d), in. (mm)	Area of fireplace opening, sq.in. (m²)	Nominal flue sizes (based on 1/10 area of fireplace opening),† in. (mm)
Single-face	36 (910)	26 (660)	20 (510)	936 (0.60)	12x16 (300x400)
	40 (1020)	28 (710)	22 (560)	1,120 (0.72)	12x16 (300x400)
	48 (1220)	32 (810)	25 (630)	1,536 (0.99)	16x16 (400x400)
	60 (1520)	32 (810)	25 (630)	1,920 (1.24)	16x20 (400x510)
Two-face (adjacent)	39 (990)	27 (690)	23 (580)	1,223 (0.79)	12x16 (300x400)
	46 (1170)	27 (690)	23 (580)	1,388 (0.90)	16x16 (400x400)
	52 (1320)	30 (760)	27 (690)	1,884 (1.22)	16x20 (400x510)
	64 (1630)	30 (760)	27 (690)	2,085 (1.35)	16x20 (400x510)
Two-face (opposite)	32 (810)	21 (530)	30 (760)	1,344 (0.87)	16x16 (400x400)
	35 (890)	21 (530)	30 (760)	1,470 (0.95)	16x16 (400x400)
	42 (1070)	21 (530)	30 (760)	1,764 (1.14)	16x20 (400x510)
	48 (1220)	21 (530)	34 (860)	2,016 (1.30)	16x20 (400x510)
Three-face	39 (990)	21 (530)	30 (760)	1,638 (1.06)	16x16 (400x400)
	46 (1170)	21 (530)	30 (760)	1,932 (1.25)	16x20 (400x510)
	52 (1320)	21 (530)	34 (860)	2,184 (1.41)	20x20 (510x510)

*Adapted from Amrhein 2004.

**Fireplace types and dimensions *w*, *h* and *d* are shown in Fig. 8-3.

†A requirement of the U.S. Federal Housing Administration if the chimney is 15 ft. (4.6 m) high or over; ⅛ ratio is used if chimney height is less than 15 ft. (4.6 m). See Table 8-2 for nominal and actual flue sizes and inside areas of flue linings.

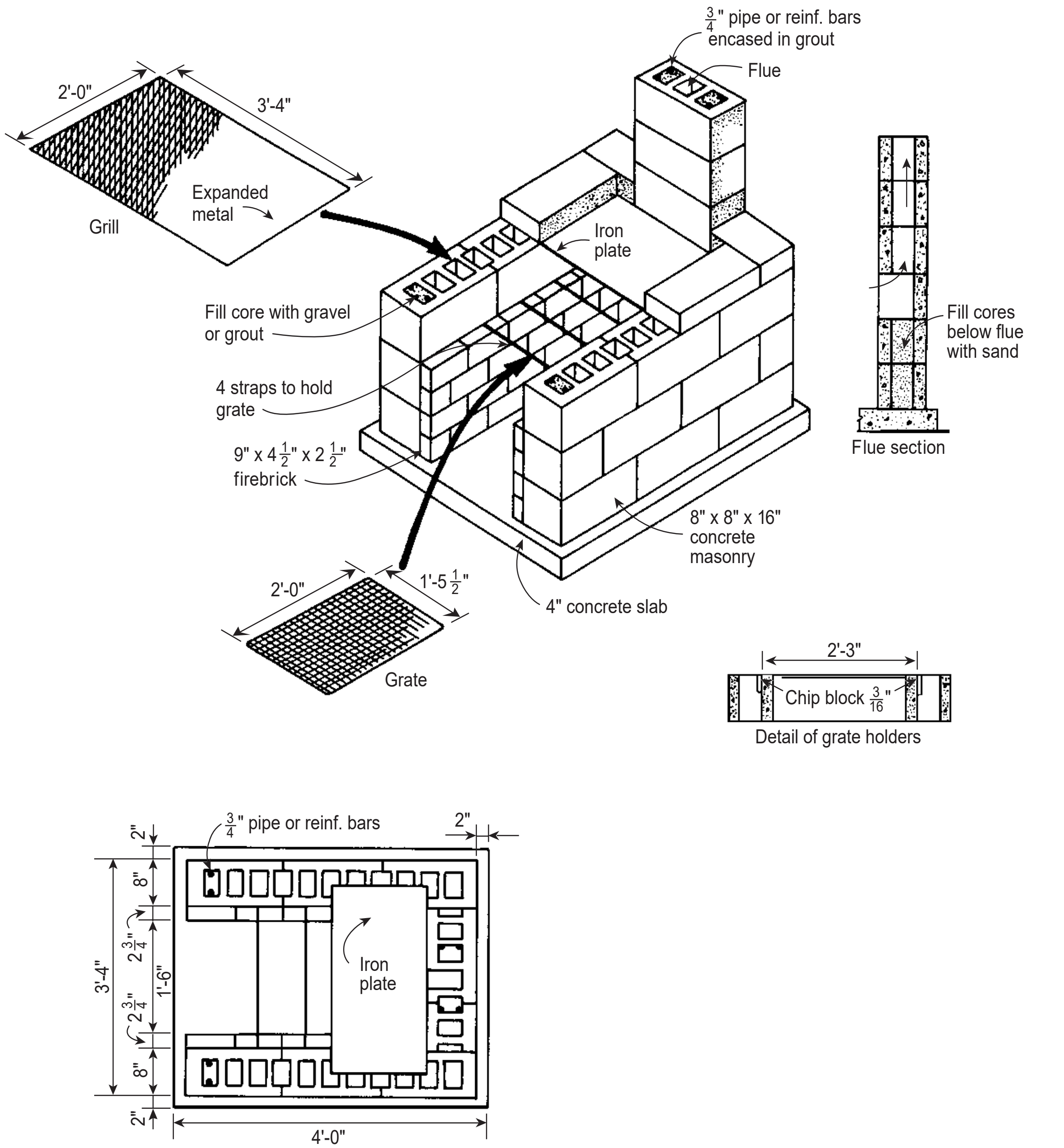


Fig. 8-4

Details of a simple barbecue. The concrete masonry flue must be kept at least 24 in. (610 mm) clear of any combustible construction.

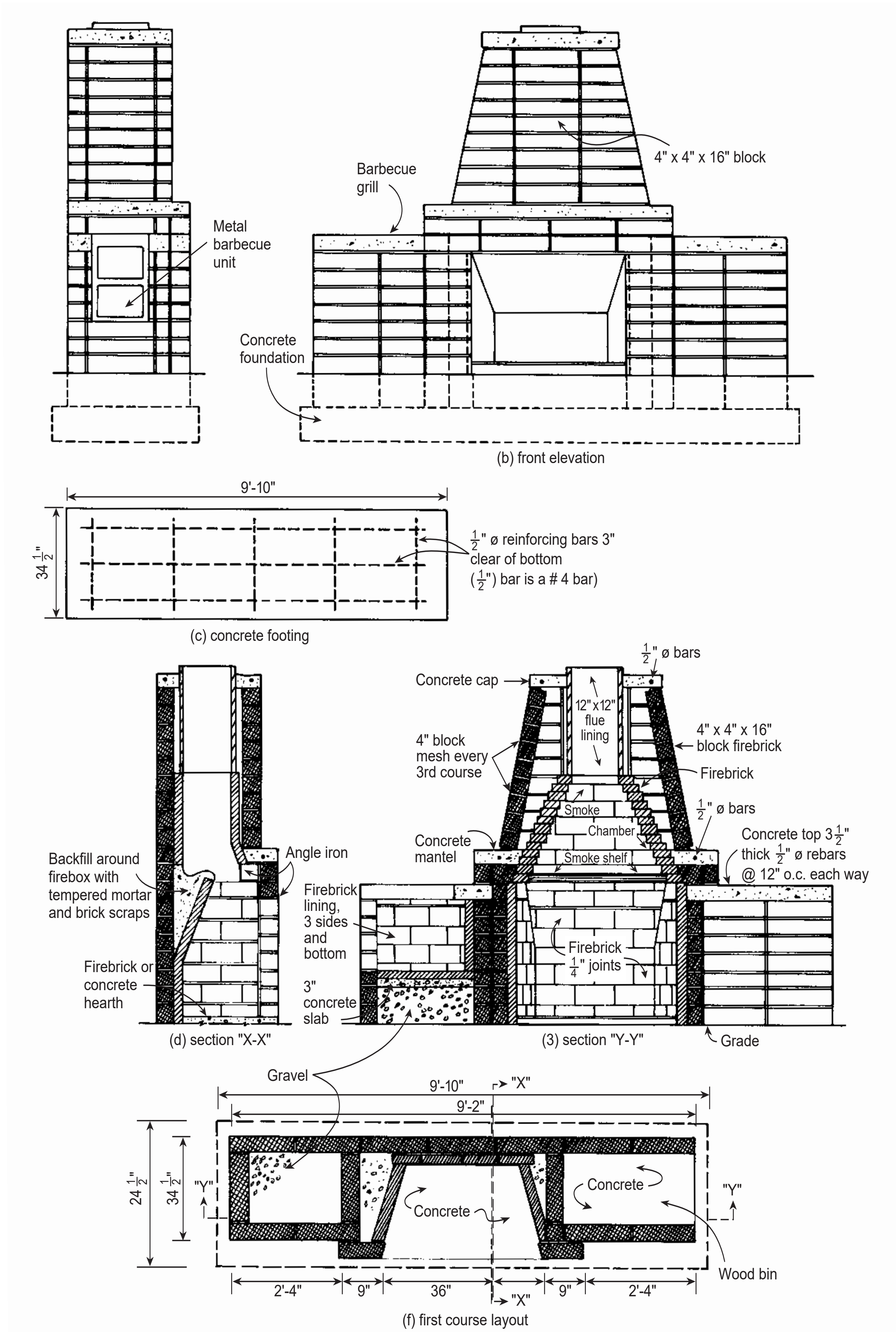


Fig. 8-5

Details of a more elaborate barbecue.

Fireplace Elements

Only the major elements of a fireplace are discussed below, but the details of a typical unreinforced concrete masonry fireplace are shown in Fig. 8-6. For more information see NFPA 1984.

Hearth

The floor of the fireplace is called the hearth. The inner part of the hearth is lined with firebrick and the outer hearth consists of noncombustible material such as firebrick, clay brick, natural stone, concrete brick, concrete block, or reinforced concrete. The outer hearth should be supported on concrete that may be a part of the foundation, a ground floor, or a cantilevered section of the slab supporting the inner hearth.

Lintel

The fireplace lintel is the horizontal member that supports the front face or mantel of the fireplace above the opening. It may be made of reinforced masonry or a steel angle, the same as other lintels discussed in Chapter 4. It is also possible to eliminate the lintel by use of a masonry arch.

Firebox

The combustion chamber where the fire occurs is called the firebox. Its sidewalls are slanted slightly to radiate heat into the room, and its rear wall is curved or inclined to provide an upward draft to the throat (described below) and to help radiate heat into the room.

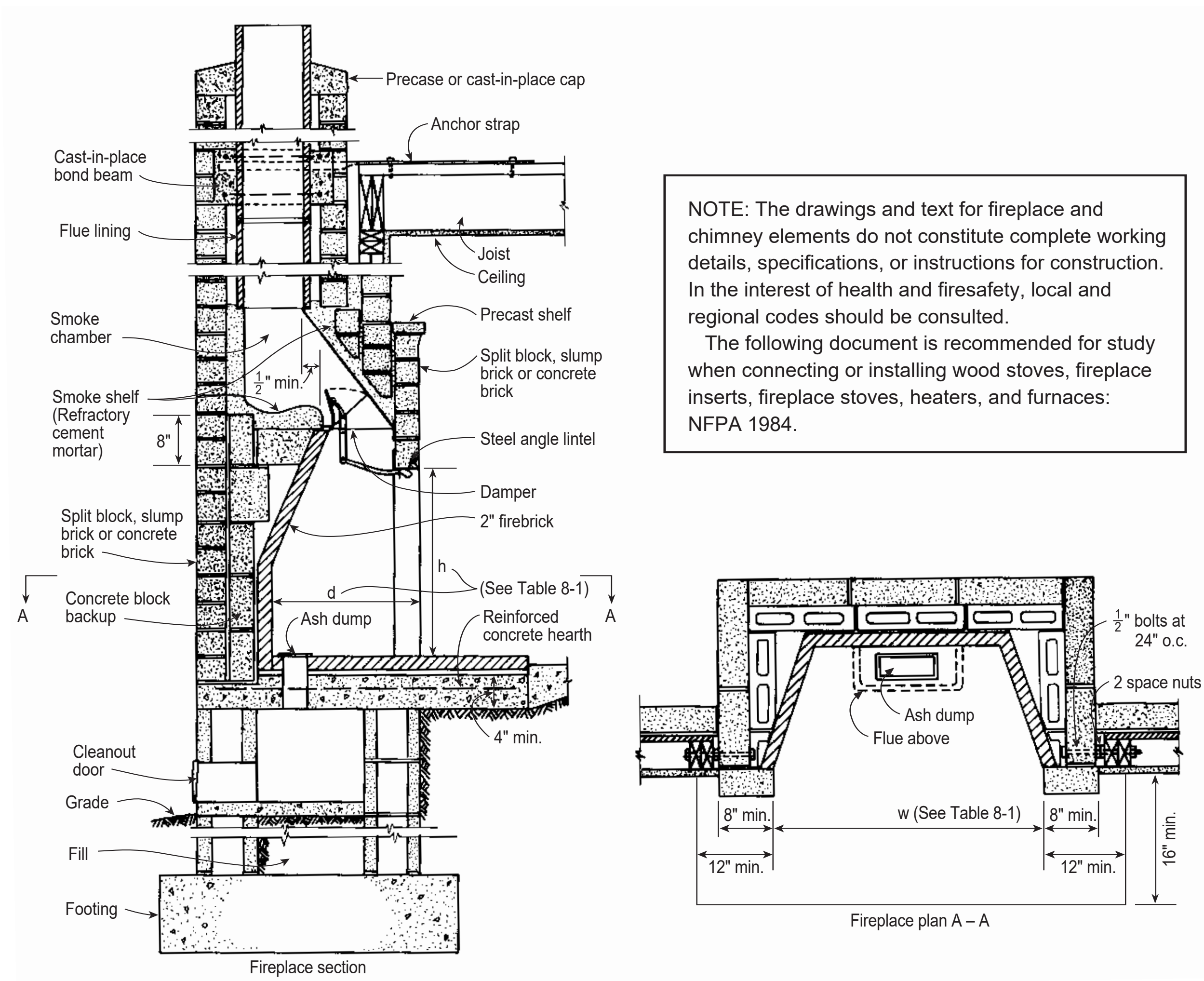


Fig. 8-6

Unreinforced concrete masonry fireplace and chimney. Some building codes require that the concrete masonry units be solid units (see definition in "Hollow and Solid Units," Chapter 1).

Unless the firebox is of the metal preformed type—at least ¼ in. (6.4 mm) thick—it should be constructed with firebrick that is at least 2 in. (51 mm) thick. The firebrick should be laid with thin joints of fireclay (refractory) mortar, not portland or masonry cement mortar, because the latter disintegrate in time under direct fire exposure. The back and sidewalls of the firebox should be at least 8 in. (203 mm) thick to support the weight of the chimney above. Woodwork and other combustible material must not be placed within 6 in. (152 mm) of the fireplace opening.

In a generally accepted method of construction, the fireplace is laid out and its back constructed to a scaffold height of approximately 5 ft (1.52 m) before the firebox is constructed and backfilled with mortar and brick scraps. Masons should not backfill solidly behind the firebox wall; rather, they should "slush in" the mortar loosely to allow for some expansion of the firebox.

Throat

The throat of a fireplace is the slot-like opening directly above the firebox through which flames, smoke, and other combustion products pass into the smoke chamber. Because of its effect on the draft, the throat must be carefully designed and constructed to be not less than 6 in. (152 mm) and preferably 8 in. (203 mm) above the highest point of the fireplace opening, as shown in Fig. 8-6.

The sloping or inclined back of the firebox should extend to the same height as the throat and form the support for the hinge of a metal damper placed in the throat. The damper extends the full width of the fireplace opening and preferably opens both upward and backward.

Smoke Chamber

The smoke chamber acts as a funnel to compress the smoke and gases from the fire so that they will enter the chimney flue above. The most convenient shape of a smoke chamber would be symmetrical with respect to the center line of the firebox. However, when two- or three-faced fireplaces are constructed, the smoke shelf may be located in the area adjacent to but not over the firebox. The back of the smoke chamber is usually vertical and its other walls are inclined upward to meet the bottom of the chimney flue lining. If the wall thickness is less than 8 in. (203 mm) of solid masonry, the smoke chamber should be parged with ¾ in. (19 mm) of fireclay finished to a smooth texture. Metal lining plates are available to give the chamber its proper form, provide smooth surfaces, and simplify masonry construction.

Chimney Elements

A fireplace chimney serves a dual purpose: (1) to create a draft, and (2) to dispose of the products of combustion. Careful consideration must be given to chimney design and erection in order to assure efficient operation and freedom from fire hazards. Some of the requirements for chimney construction are mentioned below. For more information, see NFPA 1984.

To prevent upward draft from being neutralized by downward air currents, the chimney should be extended at least 3 ft (914 mm) above a flat roof, 2 ft (610 mm) above the ridge of a pitched roof, or 2 ft (610 mm) above any part of the roof within a 10-ft (3.05-m) radius of the chimney. If a chimney does not draw well, increasing its height will improve the draft. A typical unreinforced concrete masonry chimney is shown with the fireplace in Fig. 8-6.

Foundation

Usually made of cast-in-place concrete, the foundation for a chimney is designed to support the weight of the chimney and any additional load. Because of the large mass and weight imposed, it is important that the unit bearing pressure on the soil beneath the chimney foundation be approximately equal to that beneath the house foundation; this will minimize the possibility of differential settlement. The concrete in the chimney foundation is generally unreinforced, with only the chimney reinforcement (where required by local building codes) extending from it.

The footing thickness should be at least 8 in. (203 mm) for 16-in. (406-mm) square chimney units. A typical concrete footing is 30 in. (762 mm) square and 12 in. (305 mm) thick. The bottom of the footing should be at least 18 in. (457 mm) below grade and extend below the frost line.

Chimney Flue

This discussion of flues deals only with residential fireplace chimneys. Commercial and industrial chimneys have more stringent requirements.

A fireplace chimney flue must have the correct cross-sectional area and shape to produce a proper draft. Relatively high velocities of smoke through the throat and flue are desirable. Velocity is affected by the flue area, the firebox opening area, and the chimney height.

Generally the required cross-sectional area of the flue should be approximately 1⁄10 of the area of the fireplace opening. However, since some codes may specify ⅛ or ½ under some conditions, the local building department should be consulted. Typical sizes of fireplace flues and flue linings are given in Tables 8-1 and 8-2.

Table 8-2. Clay Flue Lining Sizes*

Nominal size, in. (mm)	Manufactured size (modular), in. (mm)**	Inside area, sq. in. (m^2)
4x8 (100x200) 4x12 (100x300) 4x16 (100x400)	3½ x 7½ (90x190) 3½ x 11½ (90x290) 3½ x 15½ (90x395)	15 (0.010) 20 (0.013) 27 (0.017)
8x8 (200x200) 8x12 (200x300) 8x16 (200x400)	7½ x 7½ (190x190) 7½ x 11½ (190x290) 7½ x 15½ (190x395)	35 (0.023) 57 (0.037) 74 (0.048)
12x12 (300x300) 12x16 (300x400)	11½ x 11½ (290x290) 11½ x 15½ (290x395)	87 (0.056) 120 (0.077)
16x16 (400x400) 16x20 (400x510)	15½ x 15½ (395x395) 15½ x 19½ (395x495)	162 (0.105) 208 (0.134)
20x20 (510x510) 20x24 (510x610)	19½ x 19½ (495x495) 19½ x 23½ (495x595)	262 (0.169) 320 (0.206)
24x24 (610x610)	23½ x 23½ (595x595)	385 (0.248)

*Source: Clay Flue Lining Institute, www.rumford.com/CFLI.html (Web site hosted by Rumford).

**Actual dimensions may vary somewhat, but the flue lining must fit into a rectangle corresponding to the nominal flue size.

A fireplace chimney can contain more than one flue, but each flue must be built as a separate unit entirely free from the other flues or openings. Flue walls should have all joints completely filled with mortar. All chimney flues should be lined. Clay flue liners are the common requirement and are covered by ASTM C315, Standard Specification for Clay Flue Linings. Firebrick can also be used. Concrete flue liners made with perlite aggregate and portland cement have been approved in Research Committee Recommendation Report No. 2602 of the International Conference of Building Officials (ICBO).

Flue linings should start at the top of the smoke chamber and extend continuously to 4 in. to 8 in. (100 mm to 203 mm) above the chimney cap. The chimney walls are constructed around the flue lining segments, which are embedded one upon the other in a refractory mortar, such as fireclay. Only enough refractory mortar should be used to make a good joint and hold the liners in position. The joints in the clay liners are left smooth on the inside. Liners should be separated from the masonry in the chimney wall by at least ½ in. (13 mm) of air space, and the space between the liner and masonry should not be filled. The air space allows the liner to expand and contract independently of the chimney wall. If the air space is inadvertently filled with mortar, extensive cracking can occur throughout the chimney.

The minimum air space between the chimney and any framing material should be 2 in. (51 mm). Firestopping in between must be made of noncombustible material. Firestopping can be galvanized steel (26 gauge minimum) or sheet materials not more than ½ in. (13 mm) thick.

Modular-size, solid masonry units (Fig. 8-7) can be combined with modular-size flue lining for modular-size concrete masonry construction. Minimum wall thickness measured from the outside of the flue lining should be 4 in. (102 mm) nominal. The exposed joints inside the flue are struck smooth and the interior surface is not plastered.

Smoke pipe connections should enter the side of the flue at a thimble or flue ring that is built of fireclay or firebrick set with fireclay mortar. The metal smoke pipe should not extend beyond the inside face of the flue, and the top of the smoke pipe should be not less than 18 in. (457 mm) below the ceiling. No wood or combustible materials should be placed within 6 in. (152 mm) of the thimble.

When a chimney contains more than two flues, they should be separated into groups of one or two flues by 4-in.-thick (102-mm) masonry bonded into the chimney wall, or the joints of the adjacent flue linings should be staggered at least 7 in. (178 mm). The tops of the flues should have a height difference of 2 in. to 12 in. (51 mm to 305 mm) to prevent smoke from pouring from one flue into another. A fireplace on an upper level should have the top of its flue higher than the flue of a fireplace on a lower level as shown in Fig. 8-2.

For reasons of appearance, chimneys are often built to the same widths as attached fireplaces, and these wide chimneys sometimes contain only a single flue. It can be located anywhere within the chimney. Consideration should be given to reinforcing a wide chimney wall against lateral forces (see “Reinforcement and Chimney Anchorage” this chapter).

Practically any size or shape of single- or multiple-flue chimney can be constructed with only three different sizes of solid concrete masonry units (designated Nos. 1, 2, and 3 in Fig. 8-7).

Chimneys should be built as nearly vertical as possible, but a slope is allowed if the full area of the flue is maintained throughout its length. When a slope from the vertical is required in a flue for design reasons, it should not exceed 30 degrees. Where offsets or bends in a flue are necessary, they should be formed by

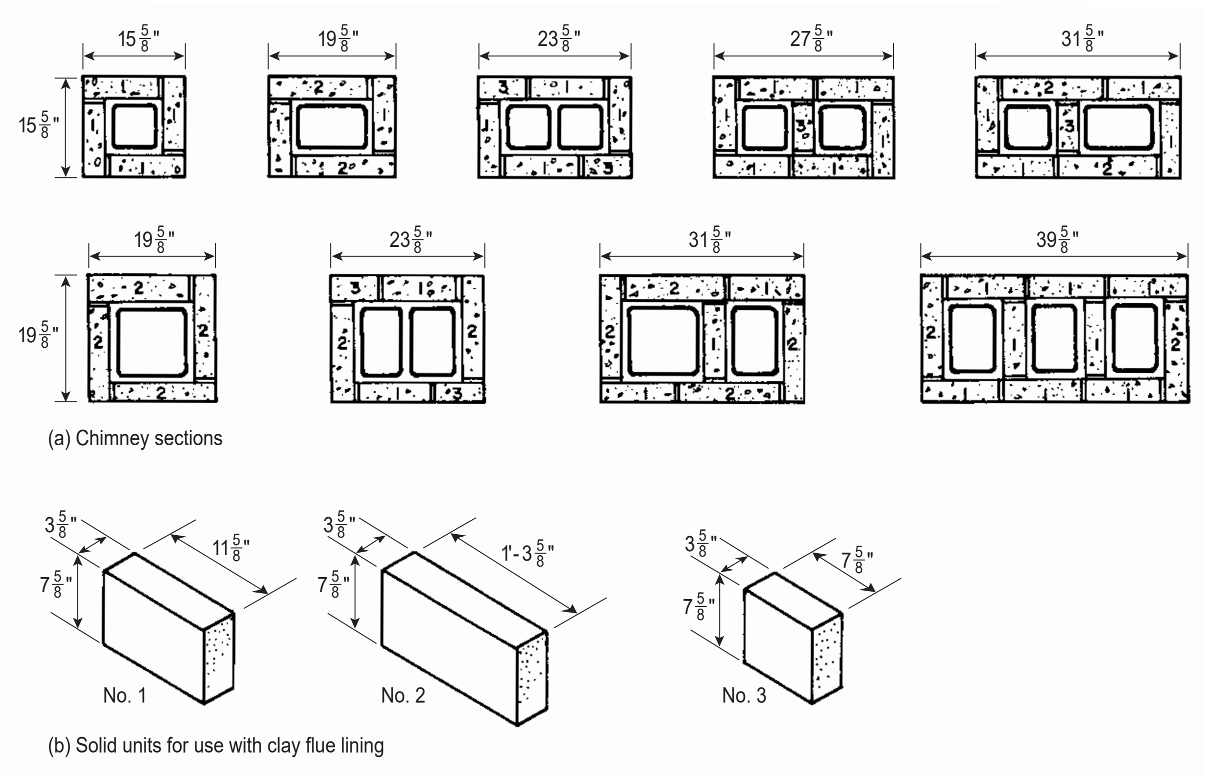


Fig. 8-7

Residential concrete masonry chimney sections. See Table 8-2 for dimensions of clay flue linings.

mitering both ends of abutting flue liner sections equally; this prevents reduction of the flue area.

Chimney Cap and Hood

The top of the chimney wall should be protected by a concrete cap conforming with the architectural design of the building (Figs. 8-6 and 8-9). The cap should slope not only to prevent water from running down next to the flue lining and into the fireplace, but also to prevent standing water from creating frost or moisture problems. In addition, since chimney flues should project 4 in. to 8 in. (102 mm to 203 mm) above the cap, a sloping cap improves draft from the flue as well as the smoke exhaust characteristics of the chimney. If the cap projects beyond the chimney wall a few inches, a drip slot in its lower edge should be included to help keep the wall dry and clean. Also, the flue liner should be isolated from the chimney cap to allow thermal expansion and contraction. A thin sheet of plastic or metal (flashing) may be used as a bondbreaker to help separate the cap and liner. A sealant should be used at the top of the bondbreaker to close the space and protect it from weather and insect infestation.

A chimney hood gives a finished touch to the silhouette of the building. It protects the chimney and fireplace from rain and snow. Also, when the building is located below adjoining buildings, trees, and other obstacles, a hood prevents downdrafts. The hood must have at least two sides open, with the open areas larger than the flue area. The openings are sometimes enclosed with heavy screening to keep out small animals and birds, but insurance company regulations on such screens should be checked—they can become clogged by frozen gas condensate in winter.

Concrete chimney hoods should be reinforced with steel bars or welded-wire fabric. If a hood projects out from the face of a chimney wall, a drip slot under the edge should be included. A simple concrete chimney hood is shown in Fig. 8-8.

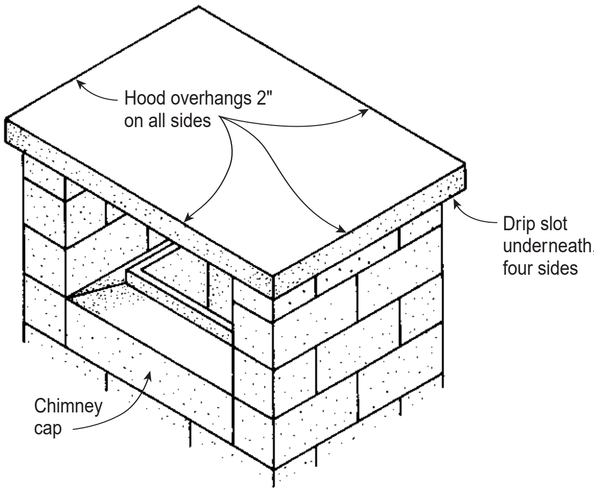


Fig. 8-8

A simple concrete chimney hood keeps rain and snow out, prevents downdrafts, and improves the appearance of the chimney.

Reinforcement and Chimney Anchorage

Depending on local building codes, fireplaces and chimneys have to be reinforced in areas subject to earthquakes or high wind loads. A typical reinforced concrete masonry fireplace and chimney are shown in Fig. 8-9.

The reinforcement, consisting of at least four # 4 (#13) deformed bars, should extend the full height of the chimney and be tied into the footing and chimney cap. Also, the bars should be tied horizontally with ¼-in.-diameter (6.4 mm) ties at not more than 18-in. (457-mm) intervals. If the width of a reinforced masonry chimney exceeds 40 in. (1.02 m), two additional #4 (#13) vertical bars should be provided for each additional flue incorporated into the chimney, or for each additional 40-in. (1.02-m) width or fraction thereof.

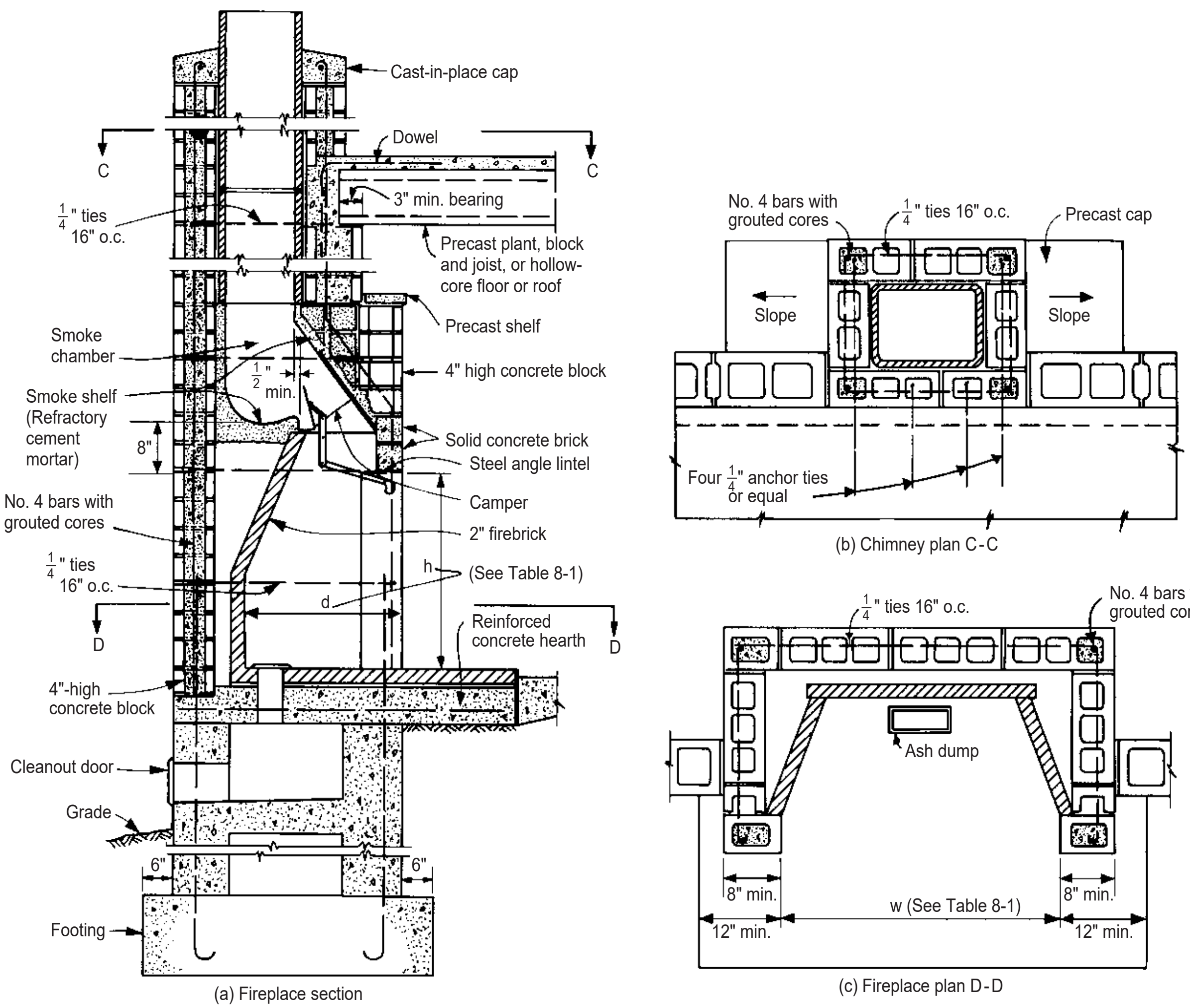


Fig. 8-9

Reinforced concrete masonry fireplace and chimney.

All chimneys not located entirely within the exterior walls of a residence should be anchored to the building at each floor or ceiling line 6 ft (1.83 m) or more above grade, and at the roof line. The anchors should consist of ¼-in.-thick (6.4-mm) steel straps wrapped around vertical reinforcement or chimney flues, as shown in Fig. 8-6. Each end of the strap is attached to the structural framework of the building with six 16d nails, two ½-in.-diameter (13-mm) bolts, or two ¾-in.-diameter by 3-in.-long (19 x 76 mm) lag screws. Reinforced chimneys must have equivalent anchorage, as shown in Fig. 8-9.

When a chimney extends considerably above the roof level, an intermediate lateral support or tie is often placed between the roof line and the chimney.

Screen Walls

Concrete masonry screen walls are functional, decorative elements. These walls, constructed with over 25% open areas, combine privacy with a view, interior light with shade and solar heat reduction, and airy comfort with wind control. Curtain walls, sun screens, decorative veneers, room dividers, and fences are just a few of the many applications of the concrete masonry screen wall.

Materials

Whether constructed with conventional concrete block or the specially designed screen wall units (grille block), concrete masonry offers a new dimension in screen wall design. The many sizes, shapes, colors, patterns, and textures available help in creating imaginative designs. Several units may make up a design, or each screen wall unit may constitute a design in itself.

Although the number of designs for concrete masonry screen units is virtually unlimited, it is advisable to check on availability of any specific unit during the early planning stage. Some designs are available only in certain localities and others are restricted by patent or copyright. A few screen units are shown in Figs. 1-23, 1-24, and 8-10 through 8-13.

Screen units should be of high quality, even though they are not often used in load-bearing construction. When tested with their hollow cells parallel to the direction of a test load, screen units should have a minimum compressive strength of 1000 psi (6.9 MPa) on the gross area.

Air-entrained Type S mortar should be used for exterior screen walls, and where screen walls are required to carry any vertical load. For interior non-load-bearing walls, the mortar may be Type O or N. Grout for embedding steel reinforcement in horizontal or vertical cells should comply with the criteria described in Chapter 2.

Fig. 8-10

A comcrete grille block wall makes a pleasing backdrop and privacy screen. (IMG15888)

Design and Construction

Care must be taken that screen walls are stable and safe, although from a design standpoint they are seldom required to support more load than their own weight. They can be designed as load-bearing walls, but such construction is not permitted by some building codes. In any case, extra attention to design of screen walls for wind forces is warranted despite the relatively high percentage of open areas. The wall openings are created by using screen units with decorative openings or, occasionally, by using conventional concrete block with intermittent openings in the wall in lieu of vertical mortar joints.

Screen walls should be designed to resist all anticipated horizontal forces. Stability is provided by:

1. Using a framing system capable of carrying horizontal forces into the ground.
2. Employing adequate connection or anchorage of screen walls to the framing system.
3. Limiting the clear span.
4. Incorporating vertical reinforcement and horizontal joint reinforcement.

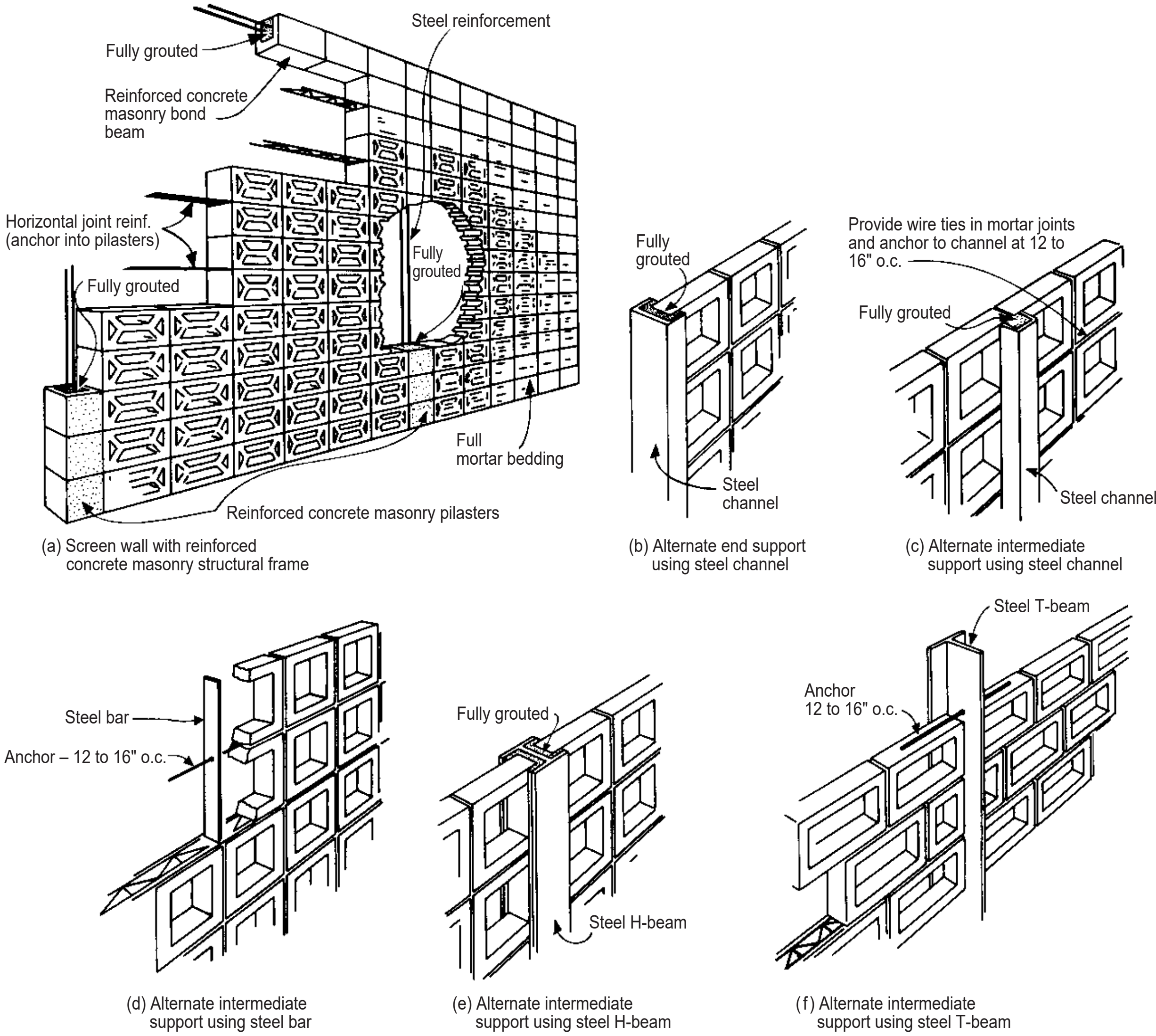


Fig. 8-11

Framing methods for screen walls. (Adapted from TEK 14-13 1970.)

Partitions built with the screen units are usually designed as non-load-bearing panels, with primary consideration given to adequate anchorage at panel ends or top edge or both, depending on where lateral support is furnished. Lateral design pressure should be at least 5 psf (239 Pa). Lateral support for screen walls for the horizontal spans may be obtained from cross walls, piers, columns, posts, or buttresses, and or vertical spans, from floors, shelf angles, roofs, bond beams, or spandrel beams. The structural frame for a screen wall may consist of reinforced concrete masonry columns, pilasters, and beams, or may incorporate structural steel members as shown in Fig. 8-11. Screen wall framing methods may also be similar to those used for fences (see next section).

When designed as a masonry veneer, the concrete masonry screen wall is attached to a structural backing with wire ties or sheet metal anchors in the same manner as other types of masonry veneer.

A non-load-bearing screen block panel may be used to fill an opening in a load-bearing masonry wall. In such cases, the panel is restrained on all four sides, and joint reinforcement is placed in the horizontal joints to anchor the panel into the wall. For an exterior wall, the panel is limited to 144 sq ft (13.4 m^2) of wall surface, or 15 ft (4.57 m) in any direction—for an interior wall, 250 sq ft (23.2 m^2) or 25 ft (7.62 m) in any direction. The lintel, sill, and jamb of the panel opening should be designed the same as for a window opening.

Non-load-bearing screen walls should have a minimum nominal thickness of 4 in. (102 mm) and a maximum clear span of 36 times the nominal thickness. For load-bearing screen walls, the minimum thickness should be increased to 6 in. (152 mm). The maximum span can be measured vertically or horizontally, but need not be limited in both directions.

Screen walls are usually capable of carrying their own weight up to 20 ft (6.10 m) in height, but above that height they must be supported vertically not more than every 12 ft (3.66 m). When screen walls support vertical loads, the allowable compressive stress should be limited to 50 psi (0.34 MPa) on the gross cross-sectional area. In some instances the compressive stress at the base of a non-load-bearing screen wall will govern the maximum unsupported height. Where screen block are not laid in a continuous mortar bed (intermittent bond), the allowable stresses should be reduced in proportion to the reduction in the mortar-bedded area.

Due to the somewhat fragile nature of concrete masonry screen walls, the use of steel reinforcement is recommended wherever it can be embedded in mortar joints and bond-beam courses, or grouted into continuous vertical or horizontal cavities. When reinforced joints are used, the thickness of the mortar joint should be a minimum of twice the diameter of the reinforcement.

For exterior screen walls, joints and connections should be constructed as fully watertight as possible. The mortar joints should be constructed according to the best construction practices. In addition, when hollow masonry units are laid with their cores vertical, the top course should be capped to prevent the entrance of water into the wall's interior.

Garden Walls and Fences

Concrete masonry garden walls and fences can take on many delightful forms, enhancing the landscape (Figs. 8-12 and 8-13). They can be built with solid or screen block units and with concrete brick or half block. If a garden wall has more than 25% open areas, it may be considered a fence. Fence framing methods are shown in Fig. 8-14.

Fig. 8-12

This wall combines split-face and screen units, providing privacy while complementing the building's façade. (IMG24188)

Fig. 8-13

Screen block used to create a dignified property-line fence. (IMG15609)

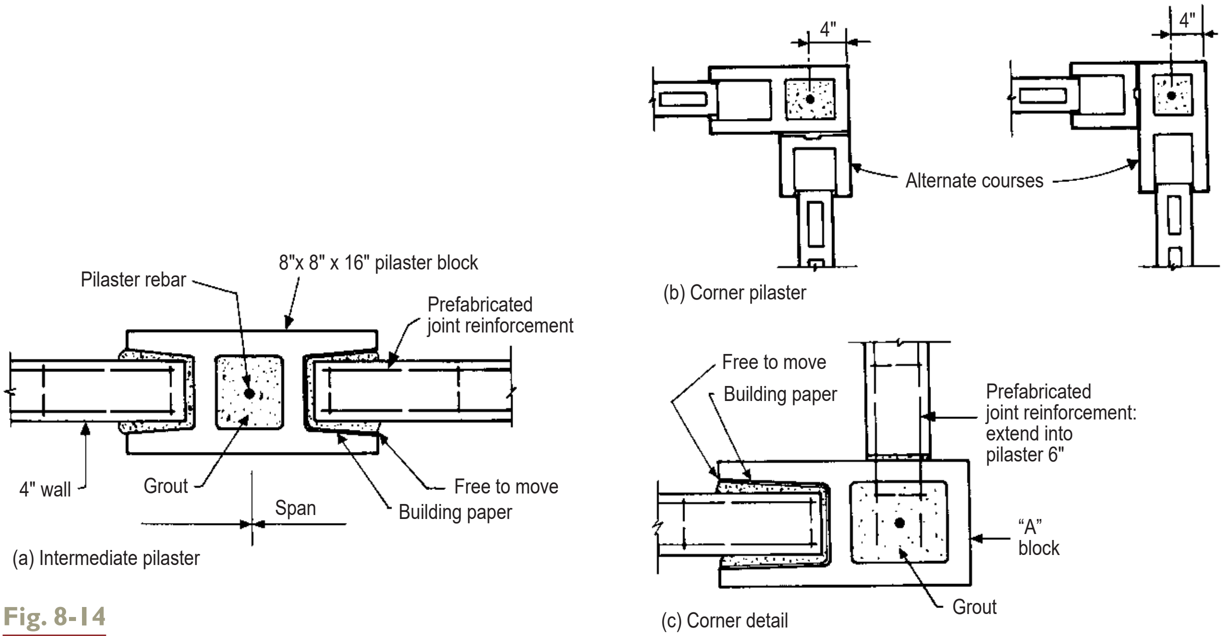
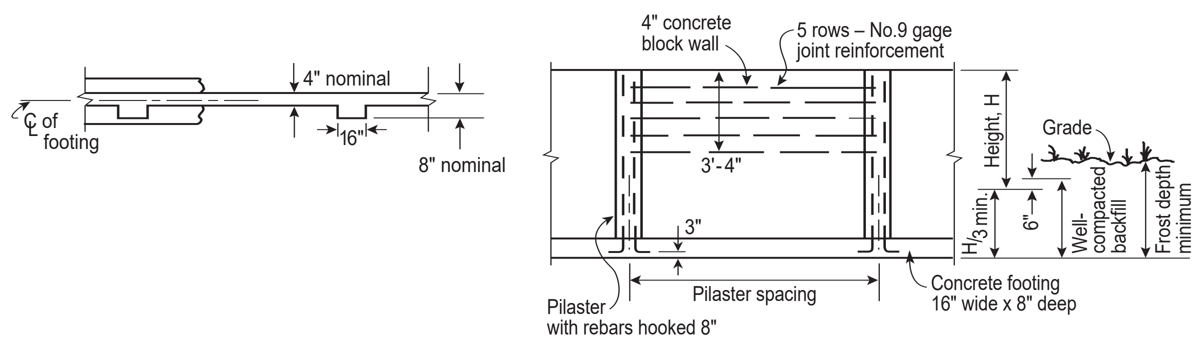


Fig. 8-14

Concrete masonry fence framing.



Pilaster spacing for wind pressure					Reinforcement for wind pressure			
5 psf	10 psf	15 psf	20 psf	*H*	5 psf	10 psf	15 psf	20 psf
19' 4"	14' 0"	11' 4"	10' 0"	4' 0"	1–No. 3	1–No. 4	1–No. 5	2–No. 4
18' 0"	12' 8"	10' 8"	9' 4"	5' 0"	1–No. 3	1–No. 5	2–No. 4	2–No. 5
15' 4"	10' 8"	8' 8"	8' 0"	6' 0"	1–No. 4	1–No. 5	2–No. 5	2–No. 5

(a) Wall or fence with pilasters

	Reinforcement for wind pressure			
H	5 psf	10 psf	15 psf	20 psf
4' 0"	1–No. 3	1–No. 3	1–No. 4	1–No. 4
5' 0"	1–No. 3	1–No. 4	1–No. 5	1–No. 5
6' 0"	1–No. 3	1–No. 4	1–No. 5	2–No. 4

(b) Wall or fence without pilasters

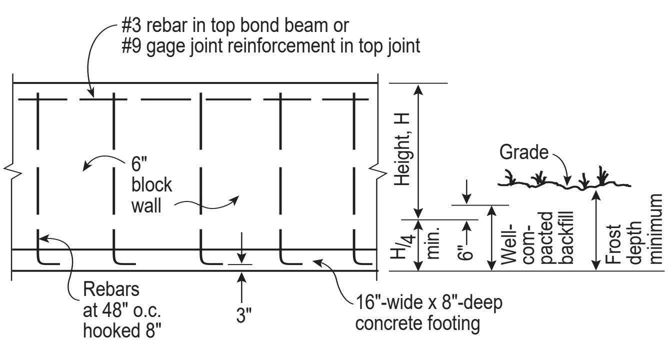


Fig. 8-15

Reinforced garden walls or fences.

Fences and garden walls should be able to safely withstand wind loads of at least 5 psf (239 Pa), and most city building codes specify a resistance to 20-psf (958-Pa) pressure. Pressures and corresponding wind gust velocities are:

Pressure, psf (Pa)	Wind gust velocity, mph (km/hr)
5 (239)	40 (64.4)
10 (479)	57 (91.7)
15 (718)	69 (111.0)
20 (958)	80 (128.7)

In hurricane prone areas, higher wind-pressure resistance is needed. Check the local building code.

Examples of reinforced garden walls or fences are shown in Fig. 8-15. Without reinforcement, high and straight garden walls or fences lack vertical tensile strength and may be unstable in strong winds. To add structural stability, these walls are reinforced. Both empirical design and allowable stress design are used (TEK 14-3A 1995, 14-7A 2004, 14-8A 2001, and 14-16B 2007). Whether or not local building codes require it, design should be performed by a structural engineer.

As an alternative to straight-line orientation, undulating curves and "folded plates" (Fig. 8-16) give this type of wall superb stability from the foundation up, and with no need for reinforcement. The serpentine alignment adds visual interest to the landscape.

Fig. 8-17 shows sample designs for serpentine walls based on proportions found safe for wind gusts with pressures up to 20 psf (958 Pa). The horizontal radius should not exceed twice the height. A limiting wall height of 15 times the wall thickness is recommended. The free end(s) of a serpentine wall should have additional support, such as a pilaster or a short-radius return as illustrated in Fig. 8-17a.

Concrete masonry wall foundations may not be durable if they frequently become frozen while saturated, as noted in the discussion of "Durability" in Chapter 2. In cold climates, therefore, the wall foundations should be constructed with cast-in-place concrete.

Fig. 8-16

A tall garden fence can be simply constructed on the serpentine principle using conventional two-core block. (IMG24201)

Retaining Walls

Concrete masonry retaining walls can be visually attractive and at the same time possess the required structural strength to resist imposed vertical and lateral loads (Fig. 8-18). Because the main purpose of a retaining wall is to hold back a mass of soil or other material, the design of the wall is affected by the earth's configuration—for example, whether the earth surface behind the wall is horizontal or inclined. The design is also affected by any additional loading (surcharge), such as from a vehicle or equipment passing near the top of the wall. A surcharge causes a horizontal thrust on a retaining wall.

Types

There are three basic types of concrete masonry retaining walls to consider: (1) gravity, (2) cantilever, and (3) counterfort or buttressed walls.

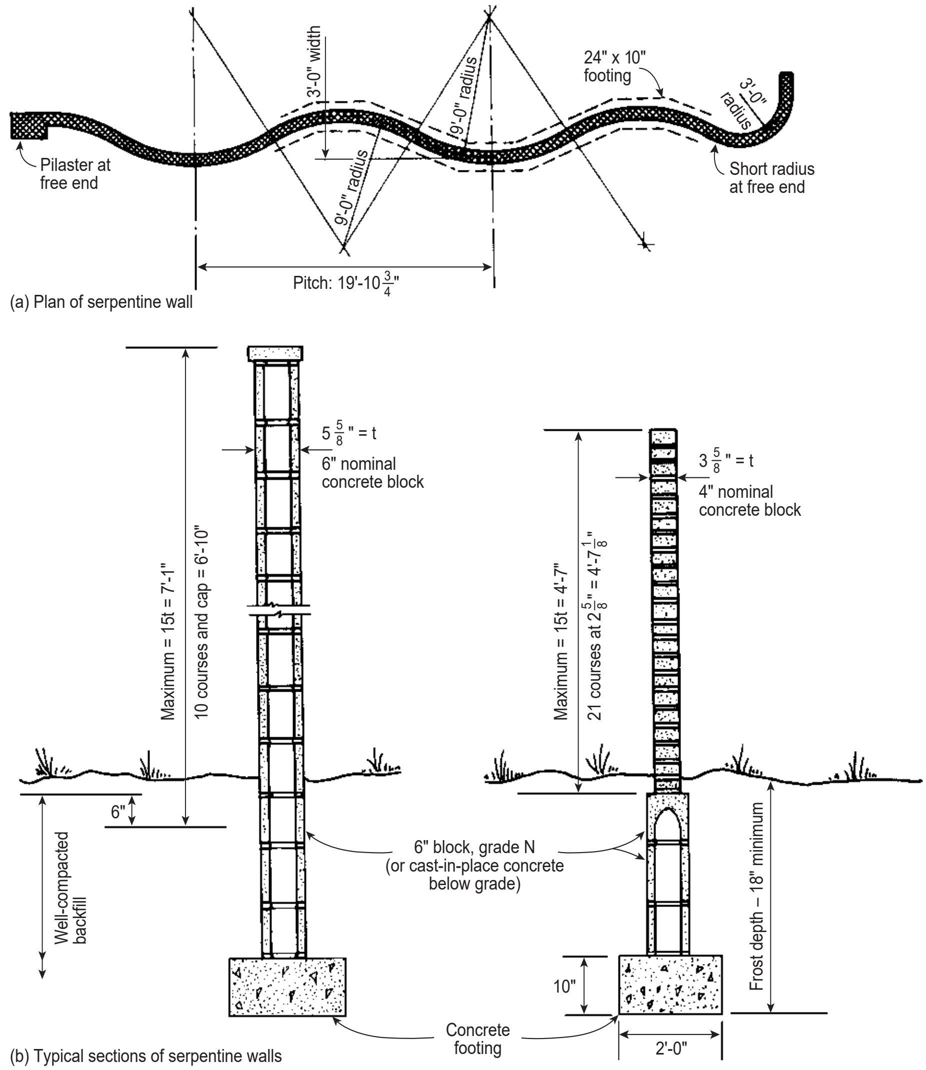


Fig. 8-17

Serpentine garden walls.

Fig. 8-18

Concrete masonry retaining wall with split-faced units. (IMG15711)

Gravity Walls

A gravity retaining wall depends upon its own weight or mass for stability. Masonry has adequate mass, and if it is laid in a trapezoidal cross-sectional shape, as shown in Fig. 8-19, little or no tensile stress occurs in the wall under loading. Most of these walls are not laid with mortared joints, but instead, the dry-stacked units are held in place and resist lateral soil pressure by frictional shear strength between courses (TEK 15-6 1995).

Since this type of gravity retaining wall ordinarily has a base thickness equal to one-half to three-fourths the wall height, it is usually more economical to build a taller retaining wall (more than a few feet—or about a meter—in height) as a cantilever wall or as a specific type of gravity wall known as a segmental retaining wall, or SRW.

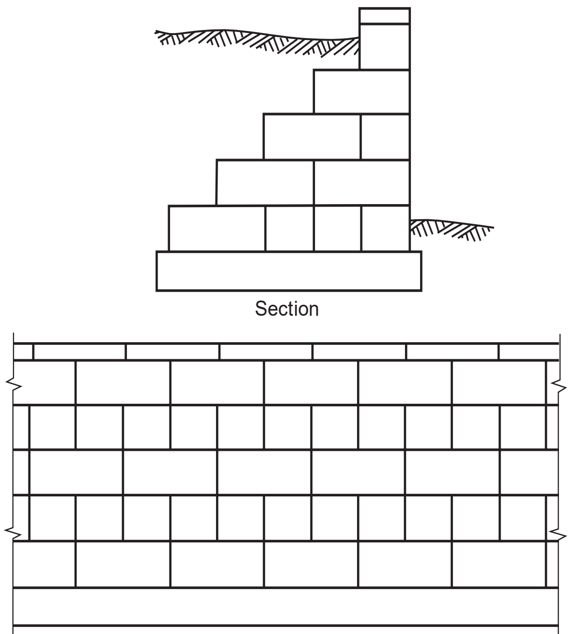


Fig. 8-19

A simple gravity retaining wall.

Fig. 8-20

Decorative interlocking concrete masonry retaining wall. (IMG15709)

Segmental retaining walls gained popularity for use as transportation structures, especially bridge abutments, and also for residential landscaping applications (Figs. 8-18, 8-20). They accommodate grade changes effectively, can be laid in any combination of curved and straight wall sections, and look good. The walls may be vertical or slightly inclined toward the side retaining earth (TEK 15-8 2004).

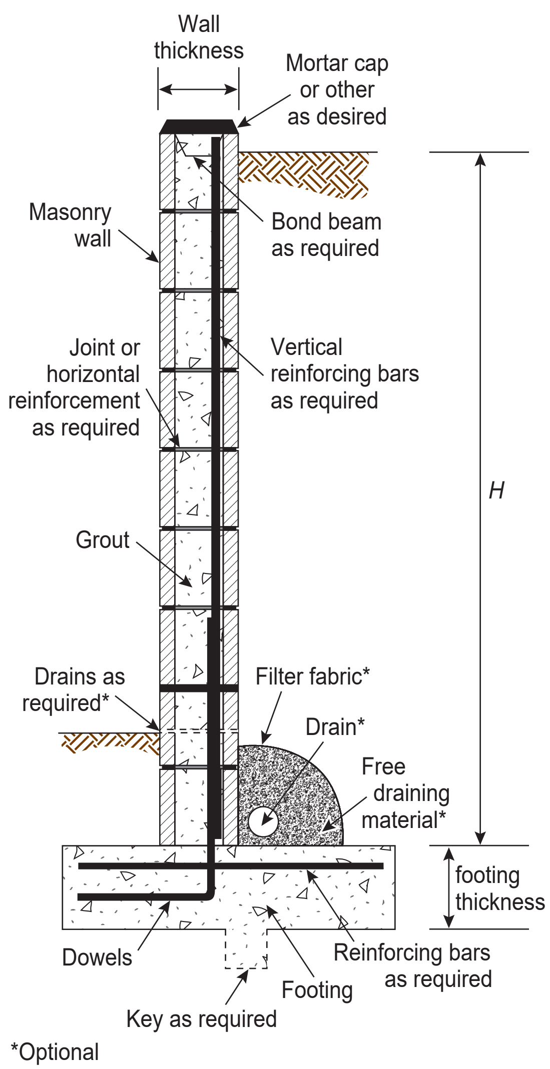
Unlike gravity walls that have a trapezoidal cross section, SRWs are single wythe. Units are designed to interlock between courses or to use mechanical devices like connecting pins to resist lateral soil pressure. Walls typically range in height from 8 in. (204 mm) to 20 ft (6.1 m). For added stability on taller walls, geosynthetic fabric can be laid between various courses and embedded in the soil as an anchor. Of the mortarless concrete masonry systems, SRWs have become the most common and are described in TEK 2-4B 2005. Design information is available in TEK 15-4A 2003, TEK 15-5A 2004, and TEK 15-9 1999.

Many types of decorative units are available for constructing retaining walls. If the units contain voids, these are often filled with solid or granular fill. Units for constructing retaining walls are described in ASTM C90, Standard Specification for Loadbearing Concrete Masonry Units, and C1372, Standard Specification for Segmental Retaining Wall Units. Both standards cover solid and hollow units and include notes to the purchaser about specifying optional characteristics such as weight classification, high compressive strength, and surface texture, finish, or color where desired.

Cantilever Walls

A cantilever-type retaining wall usually has a cross-sectional shape similar to an inverted "T" (Fig. 8-21). The stem will be located more towards the rear of the footing if soil-bearing stresses are critical, and more towards the front or toe of the footing if sliding forces are critical. An "L"-shaped cantilever wall is used along a property line, or in other situations where it is impossible to provide a toe; for such a wall, soil-bearing pressure is usually high.

With either shape of cantilever wall, the reinforced masonry wall portion or stem performs structurally as a cantilever projecting from the cast-in-place concrete footing (TEK 15-7B 2005). The portion of backfill directly above the footing contributes to the mass required for stability, and the concrete masonry stem is reinforced along its back face where the loading induces tensile stresses. The functions of the footing are to hold the stem in position and to resist the forces from the stem—the sliding, overturning, and vertical pressures created by loading—and transferring them to the soil.



Allowable Stress Design: Vertical Reinforcement for Cantilever Retaining Walls[a,b]

Wall thickness, in. (mm)	Wall height, *H*, ft (m)	Reinforcement size and spacing for equivalent fluid weight of soil, lb/ft²/ft (kN/m²/m), of:		
		30 (4.7)	45 (7.1)	60 (9.4)
8 (203)	4.0 (1.2)	No.4 @ 88 in.[c]	No.4 @ 56 in.[c]	No.4 @ 40 in.
	4.7 (1.4)	No.4 @ 48 in.	No.4 @ 32 in.	No.4 @ 16 in.
	5.3 (1.6)	No.4 @ 32 in.	No.4 @ 16 in.	No.5 @ 24 in.
	6.0 (1.8)	No.4 @ 16 in.	No.5 @ 16 in.	No.7 @ 16 in.
	6.7 (2.0)	No.4 @ 16 in.	No.7 @ 16 in.	No.9 @ 8 in.
10 (254)	4.0 (1.2)	No.4 @ 120 in.[c]	No.4 @ 88 in.[c]	No.4 @ 64 in.[c]
	4.7 (1.4)	No.4 @ 88 in.[c]	No.4 @ 48 in.	No.4 @ 32 in.
	5.3 (1.6)	No.4 @ 56 in.	No.4 @ 32 in.	No.4 @ 16 in.
	6.0 (1.8)	No.4 @ 32 in.	No.4 @ 16 in.	No.5 @ 24 in.
	6.7 (2.0)	No.4 @ 24 in.	No.5 @ 16 in.	No.5 @ 16 in.
	7.3 (2.2)	No.4 @ 16 in.	No.5 @ 16 in.	No.7 @ 16 in.
	8.0 (2.4)	No.5 @ 16 in.	No.7 @ 16 in.	No.8 @ 8 in.
12 (305)	4.0 (1.2)	No.4 @ 120 in.[c]	No.4 @ 120 in.[c]	No.4 @ 96 in.[c]
	4.7 (1.4)	No.4 @ 120 in.[c]	No.4 @ 72 in.	No.4 @ 48 in.
	5.3 (1.6)	No.4 @ 80 in.[c]	No.4 @ 48 in.	No.4 @ 32 in.
	6.0 (1.8)	No.4 @ 48 in.	No.4 @ 24 in.	No.4 @ 16 in.
	6.7 (2.0)	No.4 @ 32 in.	No.4 @ 16 in.	No.5 @ 16 in.
	7.3 (2.2)	No.4 @ 24 in.	No.5 @ 16 in.	No.5 @ 16 in.
	8.0 (2.4)	No.4 @ 16 in.	No.5 @ 16 in.	No.6 @ 16 in.
	8.7 (2.7)	No.5 @ 16 in.	No.6 @ 16 in.	No.8 @ 16 in.
	9.3 (2.8)	No.5 @ 16 in.	No.7 @ 16 in.	No.8 @ 8 in.

a. The reinforcement listed is designed to resist soil loads only. Other conditions, such as surcharges or seismic loads, also need to be considered where applicable.

b. Based on: fully grouted masonry; f'_m = 1500 psi (10.3 MPa); d = 5 in., 7 in., and 9 in. (127, 178, and 229 mm) for wall thicknesses of 8, 10, and 12 in. (203, 254, and 305 mm), respectively; level backfill to top of wall.

c. The specified reinforcement spacing is greater than six times the wall thickness. Prudent engineering practice dictates that stresses in the unreinforced masonry spanning between the reinforcing bars be designed to meet MSJC 2005.

Fig. 8-21

Reinforced cantilever retaining wall detailing. Reference provides information on both allowable stress design and strength design, but only ASD is shown here due to space limitations. See adjacent table. (Adapted from TEK 15-7B 2005.)

Counterfort or Buttressed Walls

These retaining walls are similar to the cantilever type, except that they span horizontally between vertical supports. Supports located at the back of the wall are known as counterforts (Fig. 8-22), and those supports exposed at the front of the wall are called *buttresses* (Fig. 8-23).

A small degree of forward or outward tilt under service conditions is difficult to avoid with any type of retaining wall. It is therefore good practice to batter (slope) the front of the wall slightly to offset this eventual tilt and avoid the illusion of instability. A batter on the order of ½ in. per foot (42 mm/m) is commonly used.

The selection of a particular type of retaining wall for cost and efficiency depends on the wall size, loads, soil conditions, and site location. The cantilever type of wall has a slightly lower toe pressure than the gravity type and thus may be desirable where soil bearing capacity is low. However, the gravity wall has greater resistance to sliding because of its greater weight.

Construction

A civil engineer who has experience with local soil conditions should be retained for the design and construction of retaining walls. The engineer will design the cross-sectional dimensions of the wall and footing, and reinforcement if required, so that the computed pressure under the wall does not exceed the safe bearing value of the soil. Table 8-3 gives safe values for different soils.

Table 8-3. Safe Bearing Pressures of Soils

Material	Bearing capacity, psf (kPa)
Clay	2,000 (95.8)
Sand and clay mixed	4,000 (191.5)
Alluvium and silt	5,000 (239.4)
Hard clay and firm, compressed sand	8,000 (383.0)
Fine sand	9,000 (430.9)
Compacted and cemented sand	10,000 (478.8)

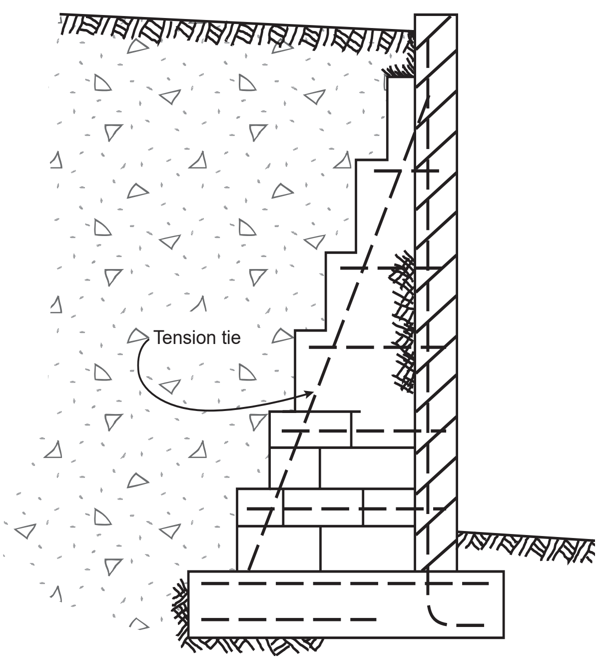


Fig. 8-22

Counterfort retaining wall.

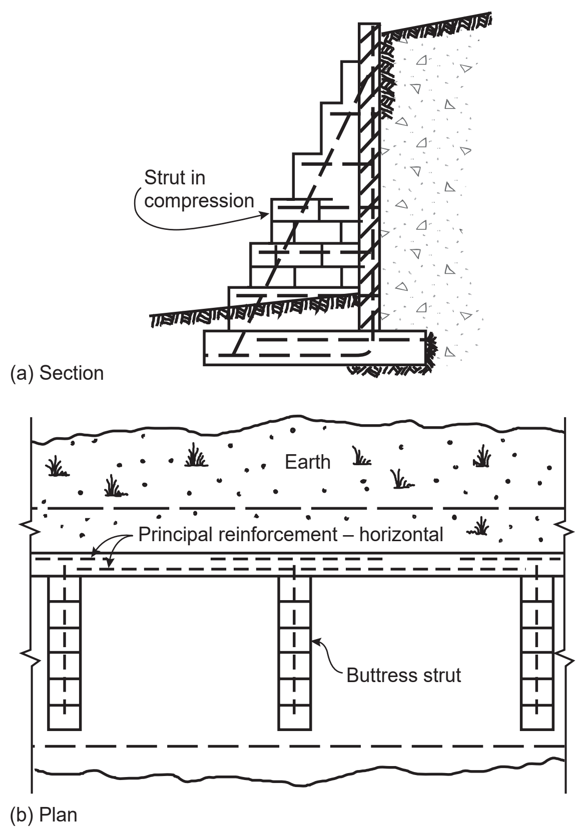


Fig. 8-23

Buttressed retaining wall.

Footing

The footing for a retaining wall should be placed on firm, undisturbed soil. In cold climates the base of the footing should be placed below the frost line. Where soil under the footing consists of soft or silty clay, 4 in. to 6 in. (102 mm to 152 mm) of consolidated granular fill can be placed under the footing slab to assure firm support and to increase the frictional resistance between the footing and the ground. This friction determines resistance to horizontal sliding of the wall.

Often a lug or key is cast into the bottom of the footing to provide assistance in resisting the tendency to slide (Fig. 8-24). The same effect is achieved by requiring that the footing excavation be made in undisturbed soil, particularly if the wall is higher than 7 ft (2.13 m) above the footing.

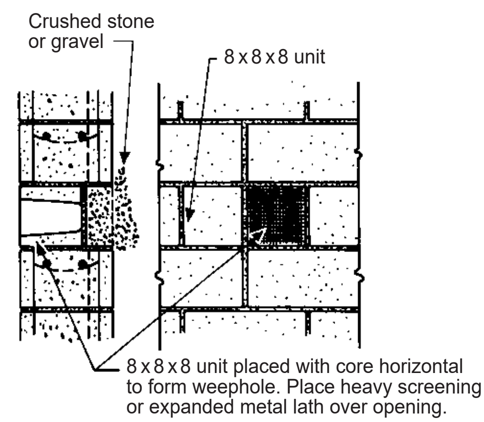
Steel dowels to connect the wall to the footing should be located so that they align with the vertical wall reinforcement when it is placed (see Fig. 8-21). A small longitudinal reinforcing bar along the dowel line near the top of the footing can help to ensure that the dowels are accurately spaced and securely tied to the vertical reinforcement.

The top of the concrete footing in the area under the masonry wall should be roughened while the concrete is still fresh. Otherwise, a 1-in.-deep by 4-in.-wide (25x102-mm) keyway should be provided to improve shear bond at the joint between the wall and the footing.

Grouting and Reinforcement

The first course of block is laid on the footing in a full mortar bed. The remaining courses may then be laid with face-shell mortar bedding and mortar on any web between a core to be grouted and a core not to be grouted. However, there appears to be little advantage in grouting only those cores containing reinforcement. If all cores are grouted, the small additional grouting material and labor costs involved are offset to some extent by eliminating the work necessary to mortar cross webs that adjoin the cores to be grouted.

The materials and procedures previously recommended for reinforced, grouted masonry walls (Chapter 6) should be followed in the construction of retaining walls. Provide some horizontal steel reinforcement to distribute stresses that occur when the



(b) Alternate weephold detail

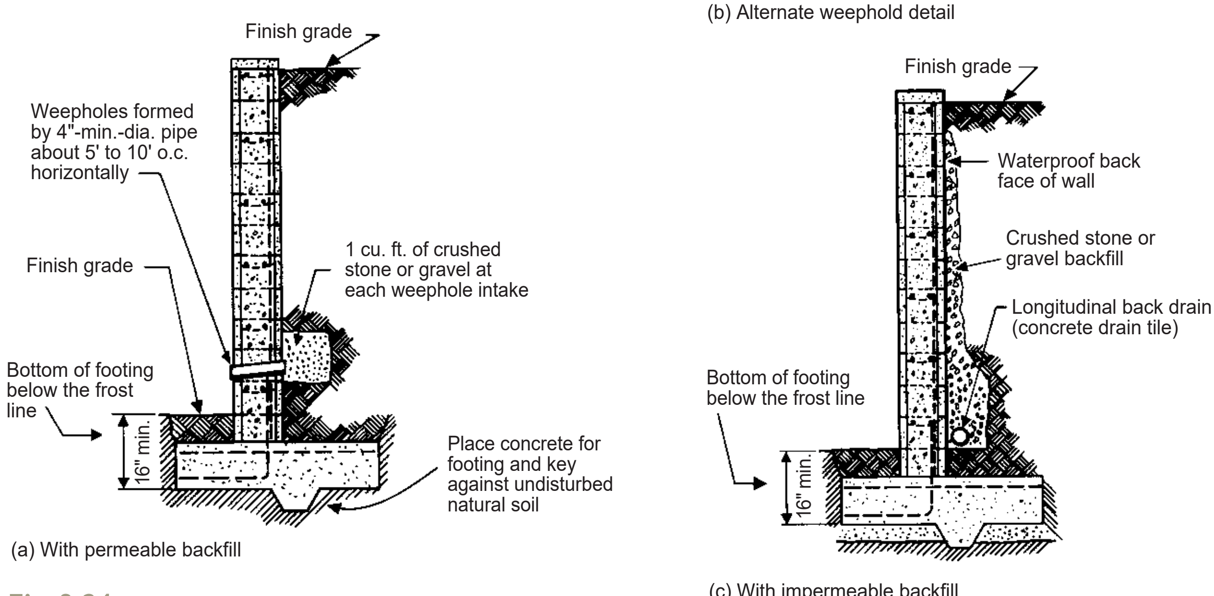


Fig. 8-24

Suggested backfilling procedures and drainage provisions for retaining walls.

wall expands or contracts. The amount of steel needed is, to a large extent, dependent on climatic conditions. For moderate conditions and 8-in. (203-mm) walls, bond beams with two #4 (#13) bars should be placed in the top course and in intermediate courses at 16 in. (406 mm) on centers. For 12-in. (305-mm) walls, the top bond beam should contain two #5 (#16) bars and the intermediate bond beams should have two #4 (#13) bars. If desired, horizontal joint reinforcement may be placed in each joint—that is, 8 in. (203 mm) on center—and the bond beams omitted.

Drainage

Provisions should be made to prevent the accumulation of water behind a retaining wall. This water can cause increased soil pressure, seepage, and in areas subject to frost action, expansive forces of considerable magnitude near the top of the wall.

As shown in Fig. 8-24a, 4-in.-diameter (102-mm) weepholes spaced at 5 ft to 10 ft (1.52 m to 3.05 m) along the base of the wall should provide sufficient drainage of a permeable backfill soil. An alternate weephole detail is shown in Fig. 8-24b. In another alternate method, mortar is left out of the head joints in the first or second course and about 1 cu ft (0.03 m^3) of gravel or crushed stone is placed around the intake for each weephole. Ideally, drains should be placed in all ungrouted cells in the first course.

With unusual conditions such as heavy, prolonged rains, seepage through weepholes may cause the ground in front of the wall and under the toe of the footing to become saturated and lose some of its bearing capacity. This undesirable condition can be avoided by installing a continuous longitudinal drain (Fig. 8-24c) surrounded by crushed stone or gravel and extending along the full length of the back of the wall. This drain should have outlets located beyond the ends of the wall, thus eliminating any need for weepholes in the wall itself. With impermeable soil and conditions tending to create excessive amounts of water in the backfill—or in areas of frequent freezing and thawing—it is advisable to provide a continuous back drain. This is a vertical layer of crushed stone or gravel covering the entire back of the wall, and should be used in addition to a longitudinal drain (see Fig. 8-24c).

Other Provisions

The top of a concrete masonry retaining wall should be capped or otherwise protected to prevent entry of water into unfilled hollow cores and spaces. Climate and type of construction will determine the need for waterproofing the back face of the wall. Since saturated mortar may not be durable in areas subject to frequent freezing and thawing, waterproofing is recommended when backfill material is relatively impermeable; it is also recommended to reduce unsightly efflorescence or leaching on the front face of the wall.

A long retaining wall should be broken into panels by means of vertical control joints, as discussed in Chapter 4. The joints not only should be capable of resisting shear and other lateral forces in order to maintain alignment of adjacent wall sections, but also permit longitudinal movement (Fig. 8-25). In some cases, to prevent seepage through a joint, it may be advisable to cover the joint on the back of the wall with a strip of waterproofing membrane.

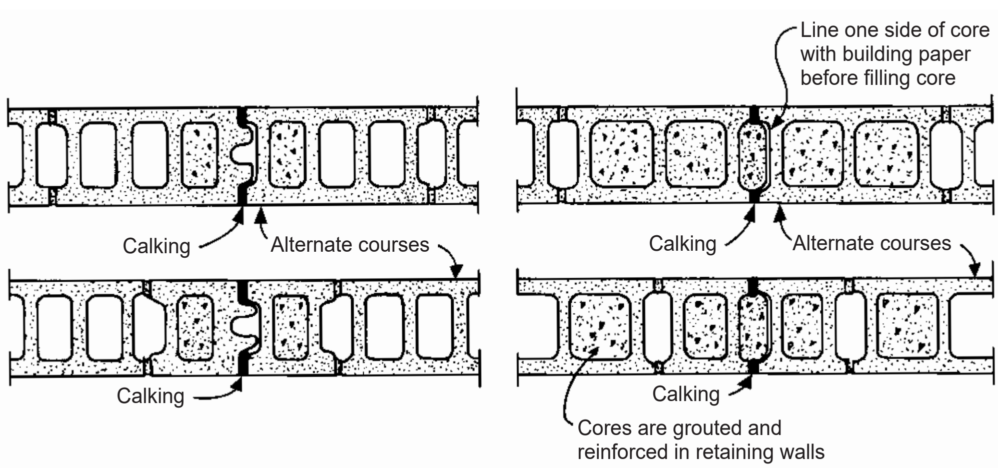


Fig. 8-25

Shear-resisting control joints for retaining walls.

Care should be taken when backfilling against a retaining wall. Backfilling should not be permitted for at least 7 days after grouting. It is a good practice to build up the backfill material all along the wall at as nearly uniform a rate as practical. If heavy equipment is used for backfilling a wall designed only to resist earth pressure, the equipment should stay away from the wall a distance equal to the height of the wall. Care should also be taken to avoid large impact forces on the wall, such as those caused by a big mass of moving earth or huge stones.

Where the finished grade at the back of a retaining wall is level with the top or nearly so, a fence or railing on top of the wall may be needed for safety. To accomplish this with concrete masonry, the wall itself could be built higher by using screen block units.

See TEK 15-7A 1996; Sears 1973; Beall 2003; TEK 2-4B 2005; TEK 15-6 1995; and TEK 15-8 2004. for more information on the design and construction of concrete masonry retaining walls.

Paving

Concrete masonry units are used for paving driveways, access lanes, parking areas, streets, plazas, shopping malls, walks, patios, and floors on grade, to name just a few applications. They are also used for slope paving under highway or railway grade separation structures and on other steep embankments to prevent costly and often dangerous soil erosion, particularly where grass will not grow to protect the surface. Produced in a wide range of shapes and colors, paving units are easy to handle and install, requiring only a few tools.

Vehicular and Pedestrian Traffic

The concrete masonry industry offers a variety of interlocking paving units that are also sometimes called pavers, concrete pavers, paving stones, concrete paving block, or brick pavers. The units are available in interesting patterns, bright with color and human in scale (Figs. 8-26, 8-27, 8-42, and 8-43). They are used for foot traffic, light vehicular traffic, and special units are used for heavy traffic.

Paving units are manufactured to meet the requirements of ASTM C936, Standard Specification For Solid Concrete Interlocking Paving Units, which requires that units be not greater than 6½ in. (165 mm) wide, 9½ in. (241 mm) long, and 5½ in. (140 mm) thick, and that they have a compressive strength of at least 8000 psi (55.2 MPa) and an absorption capacity of not greater than 5%. Conventional concrete ingredients are



Fig. 8-26

Interlocking concrete paving units. Slide Nos. (top to bottom) (IMG15707, IMG15710, IMG15702)

Fig. 8-27

Interlocking concrete pavers provide a durable and attractive walkway for this precast concrete office building. (IMG15708) Construction of this walkway is illustrated in Figs. 8-28 through 8-42.

Fig. 8-28

Once the subgrade is excavated, leveled, and free of organic matter, soft spots, and foreign material, the edge restraint system can be installed. Cast-in-place concrete curbs (illustrated here) provide the best edge security for pavers. (IMG15705)

Fig. 8-29

A 5-in.-thick (127-mm) granular base consisting of ¾-in. (19-mm) maximum size crushed stone is placed over the subgrade. Also note that concrete curbs are covered with wet burlap and plastic sheets for moist curing. (IMG15704)

Fig. 8-30

The crushed stone base is compacted to 95% density with a vibratory plate compactor. (IMG15706)

Fig. 8-31

The base should be compacted with hand tampers in locations, such as corners, that are not accessible to mechanized vibrators. (IMG15703)

Fig. 8-32

A fine aggregate bedding course is next placed over the coarse aggregate base (some contractors use a filter cloth between the crushed stone base and the sand bedding course to prevent sand from migrating into the voids of the granular base). Sand—the preferred bedding material—should meet the requirements of ASTM C33 for fine aggregate for concrete. Aggregate rakes are very helpful for distributing the sand. (IMG15699)

Fig. 8-33

The sand is leveled to a thickness of 1½ in. (38 mm). A cement mason's trowel is helpful with this screeding procedure. The sand bedding course is not compacted at this stage of construction. It is assumed that after the pavers are placed and vibrated, the elevation of the sand will be approximately ½ in. (13 mm) lower than the screeded level. (IMG15701)

Fig. 8-34

Paving units are placed hand-tight directly on the leveled but uncompacted sand. Placement should start from a corner. Most paver designs include special edge units that can be used to greatly minimize cutting of units. (IMG15700)

Fig. 8-35

On small jobs the units are usually placed one at a time by hand, although machines are available that can place 35 to 40 units at a time. For efficiency, a good supply of units should be kept near the mason. A rubber mallet is used to help set the pavers and keep the rows of pavers aligned. (IMG15696)

Fig. 8-36

A stringline *(bottom of photo)* controls the paver elevation; on this job it was set ½ in. (13 mm) above the elevation of the edge restraints (concrete curbs) to allow for minor future settlement. The pavement should be sloped for drainage; this project was slightly crowned to provide side-to-side drainage. (IMG15698)

Fig. 8-37

Pavers can be cut with a wet or dry table saw using diamond blades (wet is pictured) or a masonry splitter (called a guillotine). To reduce installation costs, the layout should be carefully designed to avoid unnecessary cutting of pavers, however, most jobs will require some cutting. (IMG15697)

Fig. 8-38

Along the curb edge restraint, special edge units can be installed or the units can be cut to the required dimension. The pavers should be placed snugly against the edge restraint. Cut units shown being installed here are dark in color because they are wet from sawing; special edge units can be seen stacked next to the mason. (IMG16233)

Fig. 8-39

After all the pavers have been placed, dry sand is broomed onto the surface. A fine masonry sand is usually used because the small particles easily penetrate the joints between the pavers. (IMG16234)

Fig. 8-40

The pavers are compacted into the loose bedding sand below with a vibratory compactor. The sand that was broomed onto the surface fills the joints and locks the units into place. This operation also should correct any slight height variations between pavers, leaving a smooth level surface. Some specifications require one pass of the compactor prior to surface sanding. Sand is added as needed and compaction continues until the joints are full. The compactor shown has rubber rollers to help prevent marring of the paver surface. (IMG16235)

Fig. 8-41a & b

After compaction, the excess sand is broomed off *(top)* (IMG16231), and the surface rinsed clean by hosing with water *(bottom)* (IMG15695)

Fig. 8-42

Completed pavement. (IMG15694)

Fig. 8-43

Interlocking concrete masonry pavers were used for this attractive plaza, which surrounds St. Louis' Mercantile Center. (IMG15211)

used in the manufacture of pavers. To prevent scaling of units that will be exposed to deicing chemicals in service, use of supplementary cementitious materials, especially fly ash, should be limited. The building code restricts fly ash content to a maximum of 25% (by mass of cement) for concrete exposed to deicing chemicals (ACI 318 2005).

With regard to scaling, results of a recent study (Ghafoori and Mathis 1997) concluded that a maximum absorption capacity of 4%, and a minimum compressive strength of nearly 8900 psi (61.2 MPa)—which corresponds to a cement content of 600 lb per cu yd (356 kg/m^3)—should be used in the manufacture of paving units to ensure minimal scaling when the units are exposed to freezing and thawing in the presence of deicing salts. However, it should be noted that this study used ASTM C672 to test for resistance to freezing and thawing, whereas ASTM C936, the standard for paving units, requires the use of Section 8 of ASTM C67 for determining freeze-thaw resistance (for more information, see Ghafoori and Mathis 1997).

Design procedures are available in the ICPI publication, *Structural Design of Interlocking Concrete Pavement for Roads and Parking Lots* (ICPI TS No. 4 2004). However, structural design is only required for the more heavily loaded industrial pavements.

Installation of paving units can begin in the spring as soon as the frost is gone and the ground is dry and firm. In the fall, installation can continue until frozen ground prevents proper compaction of the subgrade material. The final job will be only as stable as the subgrade.

Requiring careful preparation, the subgrade should be uniform, hard, free from foreign matter, and well drained. The best masonry paving installations are made by removing all organic matter such as grass, sod, and roots. Hard spots are loosened and tamped to provide the same uniform support as the rest of the subgrade. Mucky spots are dug out, filled with soil similar to the rest of the subgrade or with granular material (such as sand, gravel, crushed stone, or slag), and compacted thoroughly. All fill materials should be uniform, free of vegetable matter, large lumps or stones, and frozen soil.

Paving units are usually bedded in sand or sometimes in a durable air-entrained mortar. Sand bedding is the most common method. It can give excellent, long-lasting results, and sand bedding is suitable for residential as well as commercial and industrial applications. It is ideal for the do-it-yourselfer in such applications as sidewalks, driveways, and patios. The units are easily removed for maintenance work or relocated if desired.

Edge restraint, such as cast-in-place or precast concrete curbs, anchored timber, anchored steel or plastic strips, or existing structures usually is needed to prevent the units from creeping apart over time. The better the edge restraint, the better the long term success in keeping joints between the units snug. Cast-in-place concrete curbs are by far the best edge restraint, but existing concrete foundations, pavements, (and curbs) incorporated into an installation, where possible, also will provide excellent edge restraint.

Detailed photographs illustrating the construction of an attractive concrete paver walkway are shown in Figs. 8-27 to 8-42. For additional information on construction, cleaning, and sealing of interlocking concrete pavements, see ICPI TS No. 2 (2007) and No. 5 (2004). For a listing of other topics in the Tech Specs series, see www.icpi.org.

Fig. 8-44

Concrete masonry slope paving units are laid under a highway bridge to prevent erosion. (IMG24189)

Slope Paving

With ungrouted or grouted joints, concrete masonry is an economical and pleasing solution to the slope paving problem. Construction costs are low due to minimal materials-handling at the jobsite and the ease of placing units on a slope (Fig. 8-44).

Masonry Units Required

Different sizes and shapes of paving units (Fig. 8-45) are used for slope paving, with unit thickness varying from 4 in. to 8 in. (102 mm to 203 mm). The thicker units are used for severe exposures, such as on riverbanks. The slope paving units most often specified are standard 8x16-in. (203x406-mm) solid units (Fig. 8-45a), although it is possible to manufacture paving units in sizes up to about 16x24 in. (406x610 mm). Solid units for paving have no voids (100% solid), whereas solid units for other applications may have up to 25% voids.

In areas where there are no freezing temperatures, or there is proper drainage, cored masonry units can be used successfully. They are lighter in weight and often less expensive to lay than the 100% solid units. However, solid units are preferred in freeze-thaw climates because there is no chance of water freezing in core spaces. Also, the additional weight of 100% solid units discourages vandalism, especially in ungrouted installations.

Any concrete masonry unit selected for slope paving should have a minimum compressive strength of 3000 psi (20.7 MPa) on the gross cross-sectional area at the time of delivery to the jobsite.

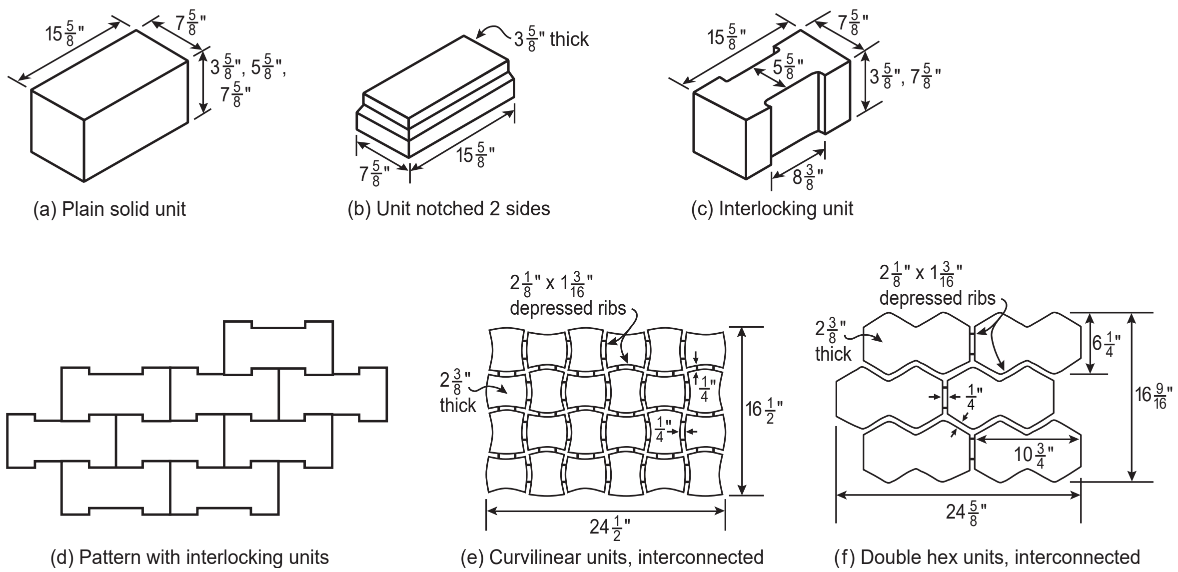


Fig. 8-45

Some typical concrete masonry slope paving units.

Construction Features

Some specifications for slope paving limit the maximum angle of slope to 35 degrees; others specify a maximum slope commensurate with the angle of repose of the underlying soil. In fact, ungrouted masonry paving units can be laid on any angle at which the underlying material can be stabilized.

A 2 in. to 4 in. (51 mm to 102 mm) layer of granular material—sand, gravel, or crushed stone—should be installed immediately below the masonry units to facilitate drainage and minimize the possibility of frost heave. When levelness between units is important, sand is used because it can be struck off smoothly. The allowable surface variation is ¼ in. in 10 ft (6.4 mm in 3.05 m).

When slope paving units are not grouted together, they are laid hand-tight against each other. If grouting is required, ¾-in. or 1-in.-wide (19-mm or 25-mm) joint spaces can be left for grout fill. Some contractors use wooden spacers to ensure this width, since spacing closer than ¾ in. (19 mm) makes it difficult to completely fill the joints with grout. Grout proportions should be 1 part portland cement to 3 parts sand by volume, with just enough water added to make the grout workable. Interlocking units (Fig. 8-45) do not require grouted joints. An ungrouted installation offers several advantages:

1. If there is settlement or frost heave, the paving units can be adjusted individually.
2. If appearance allows, the underlayment need not be carefully struck off, and thus the use of gravel or crushed stone becomes more feasible.
3. Ungrouted construction is less expensive, and the units can be easily replaced.

The advantages of grouted construction are:

1. Percolation of water between and under paving units is greatly diminished.
2. There is less chance of undermining the slope protection.
3. The units are more securely held in place, deterring vandalism and theft.

Most concrete masonry slope paving installations are constructed with some type of support at the bottom or toe of the slope. This support prevents sliding of the units and provides a straight, firm foundation for the first course of masonry. In some cases the support may be provided by a compact, level surface of embankment material. However, toe construction will vary, depending on conditions of drainage, paving, and grade at the bottom of the slope (Fig. 8-46).

Instead of a large support at the bottom of the slope, smaller intermittent supports may be made on the slope itself. For example, every tenth course of masonry could be embedded into the slope—the long dimension of the block perpendicular to the slope.

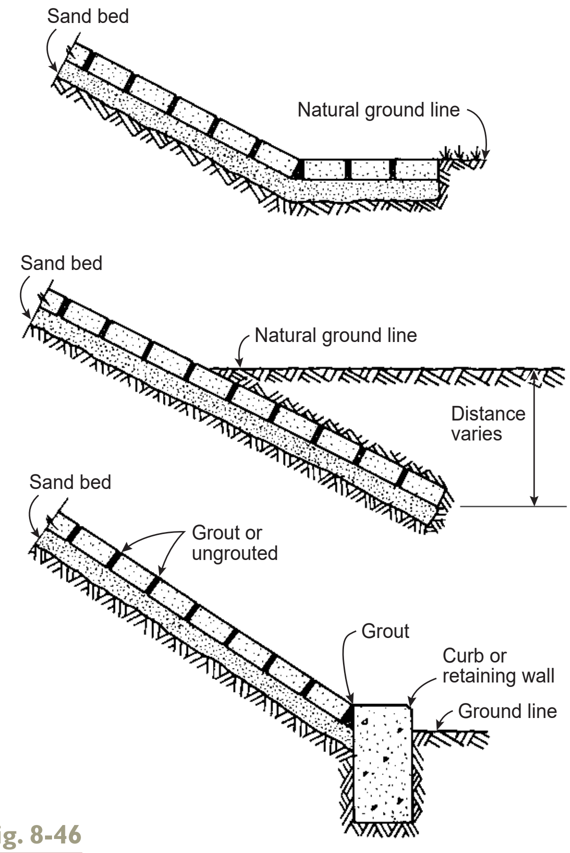


Fig. 8-46

Details at toe of slope paving.

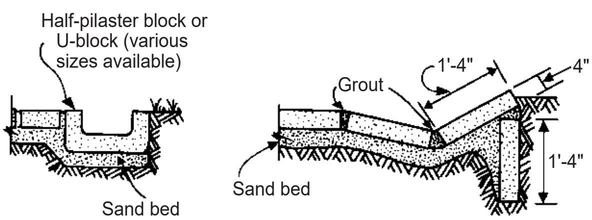


Fig. 8-47

Edge drains for slope paving.

Drain troughs are often provided at the sides of the slope-paved area (Fig. 8-47), and channeled waterways also carry water from the toe of the slope to a natural outlet. These waterways should be paved for a sufficient distance from the slope to eliminate any possibility of undermining by erosion.

Where drains are not necessary, care should be exercised that the fill material at the edge of the paving units is level with the top of the units. This is important to hold the edge units in place, especially when joints are not grouted.

Riverbank Revetments

As an alternative to stone riprap, special concrete revetment block are available for controlling erosion along the banks of rivers and lakes. The perforated waffle units (Fig. 8-48a) may be laid on the bank beneath the water, one unit adjacent to the next. Grout is needed only on the perimeter of the revetment to keep these units in place. Construction costs can be lowered by inserting precast keys or stakes in the preformed key holes. The cores in the units may be filled with sand and gravel, and vegetation will grow through the cores, further securing the units in position. Such a revetment functions as an articulated mat, with each unit settling individually to a firm resting position.

The ribbed waffle units (Fig. 8-48b) used for erosion control are 90-lb (41-kg) units that can be laid by unskilled volunteers during flood emergencies. Interlocking or articulated units (Fig. 8-45c) are also used for erosion control. See TEK-11-9A 2004 for more details on articulated concrete block for erosion control.

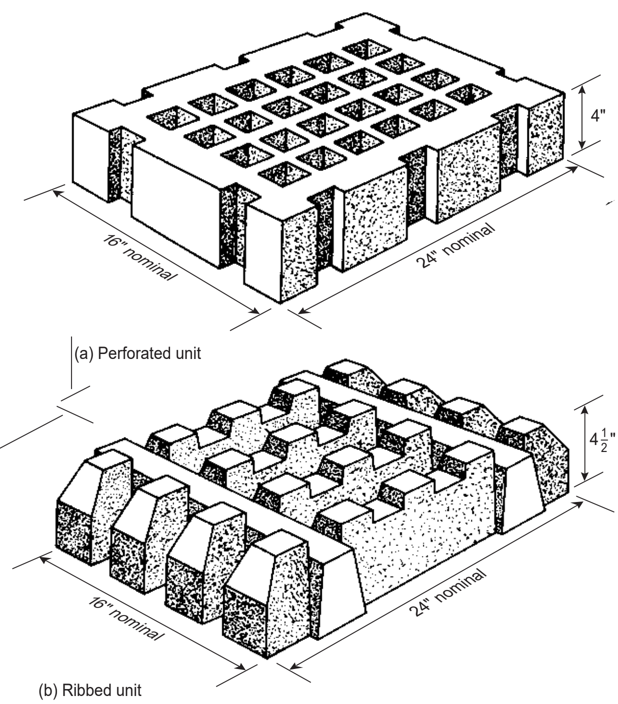


Fig. 8-48

Riverbank-revetment waffle units. These units are also used as "grass pavers."

Fig. 8-49

This parking area was created using turf blocks, also known as "grass pavers." (IMG24190)

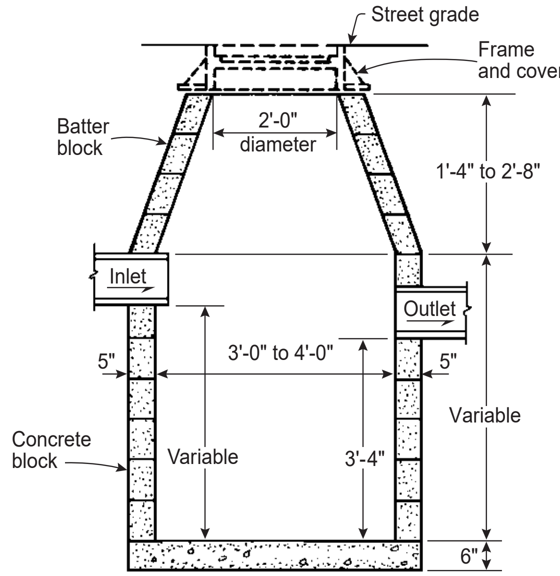


Fig. 8-50

A typical catch basin.

Other Paving

Waffle units (Fig. 8-48) are useful as turf block or "grass pavers," as pictured in Fig. 8-49. They are laid to create light pavements at access lanes and parking areas. Grass will grow in the cores or between the ribs despite frequent traffic or parking of vehicles.

Patio block are commonly 8x16-in. (203x406-mm), with thicknesses of 1⅝ in. (41 mm), 2¼ in. (57 mm), and 3⅝ in. (92 mm). Units of various shapes are available in natural gray, white (by use of white cement), or tones of red, black, brown, green, or yellow. Almost any pattern used for masonry walls may be used for patio block.

Catch Basins and Manholes

Concrete masonry construction is an acknowledged method for building catch basins, inlets, manholes, valve vaults, pump wells, and other shallow-depth, circular, underground structures. A typical catch basin and a few typical sewer manholes are shown in Figs. 8-50 and 8-51, respectively.

Catch basins have space at the bottom for the settlement and storage of suspended solids that would otherwise be carried away and deposited in the pipeline. If the catch basins are part of a sanitary sewer system, they should be provided with solid covers to prevent sewage odors from reaching the street.

Drop manholes are constructed at intersecting lines, or where there is an abrupt drop in elevation in a sewer line. The arrangement shown in Fig. 8-51c is desirable; it reduces turbulence and prevents sewage from splashing on men working in the manhole. Such construction still permits cleaning of the sewer.

Materials

Concrete block should meet the absorption and strength requirements of ASTM C139, Standard Specification for Concrete Masonry Units for Construction of Catch Basins and Manholes. This specification is for segmental masonry units. When concrete brick are used, they should be plastered on the outside with Type S mortar.

Batter block (Fig. 1-23, Chapter 1) are very useful for cone construction atop the barrel of a catch basin or manhole (Fig. 8-52). The cone reduces the inside diameter to 2 ft (610 mm) at the top to receive a standard manhole cover, as shown in Figs. 8-50 and 8-51. No cutting of units is necessary because block producers have predetermined the exact number and size of batter block required.

For manhole cover sizes for which batter block are not available, the masonry wall of the structure is continued to the top without reduction in diameter. Then, a precast or cast-in-place concrete slab is added.

Construction

For a catch basin or manhole, excavation should be to the depth and dimensions specified. If rock is encountered, the bottom of the excavation should be carried down at least 6 in. (152 mm) below the elevation of the bottom of the structure and backfilled with sand.

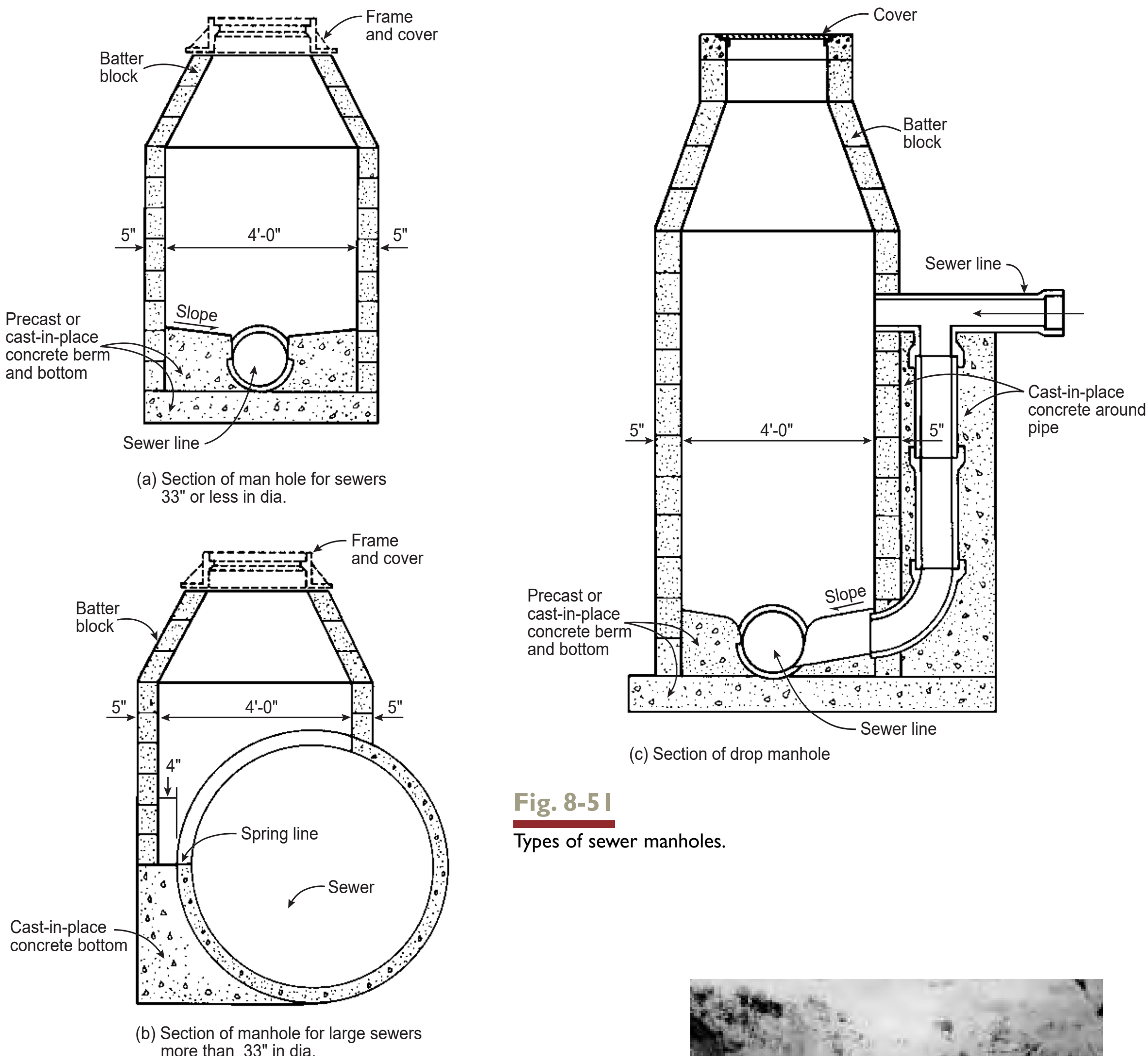


Fig. 8-51

Types of sewer manholes.

The bottom of the structure may be constructed of cast-in-place concrete or a precast concrete slab. In either case, the concrete should have a water-cement ratio, by weight, of not more than 0.50 and a minimum compressive strength of 3000 psi (20.7 MPa) at 28 days. The use of a precast concrete bottom is finding increasing acceptance because it minimizes the time the excavation must be kept open. It is particularly advantageous during wet weather, or when the excavation is in a wet subsoil.

The masonry wall of the structure is built in horizontal courses, with vertical joints staggered, and all joints completely filled with Type M mortar. Any castings that will be used should be set in a full bed of mortar. The masonry units around inlet or outlet pipe are carefully laid and sealed with mortar to prevent leakage.

Fig. 8-52

Concrete block catch basin in a storm sewer system. (IMG24200)

Special block are useful in framing around inlet and outlet pipe.

Heavily galvanized or other noncorrosive ladder rungs may be attached to a manhole wall or embedded in it on about 16-in. (406-mm) centers. Otherwise, a complete ladder may be installed in the manhole.

Granular material such as sand, gravel, or crushed stone is used to backfill the completed structure. Backfill material may be governed by specifications or approval of the engineer.

Storage Bins

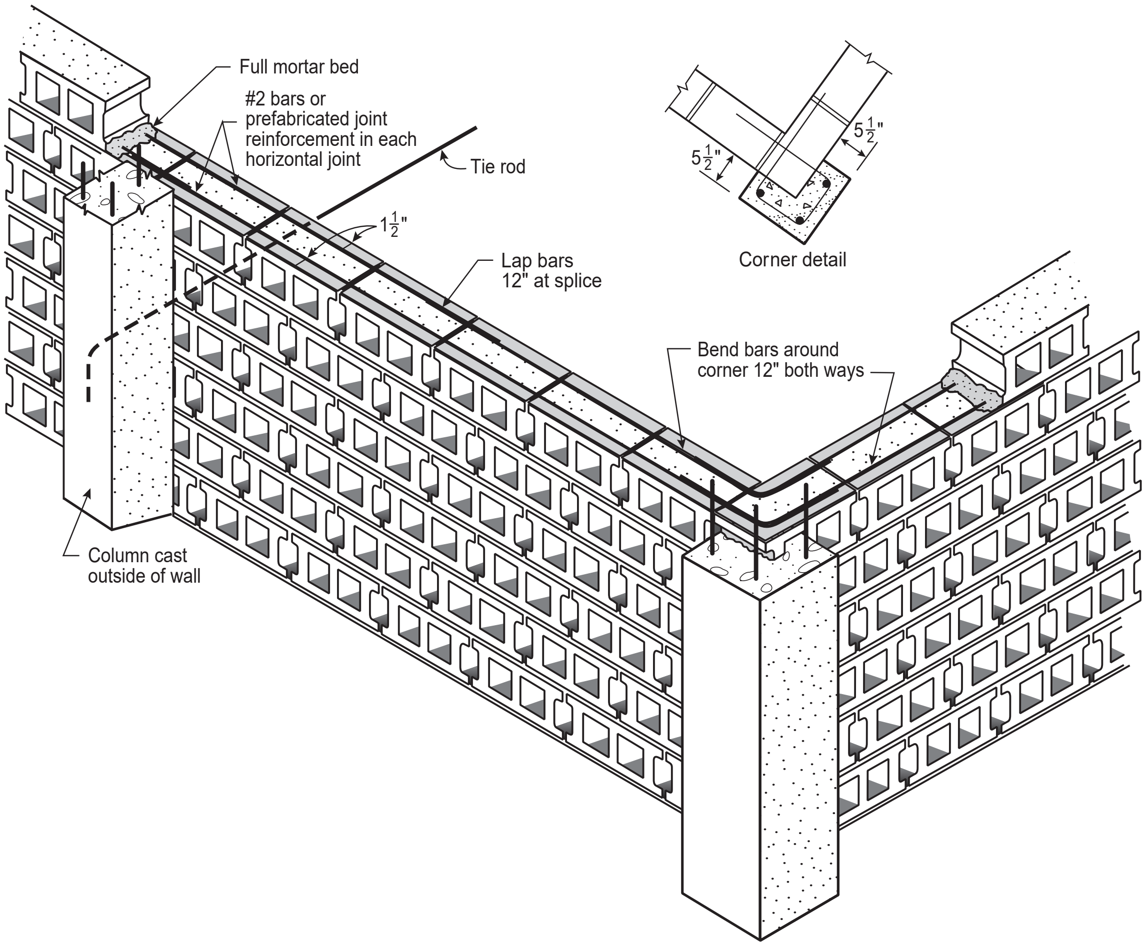
Concrete masonry units are popular for construction of storage bins for grains, fruits, and vegetables. Where drying of the stored produce is not important, masonry units are laid in the conventional manner. Where produce drying is necessary, the units are laid with their cores horizontal, as shown in Fig. 8-53.

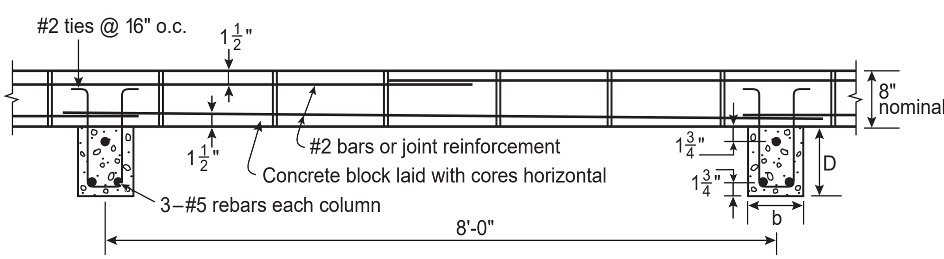
Details of construction for a concrete masonry corn storage crib are given in Fig. 8-54. Columns or pilasters for lateral support against the pressure of the stored produce may be built of reinforced concrete masonry or cast-in-place reinforced concrete. They may be placed outside the walls (Fig. 8-54) or flush (Fig. 8-53).

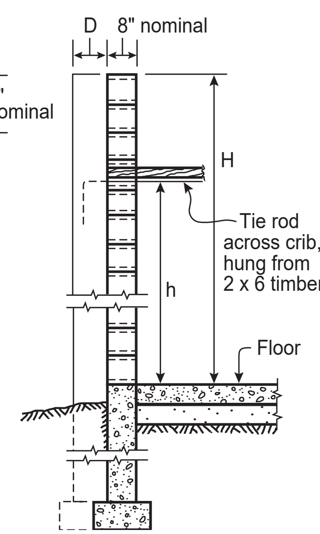
Protection against rodents is provided by installation of hardware cloth and metal joint strips, as shown in Fig. 8-55.

Fig. 8-53

Constructed of concrete block laid with cores horizontal, this rectangular crib provides durable, safe storage for ear corn. (IMG24191)







				Choice of tie rod	
H	*h*	*D*	*b*	Reinforcing bar	Threaded bar, dia.
10'0"	8'0"	10"	8"	No. 4	5/8"
12'0"	8'8"	12"	8"	No. 5	3/4"
14'0"	9'4"	12"	12"	No. 7	1"

Fig. 8-54

Details of rectangular concrete masonry corn crib.

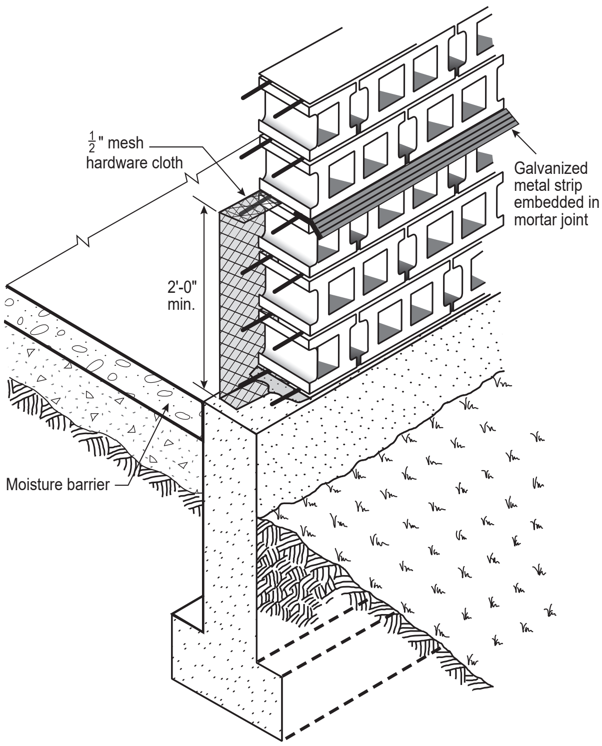


Fig. 8-55

Details of installation of metal strip shield and hardware cloth to keep rodents out of a concrete masonry corn crib.

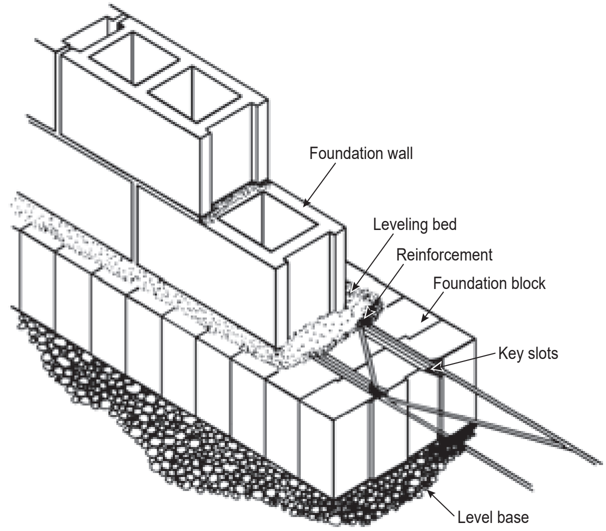


Fig. 8-56

A concrete masonry foundation system using 4x8x16-in. (102x203x406-mm) interlocking footer block.

Foundation Block

Foundation block, or footer block, are concrete masonry units designed to replace conventional cast-in-place concrete footings. A complete foundation system of interlocking units can be used for 1- and 2-story residential, commercial, and agricultural structures. Do-it-yourself homeowners will find the units easy to use as foundations for garages, house additions, sunrooms, greenhouses, and storage buildings.

In one proprietary system for 8-in.-thick (203-mm) walls, footer unit dimensions are 4x8x16-in. (102x203x406-mm), and each block weights about 24 lb (11 kg). Details of a foundation system using these block is shown in Fig. 8-56. The footer units are placed 12 in. (305 mm) below the frost line and directly on undisturbed soil that is finished and leveled with crushed stone, gravel, mortar, or lean concrete. The block foundation should meet the requirements of applicable building codes for masonry footings. For more information, see NCMA IDR 4016 1987 and TEK 15-4 1988.

Manufactured Stone

Manufactured-stone concrete masonry units are available in a multitude of colors and shapes to provide a natural stone-like appearance to residential, commercial, and industrial structures. The units can be made to resemble cobblestone, limestone, granite, lava, and other stones in ledge or boulder fashion (Fig. 8-57). The units are usually made with lightweight aggregate to reduce the weight of the units for ease in handling and to reduce the dead load of a structure. For more information, see SSP 1989.

Fig. 8-57

Ledge rock type manufactured stone (IMG24202).

Floors and Roofs

Accompanying the continuously expanding use of concrete masonry units for walls and partitions of buildings has been a steady interest in the use of concrete masonry units for floor and roof construction. Concrete masonry floors and roofs are well suited to all types of structures, except perhaps those involving very heavy loads.

The original use of concrete masonry for floor and roof construction began many years ago with the application of concrete masonry filler units between cast-in-place concrete joists. The more recent development of industrialized systems and methods of construction has encouraged the further refinement of floor and roof construction with masonry units. The newer systems, such as the recently introduced proprietary "BLOCK JOIST System" (Fig. 8-58), have resulted in decreased costs and reduced expenditure of jobsite time, as well as improved structural performance—that is, greater load-carrying capacity and smaller dead-load deflections.

The Block Joist System

There are two types of Block Joist systems:

1. The fire-resistive block joist system that contains reinforcing steel bars as the main reinforcement. It is designed as a simple-span reinforced concrete slab and can provide a 2- or 3-hour fire-resistance rating. A fire-resistant assembly is referred to as a "protected" system.
2. The noncombustible Block Joist system that contains no reinforcing bars. It is designed as a simple-span composite concrete slab and has no fire- resistance rating. This assembly is referred to as "unprotected" because it has no fire-resistance rating.

The Block Joist system consists primarily of ASTM C90 concrete masonry units, either 8x8x16-in. (203x203x406-mm) or 8x8x24-in. (203x203x610-mm) block, and a proprietary 7-in.-high (178-mm) steel joist manufactured to meet the requirements of the Steel Joist Institute (see Figs. 8-59 and 8-60). The 16-in. (406-mm) block joist system has been evaluated for both structural characteristics and as a fire-resistant assembly—that is, protected—while the 24-in. (610-mm) Block Joist system has been evaluated only for structural characteristics and is unprotected (see BOCA 1997).

The 7-in.-high (178-mm) steel joists are spaced 16¾ in. (425 mm) on center for the system using 16-in.-long (406-mm) masonry units or 24¾ in. (629 mm) on center for the system using 24-in.-long (610-mm) masonry units. The masonry units are oriented with their faces laid flat on the bottom chord of the steel joists. When a floor or roof assembly is designed as a protected system, steel reinforcing bars are placed between the block webs and the joist webs and grouted into place. Also, fire-resistive assemblies require specific masonry units. In all assemblies, whether fire-resistant or not, W1.7 deformed reinforcing wires are placed parallel and at right angles to the joists in preformed grooves—½-in.-wide (13-mm) by ¾-in.-deep (19-mm)—located in the top face of each concrete masonry unit. The

Fig. 8-58

Installation of a Block Joist floor system. (IMG24192)

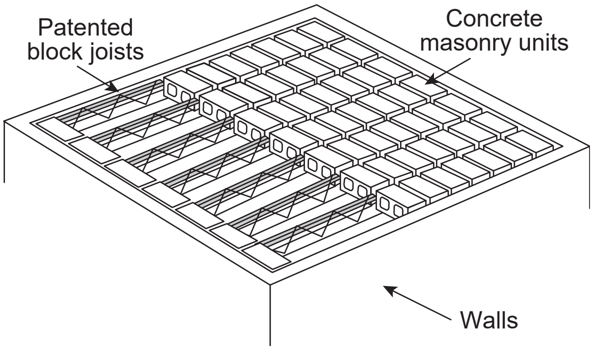
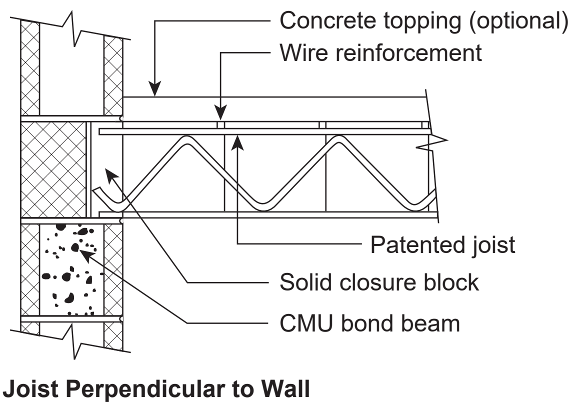


Fig. 8-59

The three main components of the system — walls, block joists, and concrete masonry units — are shown in this schematic of a partially completed floor.



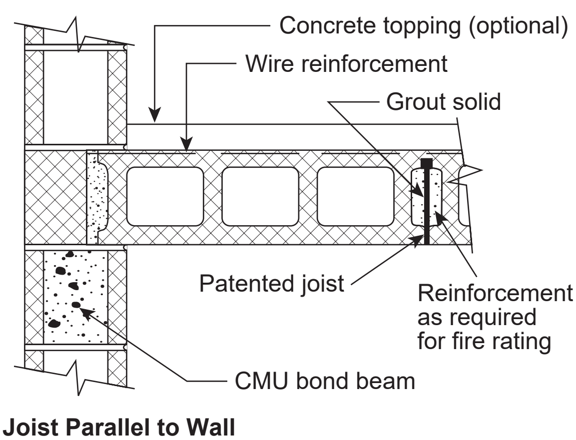


Fig. 8-60

Details of the Block Joist floor system.

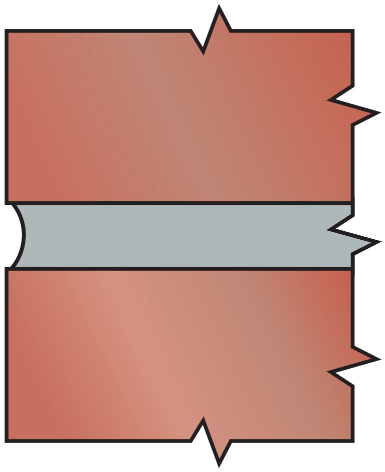
wires, which extend across the full width of the floor or roof assembly, are also grouted in place.

Grout consisting of portland cement, masonry sand, and water is poured into the spaces or troughs containing the top chord of the joists and reinforcing bars (if supplied). When poured from two or three locations along the joists, the fluidity of the grout should be sufficient to visibly fill the troughs. After the joists have been grouted, the same grout is poured onto the slab and spread with a wide squeegee to fill the grooves containing the transverse wires. The result after grouting should be a smooth, level concrete slab. With the addition of a 1½-in. (38-mm) concrete topping, a 2-hour fire-rated 16-in. (406-mm) Block Joist system can be upgraded to a 3-hour fire-rated assembly. The two protected systems are similar, except for the topping.

Spans of up to 20 ft (6.10 m) can be constructed. The joists weigh less than 4.5 lb per linear ft (6.7 kg/m), so a 20-ft-long (6.10-m) joist can be comfortably handled by two workers—one, if necessary. An 8x8x16-in. (203x203x406-mm) lightweight concrete masonry unit weights about 30 lb (13.6 kg). All components of the system are carried by hand to their final location in the floor or roof. Because the components are relatively light in weight—and are installed by personnel working on top of the actual slab they are building—the Block Joist system can be constructed quickly, safely, and economically.

Block Joist floor and roof systems are designed to be simply supported slabs in accordance with provisions of the ACI 318 Building Code (ACI 318 2005) with certain conservative exceptions. Load tables and construction requirements are given in BOCA 1997 and BJC 1995.

Only a few simple tools—gloves, a spirit level, a pinch bar, a wide squeegee, a plastic funnel and bucket—are required by the workers constructing a block joist floor or roof system. Your local concrete masonry producer —if a Block Joist licensee—can furnish all the necessary materials.



Maintenance of Masonry Structures

CHAPTER 9

Maintenance is an important part of all structures. The useful life of a building can be directly associated with the quality of the maintenance. Without preventative maintenance and prompt repair when needed, costly damage can be incurred by the building and its contents. A good maintenance program will greatly reduce the chances of major problems in a structure. The cost of repair of major damage usually far exceeds the cost of proper and timely maintenance. Concrete masonry is a very durable construction material and usually requires little or no maintenance. Maintenance problems, when they do occur, are often the result of poor design or construction practices. This chapter reviews common maintenance and repair issues. For additional information on maintenance of concrete masonry walls, see TEK 8-1A 2004.

Inspection

Masonry structures should be periodically inspected for any signs of unit deterioration, water leakage, joint deterioration, or other problems. For example, cracking can be a sign of structural problems or simple settlement; without repair, the crack can result in accelerated deterioration of a wall and excessive water leakage. Most movement joint sealants have a limited life and must be replaced periodically.

In-house inspections should be performed annually, and an inspection by a masonry or building specialist should be made every five years. The owner of a structure should have copies of all building drawings and material specifications, a list of suppliers of products and materials used in the structure, test reports, and other applicable construction documents.

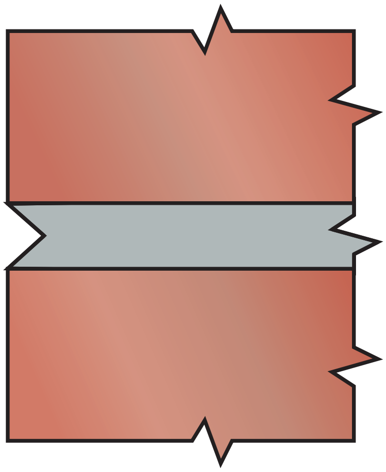
The inspection should identify areas in the building that may have potential problems, and these areas should be monitored over time. The inspector should compare protected parts of a structure with weather exposed areas to monitor deterioration or problem development due to weathering.

The inspection should first reveal if a problem exists. The extent and cause of the problem is then determined. A problem in one part of the masonry may not be obvious, but the results of the problem can appear in another part of the structure. For example, damaged flashing may not be apparent to the casual observer at the flashing location, but water stains several feet away may be readily recognizable. Once the location and cause of a problem are known, a repair procedure can be designed and implemented. After the repair is complete, the area should be monitored for the development of similar problems.

Usually a visual inspection will detect most problems. Special equipment such as the borescope in Fig. 9-1 is available to help analyze problems. Nondestructive and destructive testing are also helpful.

Fig. 9-1

Fiber-optic borescopes allow investigators to look inside masonry walls in order to analyze conditions therein; inset photo shows view through a borescope. Photos courtesy Atkinson-Noland. (IMG25744, inset IMG25745)



Left: Concave and V-joints are the most weather resistant. See Figs. 9-7 and 9-8.
Right: Fiber-optic borescope. See Fig. 9-1. (IMG15693)

Weathering and Frost Damage

Weathering and frost damage of masonry is characterized by spalls, cracks, and surface erosion. Masonry building elements exposed to weathering on both sides, such as parapet walls, screen walls, fences, fully exposed columns, and free standing walls, are especially vulnerable. Spalled units near shelf angles can indicate structural problems. Masonry beneath recesses or projections, or in locations prone to collect water, should be closely monitored, especially if flashing was not used.

To prevent the disruptive forces of ice formation, water should not be allowed to accumulate in the cores of concrete masonry units. Water expands about 9% upon freezing and can exert enormous pressure on a unit, far exceeding its strength. Severely deteriorated masonry units can be replaced. For extreme conditions involving an entire wall, one repair solution may be to apply exterior insulation and portland cement plaster (see "Exterior Insulation and Finish Systems" in Chapter 7).

Mortar joints should be inspected for weathering and frost damage. Deteriorated mortar often expands, interrupting the alignment of units. The condition of mortar in a joint can be assessed by scratching the mortar surface with a knife or nail. A slight amount of dusting of old mortar is common and usually not a problem. Sometimes mortar deteriorates to such a degree that it falls out of the joint. Separation of mortar from the unit can occur due to incompatibility between mortar and unit (due to absorption of the unit), bulging of the wall, and other reasons. Mortar can be replaced by tuckpointing, discussed later in this chapter.

Cracks and Spalls

Cracks, spalls, and wall deflection or bulging are all signs of uncontrolled or unaccommodated movement. Wall deflection or bulging can be the result of ice formation in a cavity, insufficient anchoring of wythes with ties, rusted ties, or structural failure. Cracks and spalls often accompany masonry deflection or bulging. Proper construction and spacing of control joints should accommodate movement resulting from moisture and temperature changes. Masonry building elements exposed to weather on both sides experience more thermal and moisture-induced movement than non-exposed masonry and therefore tend to have more cracks.

A lack of proper jointing can be corrected by cutting new joints into a wall. Sometimes a joint may not perform properly because it is inadvertently bridged with mortar. This condition is easily corrected by cleaning the hardened mortar from the joint. Other conditions that restrain joint movement should also be corrected.

Cracks can occur where a change in materials occurs. Vertical cracks may form in the center of walls that are overloaded. Cracks often occur around improperly designed openings in masonry—around windows, for example—as well as near corners that are twisting due to structural restraint. Bond-breaking flashing should be provided between masonry and the foundation to prevent spalls and cracks at foundation corners.

Cracks may form due to extensive rusting of lintels and shelf angles. In repairing shelf angles, stress should be relieved from the top down to avoid damage to headers or transverse bond within mortar joints. Stress relief is provided by cutting new movement joints or relieving restraint at existing movement joints.

Wall deflection or bulging due to a lack of ties can be corrected by installing special repair anchors or ties that are properly spaced throughout the wall. Bulged masonry must be straightened and reanchored prior to other repairs. Spalled or cracked units can be replaced and damaged mortar joints can be tuckpointed. The degree of repair depends on the exposure condition and the amount of damage incurred.

Sealants

Joint sealants can deteriorate and crack over time due to movement fatigue and weather exposure—especially drying and exposure to ultraviolet light. The sealant may break away from the masonry (adhesion failure) or tear within the sealant (cohesion failure). Without replacement, rain can enter the joint and cause water damage within the building, rust lintels and shelf angles, or add to efflorescence or freeze-thaw damage of masonry units. The old, deteriorated sealant should be completely removed and the joint cleaned and primed before installation of the new sealant. Small grinders are available for removing sealants, however, they may not work well because the high speed of the cutting wheel generates heat that melts the existing sealant. A vibratory tool—a knife of sorts—is available to remove sealants. The knife blade is inserted at the interface between the sealant and the masonry, and the sealant is essentially severed from the masonry.

Movement joints must be properly spaced and of proper width to prevent over-extension or compression of sealants. The type of sealant, the shape of the sealant reservoir (width and depth), and the amount of restraint on the sealant dictate its performance upon deformation. The depth of the sealant should be about one-half the sealant width.

Several types of control joints for concrete masonry are described in Chapter 4. See Figures 4-19 through 4-23, 4-25, and 4-26. A detail of a control joint constructed using specially-shaped units is shown in Figure 9-2. See TEK 10-2B 2005 for this and other control joint details.

Adhesive failure usually indicates poor surface preparation prior to application of the sealant. Porous surfaces should be primed and closed-cell backer rod should be compressed about 50% during installation. A bond breaker should be used to prevent adhesion at the bottom of the sealant. Cohesive failure occurs when

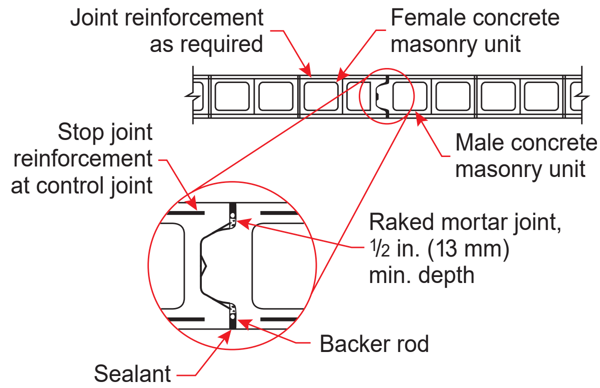


Fig. 9-2

Detail for control joint with torgue and groove units (TEK 10-2B 2005).

the wrong sealant is used, the shape of the sealant reservoir is poor, or the joints are too far apart, putting excessive stress on the sealant.

Water and Air Permeation

Water and air can permeate a wall through: (1) failed joint sealants, (2) cracks in mortar or masonry units, (3) areas around improperly placed flashing, or (4) areas where there is no flashing. The importance of weepholes to ensure proper drainage can not be overemphasized. Efflorescence on the surface of the masonry or puddles on the floor in a building are usually evidence that water has permeated a wall.

Air moving in and out through cracks and openings can convey moisture through masonry walls. Upon exposure to cool temperatures, the moisture can condense into water in or on the wall. In high-rise buildings, air leakage is aggravated by the "stack effect"—the inward (at the bottom) and outward (at the top) movement of air due to pressure differences generated by temperature and density variance between inside and outside air.

Patterns of efflorescence or dampness (sometimes frost in winter) seen on the masonry near the tops of buildings at certain times of the year are evidence of the outward flow of air. A crack between a masonry wall and a column, slab, or crosswall is an obvious path for air leakage, as well as where window frames, door frames, and ducts penetrate a wall. Proper application of a joint sealant can stop this leakage effectively.

A continuous vapor retarder installed on the warm side of a wall can prevent the accumulation of a damaging level of moisture in the masonry units.

The presence of moist air or water in a wall may rust ties, lintels, and other metal components, resulting in cracks and wall deflection or bulging. Also, frost damage can occur within the units and mortar when frozen in a wet condition. For water to enter a wall, rain must be present on the wall surface, cracks or other openings must be present, and the rain must be driven or drawn into the wall by wind, gravity, or differential air pressure. To prevent water permeation, through-the-wall flashing should be used, including locations below caps and sills. The flashing should not stop short of the exterior part of the unit. Water should drain past the surface of the masonry and not drip into the unit. Drips are helpful in allowing water to fall away from a wall surface. Sills should: (1) extend beyond the wall surface, (2) be sloped to drain water away from the wall, and (3) include a drip on the underside.

Unless repaired promptly, water leakage and water accumulation in walls can induce severe problems in masonry structures. The location of water leakage can be found by spraying water on the masonry with a hose and observing any leakage. Properly designed cavity walls with flashing provide excellent resistance to water permeation. Breathable, water-repelling sealers are helpful in reducing water leakage, however, asphaltic coatings should be avoided as they may trap moisture in the wall.

Efflorescence

Efflorescence is a crystalline deposit, usually white, that may develop on the surfaces of masonry construction (see Fig. 9-3). Often it appears just after the structure is completed. Although unattractive and generally harmless, efflorescence deposits can occur within the surface pores of the material causing expansion that may disrupt the surface. This condition is sometimes termed cryptoflorescence.

Fig. 9-3

Severe efflorescence on a concrete masonry wall. (IMG15607)

Causes

A combination of three common circumstances causes efflorescence:

- soluble salts in the masonry or adjoining materials
- moisture to pick up the soluble compounds and carry them to the surface
- evaporation or hydrostatic pressure that causes the solution to move.

If any one of these conditions is eliminated, efflorescence will not occur.

All masonry and concrete materials are susceptible to efflorescence. Water-soluble compounds that appear in chemical analyses as only a few tenths of one percent are sufficient to cause efflorescence when leached out and concentrated at some point on the surface. The amount and character of the deposits vary according to the nature of the soluble materials and the atmospheric conditions.

Deposits from efflorescence are less noticeable on lighter-colored surfaces than on darker-colored surfaces. Efflorescence is particularly affected by temperature, humidity, and wind. In summer, even after long rainy periods, moisture evaporates so quickly that comparatively small amounts of dissolved solids are brought to the surface. Usually efflorescence is more common in winter when a slower rate of evaporation allows migration of water-soluble compounds to the surface. With the passage of time, efflorescence decreases in severity unless there is recurrent moisture movement through the wall.

In most cases, compounds that cause efflorescence come from beneath the surface; but chemicals in the materials can react with chemicals in the atmosphere to form the efflorescence. For example, in concrete masonry, mortar, or stucco, hydrated portland cement contains a substantial amount of calcium hydroxide as an inevitable product of the reaction between cement or lime and water. Calcium hydroxide brought to the surface by moisture combines with carbon dioxide in the air to form calcium carbonate, which appears as a whitish deposit. Since calcium hydroxide is much more soluble in water at cold temperatures than at warm temperatures, such deposits are again more common in winter than summer.

Another source of soluble compounds is the soil in contact with basement and retaining walls. If the walls are not protected with an effective moisture barrier, the soluble compounds may migrate a foot or two above grade.

Other sources of efflorescence may be seawater exposure or previous attempts at cleaning that did not remove contaminants from the surface.

Preventing Efflorescence

Since many factors influence the formation of efflorescence, it is difficult to predict if and when any will appear: There is no accepted standard test method for measuring the efflorescence potential of masonry mortar. Several experimental methods have been proposed, but none has been accepted as effectively predicting the performance of masonry materials in actual use.

ASTM C67 contains an efflorescence test for clay brick. The test is helpful in indicating whether or not clay units will effloresce by themselves when exposed to moisture. However, it does not address the potential for efflorescence resulting from cement-brick reactions or other external conditions that may occur in service.

Given the characteristics of masonry materials and construction, it is virtually impossible to eliminate all the soluble compounds, construct walls containing no free moisture, or completely eliminate paths of moisture migration. However, steps can be taken to minimize the extent of these three contributing factors. Good workmanship is one of the most effective means of limiting the potential for efflorescence.

Most efflorescence can be classified as temporary. Often termed "new building bloom," indicating its link to the exposure conditions and excess moisture that accompany new masonry construction, it is harmless and should not cause undue concern. On the other hand, recurrent efflorescence indicates a chronic moisture problem. Efforts should be taken to correct the moisture problem, thereby preventing and eliminating recurrent efflorescence. The following recommendations are targeted toward that goal:

- Good drainage:
  - Limit entry of water and provide for quick exit by giving proper attention to design details for correct installation of waterstops, flashing, weepholes, and copings. Maintain clean cavities and unobstructed weepholes during the construction of cavity walls.
- Good mortar joints:
  - Tool all mortar joints with a V- or concave-shaped jointer to compact the mortar at the exposed surface and create a tight bond between mortar and masonry unit. Weeping, raked, and untooled struck joints are not recommended in exposed applications.
  - Assure that joints are properly filled. Deteriorated or defective mortar joints should be repointed to keep moisture out of the wall.
- Proper curing:
  - Assure adequate hydration of cementitious materials by protecting masonry from cold temperatures, premature drying, or improper use of admixtures.
- Limited water entry:
  - Apply paint or other proven protective treatment to the outside surfaces of porous masonry units. Caulk around window and door openings. Seal or otherwise repair cracked joints in walls. Also, use through-wall flashing at ground level to prevent capillary rise of ground moisture.
  - Install vapor barriers in exterior walls (interior surfaces of exterior walls) or apply vaporproof paint to interior surfaces and use designs that minimize condensation within masonry.
  - Carefully plan the installation of lawn sprinklers or any other water source so that walls are not subjected to unnecessary wetting.
  - If feasible, use wide overhanging roofs to protect walls from rainfall.
- Limited driving forces:
  - Provide for pressure equalization between the outside and the void within the masonry wall by appropriate venting of cavities.

Coordinating design and construction activities is key to producing weather-resistant masonry and eliminating recurrent efflorescence. For a more complete discussion on preventing water penetration of masonry construction, see PCA IS220 1992.

To reduce the potential for efflorescence associated with new construction, the following steps may be taken to limit the moisture introduced into the wall during construction and reduce the level of efflorescing compounds.

- Keep masonry units stored at job site covered and on pallets placed in well drained locations.

- Cover the top course of masonry at the completion of each day's work, particularly when rain (or snow) is expected.
- Use washed ASTM C144 sand.
- Do not use units known to effloresce while stockpiled. Use brick that pass the ASTM C67 efflorescence test.
- Use clean mixing water free from harmful amounts of acids, alkalies, organic material, minerals, and salts. Do not use seawater or brackish water for mixing mortar.
- Use insulating material free of soluble compounds when walls of hollow masonry units are to be insulated by filling the cores.
- Be certain that mixer, mortar box, mortarboards, and tools are not contaminated or corroded. Never deice this equipment with salt or antifreeze material.
- Use mortar materials of lower alkali content.

Note that "reducing moisture content of masonry" does not mean arbitrarily reducing the water content of mortar or allowing walls to prematurely dry out. Both of these measures will contribute to increased permeability of the masonry construction and thus increased potential for recurrent efflorescence.

How to Remove Efflorescence

Where there is efflorescence, the source of moisture should first be determined and corrective measures taken to keep water out of the structure prior to removing the efflorescence.

Since efflorescence often occurs during or immediately following construction, the first impulse is to wash it off immediately with water or a masonry cleaning solution. This is not advisable, particularly in cool or cold damp weather when the primary result of such action will be to introduce more water into the masonry wall. Given time, efflorescence will often disappear by itself or at most may require mild cleaning measures such as dry brushing or rinsing and brushing with a stiff brush.

Most efflorescence can be removed by dry brushing, water rinsing with brushing, light waterblasting, or light sandblasting followed by flushing with clean water (see ASTM D4261). If this does not produce satisfactory results, it may be necessary to wash the surface with a proprietary masonry cleaning solution or a very dilute solution of muriatic acid (1% to 10%). Prior to using a proprietary cleaner or muriatic acid solution, the cleaning agent's compatibility with the masonry units should be verified with the manufacturer of the units. Where integrally colored concrete masonry units or mortars are involved, use only a 1% to 2% acid solution or a proprietary cleaner specifically recommended for that application. The wall should be dampened from the bottom up with clean water to prevent the acid from being absorbed deep into the wall where it may cause damage. Following the cleaning treatment, the surface should be immediately and thoroughly flushed with clean water to remove all traces of acid or cleaner. If the surface is to be painted, after flushing with water, allow the surface to dry. Refer to ASTM D4260 for more information. In all cases, care should be taken to assure that the cleaning solution and technique do not etch the surface of masonry units or mortar joints. Improper cleaning can significantly change the appearance of the masonry, damage mortar joints and units, and contribute to additional efflorescence or staining.

It is often helpful to determine the type of water-soluble compounds in the efflorescence so that a cleaning solution can be found to dissolve the efflorescence without adversely affecting the masonry. See PCA IS239 2004 for additional information on types of surface deposits and appropriate cleaning methods. Before any treatment is used on any masonry wall, the method should be tested on a small, inconspicuous area to be certain there is no adverse effect. In cases involving recurrent efflorescence, the source of moisture should be determined and corrective measures taken to keep water out of the structure prior to attempted removal of the efflorescence.

Tuckpointing

Tuckpointing of mortar joints is the act of cutting out and replacing defective mortar with new mortar. There are two basic reasons why tuckpointing may be necessary: (1) leaks in the mortar joints, and (2) deterioration of joints. Tuckpointing should produce a weathertight wall and help to preserve the structural integrity and appearance of the masonry.

If a wall is being tuckpointed to make it weathertight, all mortar joints in the wall should be tuckpointed. Minute cracks that could pass a visual inspection might still allow moisture to pass through the masonry.

Before the start of any tuckpointing intended to produce a weathertight masonry wall, a thorough inspection of all flashing, lintels, sills, and sealed joints should be made. This is to ensure that water is not leaking through any of these elements.

If it is obvious that water is leaking through only one crack, it may be sufficient to tuckpoint only the mortar joints in the vicinity of that crack.

Preparation of Joints

The mortar in joints to be tuckpointed should be cut out to a depth of at least ½ in. (13 mm), and in all cases the depth of mortar removed should be at least as great as the thickness of the mortar joint (see Fig. 9-4). If the mortar is unsound, the joint should be cut out deeper until only sound material remains. Mortar that is cut out too shallow (Fig. 9-5) or furrow-shaped (Fig. 9-6) may result in poor tuckpointing.

Use of a tuckpointer's grinder with an abrasive blade is usually more efficient than hand-chiseling for cutting out defective mortar. All loose material should be removed with an air jet or a water stream.

The joints between clay masonry units should be dampened to prevent absorption of water from the freshly placed mortar. However, the joints should not be saturated just prior to tuckpointing because excessive free water on the joint surfaces could act to impair bond. To avoid excessive shrinkage, the joints between concrete masonry units should not be wetted before or during tuckpointing.

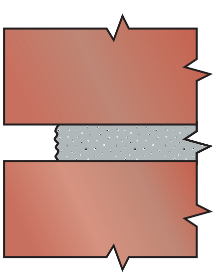


Fig. 9-4
Properly prepared joint.

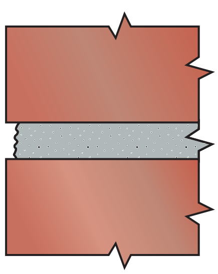


Fig. 9-5
Improperly prepared joint—too shallow.

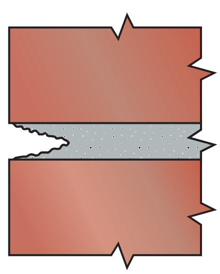


Fig. 9-6
Improperly prepared joint—furrow should be eliminated.

Mortar Ingredients

Foremost among the factors that contribute to good tuckpointing mortar is the quality of the mortar ingredients. The following material specifications of ASTM are applicable:

Portland cement—ASTM C150 (Types I, IA, II, IIA, III, or IIIA)

Masonry cement—ASTM C91 (Type N) Mortar cement—ASTM C1329 (Types N)

Blended hydraulic cement—ASTM C595 (Types IS, IS-A, IP, IP-A)

Hydrated lime for masonry purposes—ASTM C207 (Types S, SA, N, or NA) [Types N and NA lime may be used only if proven not detrimental to mortar soundness.]

Quicklime for structural uses (for making lime putty)—ASTM C5

Sand—ASTM C144

For mortar joints that are less than the conventional ⅜ in. (10 mm) thick, 100% of the sand should pass the No. 8 (2.36 mm) sieve and 95% the No. 16 (1.18 mm) sieve.

If only portions of a wall are to be tuckpointed, the color and texture of the new mortar should closely match the old mortar. This requires careful selection and proportioning of mortar ingredients. Admixtures should not be used unless specified.

Preparation of Mortar

Tuckpointing mortar should have a compressive strength equal to or less than that of the original mortar, or should contain approximately the same proportions of ingredients as the original mortar. Recommended mortar types are shown in Table 9-1. Some masonry applications may require the use of special mortars other than those in Table 9-1, for example, applications with structural concerns, or those with severe frost or environmental concerns, such as horizontal surfaces exposed to weathering.

Following is a recommended procedure for mixing tuckpointing mortar:

1. Mix all the dry materials together, thoroughly blending the ingredients.
2. Mix in about one-half the water—enough to produce a damp mix that will retain its shape when formed by hand into a ball.
3. Mix the mortar for 3 to 7 minutes, preferably with a mechanical mixer.
4. To reduce shrinkage, allow the mortar to stand for about 1 hour—but not more than 1½ hours—for prehydration of the cementitious materials.
5. Add the remaining mixing water, and mix for 3 to 5 minutes.

Table 9-1. Tuckpointing Mortar (Vertical Surfaces)

Type of service	Mortar type (ASTM C270)* Recommended	Alternate
Interior	O	N or K**
Exterior above grade exposed on one side. Not frozen when saturated and not exposed to high wind or significant lateral load	O	N
Exterior, other than above	N	O† or mortar type based on structural or durability concerns

Adapted from ASTM C270.

*Structural concerns dictating mortar type supercede these mortar recommendations. For pavements, mortar Types M or S with applicable frost resistance should be considered. Mortar should not contain more than one air-entraining material as high air contents reduce bond and compressive strength, but some air entrainment does improve freeze-thaw durability.

** Type K mortar consists of 1 part portland cement, 2½ to 4 parts hydrated lime, and sand at 2¼ to 3 times the sum of the volumes of cement and lime.

†Type O mortar is recommended for use where the masonry is aboveground and is unlikely to be frozen when saturated or unlikely to be subjected to high winds or other significant lateral loads. Type N or other appropriate mortar should be used in other cases.

Tuckpointing mortar should have a drier consistency than the conventional mortar used for laying masonry units. During tuckpointing, evaporation and absorption may require that water be added (retempering) and the mortar remixed to regain proper workability. Retemper as needed; however, the mortar should be discarded 2½ hours after the initial addition of water to the mix. Colored mortars may lighten excessively upon the addition of water; therefore, retempering of colored mortar should be avoided.

Filling the Mortar Joints

The general method of applying mortar for tuckpointing makes use of a hawk and tuckpointing trowel. The hawk is used to hold a supply of mortar, and if held immediately adjacent to the wall just below the joint being filled, it also catches mortar droppings.

The tuckpointing trowel should be slightly narrower than the mortar joint being filled in order to obtain the proper degree of compaction. If the trowel does not fit into the joint, it will be more difficult to obtain thoroughly compacted and completely filled joints.

Mortar should be spread into a joint in layers and firmly pressed to form a fully packed joint. Firm compaction is necessary in order to prevent voids as shown in Fig. 9-7. The act of firmly compacting the mortar also helps ensure bond to masonry units and to the old mortar. Voids are undesirable in tuckpointing because they may trap water that can freeze and damage the new joint.

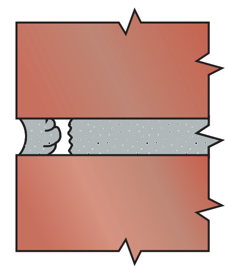


Fig. 9-7

Improperly filled joint.

Tooling Tuckpointed Joints

Tooling compacts the tuckpointing mortar to a dense surface with good durability. For weathertight construction, all tuckpointed mortar joints should be tooled to a concave or vee shape (see Figs. 9-8 and 9-9). These shapes are recommended for tuckpointing because they do not allow water to rest on the joint, and they result in the mortar being pressed tightly against both the lower and upper masonry unit. This reduces weathering and helps ensure maximum bond between the mortar and the masonry units.

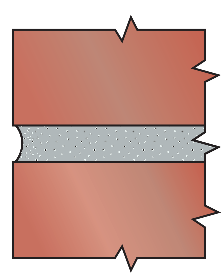


Fig. 9-8

Concave joint.

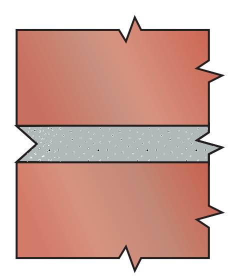


Fig. 9-9

V-joint.

Jointing tools can be made from round or square bar stock. For horizontal joints, or vertical joints in stacked bond, the tool should be considerably longer than the masonry units to avoid a wavy joint. In Chapter 2, a 22-in.-long (559-mm) tool was recommended for these joints.

Other Types of Joints for Tuckpointing

Weeping, beaded, raked, flush, struck, and weathered joints (Figs. 9-10 to 9-15) can be used for decorative effects in tuckpointing, but are not recommended for maximum watertightness and durability. These types of joints can be used satisfactorily for interior work and for exterior work where the masonry is protected from the elements, or located in climates that do not impose extremely low temperatures or water saturation.

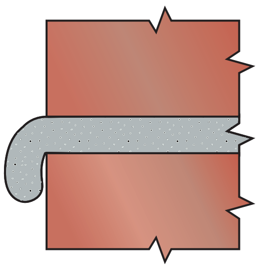


Fig. 9-10
Weeping mortar joint.

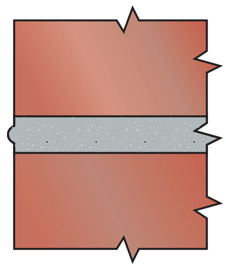


Fig. 9-11
Beaded mortar joint.

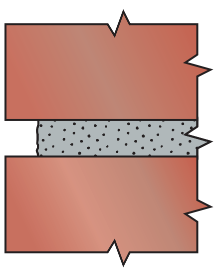


Fig. 9-12
Raked mortar joint.

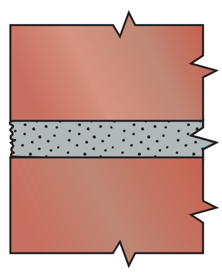


Fig. 9-13
Flush mortar joint.

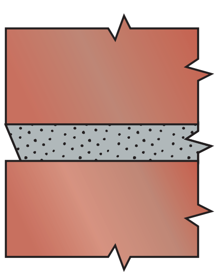


Fig. 9-14
Struck mortar joint.

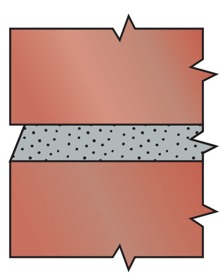


Fig. 9-15
Weathered mortar joint.

Curing

The cementitious materials in mortar require a favorable temperature and the presence of moisture to develop proper strength. The mixing water in mortar will usually provide the necessary moisture. However, freshly placed mortar should be protected from drying caused by sun and wind. With severe drying conditions—sun, wind, and low humidity—it may be necessary to cover the masonry surface with polyethylene sheeting. And on clay masonry, it may be necessary to use a fine water-fog spray for about 4 days to reduce evaporation of water from the mortar.

Cleaning Concrete Masonry Surfaces

The method selected for cleaning concrete masonry depends on the purpose of the cleaning and on the extent of the work to be done. It may entail use of a bucket and brush, a hammer and chisel, water-pressure and steam washing, abrasive blasting, chemical cleaning, or the use of special mechanical power tools.

When faced with a decision to clean concrete masonry, first a careful investigation is advisable to bring to light any unexpected facts. Accurate diagnosis of the problem is essential for effective and successful cleaning. There is no simple technique, due to these issues: (1) Water and chemical cleaners can lead to other problems caused by excessive moisture or unanticipated chemical reactions; (2) Abrasive blasting can change the texture and appearance of the surface; (3) Power tools can damage thin sections or remove more material than is desirable; and (4) Oils, grease, and certain penetrating chemicals must sometimes be removed before water or abrasive cleaning methods are used.

When cleaning concrete masonry is necessary, the following discussion should provide some guidance for selecting the least damaging method. The methods described below have merit for removing stains for aesthetic purposes, preparing surfaces for coatings and sealers, and preparing concrete masonry for repair work or plaster applications. For stain removal and some coating applications, minimize abrading of the concrete surface; on the other hand, an abraded, rough texture is desired for repair work, plastering, and certain coating applications.

Before deciding on a particular method, clean a relatively small, inconspicuous area to assess the efficiency of the method and the appearance and condition of the surface after treatment. The reasons for cleaning must be considered carefully because results with methods intended to improve only the appearance can differ substantially from results with methods to prepare the surface for coating.

For more information, see ASTM D4258 through D4263; PCA IS214 1988; and PCA IS244 2003.

Abrasive Blasting

Dry Abrasive Blasting

Dry abrasive blasting, such as sandblasting, drives an abrasive grit at a concrete masonry surface to erode away dirt, paint, various coatings or contaminants, and any deteriorated or damaged concrete. Also see "Metallic-Shot Blasting" below.

Sandblasting changes the appearance of a masonry surface. It produces a rougher texture that may hold even more dirt and pollutants than before and hasten the need for recleaning. Sandblasting removes the edges at arises and sharp detail on masonry units. On the other hand, sandblasting can provide an excellent, rough-textured surface for bonded repair work, such as plastering.

Although sandblasting is not complicated, certain procedures and precautions known to experienced operators should be followed to ensure a uniformly clean surface. A venturi-type nozzle should be used on the gun for its solid-blast pattern, rather than a straight-bore nozzle that produces lighter fringe areas. A remote control system attached to the sandblast pot gives the operator instant control of starts and stops.

The gun operator must be protected from dust and rebounding grit by a well-fitting, air-line hood in which a positive pressure of clean, filtered air is maintained. Other members of the blasting team should wear suitable protective clothing and equipment, such as an approved respirator under a hood. Silica dust is particularly dangerous because free silica can cause lung damage. The grit and dust particles must be removed by air blasting, brooming, pressurized water, or vacuum methods before a coating, sealer, or plaster is applied.

Dry abrasive blasting should be used only when other, usually less abrasive, techniques are not successful. Soft abrasives, such as nut shells and corn husks, are less destructive than sand. Some proprietary dry blasting methods are claimed to be extremely mild and have been used to clean architecturally significant structures.

Wet Abrasive Blasting

Wet abrasive blasting is very similar to dry abrasive blasting (sandblasting) except that water is introduced into the air-grit stream at the nozzle. An adapter is attached to the nozzle to secure the water supply. The water eliminates most of the visible dust, but small, harmful particles remain a hazard to health, so the same protective equipment and clothing are needed as for dry abrasive blasting. The wet-abrasive-blasting method avoids the nuisance of dust, but it involves an extra operation—rinsing the surface with water after blasting to remove residual dust and dirt scum.

In wet abrasive blasting, the water cushions the abrasiveness of the grit and therefore the method is less destructive than dry sandblasting. Wet abrasive blasting is often used on soft brick and stone and ornamental facades to avoid damaging the sharp details in this type of masonry. Friable aggregate (without silica) and water can be combined and applied at low pressure to provide a scouring action without harming the masonry.

Metallic-Shot Blasting

Self-contained, airless, portable blasting equipment can effectively clean horizontal or inclined surfaces. This equipment is primarily helpful for cleaning concrete paving units, although special equipment is available for vertical work. The removal of surface contaminants such as old paint, dirt, and loose and weakened concrete is easily accomplished by the impact of metallic abrasives thrown onto the surface to be cleaned by a rapidly rotating centrifugal wheel. The equipment includes components for dust and noise control as well as the recovery, cleaning, and recycling of the metallic abrasive.

After the abrasive impacts the surface, it is passed through an air-wash separator that removes foreign materials; the recovered abrasive is then recirculated through the blast wheel. Pulverized concrete, dust, and contaminants are removed to a filter-bag dust collector, making the method virtually pollution free.

Chemical Cleaning

The materials used in chemical cleaning can be highly corrosive and frequently toxic. They require special equipment for their application and protective clothing for workers. In addition, protection may be necessary for adjacent areas, nearby buildings, and lawns, trees, and shrubs. For these reasons, chemical cleaning is best left to the specialist. If, however, an amateur undertakes a chemical cleaning job, the directions that come with the cleaner should be carefully followed.

Chemical cleaners are often water-based mixtures formulated for use on specific types of concrete and masonry. Most of them contain organic compounds called surfactants (surface-active agents), which work as detergents, allowing water to more readily penetrate surface dirt and stains, thus hastening their removal. In addition, chemical cleaners contain a small amount of either acid or alkali, which assists in separating the dirt from the surface. Solvent-based (nonwater) cleaners are also used. Cleaning with proprietary compounds, detergents, or soap solutions generally requires the same procedure as given below for acid cleaning.

Acid cleaning is often suggested as a satisfactory method for cleaning a masonry surface. Hydrochloric acid, also known as muriatic acid, is widely used because of its ready availability. Hydrochloric acid should not be used in areas where chlorides are prohibited. The procedure for cleaning concrete masonry with a diluted acid solution is as follows:

1. Mix a 10% solution of muriatic acid (1 part acid to 9 parts clean water) in a nonmetallic container. Pour the acid into the water to mix, not the water into the acid. A stronger acid solution may have to be used if the cleaning action is insufficient.
2. Mask or otherwise protect windows, doors, ornamental trim, and metal, glass, wood, and stone surfaces from acid solutions.
3. Remove dust and dirt from the area to be cleaned, and presoak or saturate the surface with water, starting from the bottom and working up.
4. Apply the acid solution to the damp surface with spray equipment, plastic sprinkling cans, or a long-handled stiff-fiber brush. Allow the solution to remain on the surface for 5 to 10 minutes. Nonmetallic tools may be used to remove stubborn particles.
5. Rinse thoroughly by flushing with large amounts of clean water before the surface can dry. Acid solutions lose their strength quickly once they are in contact with portland cement in concrete masonry or mortar; however, even weak, residual solutions can be harmful. Failure to completely rinse the acid solution off the surface may result in efflorescence or other damage. Test with pH paper and continue rinsing until a pH of 7 or higher is obtained (see ASTM D4260 and D4262 for more information).

Steam Cleaning

In steam cleaning, water is pumped to a flash boiler where it is converted to steam and then directed onto the concrete masonry. The use of stiff-bristle brushes usually is necessary to assist in removing dirt. Today, improved methods and cleaning products have largely supplanted steam cleaning for buildings, although steam can sometimes help to remove deep-seated soil after acid cleaning and to reach awkward areas. Steam cleaning essentially leaves the concrete masonry surface intact.

Water Spraying

Low Pressure

In low-pressure water spraying, only enough water is sprayed onto the surface to keep the dirt deposits moist until they soften. Larger amounts of water are not more effective. Use of too much water might oversaturate a wall and penetrate to the building's interior, causing additional problems. Cleaning should begin at the top of the structure so that surplus water will run down the surface and presoften the dirt below. The period of time it will take to soften the dirt is found by trial; it could be a few minutes or days. On some surfaces the softened dirt can then be removed by hosing down the surface, but usually it is necessary to assist removal with the gentle use of bristle brushes and nonferrous or stainless-steel-wire brushes.

The low-pressure water spraying method is effective only when the dirt lies lightly on the surface or is bound to the wall with water-soluble matter.

High-Pressure Water Blasting

Masonry surfaces can be cleaned effectively with the recently developed ultra-high-pressure water-jetting equipment. High-pressure water blasting relies on the force of the water for cleaning rather than on abrasives. Pressures up to 55,000 psi (379 MPa) are available, however, most of the work is accomplished at pressures of 5000 psi to 10,000 psi (34 MPa to 69 MPa) or less. Although usually not needed, sand may be injected into the high-pressure water stream to enhance cutting. Oil and grease are usually removed before water blasting.

A variety of equipment is available for this type of cleaning. Nozzles range from flat-fan pattern tips to a straight jet tip. The fan pattern acts as a blade that pries up and lifts away undesirable surface accumulation. The straight jet, if held in one spot, could cut a hole completely through concrete masonry.

The techniques used are similar to sandblasting. The correct distance from the surface, the nozzle angle, and the pressure are determined by the type and amount of material to be removed. In addition to removing dirt or stains, water blasting can be used for preparing surfaces for coatings, or for abrading surfaces for repairs.

Graffiti Removal

A large number of commercially available products are suitable for removing spray-paint and felt-tip markings from concrete and masonry surfaces. These products are generally also effective for removing crayon, chalk, and lipstick. The manufacturer's directions should always be followed. If satisfactory results are not obtained with the first remover applied, a second or third attempt with other products should be made. A single product may not remove both spray-paint and felt-tip markings.

If a proprietary cleaner is not available, methylene chloride can be used. While wearing protective clothing, brush methylene chloride onto the surface, wait 2 minutes, and then rinse with water while continuously brushing. Oxalic acid or hydrogen peroxide can be used to bleach out some of the pigment that may remain in the pores of the concrete masonry. Solutions of sodium hydroxide, xylene, or methyl ethyl ketone are also helpful in removing graffiti. Effective cleaning can also be accomplished with water blasting and sandblasting.

After graffiti removal, or preferably before a structure is placed in service, an antigraffiti coating or sealer should be applied. The surface treatment should prevent graffiti from entering the pores of the masonry. This should facilitate removal of graffiti, preferably without removing the surface treatment.

Aliphatic urethanes are considered the best antigraffiti coatings because of their resistance to solvents, yellowing, and abrasion. Solvents such as mineral spirits or methyl ethyl ketone can remove most graffiti from an aliphatic polyurethane without compromising the urethane coating. Acrylics, epoxies, silanes, and siloxanes are also used as coatings to make graffiti removal easier; however, acrylics dissolve with the solvent and epoxies tend to yellow or discolor. Silanes and siloxanes may not resist certain graffiti materials as well as the urethanes, but they do maintain a high degree of breathability at the surface while resisting penetration of graffiti materials into the pores of the masonry.

Air Pollution

Airborne dirt can collect on concrete masonry surfaces and form a dark and sometimes oily buildup or stain. Buildings may need to be cleaned of air pollution-induced dirt deposits to regain their original appearance. Some dirt can be removed by scrubbing with detergent and water or a solution made of 1 part hydrochloric acid in about 20 parts of clean water. However, special proprietary cleaners, made to remove dirt with minimal attack of the masonry, are often preferred over hydrochloric acid solutions that attack the cement paste in concrete masonry.

A solution made of 1 part phosphoric acid to about 3 parts clean water can be used to scrub away light to moderate amounts of dirt with little to no attack of the masonry surface. Proprietary cleaners made with hydrochloric acid and buffers to protect the concrete are used to remove severe dirt buildup. An alkaline prewash followed by an acetic acid wash is another cleaning method. Special cleaning solutions can be designed to remove any particular type of dirt.

The methods used to remove oil can be helpful in removing very oily dirt. Steam cleaning and light sandblasting or waterblasting are also effective as discussed earlier.

Once a surface is cleaned, good practice is to apply a clear, breathable sealer (such as a methacrylate or acrylic-based material) or a clear water-repellent penetrating sealer (such as silane or siloxane) to resist dirt buildup and make future cleaning easier. Some cleaning specialists prefer silane or siloxane treatments because of their high breathability (often with a 95% vapor transmission). Also see "Graffiti Removal" above.

Stain Removal

Concrete masonry may become stained by many substances. The first step in stain removal is to determine what caused the stain. Water-based or water-soluble stains, such as many foods, beverages, and soil, can be removed with water cleaning methods as discussed earlier. A detergent, water, and a stiff-bristle brush can be very effective in removing many common stains. The cleaning techniques presented under "Cleaning Concrete Masonry Surfaces" are also applicable to removing stains. For more information on removing specific stains, refer to *Removing Stains and Cleaning Concrete Surfaces* (PCA IS214 1988). This publication discusses the removal of many common stains ranging from aluminum and food stains to oil, smoke, and wood stains. Discussions on removing efflorescence, dirt, and graffiti were presented earlier in this chapter.

Covering Stains

After cleaning concrete masonry, the surface appearance may not be as good as desired. A shadow of the stain may remain. Some stains or discoloration may be so severe or extensive that it may not be economical or possible to remove them adequately. In such cases, it may be necessary to coat the masonry—to cover up the stain to restore a more pleasant and uniform surface appearance. Many coatings also facilitate future surface cleanup.

Before using a coating, be sure it: (1) can breathe as required, (2) will properly adhere to the concrete masonry, (3) will be durable under the exposure conditions, (4) will not discolor or fade, and (5) will not allow the stain to bleed through. The tendency of a stain to bleed can be tested by coating an inconspicuous area and observing it for bleeding over a few days. Because of the bleeding tendency of some stains, an impermeable sealer or pretreatment may need to be applied prior to the coating application. Most coatings require some surface preparation (cleaning or roughening) to bond properly to the substrate.

Coatings (colored or white) commonly consist of polymer-modified cementitious materials, silicone emulsions, and other substances. The concrete masonry must be sufficiently dry for certain coatings to be applied (see ASTM D4263). Special staining materials, such as penetrating acrylic resin and pigment stains, may be used in an attempt to color the surface and blend in the discoloration to produce a more uniform appearance. Cement plaster can be applied to hide unsightly areas.

Protective Surface Treatments

For new and newly cleaned masonry, a clear (or colored) surface treatment can be applied to prevent future staining materials from penetrating the surface, to facilitate stain or dirt removal, and to repel water from the surface to reduce water permeation. The sealer should be durable under the anticipated exposure conditions, should properly adhere to or penetrate the concrete masonry surface, not discolor or yellow, and have the appropriate breathability properties. Many sealers need a surface pretreatment. Most clear coatings or penetrating sealers enhance or may not affect the masonry's appearance.

Materials used to protect masonry surfaces include aliphatic urethane, methyl methacrylate, various modified acrylics, and epoxy sealers as well as penetrating water-repellent sealers such as silane and siloxane. The silanes and siloxanes have a high degree of breathability or vapor transmission, which is important for concrete masonry structures.

Where colored surface treatments are required, the acrylics and styrene butadiene perform well. Asphaltic cement and other nonbreathable coatings should not be used unless all moisture in the masonry is removed. Moisture trapped in the masonry by the asphalt can cause deterioration of units and rusting of metal components. For locations in which a chemical might attack the concrete masonry, an appropriate sealer that can resist the environment must be used (see TEK 19-1 2006 and PCA IS001 2001).

References on Concrete Masonry

Since this handbook points out only the most essential facts concerning concrete masonry and its constituent materials, references have been made to many of the following publications to indicate the sources of material presented in the text. This list of references is also intended to serve as a guide for further study.

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A616 Specification for Rail-Steel Deformed and Plain Bars for Concrete Reinforcement

A617 Specification for Axle-Steel Deformed and Plain Bars for Concrete Reinforcement

A706 Specification for Low-Alloy Steel Deformed Bars for Concrete Reinforcement

C5 Specification for Quicklime for Structural Purposes

C11 Terminology Relating to Gypsum and Related Building Materials and Systems

C31 Practice for Making and Curing Concrete Test Specimens in the Field

C33 Specification for Concrete Aggregates

C39 Test Method for Compressive Strength of Cylindrical Concrete Specimens

C43 Terminology of Structural Clay Products

C51 Terminology Relating to Lime and Limestone (as used by the industry)

C55 Specification for Concrete Brick

C67 Test Methods of Sampling and Testing Brick and Structural Clay Tile

C73 Calcium Silicate Face Brick (Sand-Lime Brick)

C90 Specification for Loadbearing Concrete Masonry Units

C91 Specification for Masonry Cement

C94 Specification for Ready-Mixed Concrete

C129 Specification for Nonloadbearing Concrete Masonry Units

C139 Specification for Concrete Masonry Units for Construction of Catch Basins and Manholes

C140 Test Methods of Sampling and Testing Concrete Masonry Units

C143 Test Method for Slump of Hydraulic Cement Concrete

C144 Specification for Aggregate for Masonry Mortar

C150 Specification for Portland Cement

C207 Specification for Hydrated Lime for Masonry Purposes

C219 Terminology Relating to Hydraulic Cement

C236 Test Method for Steady-State Thermal Performance of Building Assemblies by Means of a Guarded Hot Box

C270 Specification for Mortar for Unit Masonry

C315 Specification for Clay Flue Linings

C387 Specification for Packaged, Dry, Combined Materials for Mortar and Concrete

C404 Specification for Aggregates for Masonry Grout

C423 Test Method for Sound Absorption and Sound Absorption Coefficients by the Reverberation Room Method

C426 Test Method for Drying Shrinkage of Concrete Masonry Units

C476 Specification for Grout for Masonry

C595 Specification for Blended Hydraulic Cements

C617 Practice for Capping Cylindrical Concrete Specimens

C631 Specification for Bonding Compounds for Interior Plastering

C634 Terminology Relating to Environmental Acoustics

C672 Test Method for Scaling Resistance of Concrete Surfaces Exposed to Deicing Chemicals

C744 Specification for Prefaced Concrete and Calcium Silicate Masonry Units

C780 Test Method for Preconstruction and Construction Evaluation of Mortars for Plain and Reinforced Unit Masonry

C847 Specification for Metal Lath

C887 Specification for Packaged, Dry, Combined Materials for Surface Bonding Mortar

C896 Terminology Relating to Clay Products

C897 Specification for Aggregate for Job-Mixed Portland Cement-Based Plasters

C901 Specification for Prefabricated Masonry Panels

C904 Terminology Relating to Chemical-Resistant Non-metallic Materials

C920 Specification for Elastomeric Joint Sealants

C926 Specification for Application of Portland Cement-Based Plaster

C932 Specification for Surface-Applied Bonding Agents for Exterior Plastering

*ASTM, 100 Barr Harbor Drive, West Conshohocken, PA 19428. Phone (610) 832-9500. FAX: 610-832-9555.

C933 Specification for Welded Wire Lath

C936 Specification for Solid Concrete Interlocking Paving Units

C946 Practice for Construction of Dry-Stacked, Surface-Bonded Walls

C952 Test Method for Bond Strength of Mortar to Masonry Units

C1006 Test Method for Splitting Tensile Strength of Masonry Units

C1012 Test Method for Length Change of Hydraulic-Cement Mortars Exposed to a Sulfate Solution

C1019 Test Method for Sampling and Testing Grout

C1032 Specification for Woven Wire Plaster Base

C1038 Test Method for Expansion of Portland Cement Mortar Bars Stored in Water

C1063 Specification for Installation of Lathing and Furring to Receive Interior and Exterior Portland Cement-Based Plaster

C1072 Test Method for Measurement of Masonry Flexural Bond Strength

C1093 Practice for Accreditation of Testing Agencies for Unit Masonry

C1142 Specification for Extended Life Mortar for Unit Masonry

C1148 Test Method for Measuring the Drying Shrinkage of Masonry Mortar

C1180 Terminology of Mortar and Grout for Unit Masonry

C1193 Guide for Use of Joint Sealants

C1209 Terminology of Concrete Masonry Units

C1213 Terminology Relating to Precast Concrete Products

C1232 Terminology of Masonry

C1328 Specification for Plastic (Stucco) Cement

C1329 Specification for Mortar Cement

C1357 Test Methods for Evaluating Masonry Bond Strength

C1384 Specification for Admixtures for Masonry Mortars

C1506 Test Method for Water Retention of Hydraulic Cement-Based Mortars and Plasters

D3665 Practice for Random Sampling of Construction Materials

D4258 Practice for Surface Cleaning Concrete for Coating

D4259 Practice for Abrading Concrete

D4260 Practice for Acid Etching Concrete

D4261 Practice for Surface Cleaning Concrete Unit Masonry for Coating

D4262 Test Method for pH of Chemically Cleaned or Etched Concrete Surfaces

D4263 Test Method for Indicating Moisture in Concrete by The Plastic Sheet Method

E72 Methods of Conducting Strength Tests of Panels for Building Construction

E90 Test Method for Laboratory Measurement of Airborne Sound Transmission Loss of Building Partitions

E119 Test Methods for Fire Tests of Building Construction and Materials

E336 Test Method for Measurement of Airborne Sound Insulation in Buildings

E380 Practice for Use of the International System of Units (Sl) (the Modernized Metric System)

E413 Classification for Rating Sound Insulation

E447 Test Methods for Compressive Strength of Masonry Prisms

E492 Test Method for Laboratory Measurement of Impact Sound Transmission Through Floor-Ceiling Assemblies Using the Tapping Machine

E597 Practice for Determining a Single-Number Rating of Airborne Sound Isolation for Use in Multiunit Building Specifications

E621 Practice for the Use of Metric (SI) Units in Building Design and Construction (Committee E-6 Supplement to E380)

Details of Concrete Masonry Construction

Appendix A

On the following pages are a number of details that might be encountered in buildings using concrete masonry. These details are offered only as a guide for design. They are not guaranteed for completeness or suitability for all buildings in all places. For example, although assumed to be present, weepholes are not always illustrated with flashing details.

Building designs involve a wide range of shapes, dimensions, materials, loads, uses, and climates. While some simple details are adequate for many ordinary structures, there are circumstances that require they be refined or improved, as in regions with expansive soils, earthquakes, or high winds. The knowledgeable and experienced designer or builder will recognize the applications of various configurations and be able to refine or improve these details to fit the individual project.

The connection of floors and roofs to masonry walls deserves particular attention. Some building codes—particularly where earthquakes and high winds are common—require a positive connection between the floor or roof and the masonry wall (Yokel 1974). Although practice varies from one region to another, engineered concrete masonry structures most often have reinforcing bar connections between wall and floor or roof. Wooden framing must always be anchored. In some cases the dead-load friction of a concrete or steel deck on the wall will suffice. The following friction coefficients, which are based on a safety factor of 2, are suggested:

Connection	Friction coefficient
Steel to steel	0.12
Cast-in-place concrete to steel	0.20
Cast-in-place concrete to hardboard	0.25
Cast-in-place concrete to cast-in-place concrete	0.40
Precast concrete to concrete masonry	0.40
Cast-in-place concrete to concrete masonry	0.50

Where a floor is embedded in a wall, the connection will be stronger than for a roof that is merely resting on top of the wall. A roof may be subject to temperature and shrinkage movements. If a roof is to act as a diaphragm, and the structure is to act as a unit, some positive connection between wall and roof may be required.

The importance of construction details is well known. Not only do details affect the initial construction cost, but also they have an important influence on the behavior of the building under the traffic of use and the influence of weather. Since the cost of repairs frequently outweighs the initial cost of construction, the architect, engineer, and builder should plan and construct all details carefully.

Floor plans, designs, and details of masonry structures are available in publications from the National Concrete Masonry Association, 2302 Horse Pen Road, Herndon, Virginia 20171-3499 (Phone: 703-713-1900).

Left: IMG15841
Right: IMG15851

Foundation Details

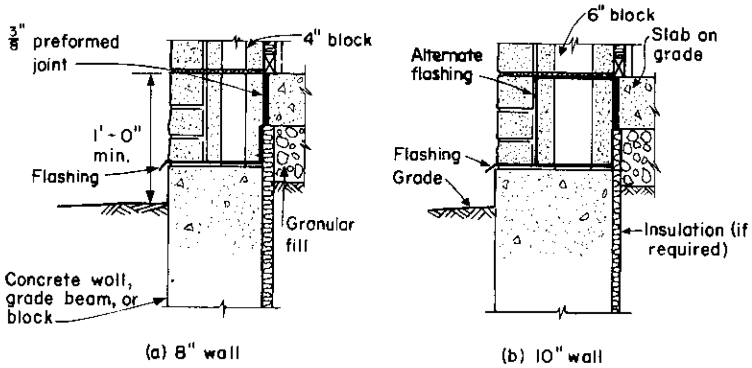


Fig. A-1

Foundation for composite wall.

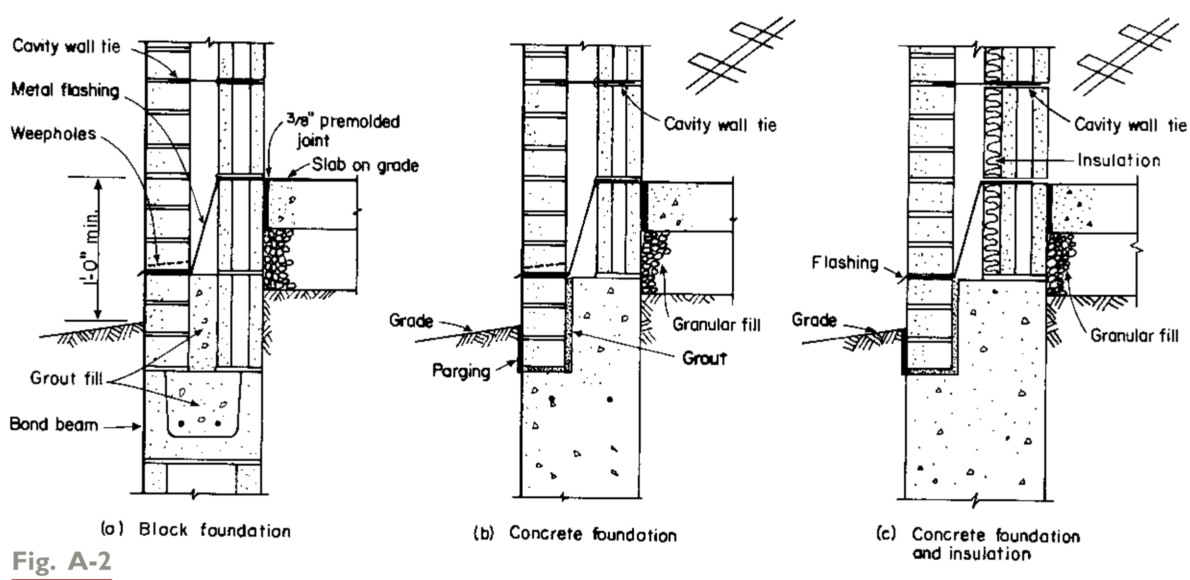


Fig. A-2

Foundation for cavity walls.

Basement Wall Details

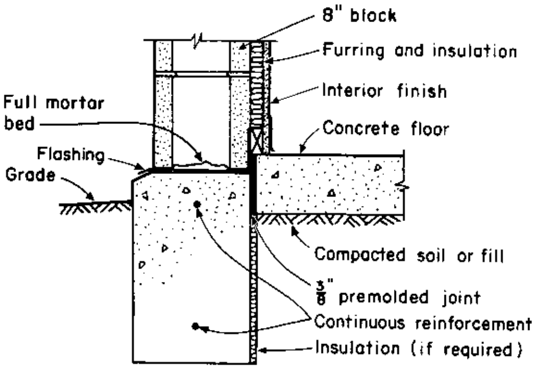


Fig. A-3

Trench-type foundation.

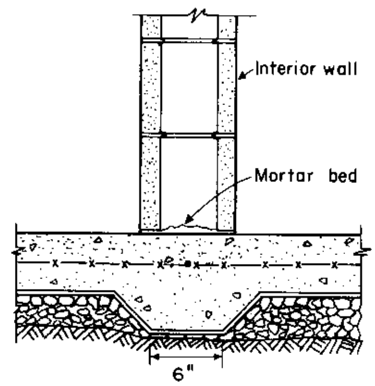


Fig. A-6

Load-bearing wall on slab.

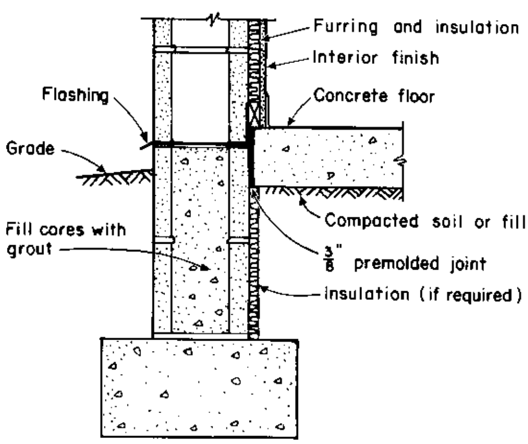


Fig. A-4

Spread footing foundation.

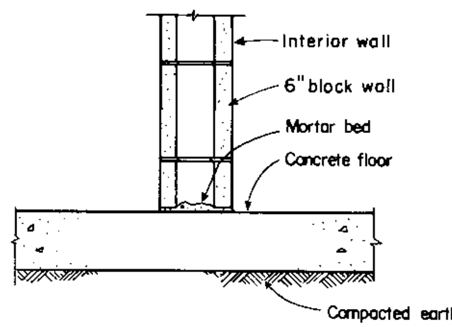


Fig. A-7

Non-load-bearing wall on slab.

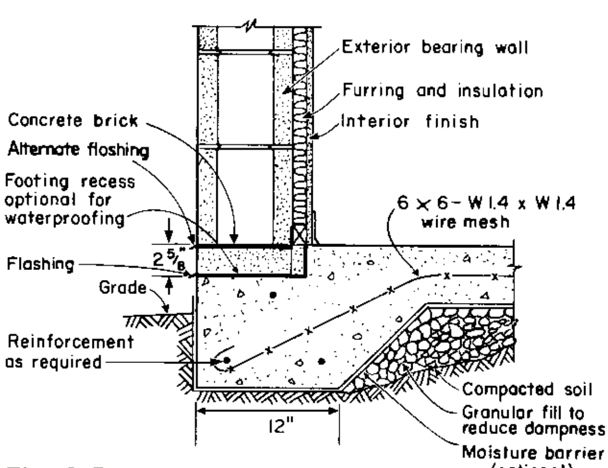


Fig. A-5

Floating slab foundation.

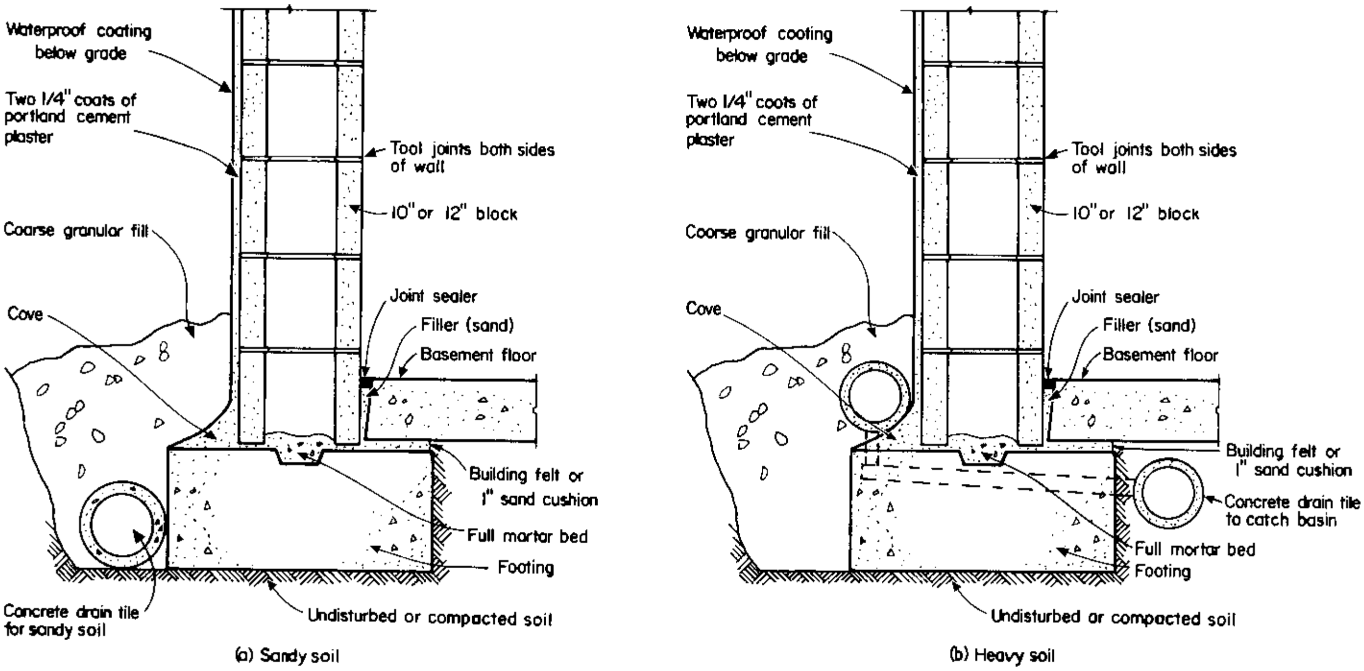


Fig. A-8

Exterior wall on footing.

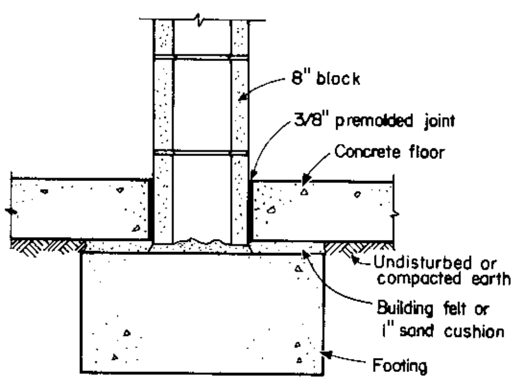


Fig. A-9

Interior wall on footing.

Wall Details at Precast Concrete Floors

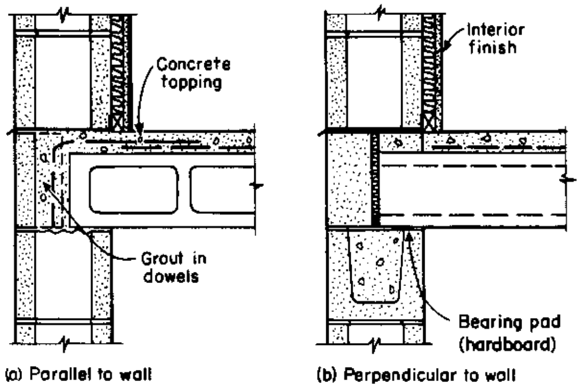


Fig. A-10

Hollow-core slab floors and single-wythe walls.

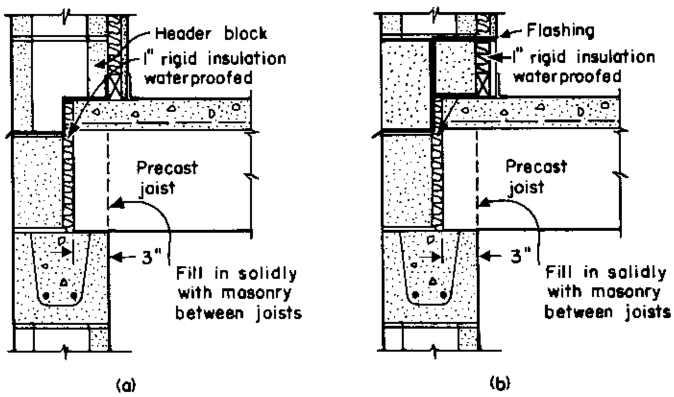


Fig. A-11

Precast joist floor and single-wythe wall.

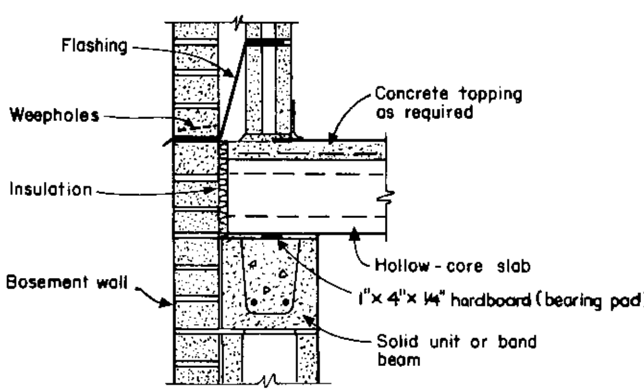


Fig. A-12

Hollow-core slab floors with cavity wall above.

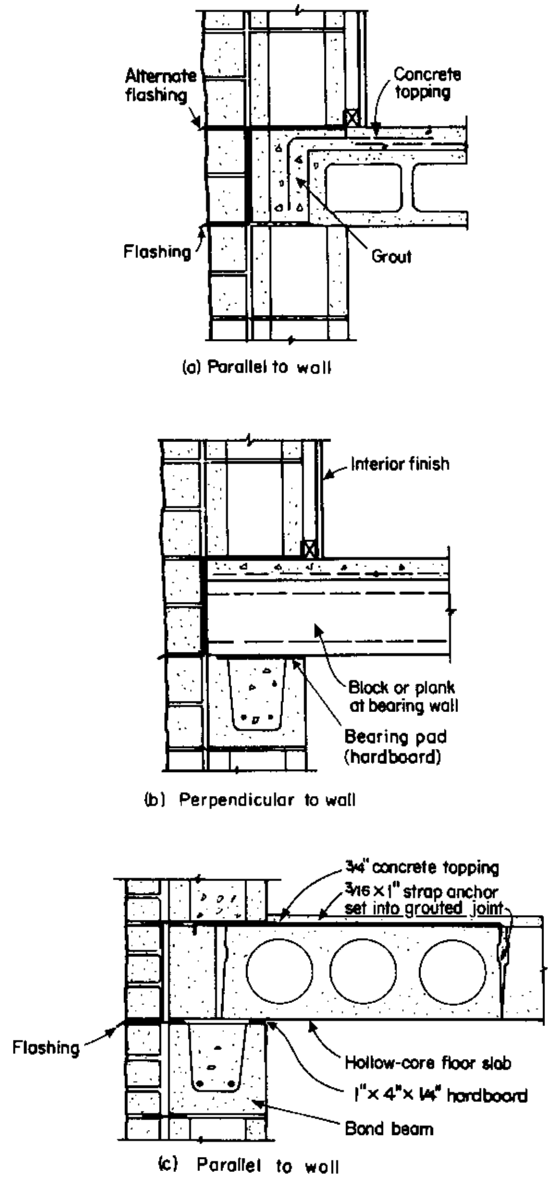
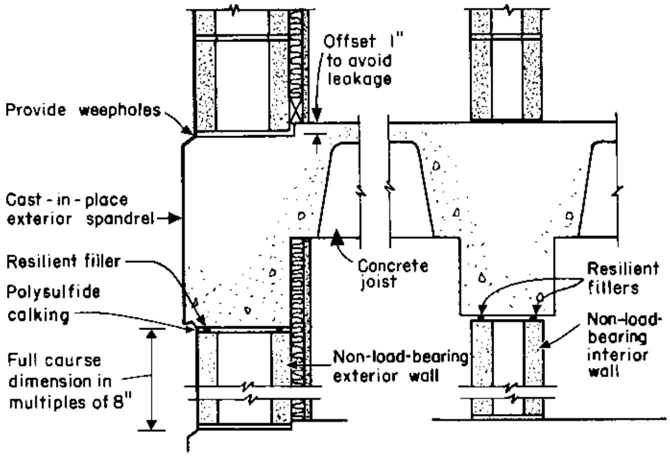


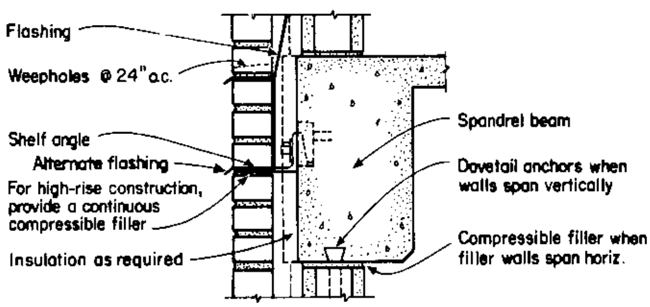
Fig. A-13

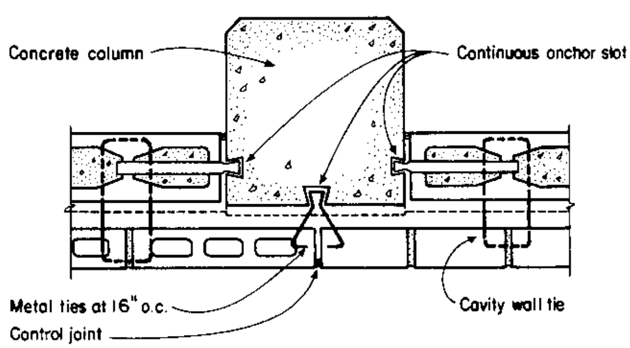
Hollow-core slab floor and composite walls.

Wall Details at Cast-in-Place Concrete Floors



(a) Single-wythe walls

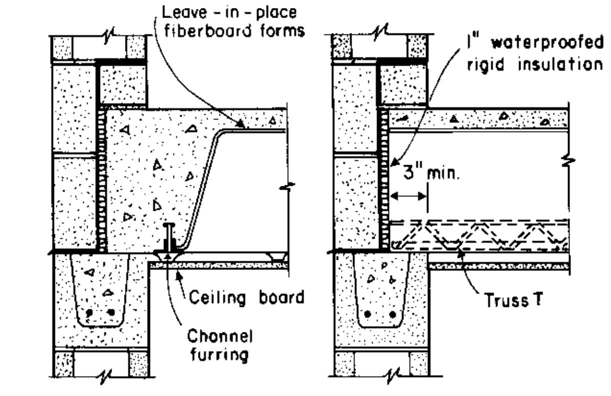




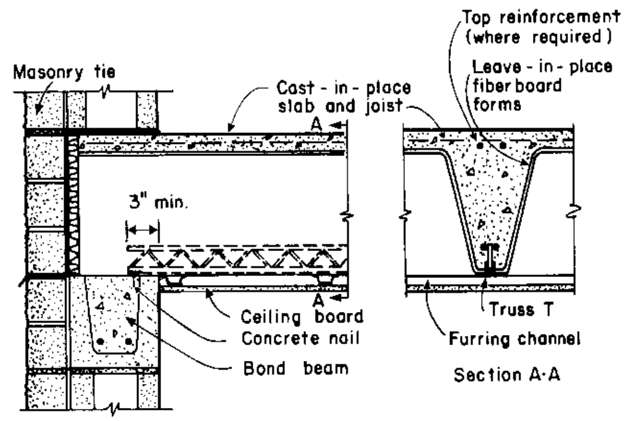
(b) Cavity walls

Fig. A-14

Curtain wall and partition with concrete frame.



(a) Single-wythe walls

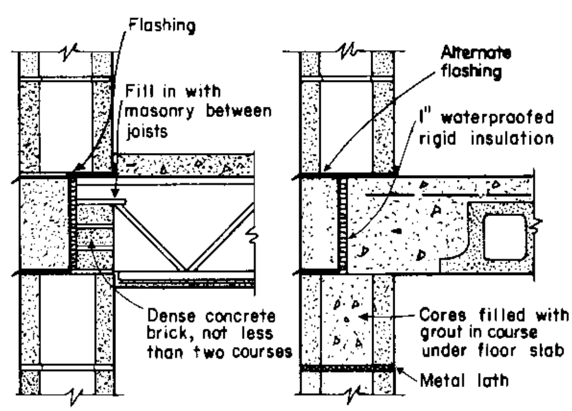


(b) Composite walls

Fig. A-15

I/D® (Integrated-Distribution) system floors.

®Trademark and servicemark of the Portland Cement Association 1971.



(a) Bar joist floor (b) Soffit block joist floor

Fig. A-16

Joist floors.

Wall Details at Concrete and Metal Roofs

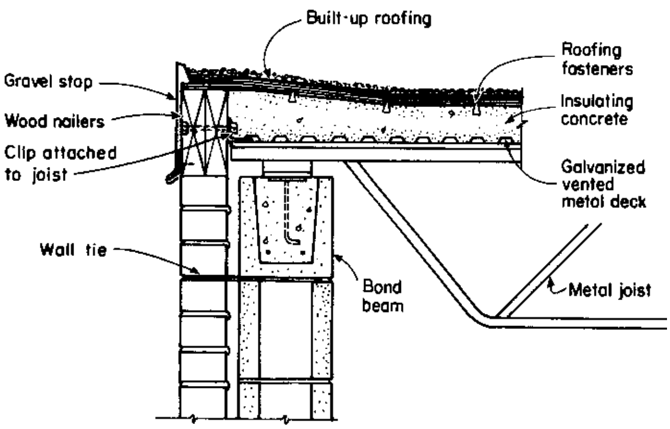


Fig. A-17

Metal deck roof.

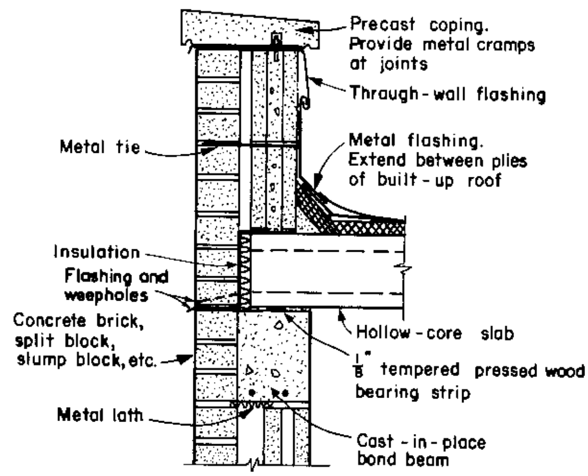


Fig. A-18

Parapet for load-bearing cavity walls.

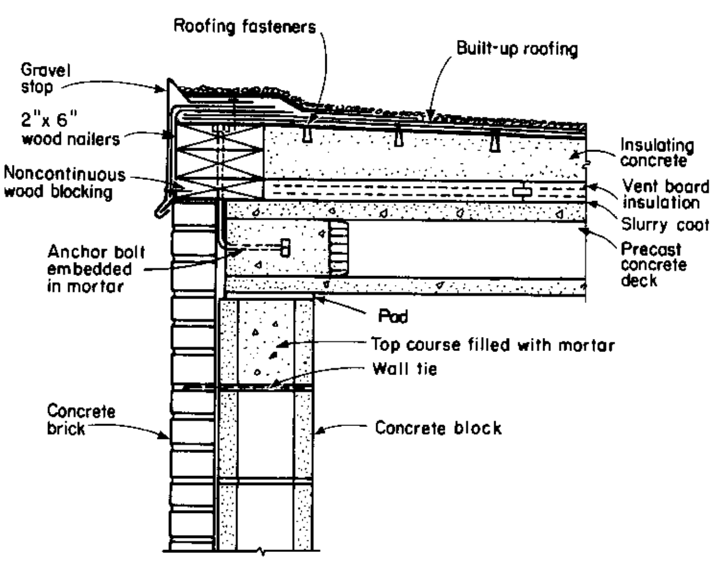


Fig. A-19

Precast concrete deck.

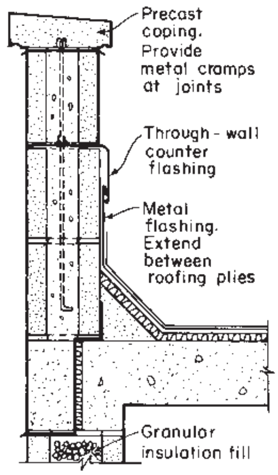


Fig. A-20

Parapet for flat concrete roof on single-wythe walls.

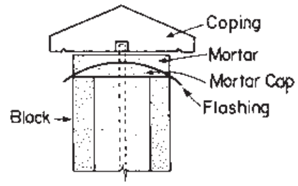


Fig A-20a

Coping anchorage and flashing detail.

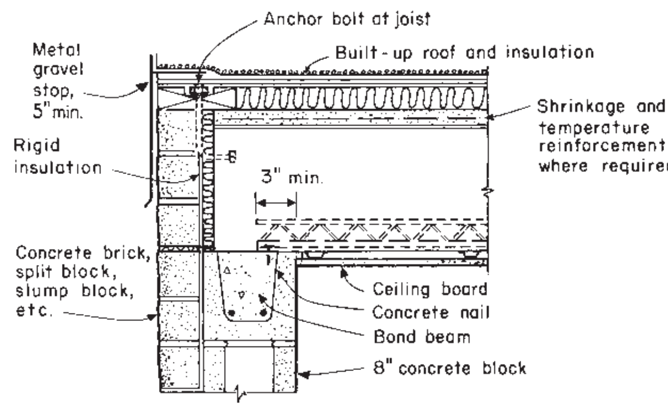


Fig. A-21

I/D® roof.

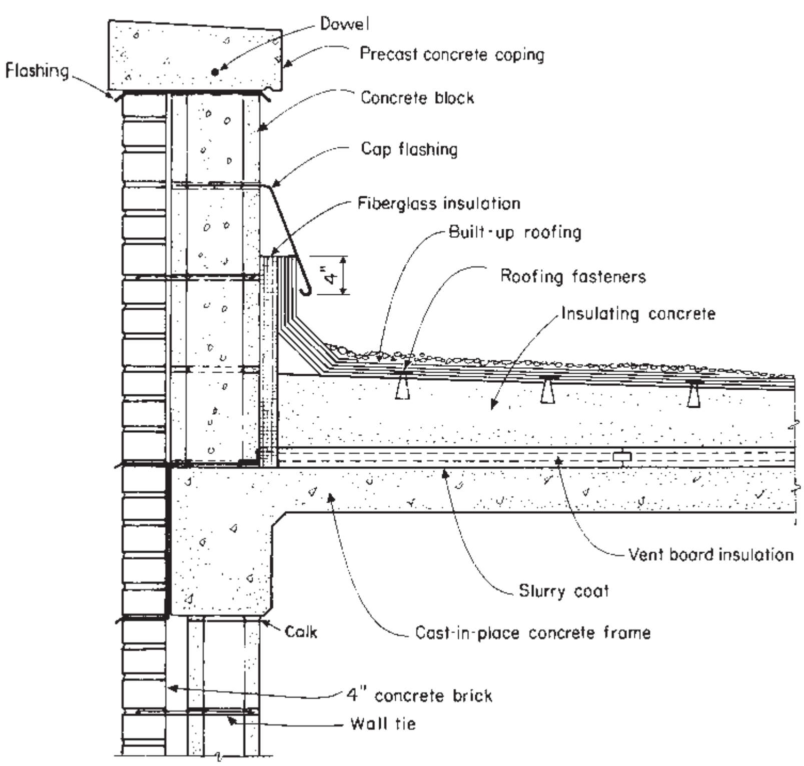


Fig. A-22

Parapet for concrete frame.

Wall Details at Wood Roofs and Floors

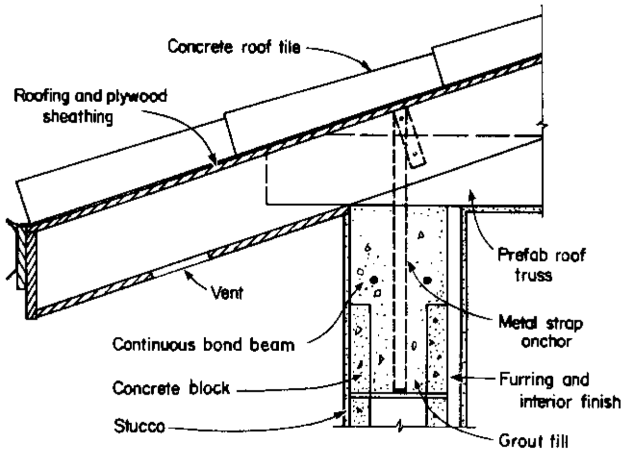


Fig. A-23

Low-sloped wood roofs with bond beam (hurricane-resistant).

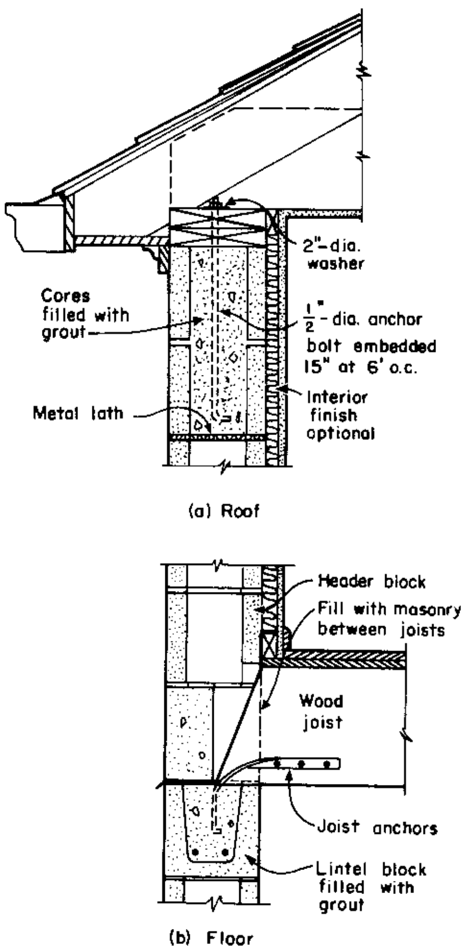


Fig. A-24

Steeply sloped wood roof with single-wythe walls.

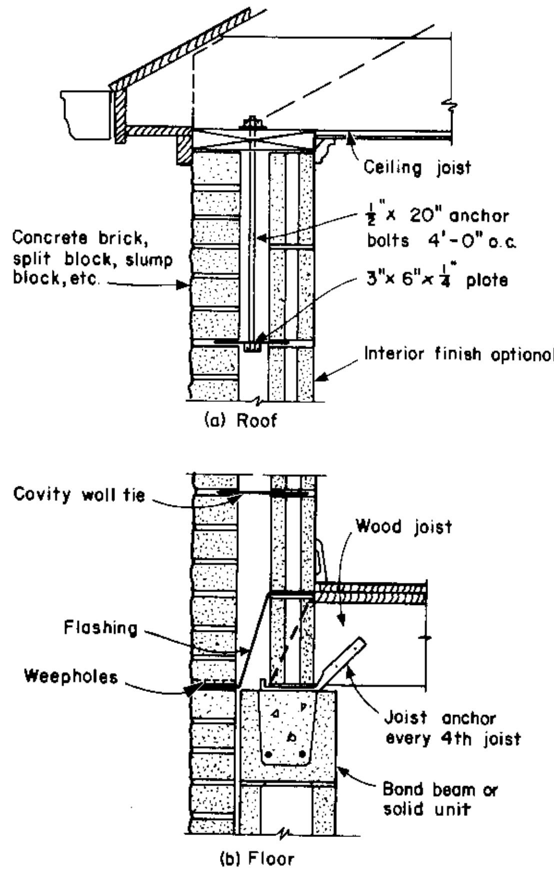


Fig. A-25

Wood floors and roofs with cavity walls.

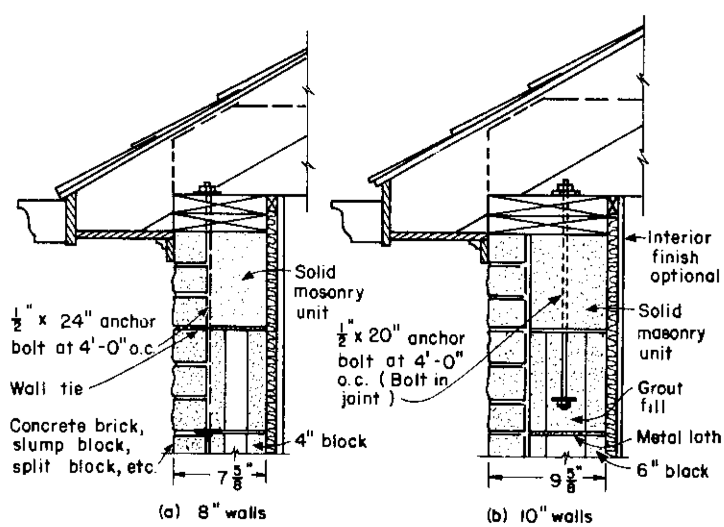


Fig. A-26

Sloped roofs with composite walls.

Door Frame Details

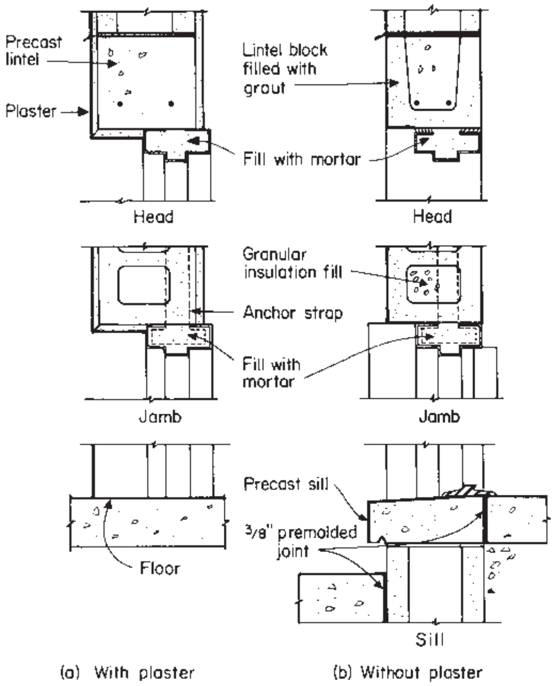


Fig. A-27
Metal door frames with and without plaster.

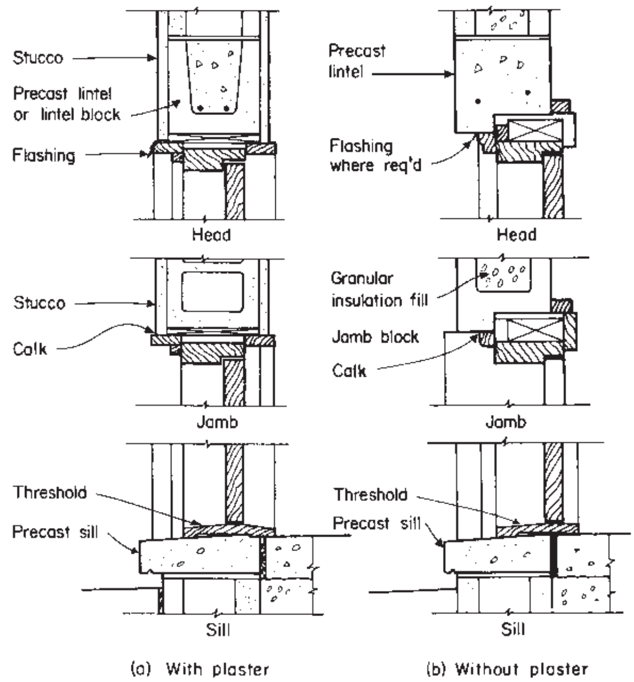


Fig. A-29
Wood door frame with and without plaster.

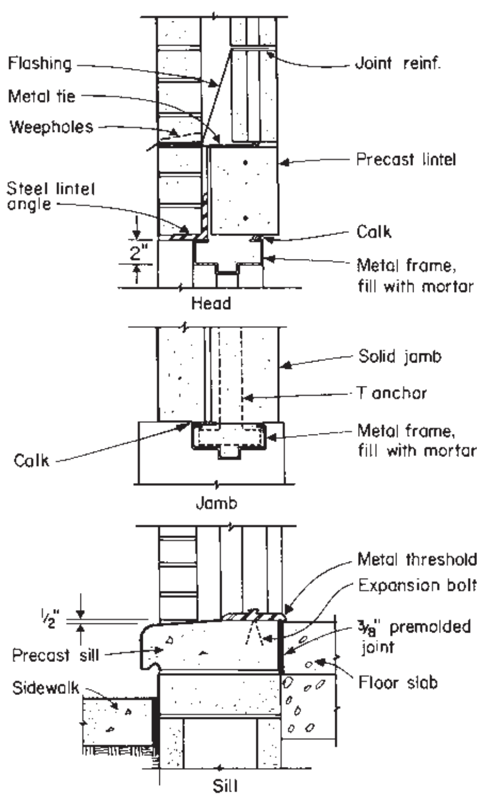


Fig. A-28
Metal door frame with cavity walls.

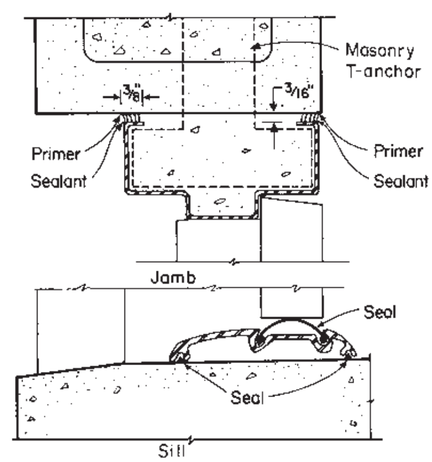


Fig. A-30
Details of metal door frames.

Metal Window Details

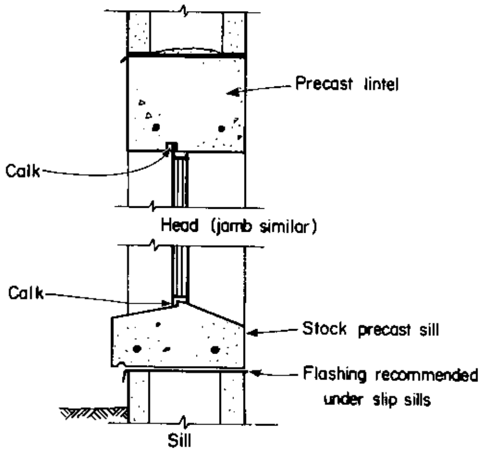


Fig. A-31

Metal basement window.

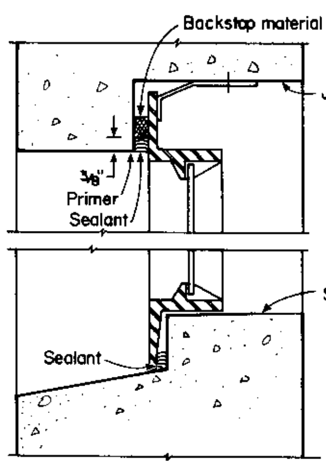


Fig. A-32

Meta; window frame.

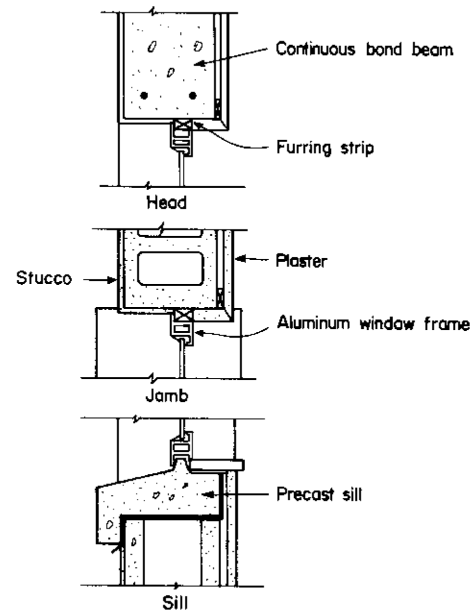


Fig. A-33

Aluminum window with plaster.

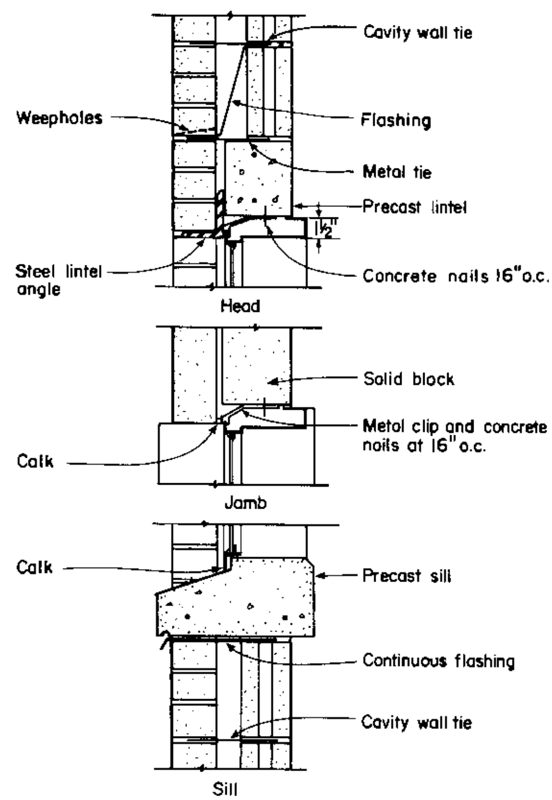


Fig. A-34

Metal windows with cavity walls.

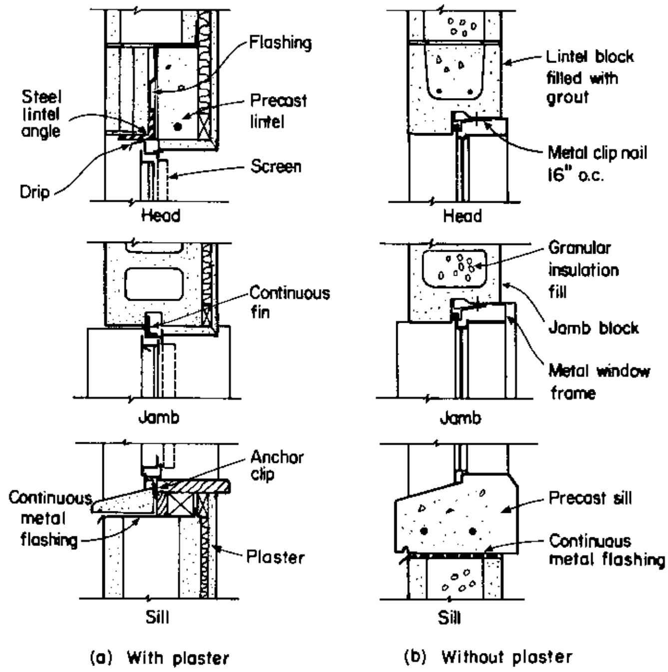


Fig. A-35

Metal windows with and without plaster.

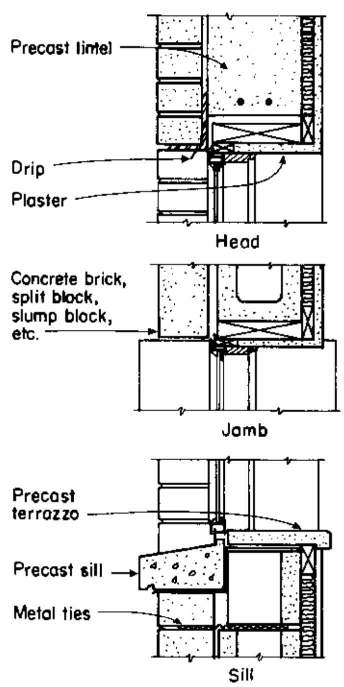


Fig. A-36

Metal windows for composite walls with plaster.

Wood Window Details

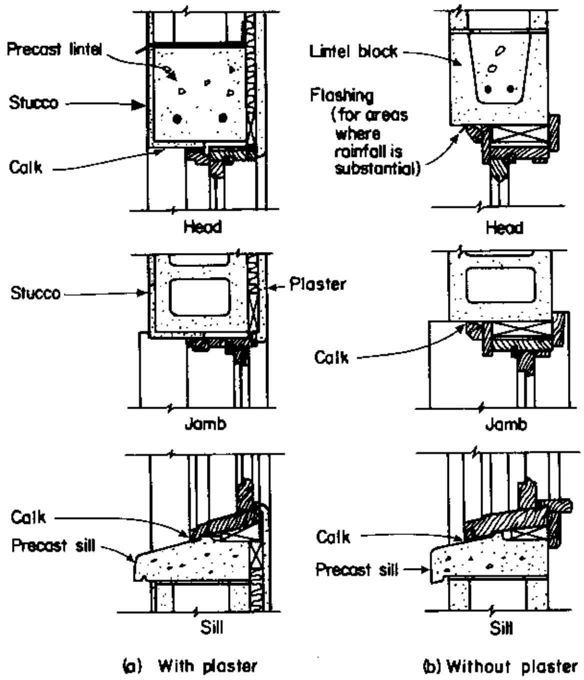


Fig. A-37

Double-hung wood windows with and without plaster.

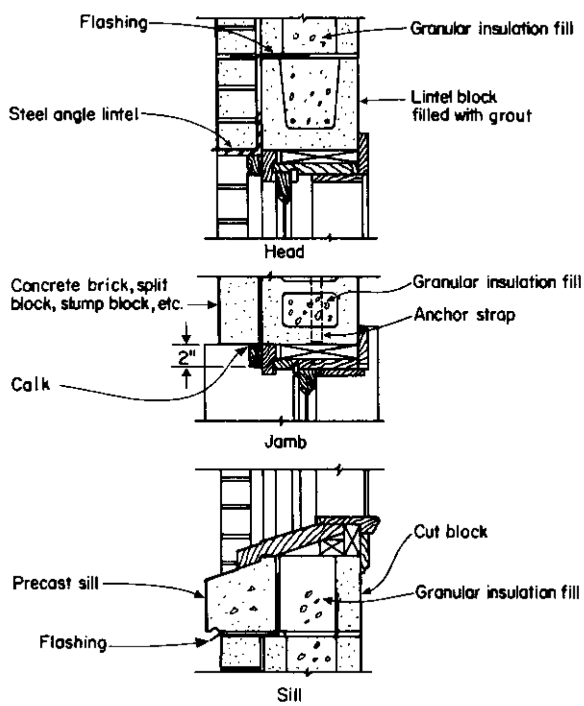


Fig. A-38

Double-hung wood windows with composite wall.

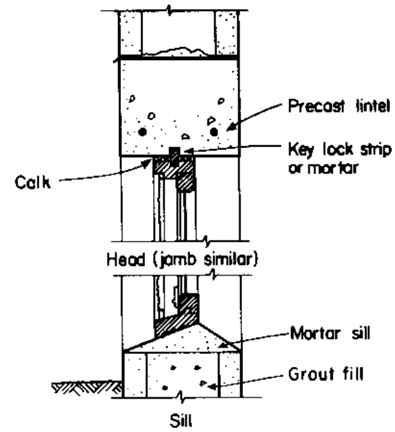


Fig. A-39

Basement wood windows.

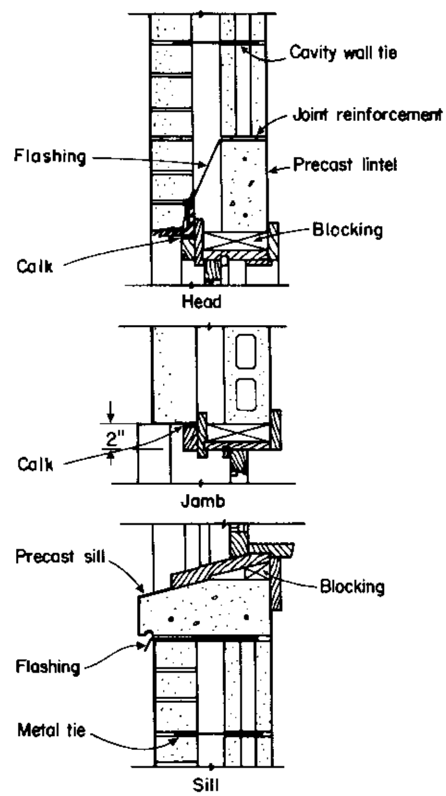


Fig. A-40

Wood windows with cavity wall.

Wall Details for Wood Framing

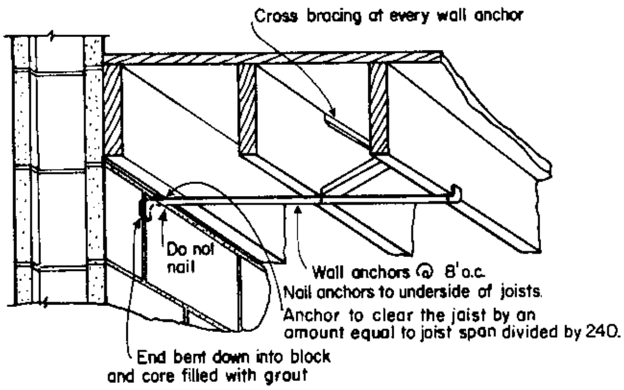


Fig. A-41

Wood joists parallel to wall.

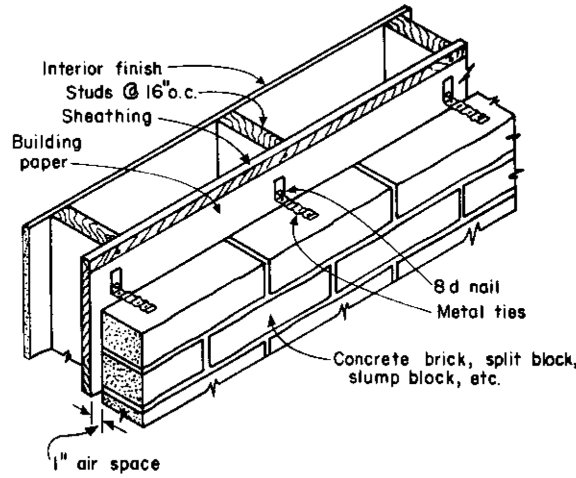


Fig. A-43

Masonry veneer anchorage.

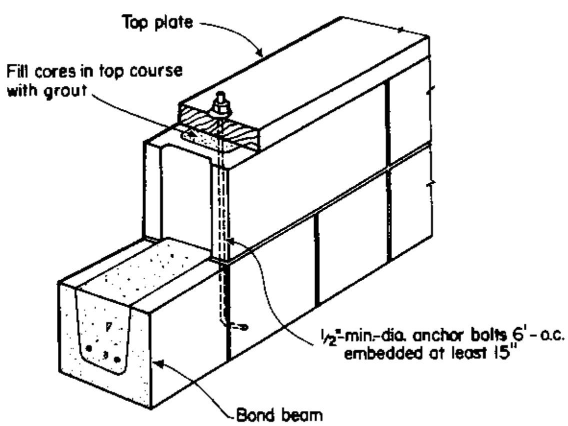


Fig. A-42

Top plate anchorage over wall opening.

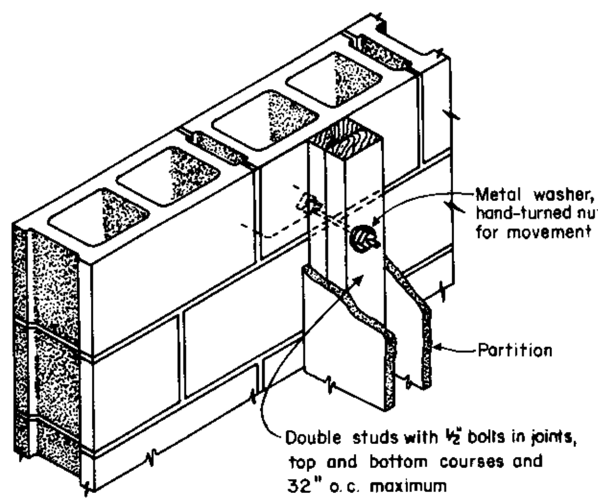
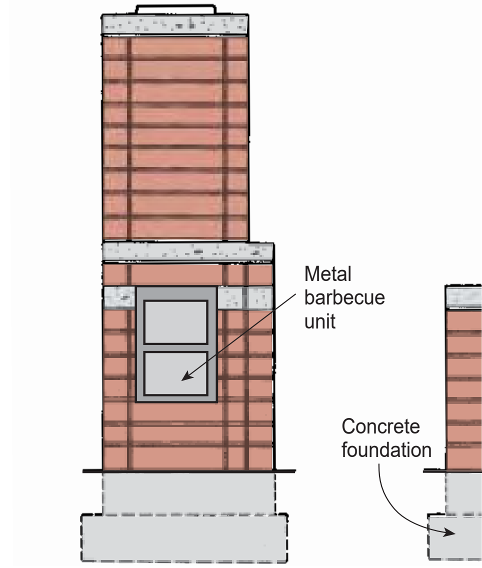


Fig. A-44

Partition anchorage.



Metric Conversion Factors

Appendix B

The following list provides the conversion relationship between U.S. customary (inch-pound) units and SI (International System) units as used in the *Concrete Masonry Handbook.* The proper conversion procedure is to multiply the specified inch-pound value on the left by the metric conversion factor on the right—exactly as given below—and then round to the appropriate number of significant figures desired.

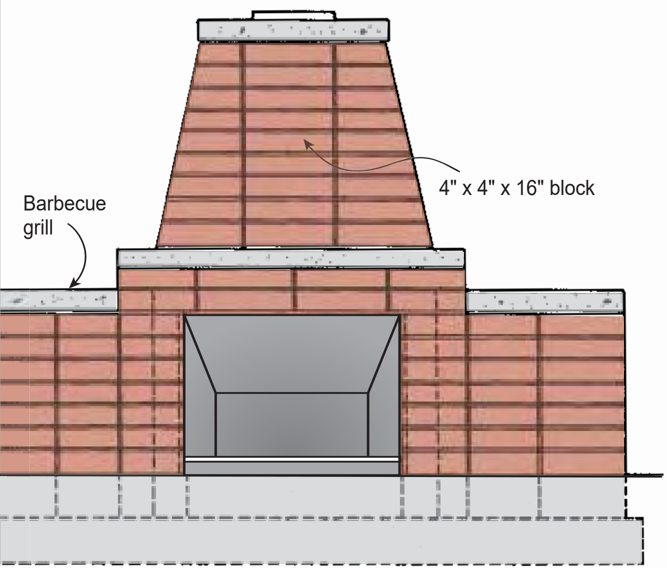
For example, to convert 20 feet to meters: 20 x 0.3048 = 6.096, which is rounded to 6.10 meters. Do not round either value before performing the multiplication, as accuracy would be reduced. In all conversions, the number of significant figures retained should be such that accuracy is neither sacrificed nor exaggerated.

Metric prefixes are used to indicate orders of magnitude. Prefixes commonly used in the *Handbook*,—milli (m), kilo (k), mega (M), and giga (G)—are equal to 0.001, 1000, 1,000,000, and 1,000,000,000, respectively. Other prefixes are listed in ASTM E380.

A complete guide to the SI system and its use can be found in ASTM E380 and E621. Also, for additional information specific to metric conversion in concrete masonry construction, see TEK 3-10A 2001.

To convert from	to	multiply by
Length		
inch (in.)	micron (μ)	25,400 E*
inch (in.)	millimeter (mm)	25.4 E
foot (ft)	millimeter (mm)	304.8 E
foot (ft)	meter (m)	0.3048 E
yard (yd)	meter (m)	0.9144 E
mile (mi)	kilometer (km)	1.609344 E

To convert from	to	multiply by
Area		
square inch (sq in.)	square meter (sq m)	0.00064516 E
square inch (sq in.)	square millimeter (sq mm)	645.16 E
square foot (sq ft)	square meter (sq m)	0.09290304 E
square yard (sq yd)	square meter (sq m)	0.83612736 E
Volume		
cubic inch (cu in.)	cubic meter (cu m)	0.00001639
cubic inch (cu in.)	cubic millimeter (cu mm)	16,387.064 E
cubic foot (cu ft)	cubic meter (cu m)	0.02831685
cubic yard (cu yd)	cubic meter (cu m)	0.7645549
gallon (U.S. liquid)**	liter (L)	3.7854118
gallon (U.S. liquid)	cubic meter (cu m)	0.00378541
ounce (U.S. fluid)	milliliter (mL)	29.57353
ounce (U.S. fluid)	cubic meter (cu m)	0.00002957
Force		
pound (lb)	newton (N)	4.448222
pound (lb) avoirdupois	kilogram (kg)	0.4535924
kip (1000 lb)	kilogram (kg)	453.6
kip (1000 lb)	newton (N)	4448.222
Pressure or stress		
pound per square inch (psi)	megapascal (MPa)	0.006894757
pound per square foot (psf)	pascal (Pa)†	47.88
pound per linear foot (plf)	N/M	14.5939
Mass (weight)		
pound (lb) avoirdupois	kilogram (kg)	0.4535924
ton (short, 2000 lb)	kilogram (kg)	907.1847



Right: IMG15711

To convert from	to	multiply by
Mass (weight) per length		
pound per linear foot (plf)	kilogram per meter (kg/m)	1.488
Mass per volume (density)		
pound per cubic foot (pcf)	kilogram per cubic meter (kg/cu m)	16.01846
pound per cubic yard (lb/cu yd)	kilogram per cubic meter (kg/cu m)	0.5933
Temperature		
degree Fahrenheit (deg F)	degree Celsius (deg C)	$t_c = (t_F - 32)/1.8$
Energy and heat		
British thermal unit (Btu)	joule (J)	1055.056
Btu/deg F·hr·ft²	W/m²·deg K	5.678263
kilowatt-hour (kwh)	joule (J)	3,600,000 E
British thermal unit per hour (Btu/hr)	watt (W)	0.2930711
Power		
horsepower (hp) (electric)	watt (W)	746.0000 E
Velocity		
mile per hour (mph)	kilometer per hour (km/hr)	1.60934

* E indicates that the factor given is exact.
** One U.S. gal equals 0.8327 Canadian gal.
† A pascal equals 1.000 newton per sq m.

Notes:
One U.S. gal of water weighs 8.34 lb at 60°F and has a volume of 0.184 cu ft.
One cu ft of water weighs 62.4 lb and contains 7.48 U.S. gal.
One mL of water has a mass of 1 g and a volume of 1 cu cm.
One U.S. bag of portland cement weighs 94 lb and its adopted metric size is 42 kg.

Glossary

Appendix C

The intent of this Glossary is to clarify terminology used in concrete masonry design and construction, with special emphasis on those terms used in the *Concrete Masonry Handbook.* Additional terminology that may not be used in the *Handbook* is included in the Glossary for the convenience of our readers.

A

A-block—A hollow concrete masonry unit with one end closed and the other end open; when laid in a wall it forms two cells. It can be placed around vertical reinforcement rather than be threaded over it. Also called a "Plumbing unit" or "Conduit unit."

Absorption—The weight of water a brick or tile unit absorbs when immersed in either cold or boiling water for a stated length of time, expressed as a percentage of the weight of the dry unit for brick, and as pounds of water per cubic foot of concrete for concrete masonry units. (Also see "Water absorption.")

Absorption rate—The weight of water absorbed when a brick is partially immersed for 1 minute, usually expressed in either grams or ounces per minute. Also called "Suction" or "Initial rate of absorption" (IRA).

Abutment—That part of a pier or wall from which an arch springs, specifically the support at either end of an arch, beam, or bridge.

Accelerator—An admixture that speeds the rate of hydration of hydraulic cement, shortens the normal time of setting, or increases the rate of hardening, of strength development, or both, of portland cement mortar, grout, or plaster.

ACI—American Concrete Institute.

Acid etch—To clean or alter (roughen) a surface by application of an acid such as a dilute solution of muriatic acid. Used to increase mechanical bond with other materials and to modify appearance of finish.

Acid-resistant brick—Brick suitable for use in contact with harsh chemicals, usually in conjunction with acid-resistant mortars.

Acoustics—Regarding a building material, the design for controlling sound. Good acoustical design in buildings can be achieved with absorptive surfaces and relatively heavy wall and floor construction.

Acrylic resin—A synthetic resin used in concrete and masonry construction as a surface sealer or a bonding agent.

Actual dimensions—The exact specified size of a masonry unit, usually a mortar joint width less than the nominal dimensions. (Also see "Nominal dimensions.")

Addition—A substance that is interground or blended in limited amounts into a hydraulic cement during manufacture—not at the jobsite—either as a "processing addition" to aid in manufacture and handling of the cement or as a "functional addition" to modify the useful properties of the cement. Improperly called an additive.

Adhered Manufactured Stone Masonry Veneer (AMSMV)—Units manufactured from a mixture of cements, mineral aggregates (both normal and lightweight), water, and additives, cast into shapes simulating natural stone, brick, and other textures and intended to be adhered to a backup wall.


Left: IMG24203
Right: IMG24206

Adhesion—The physical attraction of two substances, especially the macroscopically observable attraction of dissimilar substances. In masonry, the ability of mortar to stick to masonry units.

Admixture—A material, other than water, aggregate, and hydraulic cement, used as an ingredient of mortar, grout, or plaster and added to the batch immediately before or during mixing and intended to modify its properties.

Aggregate—A granular mineral material such as natural sand, manufactured sand, gravel, crushed stone, air-cooled blast-furnace slag, vermiculite, or perlite.

Agitating truck—Another term for a truck mixer. It is usually a truck mixer with an inclined revolving drum that slowly and continuously rotates to agitate fresh grout during transport from a ready-mix plant to a jobsite.

Air content—The total volume of air voids, both entrained and entrapped, in cement paste, mortar, or grout. Entrained air adds to the durability of hardened mortar or grout and the workability of fresh mixtures.

Air entrainment—The intentional introduction of air in the form of minute, disconnected bubbles (generally smaller than 1 mm) during mixing of portland cement mortar, grout, or plaster to improve desirable characteristics such as cohesion, workability, and durability.

Air-entraining agent—An admixture for mortar, grout, or plaster that will cause air to be incorporated into the mixture in the form of minute bubbles during mixing, usually to increase the material's workability and frost resistance.

Air void—An entrapped air pocket or an entrained air bubble in mortar, grout, or plaster. Entrapped air voids usually are larger than 1 mm in diameter; entrained air voids are smaller. Most of the entrapped air voids should be removed with mechanical vibration or rodding.

Alternate grout placement—A technique for placing grout that was employed in the accepted grout demonstration panel using construction procedures different than those in the project specification.

AMSMV—See "Adhered Manufactured Stone Masonry Veneer."

ANSI—American National Standards Institute.

Anchor—A metal rod, wire, or strap that is used to secure facing veneer to masonry backup, structural framework, or other elements.

Anchor bolt—A headed or threaded metal bolt or stud that is either cast-in-place, grouted in place, or inserted into a drilled hole, and used to attach steel, wooden, or other structural members or objects to concrete.

Angle iron—A structural steel member, "L" shaped in cross section, commonly used as a lintel to support masonry over openings, such as doors and windows.

Angular face block—See "Architectural units."

Architectural units—Also called "customized masonry" or "sculptured units," these special concrete masonry units have textured or sculptured faces. Methods used to obtain textured faces include splitting, grinding, forming vertical striations, and causing the units to "slump." Sculptured faces are obtained by forming projecting ribs or flutes, either rounded or angular, recesses, and curved faces, as well as vertical and horizontal scoring.

ASCC—American Society of Concrete Contractors.

ASCE—American Society of Civil Engineers.

ASHRAE—American Society for Heating, Refrigerating, and Air-Conditioning Engineers.

ASTM—American Society for Testing and Materials.

Ashlar—Rectangular and/or square masonry units, either concrete masonry, brick, or stone, always of two or more sizes, laid (bonded) collectively in a wall or pavement. The designs are called "Coursed ashlar," "Random ashlar," and "Patterned ashlar." If the pattern is repeated, it is called "Patterned ashlar;" if the pattern is not repeated, it is called "Random ashlar." In "Coursed ashlar," the pattern may be repeated in alternate courses.

Autoclave curing—See "High-pressure steam curing."

B

Backing—The wall or surface to which veneer is attached, such as concrete, masonry, steel framing, or wood framing. Also sometimes called "Backup."

Base coat—The total of all plaster coats applied prior to application of the finish coat. Generally, the combined scratch and brown coats are the base coat. (Also see "Portland cement plaster.")

Basket weave—A checkered pattern resembling that of a woven basket. Bricks, blocks, or modular groups of brick or block laid at right angles to those adjacent. A popular pattern used for laying interlocking concrete pavers.

Bat—A broken brick or piece of brick, usually about one-half brick in size, with one undamaged end. Also called a "Brickbat."

Batch—The quantity of mortar, grout, or plaster that is mixed at one time.

Batching—The process of weighing or volumetrically measuring and introducing into the mixer the ingredients for a batch of mortar, grout, or plaster.

Batter—(1) Recessing or sloping masonry back in successive courses; the opposite of corbeling. (2) The slight backward slope built into a retaining wall to offset the small degree of forward tilt most retaining walls experience under service conditions.

Bearing wall—Any wall that supports a vertical load in addition to its own weight.

Bed—The layer of mortar on which a masonry unit is set.

Bed joint—In masonry, the horizontal layer of mortar on which a masonry unit is laid.

BIA—See "Brick Industry Association."

Blast-furnace slag—The nonmetallic byproduct of steel manufacturing, consisting essentially of silicates and aluminosilicates of calcium and other bases, that is developed in a molten condition simultaneously with iron in a blast furnace. Depending on how the material is processed, it may be air-cooled, expanded, or granulated blast-furnace slag. The granulated form is used as a supplementary cementitious material and may be an ingredient in blended cement. See ASTM C989, C595, and C1157.

Blended aggregate block—A concrete masonry unit containing a blend of aggregates, such as pumice or expanded shale, clay, slate, or slag, in combination with calcareous and siliceous gravel passing a No. 4 (4.75 mm) sieve. The equivalent thickness of such units, important for determining fire-resistance ratings, must be calculated in accordance with procedures given in building codes. (Also see "Equivalent thickness.")

Block—A concrete masonry unit, usually containing hollow cells (sometimes referred to as "cores").

BOCA—See "Building Officials and Code Administrators International, Inc."

Bond—(1) The tying together of various parts of a masonry wall by overlapping units, or by connecting with metal ties. (2) One of a number of patterns formed by the exposed faces of masonry units in a wall ("running bond" or "stack bond"). (3) Adhesion between mortar, grout, concrete, and masonry units or reinforcement. (4) Adhesion of cement paste to aggregate. (5) Adhesion between plaster coats or between plaster and a substrate. (Also see "Chemical bond," and "Mechanical bond").

Bond beam—A course of block in a masonry wall that is grouted and frequently contains reinforcing steel bars running horizontally. A bond beam may serve as: (1) an integral beam in a wall; (2) a horizontal tie; (3) a bearing course for structural members; or (4) as a flexural member.

Bond beam block—A hollow concrete masonry unit with depressed sections forming a continuous channel in which reinforcing steel can be placed for embedment in grout to form a bond beam. Lintel units are sometimes used as bond beam blocks.

Bond course—A course of masonry units in a multiwythe wall where; the units overlap more than one wythe of masonry.

Bond strength—Resistance to separation of mortar or grout from a masonry unit, reinforcing steel, and any other materials with which it is in contact.

Bondbreaker—A material used to prevent adhesion of newly placed mortar, grout, or plaster to a substrate.

Brick—A solid masonry unit of clay or shale, formed into a rectangular prism while plastic and burned or fired in a kiln. Similarly shaped units made of portland cement concrete mixtures are called "Concrete brick."

Brick facing—See "Brick veneer" and "Face brick."

Brick Industry Association (BIA)—The trade association representing manufacturers and distributors of masonry units made from clay, shale, or other similar natural earthen materials. Formerly called the Brick Institute of America and before that the Structural Clay Products Institute.

Brick trowel—A tool with a flat, triangular steel blade in an offset handle used to pick up and spread mortar onto masonry units. The narrow end of the blade is called the point; the wide end, the heel.

Brick veneer—A separate facing wythe of brick attached to the structural face of a building or another wall, but not structurally bonded to the wall. Veneers usually are non-load-bearing walls.

Brown coat—The second base coat of a three-coat plastering job. (Also see "Base coat," "Scratch coat," and "Portland cement plaster.")

Building brick—Brick manufactured for general construction purposes, and not especially produced for its texture or color. Formerly called "Common brick." See ASTM C62.

Building Officials and Code Administrators International, Inc. (BOCA)—A founding member of the International Code Council (ICC), which was established in 1994 to develop a single set of comprehensive and coordinated national model construction codes. (Also see "National Building Code (NBC).")

Bulking—The increase in volume of a quantity of sand when in a moist condition compared to its volume when in a dry state.

Bullnose unit—A brick or concrete masonry unit having one or more rounded exterior corners.

Buttering—The process of spreading mortar on a masonry unit with a trowel before the unit is laid by the mason into a wall or other structure.

Buttress—A vertical masonry arm or projection built onto a wall to provide greater strength, support, and stability for the wall. (Also see "Counterfort retaining wall.")

C

CABO—See "Council of American Building Officials." The precursor organization of the International Code Council (ICC).

Cantilever retaining wall—A type of reinforced concrete masonry retaining wall, usually with a cross-sectional shape similar to an inverted "T," but also sometimes "L"-shaped. With either shape, the reinforced masonry wall portion or stem performs structurally as a cantilever projecting from a cast-in-place concrete footing. (Also see "Gravity retaining wall" and "Counterfort retaining wall.")

Cap block—A solid, flat concrete masonry unit, usually 2¼ in. (57 mm) thick, used as a cap or coping at the top of parapet and garden walls.

Carbonation—The reaction between carbon dioxide and a hydroxide or oxide to form a carbonate, as in the curing mechanism of lime in masonry mortar, and in cement paste, mortar, grout, and concrete.

Cast stone—A highly refined architectural precast concrete product manufactured by casting concrete or mortar in special molds and finishing the elements so as to resemble cut and dressed natural building stone. (Also see "Stone masonry.")

Cavity wall—A masonry wall built of two or more wythes, arranged to provide a continuous air space within the wall (with or without insulation), and tied together with non-corrosive metal ties.

COE—See "U.S. Army Corps of Engineers."

Cell—In masonry terminology, "cell" typically refers to the larger openings in concrete units (greater than 25% void area hollow units). Though not technically accurate, "cell" and "core" are often used interchangeably, as in: (1) The molded open space in a concrete masonry unit formed by the face shells and webs, and (2) The holes in clay units. See "Core."

Cement paint—A paint for concrete and concrete masonry made mostly of white portland cement, water, hydrated lime, and pigments.

Cement paste—A constituent of mortar, grout, concrete, and plaster consisting of cement and water.

Cementitious material—Any material having cementing properties including "pozzolans." When proportioning masonry mortars, the following are considered cementitious materials: portland cement, blended hydraulic cement, masonry cement, mortar cement, quicklime, hydrated lime, fly ash, and slag.

Channel block—A hollow concrete masonry unit with depressed webs that form a continuous channel for reinforcing steel and grout. Also called a "low-web bond beam."

Chase—A groove or continuous recess built into a (masonry) wall to accommodate pipes, ducts, conduits, etc.

Chemical bond—The bond between materials resulting from cohesion and adhesion developed by chemical reaction.

Chimney block—Special concrete masonry units made for the construction of chimneys.

Chimney cap block—A special concrete masonry unit conforming with the architectural design of a building and intended to protect the top of a masonry chimney. (Also see "Chimney hood.")

Chimney hood—A cover for the top of a masonry chimney, usually a concrete or concrete masonry slab, designed to give a finished touch to the silhouette of a building, protect the chimney and fireplace from rain and snow, and prevent downdrafts. (Also see "Chimney cap block.")

Chimney lining—A tubular, non-load-bearing, fired-clay unit used inside a chimney to convey hot gases.

Cinder block—Archaic. See "Concrete masonry unit."

Cleanout openings—Small openings in the first (bottom) course of single-wythe brick walls, or cutouts in the face shell of the first course of a concrete block wall, for the purpose of cleaning out cavities, cells, or cores before grouting.

Closure block—The last masonry unit laid in a course. It may be a whole unit or a portion of a unit. Supplementary or short-length units are used at corners or jambs to maintain bond patterns.

CMU—See "Concrete masonry unit."

Cohesion—The mutual attraction by which elements of a substance are held together.

Collar joint—The continuous vertical and horizontal space between the wythes of masonry, or between a masonry wythe and backup material, which may or may not be filled with mortar or grout.

Common bond—A method of tying together parts of two or more wythes of masonry by overlapping units; in common bond, every fifth or sixth course consists of headers, the other courses being stretchers.

Common brick—See "Building brick."

Compaction—The process of inducing a closer arrangement of the solid particles in freshly mixed and placed mortar, grout, or concrete by reduction of voids, usually by vibration, tamping, rodding, puddling, or a combination of these techniques. Also known as consolidation.

Composite action wall—A multiwythe wall designed to act as a single member in response to loads.

Compressive strength—The maximum resistance that a mortar, grout, or concrete specimen will sustain when loaded axially in compression at a specified rate; usually expressed as force per unit of cross sectional area, such as pounds per square inch (psi) or megapascals (MPa).

Concave joint—A recessed masonry joint formed in mortar by the use of a tubular steel jointing tool. A properly tooled concave joint is very effective in resisting rain penetration.

Concrete block—See "Concrete masonry unit."

Concrete brick—A solid concrete masonry unit, similar in size and shape to clay brick, but made from portland cement, suitable aggregates, water, and frequently a pigment.

Concrete masonry unit (CMU)—A hollow or solid masonry unit made from cementitious materials, aggregates, and water, usually formed into a rectangular prism. Once known as "cinder block," a modern CMU is rarely, if ever, made with cinders. (Also see "Hollow masonry unit" and "Solid masonry unit.")

Consistency—The relative mobility or ability of freshly mixed mortar, grout, or concrete to flow. (Also see "Slump.")

Continuous metal ties—See "Joint reinforcement."

Control joint—A continuous formed, sawed, or tooled joint designed and installed in a concrete masonry structure to create a weakened plane to accommodate volume changes and regulate cracks that may form due to localized drying shrinkage and dimensional changes in various parts of the structure.

Coping block—A solid concrete masonry unit used as the top and finishing course in wall construction. Coping protects the masonry below from water penetration. The unit should be shaped for good drainage and overhang the wall slightly to provide a decorative as well as a protective feature.

Core—In masonry terminology, "core" typically refers to smaller openings (less than 25% void area in solid units). Though not technically accurate, "core" and "cell" are often used interchangeably, as in: (1) The molded open space in a concrete masonry unit formed by the face shells and webs, and (2) The holes in clay units. See "Cell."

Corner angle unit—See "Return block."

Corner block—A concrete masonry unit with one flat end for use in construction of the end or corner of a wall.

Corps of Engineers, U.S. Army—See "United States Army Corps of Engineers."

Corrosion—In masonry work, disintegration or deterioration of metal reinforcement due to electrolysis or chemical attack.

Council of American Building Officials (CABO)—The precursor organization of the International Code Council (ICC).

Counterfort retaining wall—Also called "Buttressed," this type of concrete masonry retaining wall is similar to the cantilever type, except that it spans horizontally between vertical supports. The supports, when located at the back of the wall, are called counterforts; if the supports are exposed at the front of the wall, they are called buttresses. (Also see "Gravity retaining wall" and "Cantilever retaining wall.")

Course—A horizontal layer of masonry units (clay or concrete).

Creep—The time-dependent deformation of any material due to a sustained load.

Curing—The process of keeping freshly placed mortar, grout, concrete, or plaster moist and at a favorable temperature for a suitable period of time during its early stages so that the desired properties of the material may develop. Curing assures satisfactory hydration and hardening of the cementitious materials.

Curtain wall—In a framed building, an exterior wall having no structural function. A curtain wall may be supported at each floor and may be anchored to columns, spandrel beams, floors, or bearing walls.

Curved face block—See "Architectural units."

Customized masonry—See "Architectural units."

D

Dampproofing—The treatment of mortar, grout, concrete, or plaster to retard the passage or absorption of water, or water vapor, usually by application of a suitable surface treatment or coating on the exposed surfaces.

Dash-bond coat—A thick slurry of portland cement, fine sand, and water that is applied (dashed) by hand with a brush or by machine onto concrete, concrete masonry, or older concrete, masonry, or plaster surfaces, to provide a mechanical bond (a key) for subsequent coats of portland cement plaster or stucco.

Dash texture—A finish coat of thick plaster hand-dashed or machine-applied onto a well-prepared, uniformly plane surface of brown-coat plaster. Also called "Spatter-dash."

Decibel (db)—One of the two important parameters in the study of acoustics—the other is the hertz. Used to express the intensity or loudness of a sound, an increase of 10 db is a threefold increase in pressure; an increase of 20 db is a tenfold increase. (Also see "Acoustics" and "Hertz.")

Deformed bar—A steel reinforcing bar manufactured with a pattern of surface ridges designed to promote mechanical bond and prevent slippage when the bar is embedded in grout or concrete.

Density—Mass per unit volume; the weight per unit volume in air, expressed, for example, in pounds per cubic foot (kg/m^3).

Dew point—The temperature to which air, at a given pressure and water-vapor content, must be cooled to reach saturation; the temperature at which dew begins to form.

Dowel—(1) A straight metal bar used to connect two sections of masonry. (2) A steel pin, generally a plain round steel bar, extending into adjoining portions of concrete or masonry construction, as at a joint in a slab, to transfer shear loads. (3) A deformed reinforcing bar intended to transmit tensile, compressive, or shear forces through a construction joint, as at the connection between the stem and footing of a retaining wall.

Drip—A projecting piece of material, or a slot, so shaped as to cause water to drip off at that point and thus prevent water from running down the face of a wall or other surface.

Dry batching—A method of weighing, blending, and delivering dry mortar ingredients to a jobsite where water is added and the mortar is mixed. The method avoids the need to adjust a mixture for moisture in the sand and ensures consistent proportioning of sand and cementitious materials.

Dry mix—Prepackaged mortar, concrete, or plaster mixtures, usually sold in bags and containing all the necessary ingredients except water. Mortar prepared like this is referred to as "preblended mortar."

Dry stack—Concrete masonry work that is laid without mortar in the joints between units. (Also see "Surface bonding mortar.")

Drying shrinkage—(1) Shrinkage resulting from loss of moisture. (2) In ASTM C426, Test Method for Drying Shrinkage of Concrete Block, the change in linear dimension of the test specimen due to drying from a saturated condition to an equilibrium weight and length under specified accelerated drying conditions.

Durability—The ability of portland cement mortar, grout, concrete, or plaster to resist weathering action and other conditions of service, such as chemical attack and abrasion.

Dynamic thermal response—A cyclic phenomenon used by building designers when calculating heat transfer data for sizing heating and cooling equipment. A distinction is made between masonry and nonmasonry construction because of a difference in heat storage capacity of the materials. Heavy construction, such as concrete masonry, does not respond to temperature fluctuations as rapidly as lightweight construction, even though the two materials may have identical U-values. Due to a "Fly-wheel effect," the net transfer of heat through a concrete masonry wall section for a certain time period might actually be less.

E

Early stiffening—A rapidly developing rigidity in freshly mixed hydraulic cement paste, mortar, grout, plaster, or concrete.

Eccentricity—The distance between the centroidal axis of a member and an applied load.

Efflorescence—A powdery deposit or stain, usually white in color, that is sometimes found on the surface of masonry. Water soluble substances (salts or bases) emerge in solution from within the masonry and are deposited on the surface during evaporation.

Empirical design—A method of designing structures based on the application of physical limitations, which are rooted in experience or observations gained through experience, and not structural analysis. (Also see "Engineered design.")

Engineered design—A method of designing structures based on a rational structural analysis; that is, the designer considers the interrelationships of the various construction materials, their properties, and their actual design loads, in lieu of empirical design procedures. (Also see "Empirical design.")

Engineered masonry—A masonry structure that was designed based on a rational structural analysis. (Also see "Engineered design.")

Epoxy resin—A class of organic chemical bonding systems used in the preparation of special coatings or adhesives for concrete or masonry or as binders in epoxy-resin mortars and concretes.

Equivalent thickness—The hypothetical solid thickness to which a hollow concrete masonry unit would be reduced if there were no cores, cells, or voids. The equivalent thickness of a block can be calculated by using the equation: T_{eq} = % solid x actual thickness.

ESCSI—See "Expanded Shale, Clay, and Slate Institute."

Expanded Shale, Clay, and Slate Institute (ESCSI)—The trade association representing manufacturers of expanded lightweight aggregate for a variety of uses, including masonry applications.

Expansion joint—(1) A separation provided between adjoining parts of a structure to allow for small relative movements, for example, those caused by uneven settlement of different parts of a building, or those caused by thermal movements where expansion exceeds contraction. (2) In highway work, a separation between pavements, or between pavement and a bridge, that is filled with a compressible joint material. (3) Also called an "Isolation joint."

Exterior insulation and finish systems (EIFS)—Sometimes referred to as "Synthetic stucco," these cladding assemblies consist of plaster-like cementitious laminates wet-applied, usually in two coats, to rigid insulation board fastened to a wall with adhesive, mechanical fasteners, or both. The systems use lath, usually a fiberglass mesh, which is embedded in the base coat. Expanded polystyrene (EPS) board is the rigid insulation most often used. EIF systems are used extensively on residential and commercial buildings and as an applied finish on old or new concrete masonry walls.

F

Face—(1) The exposed surface of a wall or masonry unit. (2) The surface of a unit designed to be exposed in the finished masonry. (Also see "Face brick.")

Face brick—Brick made especially for exposure to view in the face of a wall. It may be made of selected clays or portland cement concrete and treated to produce a desired color or surface texture. See ASTM C216.

Face shell—The side wall of a hollow masonry unit.

Face-shell bedding—A method of laying concrete block in which mortar is applied only to the horizontal surfaces of face shells of hollow masonry units and in the head joints to a depth equal to the thickness of the face shells. Generally, face-shell mortar bedding is the preferred method of laying concrete block.

Fine aggregate—Aggregate that passes the ⅜-in. (9.5-mm) sieve, almost entirely passes the No. 4 (4.75-mm) sieve, and is predominantly retained on the No. 200 (75-mm) sieve; or that portion of an aggregate passing the No. 4 (4.75-mm) sieve and predominantly retained on the No. 200 (75-mm) sieve. (Also see "Manufactured sand," "Masonry sand," and "Natural sand.")

Fineness modulus—A factor obtained by adding the cumulative percentages by mass of material in a sample of aggregate retained on each of a specified series of sieves and dividing the sum by 100. The sieve sizes used are: No. 100 (150 μm), No. 50 (300 μm), No. 30 (600 μm), No. 16 (1.18 mm), No. 8 (2.36 mm), No. 4 (4.75 mm), ⅜ in. (9.5 mm), ¾ in. (19.0 mm), 1½ in. (37.5 mm), 3 in. (75 mm), and 6 in. (150 mm). FM is used as an index of the fineness of an aggregate—the higher the FM, the coarser the aggregate.

Finish coat—The final coat of a two- or three-coat plaster job; the decorative surface, which is usually colored and textured. (Also see "Portland cement plaster.")

Firebox—The combustion chamber where the fire occurs in a fireplace or furnace.

Firebrick—Brick made of fire clay, which is resistant to high temperatures, and is used extensively for construction of fireplaces, kilns, and ovens. (Also see "Fire clay.")

Fire clay—A refractory clay, used to make firebrick, that is capable of withstanding very high temperatures without further fusing or perceptible softening.

Fire endurance—A measure of the elapsed time during which a material or assembly continues to exhibit fire resistance under specified conditions of test and performance. Fire endurance periods for building components are typically based on physical tests conducted in accordance with ASTM E119. (Also see "Fire resistance" and "Fire-resistance classification.")

Fire wall—A partition or wall made of fire-resistant material to prevent the spread of fire from one part of a building to another. A fire wall should extend continuously from the foundation up to and through the roof.

Fire resistance—That property of a building material, element, or assembly to withstand fire or give protection from fire; it is characterized by the ability to confine a fire or to perform a given structural function, or both. (Also see "Fire endurance," "Fire wall," and "Fire-resistance classification.")

Fire-resistance classification—A standard method of rating the fire-resistance and protective characteristics of a building construction or assembly. (Also see "Fire endurance" and "Fire resistance.")

Flashing—An impermeable, corrosion resistant, tough, and easily-shaped sheet material, such as copper, stainless steel, bituminous fabrics, and plastic, that is usually placed in mortar joints and across air spaces in cavity walls to provide water drainage and prevent water penetration at parapets, copings, sills, projections, recesses, roof intersections, and the like.

Flow—A mortar property measured in the laboratory. The test indicates the percent increase in diameter of the base of a truncated cone of mortar placed on a flow table that is mechanically raised and dropped a specified number of times under specified conditions per ASTM C109.

Flow after suction—Flow of mortar measured after subjecting the mortar to a vacuum to simulate the suction of dry masonry units per ASTM C91. (Also see "Flow.")

Flue—A passageway that carries off smoke from a fireplace or furnace. (Also see "Flue lining.")

Flue lining—A smooth hollow clay tile unit used for the lining of flues in masonry chimneys. (Also see "Flue.")

Fluted face block—See "Architectural units."

Fly ash—A byproduct of the combustion of pulverized coal in electric power generating plants. May be used as supplementary cementitious material and may be an ingredient in blended cement. See ASTM C618, C595, and C1157.

Fog curing—In the field, the application of a fine water mist (atomization) during the curing of mortar, plaster, or stucco.

Footer block—See "Foundation block."

Footing—A structural element, usually of reinforced or nonreinforced cast-in-place concrete, that transmits loads from walls, columns, or piers directly to the soil.

Foundation block—Special interlocking concrete masonry units designed to replace conventional cast-in-place concrete footings in 1- and 2-story residential, commercial, and agricultural buildings. In one proprietary system for 8-in.-thick (203-mm) walls, block dimensions are 4x8x16-in. (102x203x406-mm), and each unit weighs about 24 lb (11 kg). Also called "Footer block."

Frog—A recessed panel or depression on one of the larger faces of a brick, and intended to reduce the weight of the units, provide better mechanical bond, and prevent units from floating when laid in a wall.

Frost line—The depth to which the earth freezes at a specific location.

Furrowing—The practice of using a trowel to strike a V-shaped trough in a bed of mortar.

G

Glass unit masonry—Non-load-bearing masonry composed of hollow or solid glass block units bonded by mortar.

Glazed block—Concrete masonry units having one or more faces finished with glazing. (Also see "Glazing.")

Glazing—The fired, glass-like finish on the face(s) of concrete masonry units used in walls and partitions of schools, locker rooms, bottling plants, hospitals, and laboratories where decoration, cleanliness, and low maintenance are desired. (Also see "Prefaced block.")

Gradation—The size distribution of aggregate particles, determined by separation with ASTM standard screen sieves.

Granulated blast-furnace slag—See "Blast-furnace slag."

Gravity retaining wall—A type of concrete masonry retaining wall that depends upon its own weight or mass for stability. Basically, it is massive masonry laid so that little or no tensile stress occurs in the wall under loading. Its cross-sectional shape is usually trapezoidal. (Also see "Cantilever retaining wall" and "Counterfort retaining wall.")

Grid pavers—An open type of concrete masonry unit that allows grass to grow through the openings, while at the same time providing a solid base to support vehicular traffic; they are used for soil stabilization in parking areas, along the shoulders of highways and airport runways, and for embankment erosion control and fire engine lanes. Also called "Grass pavers," "Turf block," and "Waffle units."

Grille block—See "Screen block."

Gross cross-sectional area—The area delineated by the out-to-out dimensions of masonry in the plane under consideration. (Also see "Net cross-sectional area.")

Grounds—Wooden nailing strips placed in masonry walls as a means of attaching trim or furring.

Grout—A mixture of cementitious material and aggregate to which sufficient water is added to produce a pouring or pumping consistency without segregation of the constituent materials. See ASTM C476.

Grout lift—The height to which an increment of grout is pumped or poured in a single continuous operation. There may be one or more grout lifts in a grout pour. (Also see "Grout pour.")

Grout pour—The entire height of grouting completed prior to erection of additional masonry units. A grout pour may be composed of one or more successively placed grout lifts. (Also see "Grout lift.")

Grouted masonry—Masonry wall construction, single or multiwythe, in which empty cells, cores, cavities, or collar joints are filled solidly with grout. Walls may be partially or fully grouted (some or all cells) and may contain steel reinforcement.

H

H-block—A specially-shaped hollow concrete masonry unit for constructing bond beams; both ends of the unit are open, and sometimes the intersecting web is depressed to hold horizontal reinforcing bars.

Hawk—A tool to hold and carry plaster or mortar; generally a flat piece of metal about 10 to 14 in. sq. (254 to 356 mm sq), with a wooden handle fixed to the center of the underside.

Head joint—The vertical mortar joint placed between masonry units within a wythe at the time the units are laid.

Header—(1) A stretcher unit laid transversely to overlap units of the adjacent wythe or a special-shaped header unit. (2) A unit that overlaps two or more adjacent wythes of masonry to tie them together. (Also see "Header block" and "Header course.")

Header block—A concrete masonry unit with a portion of one face shell removed to facilitate bonding with an adjacent wythe in a composite wall; header units are essentially no longer used in new construction of exterior walls. (Also see "Header" and "Header course.")

Header course—In a composite wall, a continuous bonding course of header units. (Also see "Header" and "Header block.")

Hearth—The floor of a fireplace; also that portion of the floor immediately in front of the fireplace, often called the "Outer hearth."

Hertz—One of the two important parameters in the study of acoustics—the other is the decibel. A hertz (Hz) is one vibration per second, or one cycle per second (1 cps). The tone of a sound depends on the number of vibrations per second, or the frequency. (Also see "Acoustics" and "Decibel.")

High-lift grouting—A procedure in which grouting is delayed until walls have been laid up to full-story-height before grouting commences in lifts not exceeding 12.67 ft (3.86 m). Higher lifts are possible if proven via a demonstration panel. (Also see "Alternate grout placement.")

High-pressure steam curing—A process of curing hydraulic cement-bound products in an autoclave at maximum ambient temperatures, generally between 340°F and 420 °F (170°C and 215°C). Also called "Autoclave curing," the process is rarely used today for curing concrete block.

Hollow brick—A masonry unit of clay or shale whose net cross-sectional area in any plane parallel to the bearing surface is 60% to 75% of its gross cross-sectional area measured in the same plane. See ASTM C652.

Hollow masonry unit—A unit whose net cross-sectional area in any plane parallel to the bearing surface is 75% or less of its gross cross-sectional area measured in the same plane.

Hollow wall—See "Cavity wall."

Hydrated lime—A dry powder obtained by treating quicklime with sufficient water to satisfy its chemical affinity for water; consists essentially of calcium hydroxide or a mixture of calcium hydroxide and magnesium oxide or magnesium hydroxide, or both.

Hydration—In mortar, grout, concrete, and plaster, the chemical reaction between hydraulic cement and water in which new compounds with strength-producing properties are formed.

Hydraulic cement—A cement that sets and hardens by chemical reaction with water, and is capable of doing so under water.

I

ICBO—See "International Conference of Building Officials."

IMI—International Masonry Institute.

IMIAWC—International Masonry Industry All-Weather Council.

Imitation stone—Special concrete masonry units manufactured in colors, textures, and shapes to provide a natural stone-like appearance, for example, cobblestone, limestone, granite, lava, and other rocks in ledge or boulder fashion. See also "Adhered Manufactured Stone Masonry Veneer" (AMSMV).

Impact noise isolation—Refers to impact noises related to floors, such as those caused by footsteps or movement of furniture, and is measured by the number of decibels lost through a floor from standardized impacts on top of the floor (or floor covering). Also called "Impact sound isolation." For an effective sound barrier, a floor should have an "Impact sound isolation rating" (IIC) of at least 40 db.

Impact sound isolation—See "Impact noise isolation."

Inch-pound units—The units of length, area, volume, weight, and temperature commonly used in the United States at this time. These include, but are not limited to: (1) length—inches, feet, yards, and miles; (2) area—square inches, square feet, square yards, and square miles; (3) volume—cubic inches, cubic feet, cubic yards, gallons, and ounces; (4) weight—pounds and ounces; and (5) temperature—degrees Fahrenheit.

Initial rate of absorption (IRA)—The weight of water absorbed (expressed in grams per minute) when a brick is partially immersed for 1 minute. Also called suction. See ASTM C67.

Interlocking concrete pavers—Solid masonry units capable of transferring loads and stresses laterally by arching or bridging action between units when subjected to vehicular and pedestrian traffic. Also called pavers, concrete pavers, paving stones, paving block, and brick pavers. (See also "Paving block.")

International Conference of Building Officials (ICBO)—A founding member of the International Code Council (ICC), which was established in 1994 to develop a single set of comprehensive and coordinated national model construction codes. (See also "Uniform Building Code.")

IRA—See "Initial rate of absorption."

J

Jamb—The side of an opening, such as a doorway or window.

Jamb block—See "Sash block."

Joint reinforcement—Metal wires, usually prefabricated, to be placed in mortar bed joints to act as horizontal reinforcement for control of cracking and to bond wythes together. Also called "Continuous metal ties" and "Ladder reinforcement."

Jointer—A tool used by masons to form the principal types of mortar joints used between courses of masonry, for example, the vee, concave, and beaded joints. (Also see "Jointing" and "Concave joint.")

Jointing—In masonry, the process of using a tool to compress and shape the mortar face of a joint between courses of masonry. (Also see "Jointer.")

L

Ladder reinforcement—See "Joint reinforcement."

Lateral support—The bracing of walls in structures either vertically or horizontally by columns, pilasters, cross walls, beams, floors, roofs, and the like. May be temporary, as in wind bracing, or permanent, as in cross walls.

Lightweight concrete masonry unit—A masonry unit made from concrete with an oven-dry density of less than 105 lb/ft^3 (1680 kg/m^3).

Lime—A general term that includes the various chemical and physical forms of quicklime, hydrated lime, and hydraulic lime. It may be high-calcium, magnesian, or dolomitic.

Lime putty—A product obtained by the slaking of quicklime with water in accordance with the manufacturer's directions, or by mixing hydrated lime and water to the desired consistency.

Line pin—A metal pin driven into a hardened mortar joint and used to attach a string line for alignment of a course of masonry units.

Line twig—See "Twig" and "Twig brick."

Lintel—(1) A reinforced horizontal member for spanning openings in concrete masonry walls. (2) A fireplace lintel is the horizontal member or arch that supports the front face or mantel of the fireplace above the opening. (Also see "Lintel block.")

Lintel block—A special "U"-shaped concrete masonry unit used for constructing lintels. The units are laid end to end to form a channel for placement of reinforcing steel and grout. (Also see "Lintel.")

Load-bearing wall—Any wall which, in addition to supporting its own weight, supports weight from the building or structure above. (Also see "Bearing wall.")

Low-lift grouting—A procedure in which single-wythe walls are built to a height of not more than 5 ft (1.52 m) before grout is pumped or poured into cores of the masonry units.

M

Manhole block—Special concrete masonry units made for the construction of sewer manholes, catch basins, valve vaults, and other underground structures. Some unit designs include matching tongue and groove ends.

Manufactured sand—A granular material with notably sharp, angular particles obtained by crushing stone, gravel, or air-cooled blast-furnace slag. These sands generally produce less workable mortars than those obtained with natural sand. (Also see "Fine aggregate," "Mortar sand," and "Natural sand.")

Mason—A person skilled in laying concrete block, brick, tile, stone, and glass block.

Masonry—Concrete masonry units, clay brick, structural clay tile, stone, terra cotta, and the like, or combinations thereof, bonded with mortar, dry-stacked, or anchored with metal connectors to form walls, building elements, pavements, and other structures.

Masonry bond—The process in building masonry walls of connecting wythes with overlapping header units. (Also see "Header," "Header block," and "Header course.")

Masonry cement—A hydraulic cement, primarily used in masonry and plastering construction, consisting of a mixture of portland or blended hydraulic cement and plasticizing materials (such as limestone or hydrated or hydraulic lime) together with other materials introduced to enhance one or more properties such as setting time, workability, water retention, and durability. See ASTM C91.

Masonry sand—A clean sand, natural or manufactured, that meets the special gradation requirements of ASTM C144. Used primarily for making mortar and plaster. (Also see "Fine aggregate," "Manufactured sand," and "Natural sand.")

Masonry unit—Natural or manufactured building units of concrete, clay, stone, glass, or calcium silicate.

Mason's level—A mason's tool similar to a carpenter's level, but longer.

Mechanical bond—The tying together of masonry units with metal ties, reinforcing steel, or keys.

Medium weight concrete masonry unit—A masonry unit made from concrete with an oven-dry density of at least 105 lb/ft^3 (1680 kg/m^3), but less than 125 lb/ft^3 (2000 kg/m^3).

Metal lath—Plain or galvanized steel coil or sheet steel that has been slit and expanded or stamp-punched. There are two types: (1) diamond mesh lath, which may be flat or self-furred with impressed indentations, and (2) rib lath. During manufacture, metal lath not fabricated from galvanized steel is coated with a rust-inhibiting paint.

MIA—Masonry Institute of America.

Modified mortar—Conventional masonry mortars altered by either the addition of an admixture at the mixing location or the replacement of one of the basic mortar ingredients. Modifiers used in the masonry industry are essentially similar to those used in the concrete industry, for example, air-entraining agents, bonding agents, plasticizers, set retarders and accelerators, water reducers and repellents, coloring agents, and pozzolanic materials.

Modular masonry unit—A unit that has nominal dimensions based on a 4-in. (102-mm) module. (Also see "Modular planning" and "Nominal dimensions.")

Modular planning—A method of coordinating the dimensions of various building components to simplify work and lower construction costs, for example by minimizing cutting and fitting of masonry units on the job. In a modular plan for concrete masonry, all horizontal dimensions are given in multiples of half the nominal length of a concrete block, usually 8 in. (203 mm). Vertical dimensions are given in multiples of the full nominal height of the block. (Also see "Modular masonry unit.")

Moist-air curing—Curing with moist air (no less than 95% RH) at atmospheric pressure and a temperature of about 73°F (23°C).

Moisture-controlled concrete masonry unit—Outdated terminology. A concrete masonry unit with a moisture content that conformed to the requirements for the Type I classification of ASTM Specifications C55, C90, or C129. Types I and II classifications were removed from these three standards in 2000-2001.

Mortar—A mixture of cementitious materials, fine aggregate, and water, which may contain additives and admixtures, and is used to bond masonry units.

Mortar board—A platform or tray, frequently a square piece of plywood, for holding freshly mixed mortar.

Mortar bond—The adhesion of mortar to masonry units.

Mortar joint—The layer of mortar between masonry units. (Also see "Bed joint," "Collar joint," and "Head joint.")

Mortar sand—A key constituent of mortar; a natural or manufactured sand meeting the special gradation requirements of ASTM C144. Also called "Masonry sand." (Also see "Manufactured sand" and "Natural sand.")

MSJC—Masonry Standards Joint Committee.

Multiwythe wall—A wall consisting of two or more wythes of masonry.

Muriatic acid—A weak solution of hydrochloric acid used for cleaning and etching masonry work. (Also see "Acid etch.")

N

National Building Code (NBC)—The model building code commonly adopted in the northeast U.S. prior to introduction of the I-Codes in 2000. Published by the Building Officials and Code Administrators International, Inc. (BOCA).

National Concrete Masonry Association (NCMA)—The trade association representing manufacturers of concrete masonry units.

Natural sand—A granular material resulting either from natural disintegration and abrasion of rock over time or processing (crushing and screening) friable sandstone. Natural sand usually has rounder, smoother particles than manufactured sand. (Also see "Fine aggregate," "Manufactured sand," and "Mortar sand.")

NBS—National Bureau of Standards. (Now called the National Institute of Standards and Technology, or NIST.)

NCMA—See "National Concrete Masonry Association."

Net cross-sectional area—The area of masonry units, grout, and mortar crossed by the plane under consideration based on out-to-out dimensions. (Also see "Gross cross-sectional area.")

NFPA—National Fire Protection Association.

NIST—National Institute of Standards and Technology. (Formerly called the National Bureau of Standards, or NBS.)

Noise reduction coefficient—NRC is the amount of sound energy absorbed as compared to a perfectly absorptive surface such as an open window; it is calculated by averaging SAC values at frequencies of 250, 500, 1000, and 2000 Hz. (Also see "Sound absorption coefficient"—SAC.)

Nominal dimensions—Specified dimensions of a masonry unit in terms of thickness, height, and length, usually stated as whole numbers. Nominal dimensions are actual unit dimensions plus the thickness of one mortar joint, usually ⅜-in. (10-mm). (Also see "Actual dimensions.")

Non-load-bearing wall—A wall that supports no vertical loads other than its own weight.

Normal weight concrete masonry unit—A masonry unit made from concrete with an oven-dry density of 125 lb/ft^3 (2000 kg/m^3) or greater.

O

Offset block—See "Return block."

OSHA—Occupational Safety and Health Administration, a division of the U.S. Department of Labor.

P

Parapet wall—That part of a wall that extends above the roof level.

Parging—The process of applying a coating of portland cement mortar to the inner side of the facing or backup material in multiwythe wall construction. Also, application of mortar to the face of rough masonry or the earth side of foundations and basements to minimize passage of ground moisture into the wall.

Partition wall—An interior wall of a building that has no structural function.

Party wall—(1) A wall used as part of a continuous structure. (2) A wall on an interior lot line. (3) A wall fit for joint service between two buildings or adjacent habitable space.

Paving block—Solid, flat, concrete masonry units produced in a wide range of shapes and colors for use in paving roads, streets, driveways, walkways, patios, access lanes, parking areas, and slope paving under highway or railway bridges, to name a few applications. (Also see "Interlocking concrete pavers.")

PCA—Portland Cement Association.

Perm—A unit of measurement of water vapor permeance.

Permeability—That property of allowing passage of fluids (or gases). In construction, permeability ordinarily refers to water vapor permeability of sheet material or an assembly, and is measured as water vapor permeance per unit thickness. (Also see "Water vapor transmission," "Perm," and "Permeance.")

Permeance (water vapor)—The ratio of the rate of water vapor transmission (WVT) through a material or assembly between its two parallel surfaces to the vapor pressure differential between the surfaces. (Also see "Water vapor transmission," "Permeability," and "Perm.")

pH—The chemical symbol for the logarithm of the reciprocal of hydrogen ion concentration in gram atoms per liter, used to express the acidity or alkalinity of a solution on a scale of 0 to 14, where 7 represents neutral(ity), less than 7 represents acidity, and more than 7 alkalinity.

Pier—An isolated column of masonry used to support heavy, concentrated vertical roof or floor loads, and to provide lateral support to the walls of a building. (Also see "Pilaster.")

Pilaster—A column or thickened wall section built contiguous with and forming part of a masonry wall; a pilaster may project from one or both sides of a wall. As do piers, pilasters may support heavy, concentrated vertical roof or floor loads, as well as provide lateral support for the walls of a building. (Also see "Pier.")

Pilaster block—Special concrete masonry units designed for use in construction of plain or reinforced concrete masonry pilasters and piers. (Also see "Pier" and "Pilaster.")

Plaster—See "Portland cement plaster" and "Stucco."

Plastic cement—A special hydraulic cement product manufactured for plaster and stucco application. One or more plasticizing agents (not more than 12% by volume) are interground or blended with the cement to increase the workability and molding characteristics of the resultant mortar, plaster, or stucco. See ASTM C1328.

Plasticity—That property of freshly mixed cement paste, mortar, grout, or plaster that determines its workability, resistance to deformation, or ease of molding.

Plasticizer—An additive or admixture that increases the plasticity of portland cement mortar, grout, concrete, or plaster. Plasticizing agents include hydrated lime or lime putty, air-entraining agents, organic additions, and finely ground or processed inorganic substances.

Plumb—Exactly vertical. Usually measured with a plumb line, but in masonry work a mason's level also is used.

Pointing—Troweling mortar into a joint after a masonry unit has been laid, usually to replace mortar fallen from a unit while a block is being lifted into a wall. This is not considered good masonry practice because it may cause insufficiently filled head joints, resulting in leaky walls.

Polyester resin—One of a group of synthetic resins, chiefly produced by reaction of dibasic acid with dihydroxy alcohol; used in concrete and masonry work, for example, as binders in resin mortars and concretes, fiber laminates, and adhesives.

Portland blast-furnace slag cement—A hydraulic cement consisting of an intimately interground mixture of portland-cement clinker and granulated blast-furnace slag or an intimate and uniform blend of portland cement and fine granulated blast-furnace slag in which the amount of the slag constituent is within specified limits.

Portland cement—A hydraulic cement produced by pulverizing portland-cement clinker, and usually containing calcium sulfate. (Also see "Hydraulic cement.")

Portland cement plaster—A mixture of various cementitious materials (portland cement, blended hydraulic cement, masonry cement, plastic cement, or lime), fine aggregate, and water. In a plastic state, the mixture is spread over a substrate, such as concrete block or metal lath; in a hardened state, it protects and architecturally completes a wall surface. (Also see "Plastic cement" and "Stucco.")

Portland-pozzolan cement—A hydraulic cement consisting of an intimate and uniform blend of portland cement or portland blast-furnace slag cement and fine pozzolan produced by intergrinding portland cement clinker and pozzolan, by blending portland cement or portland blast-furnace slag cement and finely divided pozzolan, or a combination of intergrinding and blending, in which the amount of the pozzolan constituent is within specified limits. (Also see "Pozzolan.")

Pozzolan—A siliceous or siliceous and aluminous material, which in itself possesses little or no cementitious value but which will, in finely divided form and in the presence of moisture, chemically react with calcium hydroxide at ordinary temperatures to form compounds possessing cementitious properties.

Preblended mortar—A dry mix of mortar ingredients including cement, sand, and admixtures to which only water is added at the jobsite to produce mortar.

Prefaced block—Special concrete masonry units with face glazing. (Also see "Glazing.")

Prism—(1) A small, hardened grout specimen—at least 3-in. (76-mm) square in cross-section and twice as high as wide—used to determine the compressive strength of grout in masonry construction. See ASTM C1019. (2) A small assemblage of single-wythe concrete masonry units laid in stack bond with ⅜-in. (10-mm) mortar joints, and used to determine the compressive strength of concrete masonry. See ASTM E447.

Puddling—Consolidating, compacting, and settling of grout in a masonry wall by agitating the mixture with a stick or rod to remove air voids. (Also see "Compaction.")

Q

Quality assurance—The administrative and procedural requirements to assure that constructed masonry is in compliance with the contract documents. Quality control is a part of quality assurance.

Quality control—(1) Actions taken by a producer or contractor to provide control over what is being done and what is being provided so that the applicable standards of good practice for the work are followed. (2) In masonry work, determining that the quality of the finished construction is as desired or as shown on plans, drawings, or specifications.

Quicklime—A calcined limestone, which consists mostly of calcium oxide or calcium oxide in association with magnesium oxide. (Also see "Lime putty.")

R

Raked joint—A type of mortar joint used in masonry construction for its aesthetic appeal, where the mortar is removed (raked) to a specified depth, not more than ½ in. (13 mm), while still green. (Also see "Raking.")

Raking—(1) Removing slightly hardened mortar from joints in masonry walls to accent horizontal lines. (2) Preparing control joints for sealing. (3) Removing hardened mortar from joints in preparation for tuckpointing. (Also see "Raked joint" and "Tuckpointing.")

Ready-mixed mortar—Mortar consisting of cementitious materials, aggregate, water, and a set-controlling admixture. The ingredients are measured and mixed at a central location using weight- or volume-control equipment, then delivered to a jobsite where mortar remains usable for a period of 24 to 36 hours. Also called "extended life mortar." See ASTM C1142.

Recessed face block—See "Architectural units."

Reglet—In masonry work, a groove in a mortar joint, or in a special masonry unit, to receive and seal flashing or other material into the masonry.

Reinforced masonry—Masonry units with reinforcing steel so placed and embedded in portland cement grout that the masonry and steel act together in resisting loads. (Also see "Unreinforced masonry.")

Relative humidity—The ratio of the quantity of water vapor actually present in the atmosphere to the amount of water vapor present in a saturated atmosphere at a given temperature, expressed as a percentage.

Repointing—The filling in with fresh mortar of cut-out or defective mortar in the joints of masonry construction. (Also see "Pointing.")

Retaining wall—A wall built for holding a mass of earth in place, as at the edge of a highway, terrace, or excavation. (Also see "Gravity retaining wall," "Cantilever retaining wall," and "Counterfort retaining wall.")

Retardation—The slowing down of the rate of setting or hardening of mortar, grout, concrete, or plaster. An increase in the setting and hardening times is advantageous during hot weather.

Retempering—After initial mixing, the moistening and remixing of mortar to regain the proper consistency for use. Typically allowed for up to 2½ hours after initial mixing. (Also see "Tempering.")

Return block—A special concrete masonry unit, not rectangular in plan, that is designed for use as a corner block to keep the construction modular when turning a corner. Also called a "corner angle unit" or an "offset block."

Ribbed split-face block—A special architectural concrete masonry unit made by splitting hollow ribbed units to produce pleasing stone-like textures; the units are widely used for through-the-wall applications, both indoors and out. (Also see "Split-face unit.")

Roman brick—A long, thin face brick with nominal dimensions of 4x2x12 in. (102x51x305 mm).

Running bond—A method of laying masonry units in a wall such that the head joints in successive courses are horizontally offset at least one-quarter of a unit's length. Head joints centered over the units below is called "half bond," while offsetting the head joints one-third or one-fourth of the unit's length creates "third-bond" or "quarter-bond," respectively.

***R*-value**—Like *U*-value, *R*-value is an index of heat transfer, which is a measure of the resistance that a building section, material, air space, or surface film offers to the flow of heat. The *R*-value is the reciprocal of the *U*-value for a stated thickness of a building section. *R*-values are particularly useful for estimating the effect of components of a section on the total heat flow because they can be directly added. (Also see "*U*-value.")

S

Sabin—A unit of sound absorption equal to 1 sq ft (929 cm^2) of a perfectly absorptive surface; named after W. C. Sabine. (Also see "Sound absorption.")

Sailor—A brick or block that is standing on end in a wall with its broad face showing. (Also see "Soldier.")

Sandblasting—A system of cutting or abrading a surface by using compressed air to eject a stream of sand or other abrasive material from a nozzle at high speed; often used to clean masonry walls or prepare old concrete or masonry surfaces for application of plaster or other coatings.

Sash block—A special concrete masonry unit designed to facilitate the installation of windows or doors, generally with a vertical slot to receive window or door frames. Also called "Jamb block."

SBC—See "Standard Building Code."

Scored block—See "Architectural units."

SCPI—Structural Clay Products Institute. See "Brick Industry Association."

Scratch coat—The first coat of plaster applied to a surface in a two- or three-coat plaster job. (Also see "Portland cement plaster" and "Base coat.")

Screen block—Special, aesthetically-pleasing, concrete masonry units designed for use in decorative building facades, ornamental room dividers and partitions, garden fences, and patio screens. Screen block provide privacy and diffuse strong sunlight and winds. Also called "Grille block."

Sculptured units—See "Architectural units."

Self-consolidating grout—A mixture of cementitious material, aggregate, and water which contains a chemical admixture to produce a high fluidity for ease of placing and filling voids (cores, cells) in unit masonry. Does not require mechanical vibration to place it. (Also see "Grout.")

Self-furring—Raised portions of lath, such as ribs or dimples, formed in metal lath or wire lath during manufacture. When the lath is installed, the ribs or dimples hold the lath away from the supporting surface for proper embedment of the metal in plaster.

Serpentine—Curving, as a wall or fence that curves back and forth.

Shale—A thinly stratified, consolidated, sedimentary clay with well-marked cleavage parallel to the bedding.

Shearwall—The wall portion of a structure or structural frame intended to resist lateral forces, such as earthquake or wind, acting in the plane of the wall.

Shrinkage—A decrease in either length or volume of a material that may be restricted to effects of moisture content or chemical changes. (Also see "Unrestrained shrinkage.")

Sill block—Special, solid concrete masonry units used for constructing window sills.

Silo block—A special concrete masonry unit available in some areas for use in construction of silos and similar containers that must resist internal pressure. The units usually are manufactured with matching tongue and groove ends and slots in the bed planes for keyed horizontal joints; also, the completed structures usually are hooped with steel bands to help resist internal pressure.

Silo-mixed mortar—A special technique of producing masonry mortar that overcomes problems with mixture adjustments and jobsite variability. A silo is filled with dry, properly proportioned mortar ingredients at a central plant, delivered to a jobsite by truck, and erected. At the jobsite, the silo is connected to a source of water and electricity; the contractor merely presses a button when mortar is needed. (Also see "Preblended mortar.")

Single-wythe wall—A masonry wall just one masonry unit wide.

Slag cement—A hydraulic cement consisting mostly of an intimate and uniform blend of ground, granulated blast-furnace slag and, one or both of portland cement or hydrated lime, in which the amount of the slag constituent is within specified limits.

Slope paving units—Special concrete masonry units, usually 100% solid block, used for protecting slopes under highway and railway grade-separation structures and on other steep embankments to prevent costly and often dangerous soil erosion, particularly where grass will not grow to protect the surface.

Slotted block—A special, proprietary, concrete masonry unit designed to provide unusually high sound energy absorption. Slotted openings molded into the faces of the units conduct sound into the cores, which act as damped resonators.

Slump—A measure of the consistency of freshly mixed mortar, grout, or concrete, equal to the immediate subsidence, measured to the nearest ¼ in. (6.4 mm), of a specimen molded in a specified way with a standard slump cone. See ASTM C143.

Slump block—A special, solid concrete masonry unit resembling handmade adobe produced with a finer and wetter concrete mixture than usual. During manufacture, the units are squeezed to give a bulging effect before they are set aside to harden.

Slurry—A thin mixture of an insoluble substance, such as portland cement, slag, or clay, with a liquid, such as water.

Smoke chamber—The space in a fireplace immediately above the throat where smoke and gases are compressed and funneled into the chimney flue above.

Soldier—A brick or block that is standing on end in a wall with its narrow face showing. (Also see "Sailor.")

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

Sound absorption—The amount of airborne sound energy (measured in sabins) absorbed by a wall surface adjacent to a sound. (Also see "Decibel," "Noise reduction coefficient," "Sabin" and "Sound transmission loss.")

Sound absorption coefficient—SAC is the amount of sound energy absorbed compared to a perfectly absorptive surface, such as an open window. (Also see "Sound absorption.")

Sound transmission loss—The total amount of airborne sound (measured in decibels) lost as it travels from one side of a wall or floor to the other. Sound transmission losses are measured by using ASTM E336, Test Method for Measurement of Airborne Sound Insulation in Buildings, and are reported as STC (sound transmission class) values.

Spall—A small fragment detached from the face of a concrete masonry unit by a blow, by the action of weather, or by pressure or expansion created by materials from within the unit. As an example of the latter, a small piece of glass accidentally incorporated into a concrete mixture can react chemically with cement in a block, causing expansion and a spall.

Split-face unit—An architectural concrete brick or block made from solid or hollow units that are fractured (split) lengthwise or crosswise by machine to produce a rough, stone-like texture. The split faces, which are exposed when the units are laid, are irregular and sharp, with particles of aggregate broken through in various planes of fracture. (Also see "Ribbed split-face block.")

Stack bond—A method of laying masonry units one atop the other such that head joints in successive courses are vertically aligned; used architecturally to emphasize the vertical lines formed by continuous head joints.

Standard Building Code (SBC)—The model building code commonly adopted in the south and southeast U. S. prior to adoption of the I-Codes in 2000. Published by the Southern Building Codes Congress International (SBCCI).

Stone masonry—Masonry that is composed of field, quarried, or cast stone units bonded with mortar. (Also see "Cast stone.")

Story pole—A marked pole, for example, a 1x2-in. (25x51-mm) wood strip with pencil markings 8 in. (203 mm) apart, for accurately finding the top of each masonry course during wall construction. More elaborate metal story poles are commercially available.

Stretcher unit—A masonry unit laid with its greatest dimension horizontal and its face parallel to the wall face.

Striking—The cutting away of mortar from a wall with a trowel; also the tooling of mortar joints.

Struck joint—A type of mortar joint, generally used to emphasize horizontal lines, that is recessed further at the bottom than at the top. Easy to make with a trowel, especially if the mason works from inside the wall, but not suitable for exterior walls in rainy, windy, freezing climates.

Structural Clay Products Institute (SCPI)—See "Brick Industry Association."

Stucco—Portland cement plaster and stucco are the same material. The term "Stucco" is widely used to describe the cement plaster used for coating exterior surfaces of buildings. However, in some geographical areas, "stucco" refers only to the factory-prepared finish coat mixtures. (Also see "Exterior insulation and finish systems," "Portland cement plaster," and "Plastic cement.")

Suction—The absorptive capacity of a substrate surface immediately after being subjected to application of water. (Also see "Absorption" and "Initial rate of absorption.")

Surface bonding mortar—A mortar containing hydraulic cement, glass fiber reinforcement with or without inorganic fillers, or organic modifiers, all in a prepackaged form requiring only the addition of water and mixing prior to use. These mortars are applied to the faces of dry-stacked masonry (no mortar in the joints between units) to provide wall stability and strength. (Also see "Dry stack.")

Supplementary cementitious material—cemntitious material other thn portland cement or blended cement, including fly ash and slag.

Synthetic stucco—See "Exterior insulation and finish systems."

T

Tempering—The addition of water and mixing of mortar, grout, concrete, or plaster as necessary to bring the mixture to the desired initial consistency. (Also see "Retempering.")

Throat—In a residential fireplace, the slot-like opening directly above the firebox through which flames, smoke, and other products of combustion pass into the smoke chamber.

Tie—Any material, commonly metal ties, that bonds (holds together) or connects the wythes of a multiwythe wall. Tensile bond of mortar in a collar joint is not credited. Masonry headers, though no longer common, are considered ties.

Tooling—Compressing and shaping the face of a mortar joint with a special tool to give weathertightness and an overall neat appearance to a masonry wall.

Tuckpointing—The act of cutting out leaky or deteriorated mortar in old mortar joints and replacing it with new mortar. When properly done, tuckpointing will help restore the weathertightness, structural integrity, and appearance of a masonry wall.

Twig—A small plastic or metal device used to support a mason's line at the center of a long wall. Also sometimes called a "Trig."

Twig brick—The brick that holds a line twig. Also sometimes called a "Trig brick."

U

UBC—See "Uniform Building Code."

Uniform Building Code (UBC)— The model building code commonly adopted in the western U. S. prior to adoption of the I-Codes in 2000. Published by the International Conference of Building Officials (ICBO).

U-block—See "Lintel block."

UL—Underwriters' Laboratory, Inc.

Unit metal ties—See "Tie."

United States Army Corps of Engineers (USACE)—A federal agency involved with the planning, designing, building, and operation of dams and other civil engineering projects.

Unreinforced masonry—(1) Masonry which does not contain vertical steel reinforcement. (2) Masonry in which the tensile resistance of the masonry is taken into consideration for design purposes but the resistance of the reinforcing steel is neglected. (Also see "Reinforced masonry.")

Unrestrained shrinkage—A reduction in the size of a composition—a block, a wall, a beam—that occurs during its hardening or curing process, or both, but with no external forces brought to bear that could inhibit such reduction.

USACE—See "United States Army Corps of Engineers."

***U*-value**—Essential to a designer's calculations of heat flow through walls and other building components, *U*-value is the overall coefficient of heat transmission, a standard measure of the rate at which heat flows through a unit area of a material of known thickness. *U*-value equals the total amount of heat in British thermal units (Btu) that 1 sq ft (929 cm^2) of wall (ceiling or floor) will transmit per hour for each °F (0.56°C) of temperature difference between the air on the warm and cool sides. (Also see "*R*-value.")

V

Vapor barrier—See "Vapor retarder."

Vapor retarder—A membrane placed in a building wall or under a concrete floor slab on ground to effectively minimize the transmission of water vapor, but not 100%. A "Vapor retarder" is often incorrectly referred to as a "Vapor barrier." It is generally recognized that a vapor retarder is one with a permeance of less than 0.3 U.S. perms (0.2 metric perms) as determined by ASTM E96.

Veneer—Normally, veneer is a single facing wythe of masonry anchored, but not bonded, to a structural backing, and designed to carry just its own weight. For example, it is common practice in residential construction to use masonry veneer as a non-load-bearing siding or facing material over a wood frame. (Also see "Veneered wall" and "Adhered Manufactured Stone Masonry Veneer (AMSMV).")

Veneered wall—A building wall with a facing of masonry units, or other weather-resisting, noncombustible material, secured to and supported by the backing through adhesion (adhered veneer), or secured to and supported laterally by the backing through anchors and supported vertically by the foundation or other structural element (anchored veneer). (Also see "Veneer.")

Volume change—Either an increase or a decrease in volume due to any cause. (Also see "Bulking," "Creep," "Drying shrinkage," and "Unrestrained shrinkage.")

W

Waffle units—See "Grid pavers."

Wall tie—See "Tie."

Warehouse set—The partial hardening of bagged cement, or prepackaged mixtures containing cement, caused by the absorption of atmospheric moisture during improper or lengthy storage. Also called "Warehouse pack."

Water absorption—(1) The process by which a liquid (water) is drawn into and tends to fill permeable pores in a porous solid. (2) The amount of water absorbed by a material under specified test conditions, commonly expressed as a percentage by weight of the test specimen. See ASTM C67.

Water blasting—A system of cutting or abrading a surface by using pressurized water ejected from a nozzle; used to clean masonry walls or prepare old concrete or masonry surfaces for application of plaster or other coating.

Water retentivity—That property of a mortar that resists rapid loss of mixing water (prevents loss of plasticity) to the air on a dry day or to an absorptive masonry unit.

Water vapor transmission—The rate of water vapor flow, under steady specified conditions, through a unit area of a material, between and normal to its two parallel surfaces. (Also see "Permeability," "Permeance," and "Perm.")

Web—The cross wall(s) connecting the face shells in a hollow concrete masonry unit.

Weepholes—Small openings in mortar joints or the faces of masonry units. An inseparable companion to flashing, weepholes are usually located immediately above flashing—except where flashing is located under copings—to drain away accumulated water.

Workability—That property of freshly mixed mortar, grout, concrete, or plaster that determines its working characteristics, that is, the ease with which it can be mixed, placed, molded, and finished.

Wythe—Each continuous, vertical section of a wall, one masonry unit in thickness.

Related Materials

APPENDIX D

The following PCA materials may be of interest to readers of the *Concrete Masonry Handbook.* Many of these items also appear in the "References on Concrete Masonry" but are repeated here for the convenience of our readers.

Research and Development Bulletins

(Available on compilation DVD021 and online at www.cement.org/bookstore.*)*

DX003 Investigation of the Moisture-Volume Stability of Concrete Masonry Units, by Joseph J. Shideler, 1955.

DX004 A Method for Determining the Moisture Condition of Hardened Concrete in Terms of Relative Humidity, by Carl A. Menzel, 1955.

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Index

D

Q

R

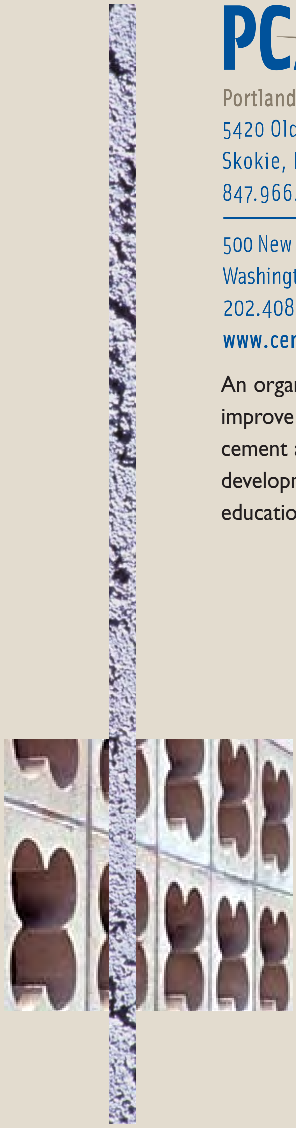
S

T

U

V

W



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