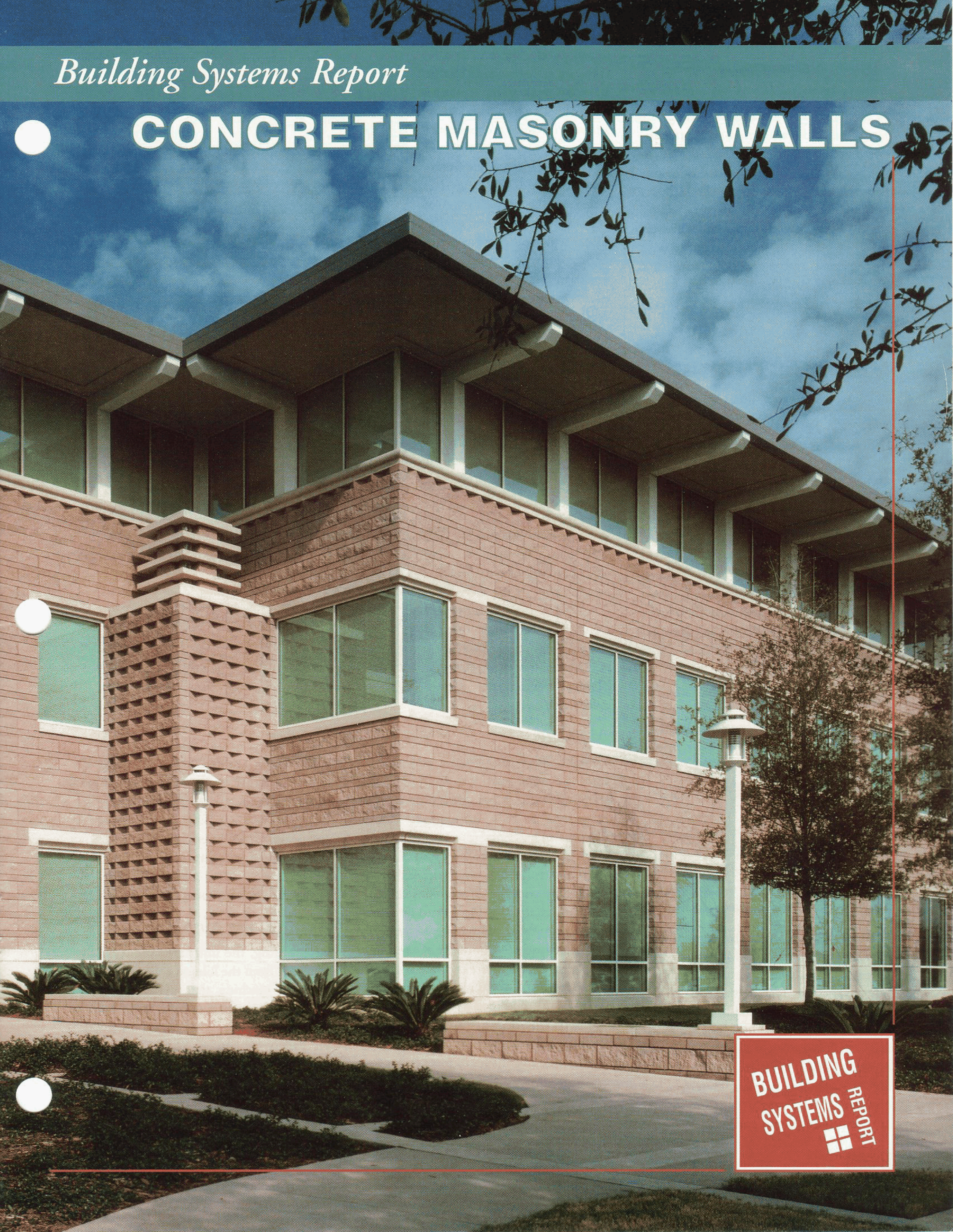
Building Systems Report

CONCRETE MASONRY WALLS



BUILDING SYSTEMS REPORT

CONCRETE MASONRY WALLS

Beauty, strength, durability – these are just some of the reasons concrete masonry is popular for commercial and residential buildings. A diverse palette of colors, textures, and shapes affords the architect boundless combinations of patterns and rhythms. But most importantly concrete masonry meets the requirements of both the designer and the building owner: a finished structure that retains its integrity and aesthetic qualities for decades with minimal maintenance.

MANUFACTURING

Concrete masonry units, including block and brick, are mass produced in plants with concrete's basic ingredients: portland cement, aggregates, and water. Supplementing these fundamental materials may be air-entraining admixtures, color pigment, water repellents, and pozzolans such as fly ash and blast furnace slag. Concrete masonry units conform to requirements of ASTM C 90, *Standard Specification for Load-Bearing Concrete Masonry Units.* Concrete bricks meet the requirements of ASTM C 55, *Standard Specification for Concrete Building Brick,* or other ASTM standards.

Materials

Specially formulated portland cement, blended cements, and blast furnace slag cements conforming to ASTM requirements are used in the manufacture of concrete masonry units.

Aggregates must meet the requirements of ASTM C 33, *Standard Specification for Concrete Aggregates,* or ASTM C 331, *Standard Specification for Lightweight Aggregates for Concrete Masonry Units.*

Normal weight units are made with aggregates such as sand, gravel, crushed limestone, and sometimes may incorporate a variety of materials like air-cooled blast funace slag, pelletized fly ash, and crushed concrete. Lightweight units are made with lightweight aggregates such as expanded shale, clay, slate, pumice, scoria, and a variety of recycled materials like expanded blast furnace slag, sintered fly ash, coal cinders, and pelletized fly ash.

Admixtures impart special qualities to the concrete that benefit production, end-use, or both. Air-entraining agents improve molding characteristics and the durability of masonry subjected to freeze-thaw cycles. Color pigments enhance the appearance of exposed concrete masonry. Water repellents decrease water penetration. Cementitious Pozzolans such as fly ash and blast furnace slag partially replace portland cement, the most expensive ingredient in concrete.

Concrete masonry conforms to specific physical requirements. ASTM C 90 sets requirements for linear shrinkage, dimensional tolerances, strength, thickness of face shells and webs, and water absorption. *ASTM C 90* includes both hollow and solid masonry units. The net cross sectional area of solid units is at least 75% of the gross area. Conversely, the net cross sectional area of hollow units is less than 75% of the gross area. ASTM C 55 identifies similar physical requirements for concrete brick.

Photo: Besser Company

MANUFACTURING CONCRETE MASONRY *Low-slump concrete is molded to the desired shape in hydraulic concrete products machines.*

Molding

Cement, aggregates, water, and admixtures are combined into a moist, low-slump concrete and molded to the desired shape in a high production block machine. The concrete mixture is automatically controlled to assure consistency of texture, color, and other physical properties. The automated machines consolidate and compact the concrete by vibration and pressure. The machine removes the freshly molded units from the mold onto steel pallets where they are automatically conveyed to kilns for curing The versitility of the block machine is one of concrete masonry's most significant attributes. By exchanging molds a variety of unit sizes and shapes to meet either aesthetic or functional needs can be achieved.

Curing

The newly molded concrete masonry units are cured at elevated temperatures to accelerate strength development The units are typically subjected to elevated temperatures for a period of 6 to 8 hours. The elevated temperatures are achieved by means of steam and/or the heat of hydration of the cement.

Storage and Shipping

After curing, the units are automatically removed from the kiln on roller racks to a stacking machine that places them in small stacks, called cubes. The 48-inch (1.2-m) cubes are either placed on wooden pallets or banded with the bottom layer of hollow units positioned horizontally to facilitate lifting. Fork lifts transport cubes to a storage area to await shipment.

DESIGN CONSIDERATIONS

The design of concrete masonry walls depends on several factors, including appearance, strength, insulation, fire resistance, acoustics, and weather protection. The nationally recognized standard for design of masonry structures is *Building Code Requirements for Masonry Structures,* ACI 530/ASCE 5/TMS 402. This standard establishes structural design requirements for concrete masonry, and is the basis for model code design provisions.

Specifications for Masonry Structures, ACI 530.1/ASCE 6/TMS 602 outlines construction requirements for masonry structures. Architects and engineers should reference this publication in project specifications and include any supplementary requirements for the specific project. Before designing with concrete masonry, architects and engineers should become completely familiar with local building codes, model building codes, and with *Building Code Requirements for Masonry Structures,* and *Specifications for Masonry Structures.*

Although ASTM C 90 and ASTM C 55 specify certain requirements for the manufacture of concrete masonry, they do not fix project requirements such as wall design, color, texture, weight, size, fire resistance, and acoustical properties. The designer must identify these properties in the construction documents. Before a designer details a building, he/she should contact local manufacturers to obtain product information.

Wall Types

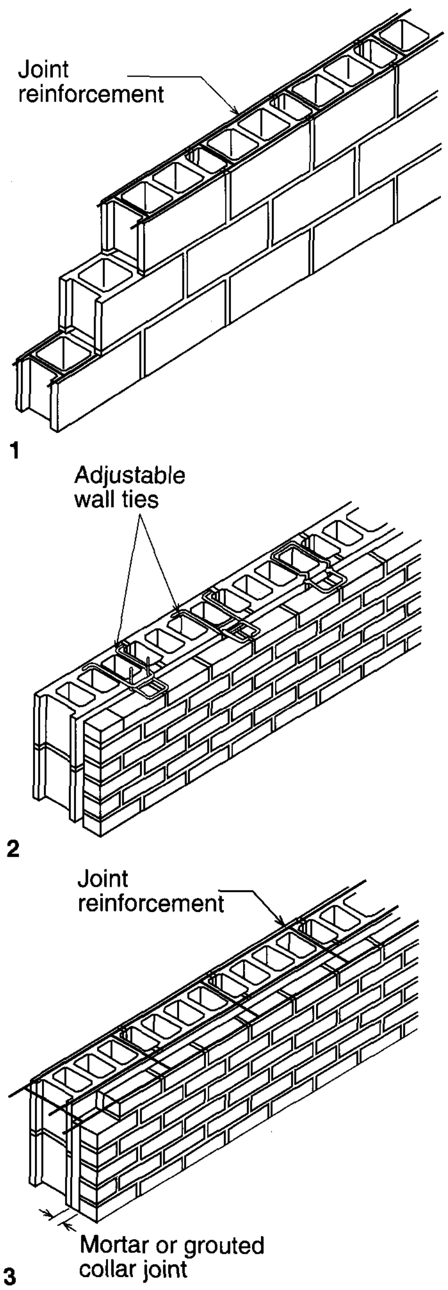
Concrete masonry walls can be single wythe or multiwythe. They can consist of one or a combination of hollow units or solid units. Concrete masonry units are available in a wide variety of sizes, shapes, weights, colors, and textures to meet virtually any architectural or structural requirement.

The simplest concrete masonry wall system is a single wythe, hollow unit assembly. The exterior surface is left exposed, painted or stuccoed. The interior surface can be exposed or covered with clear finish, paint, plaster, or gypsum board. Hollow concrete masonry can be reinforced or unreinforced depending on strength requirements. Single wythe walls also can be made using solid concrete masonry units.

Cavity walls are multiwythe walls with a load-bearing interior wythe and a nonload-bearing exterior wythe. The interior wythe is often constructed of hollow concrete masonry units, and the exterior wythe of solid units or bricks. A cavity wall is noncomposite – meaning each wythe is designed to individually carry the loads imposed on it. The two wythes are separated by a 1 in. (25 mm) or greater air space and tied together with metal ties. Rigid insulation and vapor barrier are placed against the cavity face of the interior wythe. The interior wythe can be reinforced or unreinforced depending on strength requirements.

Composite walls are multiwythe walls designed to act as a single member to resist loads. Loads are transferred and shared by the wythes through the grout filled space between each wythe (collar joint) and rigid metal ties. Often, both wythes are solid units or bricks. Composite walls can be reinforced or unreinforced depending on strength requirements. If needed, reinforcement can be placed in the cores of hollow units or in the collar joint.

Concrete masonry units and concrete bricks are also effective in nonload-bearing applications. They can be used as an exterior skin for buildings that have a frame structural system or as a veneer with a masonry or stud back-up system. Concrete masonry is also used for interior load-bearing or nonload-bearing partitions.

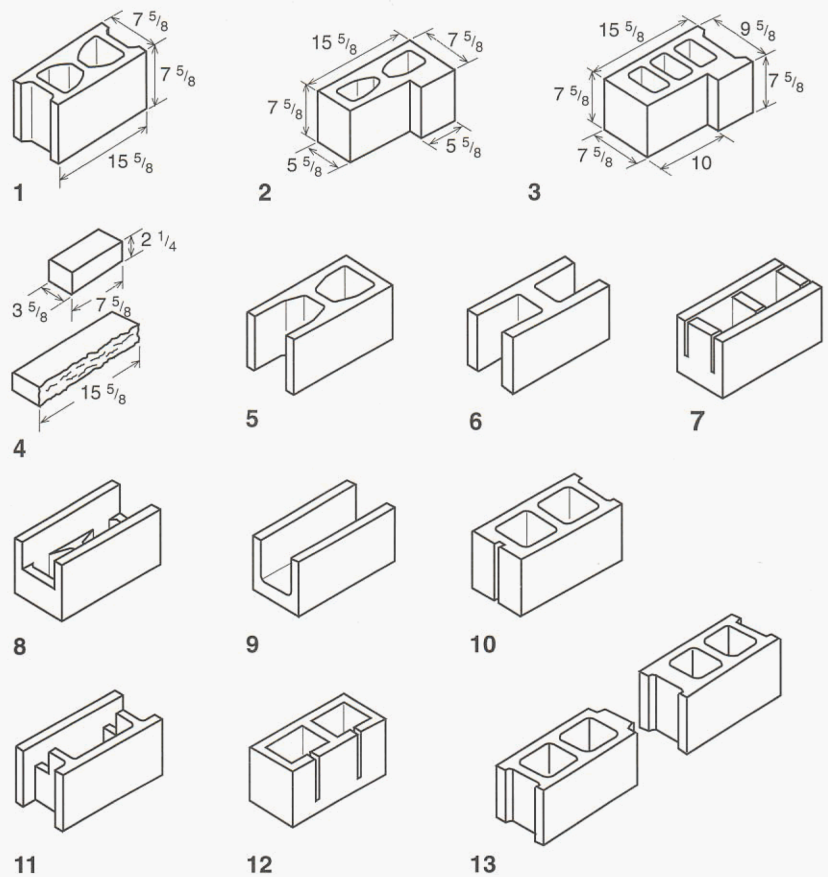


WALL TYPES *1 Single Wythe Wall 2 Cavity Wall 3 Composite Wall*

Size and Shape

Construction documents should identify the sizes and shapes of concrete masonry units and/or concrete bricks to be used for the wall construction. Selection is based on both architectural and structural requirements. Certain sizes and shapes are standard; others are proprietary. For some large projects, custom shapes are feasible. In either case, manufacturers can provide dimensional information for their standard products and their capabilities for manufacturing custom units.

Standard concrete masonry units have nominal face dimensions of 8 in. by 16 in. (200 mm by 400 mm) and are available in nominal thicknesses of 4, 6, 8, 10 and 12 in. (100, 150, 200, 250 and 300 mm). Actual dimensions are 3/8 in. (9 mm) less than nominal dimensions to accommodate the typical mortar joint of 3/8 in. (10 mm). Hollow units are typically manufactured with 2 cores per unit. Concrete bricks are available in modular sizes with nominal dimensions of 4 in. (100 mm)



SIZE AND SHAPE 1 *8 X 8 X 16 in. (200 X 200 X 400 mm) stretcher unit with 2 cores* ***2*** *Corner unit for 6 in. (150 mm) units* ***3*** *Corner unit for 10 in. (250 mm) units* ***4*** *Concrete bricks* ***5*** *Open-end or "A" shaped unit* ***6*** *Double-open-end or "H" shaped unit* ***7*** *Knockout-web bond beam unit* ***8*** *Low-web bond beam unit* ***9*** *"U" shaped lintel unit* ***10*** *Steel sash unit* ***11*** *Reduced web unit to minimize heat loss and accommodate insulating inserts* ***12*** *Acoustical unit* ***13*** *Control joint units*

Photo: Don Olshavsky, Artog

AESTHETIC APPEAL *Concrete masonry was used for the exterior and interior walls of Big Walnut High School in Sunbury, Ohio for its structural capabilities, aesthetic appeal, durability, and reasonable cost. Architect Schooley Caldwell Associates, Columbus, Ohio, was able to achieve its design intent by integrating color, size, and texture into traditional forms.*

thickness and 8, 12, or 16 in. (100, 200, or 400 mm) lengths. A wide variety of nonmodular concrete brick sizes are also available.

Special concrete masonry units are manufactured to simplify construction. Open ended "A" and "H" shaped units are used for threading around vertical reinforcing bars. Bond beam units have reduced webs or knock-out webs for placing continuous horizontal reinforcement. Lintel units are "U" shaped with flat bottoms to accommodate reinforcement over wall openings. Sash units have a vertical groove on one end face to accommodate a window sash. Control joint units have a male and female end to provide lateral load transfer across joints. Special units with reduced webs minimize heat loss and accommodate special insulating inserts. Acoustical units are designed with grooves in the face to dampen sound. Other custom shapes are available from some manufacturers.

Weight Class

There are three weight classes of concrete masonry: (1) normal weight, (2) medium weight, and (3) lightweight. The weight class of concrete masonry is based on the density of the concrete used: Normal weight has density greater than 125 pcf (2000 kg/m^3), medium weight has density of 105 to 125 pcf (1680 to 2000 kg/m^3), and lightweight has density of less than 105 pcf (1680 kg/m^3). Weight class should be specified in the construction documents.

Moisture Content

There are two types of concrete masonry units within each weight class: Type I, moisture-controlled, and Type II, non-moisture-controlled. Type I units should be used where drying shrinkage of the masonry due to loss of moisture could result in excessive stress and cracking of the wall. Concrete masonry placed in areas of the country that have low relative humidity are required to have lower moisture content at time of delivery than areas with a more humid environment. ASTM C 90 and ASTM C 55 limit moisture content for Type I units based on the humidity conditions and linear drying shrinkage of the units.

Color

The natural color of concrete masonry can vary from light to dark gray, buff, red, and brown depending on the color of the aggregates, cement, other constituents in the concrete mix, method of curing, and surface texture. For concrete masonry walls that will be covered, color variation is not critical. However, if the masonry is to be exposed, specify color in the construction documents. A sample panel on the job site is also helpful to show the acceptable range of color and workmanship for the job.

Integral color of concrete masonry can be achieved by using colored aggregates, cements, and mineral oxide pigments. Pigments must conform to the requirements of ASTM 979, *Standard Specification for Pigments for Integrally Colored Concrete.* Designers should check with local manufacturers for color availability. Use locally available natural sands, cements, and coarse aggregates to produce desired color when possible. Standard colors for pigments are tan, buff, red, brown, pink, yellow, black, and gray. Green and blue pigments also can be used, but are usually more expensive and color uniformity is sometimes difficult to achieve.

Texture

Surface texture can be varied greatly to suit the desired aesthetic and performance requirements. Changing the aggregate grading, mix proportions, and amount of compaction during molding can influence texture. Textures are classified as open, tight, fine, medium, and coarse. Open texture is defined by relatively closely spaced large voids between aggregates. Tight texture has spaces between aggregates filled with cement paste, leaving few pores and voids. A fine texture is defined as a relatively smooth surface made of small, closely spaced particles. Coarse texture is characterized by a rough surface made up of large aggregates near the surface. Medium texture is somewhere between fine and coarse. The designer should consult local manufacturers to obtain samples of different textures available since the definition of texture varies from region to region.

Where concrete masonry is to serve as a base for stucco or plaster, a coarse texture is desirable for good adhesion. If the surface is to be painted, a fine texture is desirable. Painted coarse and medium textured surfaces still provide good sound absorption, but care must be taken to avoid closing all of the surface pores. Spray painting is the preferred method of application.

Other textures and shapes are created by special molds and manufacturing processes. Split-face blocks are cast as double-size units, then split lengthwise to produce two units with a rough, stone-like surface. Split-face blocks are also available in special corner units with a rough surface on the front face and one end.

Slump blocks are formed with a concrete mix wetter than normal so that it slumps a predetermined amount when the block is removed from the mold. Slump block imparts a rustic handmade look.

Fluted and ribbed blocks can be formed in special molds. Because of the accuracy of the molding process, continuous vertical lines can be formed in the wall face even when a running bond pattern is used. Size, spacing, and texture of the ribs

Photo: Besser Company

DESIGN OPTIONS *Concrete masonry units are available in a wide variety of sizes, shapes and colors to accommodate virtually any architectural or structural application.*

Photo: A. F. Payne Photographic

TIMELESS QUALITIES *Concrete masonry was selected for the building envelope and interior walls for the City of Phoenix Police Telecommunications Building for its integrity and timeless qualities. Architect, Orcutt/Winslow Partnership, Phoenix, Arizona selected materials that express permanence and security. This intelligent blend of art and construction yields a timeless design that is durable and cost effective.*

can vary. Split-rib units can be formed similarly to split-face block.

Ground-face masonry units are formed by grinding the surface of the block to form a smooth, open-textured finish. This method exposes the aggregate at the surface and takes advantage of variation in aggregate size, type, and color. Ground-face units are often used for interior partitions and left exposed except for a colorless sealer. An alternate method for exposing aggregate is to sandblast the units before or after the units are in place.

The face of concrete masonry can be modified with prefacing materials such as resin, resin and inert filler (fine sand), portland cement and inert filler, ceramic glazes, porcelainized glazes, and mineral glazes. Standard specification for prefacing is ASTM C 744, *Standard Specification for Prefaced Concrete and Calcium Silicate Masonry Units.* These prefacing materials can produce a wide range of textures, patterns, and colors for exterior and interior applications. Because facings are resistant to water, abrasion, and effects of chemicals, they are often used for locations subject to frequent cleaning such as schools, hospitals, and food processing plants.

Mortar

Mortar is used to bond units, joint reinforcement, ties, and anchors so that all elements of the wall act as a unit. Mortar must conform to the requirements of ASTM C 270, *Standard Specification for Mortar for Unit Masonry.* Masonry mortars are composed of water, sand and either masonry cement, or a combination of portland cement or blended cement and hydrated lime.

Building Code Requirements for Masonry Structures, ACI 530/ASCE 5/TMS 402, includes design provisions for three mortar types: M, S, and N. In areas of high seismic risk, Type M or S is required. In addition, Types O and K mortar are sometimes used in nonstructural applications. ASTM C 270 provides a guide for selecting masonry mortars. One easy way to remember mortar types is to spell out the words MaSoN wOrK. Every other letter represents a mortar type in order of decreasing strength.

Mortar can be proportioned by one of two methods. The ingredients can be mixed in accordance with the predetermined proportions given in ASTM C 270. Mortar mix design can also be based on laboratory tests which show the mortar meets certain requirements for compressive strength, water retention, and air content.

White or colored mortars offer an unlimited range of architectural effects. ASTM C 270 does not specify color for mortar except to allow for admixtures such as color pigment. Mortar color must be specified by the project designer. White mortar is made with white portland cement, lime, and white sand, or with white masonry cement. Colored mortars can be obtained by using color pigments, colored cements, and colored sand. The combination of color pigment and white cement produces the most brilliant colors. Standard mortar colors are gray and buff. *Specifications for Masonry Structures,* ACI 530.1/ASCE 6/TMS 602 gives limits for the amount of color pigment that can be used in mortar.

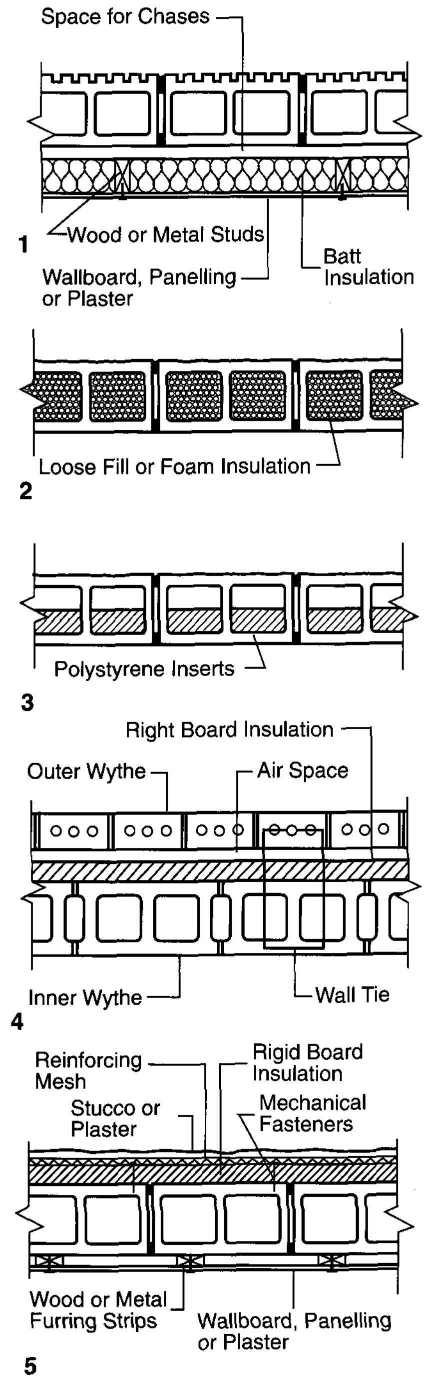
Grout

Grout, a mix of portland cement, aggregates, water, and admixtures is used to fill cores in hollow masonry and spaces between wythes of masonry so that the wall and reinforcement (if used) act as a unit to resist structural loads. Grout must conform to ASTM C 476, *Standard Specification for Grout for Masonry.*

Unless specified otherwise, grout is proportioned to have a high slump of 8 to 11 inches (200 to 280 mm) and minimum compressive strength of 2000 psi (14 MPa) at 28 days. Grout is classified as fine or coarse depending on the grading and size of aggregate used in the mix. The selection of fine or coarse grout depends on the width of grout space and maximum pour height as specified in *Specifications for Masonry Structures,* ACI 530.1/ASCE 6/TMS 602.

Energy Efficiency

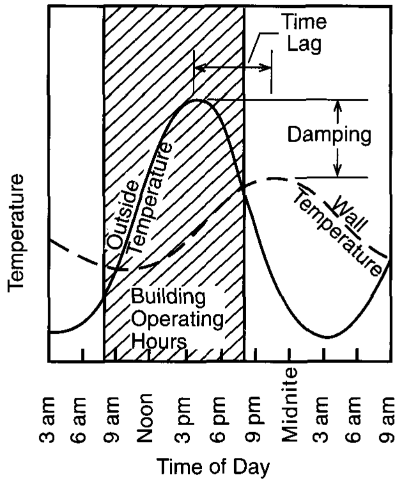
The thermal performance of a wall depends on its thermal resistance (R-value) and the thermal mass properties of the wall. R-value depends on geometry of the masonry unit, type and location of insulation, finish materials, and density of



TYPICAL INSULATION DETAILS
1 Interior insulated 2 Integrally insulated 3 Integrally insulated 4 Exterior insulated 5 Exterior insulated

masonry. Lower density concrete results in higher R-values.

Thermal mass is defined as the ability of a material to store heat. Because masonry has relatively high density, it is very effective at storing heat. Masonry remains warm or cool long after heat or air-conditioning is shut off. Thermal mass can reduce temperature swings and shift heat-



THERMAL MASS *Thermal mass is a property of concrete masonry which enables it to absorb, store, and subsequently release significant amounts of heat. This results in temperature damping and thermal lag. The result is lower cooling and heating loads and more comfortable inside conditions. In addition, the peak temperatures on the inside of the wall can be delayed to off peak hours. This lowers energy bills for the building owner.*

ing and cooling loads to off-peak hours. This results in lower utility bills and more comfortable working environments. The thermal mass effect also depends on climate, building design, and position of insulation. Generally, insulation placed on the outside face of the wall, within voids of hollow masonry, or within the air space of a cavity wall is most effective because mass is in direct contact with conditioned air.

Insulation can be placed on the interior of a masonry wall, integral with the masonry wall, or on the exterior of the wall. Interior insulation usually consists of insulation placed between studs or furring on the interior face of the wall. Fibrous batt, rigid board, or fibrous blown-in insulation can be used. Alternatively, rigid board insulation can be attached directly to the masonry wall with special clips and channels. The interior wall surface is usually finished with gypsum wall board or lath and plaster.

Integral insulation is placed within the cores of hollow concrete masonry. Insulation can be molded polystyrene inserts, expanded perlite or vermiculite granular fills, or expandable foams placed in cores that are not grouted. Granular fills are placed in the masonry wall as it is laid up by pouring directly from bags into cores. Foamed insulation is installed after the wall is completed and the installer either pumps the insulation into the cores from the top of the wall or through small drilled holes in the masonry. Special polystyrene inserts can be placed in the cores of conventional masonry or in the cores of units specially designed to provide higher R-values.

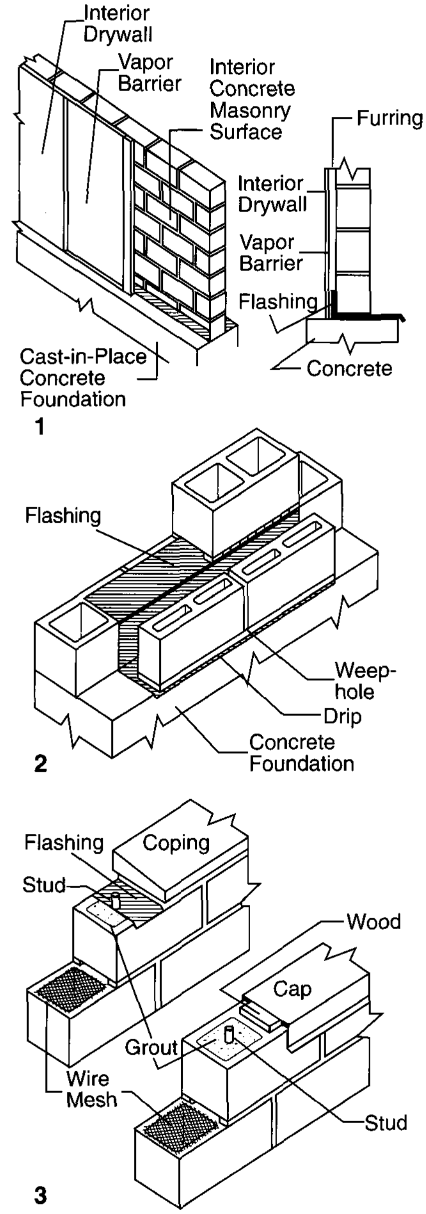
Exterior insulation can be used with single wythe or multiwythe walls. In multiwythe walls, insulation is placed between the two wythes of masonry. The interior wythe of the wall is usually built first. Rigid board insulation is attached with adhesive or mechanical fasteners before the outer wythe is installed. In single wythe construction, rigid board insulation is attached to the outside face of the masonry. Reinforcing mesh is installed over the insulation and fastened through the insulation into the masonry before a cementitious plaster or stucco finish is applied.

Weather Protection

Exterior walls must have the ability to resist the effects of rain, ice, and condensation. This can be achieved with proper detailing and materials including water repellents, flashing, insulation, and vapor barriers.

Water repellents are recommended for single wythe and multiwythe walls, but may not be necessary for cavity walls. Water repellents resist water penetration and minimize efflorescence and staining from environmental pollutants. There are two types of water repellents: surface applied and integrally mixed. In general, they must not only resist water penetration, but also allow vapor transmission so that humidity within the wall can escape.

Surface applied water repellents include clear treatments such as silicone and acrylic resins, opaque coverings such as latex and cement-based paints, and cementitious coatings like stucco. In some cases, latex or cement-based fill coats can be used to smooth and fill small voids in the wall before finish coats of paint are applied.



FLASHING DETAILS 1 *Single wythe walls* ***2*** *Cavity walls* ***3*** *Coping and cap details*

Integral water repellents are typically polymer-based products and are introduced into the concrete mix in the masonry production plant. Because they are evenly mixed in the masonry, integral water repellents do not change the appearance of the wall. When using concrete masonry containing integral water repellent, the same water repellent must be added to the mortar mix.

A properly detailed masonry wall will almost always include flashing. Water repellents and water resistant finishes normally do not preclude the use of flashing as final protection against water penetration. Stainless steel, copper or plastic flashing should be located at foundations, above bond beams, above and below openings, and at copings.

Flashing should extend from the interior of the wall, slope to the exterior, extend beyond the outside face, and terminate with a sloped drip edge. Weep holes should be placed no more than 32 in. (800 mm) apart. In addition to allowing water to escape, weep holes vent cores for single wythe construction and the air space between wythes in cavity wall construction. Proper detailing and installation will help ensure outstanding performance of the wall.

Photo: Sandra Williams

STRENGTH AND DURABILITY *Split-face and standard concrete masonry units provide an attractive, strong, durable and cost-effective exterior for this pump station maintenance and storage building, San Diego, California. Kenniston & Mosher Architects, San Diego, used concrete masonry to achieve a deliberate expression for this utilitarian building.*

Control Joints

Movements due to changes in temperature and moisture content can cause tensile stresses within a wall to build; which ultimately may result in vertical cracking. Cracks can be controlled by using horizontal reinforcement, control joints, and by limiting the moisture content of the units.

In unreinforced walls, horizontal joint reinforcement is normally used in conjunction with control joints to help control cracking. The inclusion of horizontal reinforcing bars in reinforced masonry walls can reduce the need for control joints. Joint reinforcement can be placed at 8, 16, or 24 in. (200, 400, or 600 mm) intervals or bond beams can be spaced at 4 feet (1.2 m) maximum.

Vertical control joints are spaced at regular intervals along a wall depending on the amount of reinforcement used. They should be placed at changes in wall height, at returns in "L", "T", and "U" shaped buildings, intersecting walls, and at one or both sides of openings.

Structural Design

The generally accepted standard for structural design of masonry structures is *Building Code Requirements for Masonry Structures*, ACI 530/ASCE 5/TMS 402. This standard details the structural design requirements for concrete masonry and addresses both empirical and engineered design procedures.

Empirical design is a prescriptive approach to design based on existing experimental data and historical experience. Masonry buildings and elements can be designed using the empirical method if certain seismic load, wind load, and building height restrictions are met. The design procedure then provides criteria for minimum wall thickness, maximum height to thickness ratio, maximum spacing of shear walls, and minimum length of shear wall. The empirical design provisions have proven to be reliable through years of experience.

Engineered design criteria are based on principles of allowable stress design and engineering mechanics. The standard gives procedures and values for determining allowable stresses for compression, shear, and flexure, and for material properties such as modulus of elasticity and coefficient of thermal expansion. Given these physical properties, the structural engineer can proportion members based on the distribution of loads applied to the structural elements.

Using the engineered approach, a wall can be reinforced or unreinforced depending on design requirements. Design criteria for reinforced concrete masonry walls neglects the tensile strength of masonry and reinforcement is placed and proportioned to resist all tension. Conversely, design criteria for unreinforced concrete masonry walls neglects reinforcement and relies on the tensile strength of masonry to resist tension. For buildings located in high seismic zones, reinforced masonry is required.

Limit states design or strength design of masonry structures is not specifically addressed in the standard, although *ICBO Uniform Building Code* includes provisions for strength design. Strength design allows for more predictable wall performance and can result in thinner walls and reduced reinforcement.

When using limit states methods to design slender walls, primary and secondary moments must be taken into account. Primary moments caused by lateral loads and the eccentricity of axial loads must be resisted as well as secondary moments induced by axial loads. These secondary moments are often called P-delta moments and result from the deflection of the slender wall. Calculating P-delta moments is an iterative process

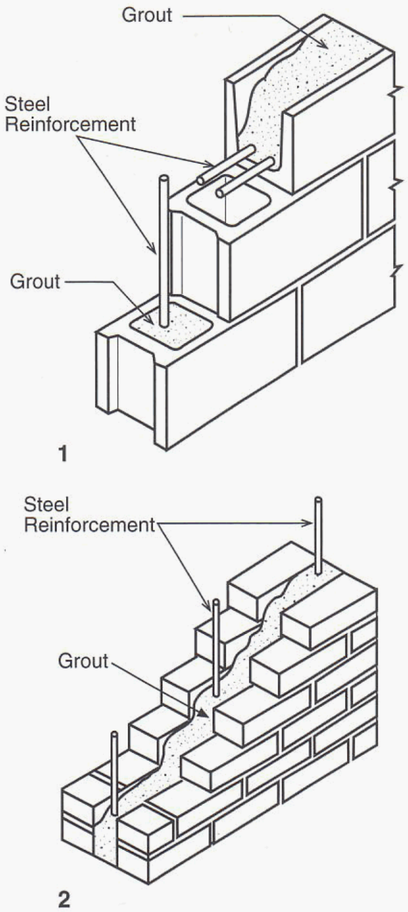


Photo: David Wakely

REINFORCED CONCRETE MASONRY
1 *Reinforcement for hollow masonry units* ***2*** *Reinforcement for solid masonry units or bricks*

TALL MASONRY WALLS *ELS/Elbasani & Logan Architects, Berkeley, California selected alternating bands of dark and light split-face concrete masonry for the tall exterior walls of the East Baybridge Center, retail shops in Emeryville, California. Concrete masonry expresses the appropriate aesthetic, echoing forms found in nearby industrial buildings.*

because the deflection of the wall is a function of the applied moment.

Connections

Proper design and detailing of connections is critical. *Building Code Requirements for Masonry Structures,* ACI 530/ASCE 5/TMS 402 includes provisions for connection design. Connections must resist gravity loads applied to the wall by the floor and roof framing. In addition, wall connections must provide lateral support for the wall and resist shear loads in the plane of the wall. Lateral loads perpendicular to the wall can act inward or outward.

Some typical floor and roof framing systems used in conjunction with concrete masonry walls are cast-in-place concrete, prestressed concrete tees, hollow core plank, structural steel, steel joists, and wood. Each system has unique requirements that must be addressed in design and detailing. Most connections are achieved by using anchor bolts, plates, and reinforcement embedded in grouted cores or bond beams. At the base of the wall, connection to the footing must be properly designed to transfer loads into the foundation. In all cases, precautions must be taken to protect connections from water penetration and differential movement caused by temperature effects.

Fire Resistance

Concrete masonry walls are often specified as a fire barrier because they are noncombustible, resist heat transmission, and prevent the passage of flame and hot gases. The fire endurance rating of a building component is determined on the basis of standard tests specified in ASTM E 119, *Standard Methods of Fire Tests of Building Construction and Materials.*

The fire endurance rating is defined as the length of time in hours that a component endures when subjected to standard fire exposure before reaching one of the following end points:

1) Structural End Point: collapse of load bearing specimens.

2) Flame Passage End Point: formation of holes or cracks which allow the passage of gases hot enough to ignite cotton waste on the unexposed side.

3) Heat Transmission End Point: temperature of the unexposed side increases more than 250°F (139°C) above its initial temperature.

Photo: PHD–Paul D'Amato

FIRE RESISTANCE *The City Commons townhomes, Chicago, Illinois, has concrete masonry load bearing exterior and party walls for superior fire resistant construction. Architect Pappageorge/Haymes Ltd. selected integrally colored concrete masonry with accents of brick and limestone to give these townhomes the level of detail, scale, and warmth consistent with the surrounding neighborhood.*

In addition, walls and partitions must not collapse when subjected to a standard hose stream test following the fire test.

Building codes allow fire endurance ratings for concrete masonry walls to be based on calculations. From information obtained through extensive fire testing programs, formulas have been developed to accurately calculate the fire ratings of concrete masonry walls.

Fire protection of joints also is an important design consideration. In many cases, building codes require joints in walls to be protected against fire, either to the same degree or sometimes lesser degree than the main wall. Flexible, noncombustible materials such as ceramic fiber blankets and ropes compressed into a joint provide thermal, flame, and smoke barriers. Details used for fire resistant joints must meet the requirements of ASTM E 119.

QUALITY OF CONSTRUCTION

As with all construction, the success of a concrete masonry project depends on strict adherence to the construction documents. This can be achieved through a comprehensive quality control and quality assurance plan in the project specifications. *Specifications for Masonry Structures*, ACI 530.1/ASCE 6 /TMS 602 includes basic requirements for quality control and quality assurance. It is extremely important to identify in the project specifications who is responsible for quality control and quality assurance and which submittals, tests, and inspections are required.

Typically, the masonry contractor is responsible for quality control; documenting materials and workmanship to demonstrate compliance with the construction documents. Submittals should include documents certifying masonry unit compliance for compressive strength, absorption, weight classification, dimensions, color and texture. Mix design for mortar and grout should be submitted for approval. Appropriate product data should also be submitted for reinforcement, ties, and anchors.

A quality assurance program assures the owner that the building is constructed in accordance with the construction documents. It is normally the architect's and engineer's responsibility to specify the requirements for the quality assurance program. Testing and inspection typically are performed during construction by an independent testing and/or inspection agency employed by the building owner. The inspections include placement of reinforcement, ties, anchors, and grout. Tests on mortar cubes or cylinders, masonry prisms, and grout cubes are also performed. Results of testing and inspection are reported to the building owner and architect.

The best way to monitor concrete masonry walls for compliance of workmanship and appearance is to require a sample panel be built by the masonry contractor for approval by the architect. A suggested panel size is 64 in. (1.6 m) long by 48 in. (1.2 m) high. The panel should include typical reinforcement, joint tooling, range of unit color and texture, and range of mortar color. The sample panel should be located on the building site where it can be readily accessed for comparison.

CONSTRUCTION

Unless otherwise specified, installation of concrete masonry walls should be in accordance with *Specifications for Masonry Structures*, ACI 530.1/ASCE 6/TMS 602. Before wall construction begins, the contractor must check the horizontal and vertical alignment of the foundation. In addition, the position of reinforcing dowels should be checked for conformance with the construction drawings. If the two do not conform, the architect/engineer should be notified so corrections can be made before wall construction begins.

Protection of Materials

Concrete masonry units must be protected from water, soil, ice, and frost before and during construction. Steel reinforcement, ties, and anchors must be cleaned of oil, dirt, or any other substance that will reduce bond. Materials used for mortar and grout must be stored under cover in a dry place. ACI 530.1/ASCE 6/TMS 602 addresses special precautions that need to be taken for cold and hot weather construction.

Mortar

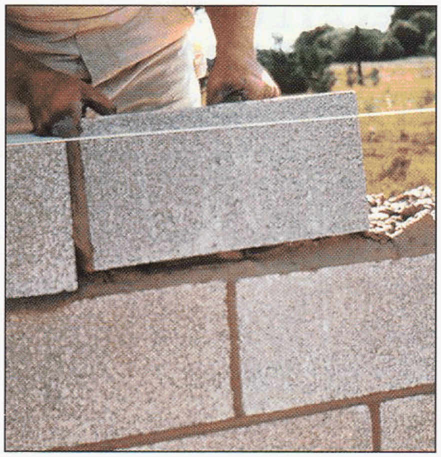
The required cementitious materials and aggregates are mixed for 3 to 5 minutes in a mechanical mixer with a sufficient amount of water to produce a workable consistency. Hand mixing is not acceptable unless specified in the construction documents. Mortar can be remixed or retempered with water, but must be discarded if it begins to set or is not used within 2-1/2 hours of initial mixing.

Placing Units

Bond pattern and mortar joint thickness should be specified in the construction documents; if unspecified, the masonry contractor will use running bond pattern with a 3/8 in. (10 mm) thick mortar joint. The bed joint at the foundation can vary from 1/4 in. (6 mm) to 3/4 in. (19 mm). Before laying the first course, the top surface of the foundation must be clean and free of laitance and loose materials.

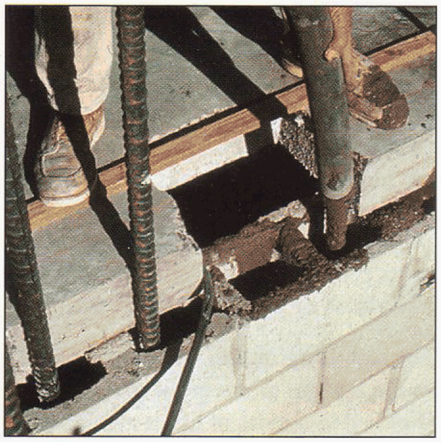
The first course is laid with a full mortar bed. For hollow units, vertical cells are aligned. Any excess mortar projecting more than 1/2 in. (13 mm) into cells to be grouted must be removed. Subsequent bed joints will have face shell mortar only for hollow units unless otherwise specified. The webs adjacent to cells to be grouted must also be mortared to contain the grout. Solid units have full mortar beds.

Head joints (vertical mortar joints) are at least the thickness of the face shell for hollow units and are full thickness for solid units. Unless otherwise specified, mortar joints are tooled with a round jointer to produce a slightly concave surface. For concrete masonry that will be covered with plaster or stucco, flush joints should be used.



__PLACING UNITS__ Bed joints for hollow masonry units are the thickness of the face shells unless otherwise specified. Solid units have full mortar beds.

__BRACING__ The masonry contractor is typically responsible for providing adequate bracing for walls during construction.



__HIGH-LIFT GROUTING__ Walls can be grouted using the high-lift grouting method. Grout is placed in a series of lifts a maximum of 5 feet (1.5 m) per lift.

Mechanical chases are built into the wall as the wall is laid up. Conduit and pipe passing through the wall horizontally are placed in steel sleeves or cored holes. Pipes and conduit parallel to the plane of the wall and within the wall must be placed while the wall is being constructed. Connectors, flashing, weep holes, vents, nailing blocks, insulation, movement joints and other accessories are coordinated and installed during wall construction.

Unless otherwise specified, the masonry contractor is responsible for designing, providing, and installing adequate bracing to support the wall during construction. The wall must be protected from weather by covering unfinished and finished work that will be subjected to weather extremes during construction. Exposed masonry surfaces must be cleaned of all dirt, stains, mortar, and grout as soon as possible after construction of each section of wall.

Reinforcement

Horizontal reinforcement is placed as the courses are being laid. Conventional deformed bar reinforcement is placed in bond beam courses. Prefabricated horizontal joint reinforcement may be used in place of or in conjunction with bar reinforcing. The longitudinal wires of the joint reinforcement are located in the face shell mortar beds and are embedded the entire length. Longitudinal wires require a minimum mortar cover of 5/8" (16 mm) when exposed to weather or earth and 1/2" (13 mm) in all other instances.

Vertical reinforcing bars can be placed before the masonry units are laid or placed after the wall is complete. If reinforcement is installed before units are laid, special open ended units can be used to avoid having to lift units over the bars. Bars placed after the wall is erected are threaded into the appropriate cell from the top of the wall. Vertical bars must be held in position with bar positioners installed in the joints of the wall, or by tying the vertical and horizontal bars together. Reinforcement should be continuous and lap splices should be used only where they are specified in the construction documents. Position of reinforcement should be held within the tolerances given in ACI 530.1/ASCE 6/TMS 602.

Wall ties for multiwythe construction are positioned while the units are being laid. Unless otherwise specified, wall ties are positioned in accordance with ACI 530.1/ASCE 6/TMS 602. Anchors and other prefabricated inserts must be held in proper position until the wall is grouted. They can be held in position by embedding them in mortar joints, tying them to reinforcing bars, or with wood templates fastened to the wall surface.

Grouting

There are two basic methods for placing grout: low-lift grouting and high-lift grouting. In low-lift grouting, no more than 5 feet (1.5 m) of a wall is constructed and grouted in one day, and no cleanouts are required at the bottom of the wall. Because of the small volume of grout placed in low-lift grouting, it is usually placed by hand with buckets.

For high-lift grouting, cleanouts are used at the bottom of the grout spaces. Grout is placed in a series of lifts a maximum of 5 feet (1.5 m) at a time, consolidated, and reconsolidated before initial set takes place. This method reduces hydrostatic pressure and avoids mortar joint blowouts. Subsequent lifts are placed and the vibrator is extended 12 to 18 in. (300 to 460 mm) into the preceding lift. ■

RELATED PUBLICATIONS

There are many excellent publications available from the Portland Cement Association and the National Concrete Masonry Association that discuss the design and construction of concrete masonry walls. Some of these publications are:

Concrete Masonry Handbook, EB008, Portland Cement Association, 1991.

Concrete Masonry Standards, TR 95 C, National Concrete Masonry Association, 1995.

Reinforced Concrete Masonry, NCMA TEK 14-2, National Concrete Masonry Association, 1995.

Typical Sizes and Shapes of Concrete Masonry Units, NCMA TEK 2-1, National Concrete Masonry Association, 1995.

Thermal Mass Handbook, Concrete and Masonry Design Provisions Using ASHRAE/IES 90.1–1989, National Codes and Standards Council of the Concrete & Masonry Industries, 1994. (Available through PCA and NCMA.)

Analytical Methods of Determining Fire Endurance of Concrete and Masonry Members – Model Code-Approved Procedures, SR267, Portland Cement Association, 1985.

Use of Flashing in Concrete Masonry Walls, NCMA TEK 19-5, National Concrete Masonry Association, 1995.

Control of Wall Movement with Concrete Masonry, NCMA TEK 10-2, National Concrete Masonry Association, 1972.

Insulating Concrete Masonry Walls, NCMA TEK 6-11, National Concrete Masonry Association, 1995.

Water Repellents for Concrete Masonry Walls, NCMA TEK 19-1, National Concrete Masonry Association, 1992.

For complete lists of published materials, contact the Portland Cement Association and the National Concrete Masonry Association to receive free catalogs.

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COVER *– Merril Lynch Operations Center, Jacksonville, Florida. Architect: Thompson, Ventulett, Stainback & Associates, Atlanta, Georgia. Photo: Brian Gassel/TVS & Associates.*

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