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ARCHITECTURAL DESIGN OF MASONRY CAVITY WALLS

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ABSTRACT

For the past few years a task committee of ASTM Committee C 15.05 has been developing a Standard Guide for Architectural Design of Masonry Cavity Walls. This paper provides excerpts of the current draft of that proposed standard. It is provided here for public review and comment. Your suggestions for improving the document should be sent to this author as chairman of the task committee. You recommendations will be greatly appreciated.

SCOPE

This standard is applicable to architectural detail drawings and related specifications for the construction of cavity walls built of manufactured masonry units and mortar. Masonry cavity walls consist of an exterior wythe, a cavity, and an interior section of masonry.

This standard includes brick, concrete masonry units (CMU), mortar, and ancillary masonry materials. It does not include dimensioned stone, cast stone, or terra cotta. It does not include solid masonry walls, composite walls, masonry bonded hollow walls, diaphragm walls, and walls of masonry veneer over concrete or studs.

SIGNIFICANCE AND USE

This standard addresses the architectural design of masonry cavity walls. When adapted to the requirements of a particular building and incorporated into appropriate construction contract documents, use of this standard will assist in avoiding masonry cracks, leaks, and stains and will extend durability. If there is compelling need to modify these recommendations for a particular project, make changes only after thorough study and contemporaneous documentation of the reason for each change.

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Design criteria for cavity walls include structure (*Building Code*...1992, Drysdale 1994, *Concrete Masonry*...1993, Matthys 1993); aesthetics (Shapes and Sizes...1988, Bonds and Patterns...1967, Brick Sizes...1993, Brick Shapes...1986); initial and operating costs (Smit 1993, Grimm 1976); differential movement (Grimm 1988, Movement...1991, Movement...1991); water permeance (Grimm 1982, Water...1985, Ruggiero and Myers 1991); heat transfer (*Cooling*...1989, *Energy*...1989, U Values...1988, Heat...1982; air permeance (*ASHRAE*...1989); vapor transmission (Moisture...1988, *ASHRAE*...1989); fire resistance (Fire...1987, Calculated...1991, Fire...1991, Balanced...1991); durability (Grimm 1985); and sound absorption (Grimm 1993); and sound transmission (Grimm 1993, Sound...1982, Sound...1970). References (Brick...1977, Brick...1978, Brick...1989, Design...1985) provide summary information on cavity wall design, detailing, and construction. A computer program design aid for cavity walls is cited (Grimm...1994). Cavity walls are superior to comparable masonry walls in resistance to rain penetration and the transmission of heat, fire, and sound. Cavity walls are less prone to crack than veneer walls over flexible steel studs, but they are somewhat weaker than solid walls in resisting lateral loads. The cost of a cavity wall is comparable to that of composite walls of the same materials with a grouted collar joint.

A multi-wythe wall with a void collar joint is not a cavity wall. Cavities may have a width ranging from not less than 50 mm (2 in.) to as much as 114 mm (4-1/2 in.) without structural engineering analysis of cavity wall ties. Wider cavities require such analysis. Cavity width is measured from the cavity face of the exterior wythe to the cavity face of the interior wythe. Specify that the cavity be kept clean. It is virtually impossible for a mason to keep an air space free of mortar droppings, if the air space is less than 50 mm (2 in.) wide. Insulation may be placed in the cavity. If rigid board insulation is placed in the cavity, secure it to the interior wythe and the spandrel. The net air space between the insulation and the exterior wythe should be not less than 50 mm (2 in.), unless a system is provided to drain water unimpeded to the flashing. The interior face of the interior wythe may be left exposed, painted, plastered directly, or furred to receive gypsum wallboard finish. If furred, additional insulation and conduit may be located in the furred space. Pipe and electrical conduit may be placed in the cavity, if a 50 mm (2 in.) air space is maintained between the interior face of the exterior wythe and the conduit or pipe.

Where these elements occur provide construction details for copings, parapets, fascia, flashing, wall anchorage, belt courses, wall recesses, heads, jams, and sills of wall openings, expansion joints, control joints, construction joints, wall-floor intersections, wall-roof intersection, wall-wall intersections, and sleeves (Brick..1978, Grimm 1995a, Grimm 1995b).

APPLICABLE DOCUMENTS

Applicable documents will be listed here.

COORDINATION OF DRAWINGS AND SPECIFICATIONS

On architectural drawings indicate the form, size, quantity, relationship, generic type, and graphic representation of construction materials. Specifications define the quality of materials and workmanship. Prepare masonry specifications in conformance with *Specifications for Masonry Structures* (1992). On the drawings:

1. locate each material, assembly, component, and accessory;
2. identify all materials, components, and equipment;
3. show dimensions of construction and sizes of field-assembled components;
4. show details of connections and flashing at a minimum scale of 1-1/2 in. = 1'-0" (7.5/1); and
5. reference related drawings of other disciplines

Generic names on drawings are preferred. Use of proprietary names requires drawing revisions if substitutions are accepted. Do not describe materials or components on the drawings, e g use "Brick" rather than "Colonial Red Brick" and "CMU" rather than "Std Wt CMU". Excessive notes obscure drawings, require extra time to find information, and increase the possibility of inconsistencies and duplication of specifications. Use *Standard Reference Symbols for Construction Documents* (*Standard*...1991).

TERMINOLOGY

Although the use of the full term is preferable, abbreviations are appropriate for use on masonry detail drawings (*Abbreviations*...1986). Do not use a period with abbreviations except with "No." for number and "in." for inch to distinguish them from "no" and "in". Capitalize all abbreviations except those for metric terms.

The following terms will be defined here: actual dimensions, anchor, building expansion joint, isolation joint, control joint, expansion joint, fastener, nominal dimention, specified dimension, and tie.

MODULAR MASONRY DIMENSIONING

Coordinate the sizes of brick, CMU, and mortar joints with the dimensions of walls. The nominal horizontal dimension of a masonry stretcher unit is the sum of the specified length of the unit plus the specified mortar joint thickness. i e specified brick length of 190 mm (7-5/8 in.) plus specified mortar joint thickness of 10 mm (3/8 in.) equals nominal brick length of 200 mm (8 in.). Standard modular brick are proportioned so one brick length plus a mortar joint is equal to two brick widths plus two mortar joints. The length of an economy norman modular brick is three brick widths plus three mortar joints. Thus, modular brick masonry is dimensioned in nominal increments of 100 mm (4 in.).

Height dimensions in modular masonry are determined in a similar way. Standard modular brick are dimensioned so the height of three brick courses (three brick plus three mortar bed joints) is 200 mm (8 in.). Three course of standard modular brick exactly match the height of one course of 200 mm (8 in.) high CMU. Two courses of nominally 100 mm (4 in.) high brick course out with one course of nominally 200 mm (8 in.) high CMU. For brick and CMU of other heights the principal is the same (Darlington 1962, Vance 1983)

MORTAR JOINTS

The actual dimension of a unit may vary from the specified dimension by the allowable dimensional tolerance permitted by the applicable ASTM specification. In modular masonry if a unit is undersized, the thickness of the adjacent mortar joint is increased by the mason to provide the correct nominal dimension. Similarly, if a unit is oversized, mortar joint thickness is reduced by the mason to provide the correct nominal dimension. In modular masonry the actual unit dimension plus the actual mortar joint thickness should always equal the nominal dimension of the unit. Similarly, the nominal dimension should equal the sum of the specified unit dimension and the specified mortar joint thickness.

Where the driving rain index (Grimm 1982) is greater than one, concave or "V" mortar joints are preferable in the exterior face of exterior walls, because they reduce water permeance. Any joint configuration is suitable for interior use.

FLASHING AND WEEP HOLES

Detail flashing to be continuous (without gaps) at heads and sills of wall openings; at base of wall; and at wall-roof intersection, copings, spandrels, lintels, and shelf angles. Lap flashing at least 150 mm (6 in.) and seal all flashing joints (Grimm 1994).

Do not require the outer edge of flashing to be placed back from the face of the wall, because water collected on the flashing will drain into the wall below. Extend the outer edge of rigid flashing beyond the exterior face of the wall and turn down to form a drip. Most flexible flashings deteriorate when exposed to ultraviolet radiation. Others may be unsightly when cut off beyond the wall face. To avoid this a secondary stainless steel drip may be used.

In some cases, protruding flashing may be aesthetically objectionable in which case return the outer edge of the flashing to partially cover the back of the sealant joint.

Seal all flashing joints, except in rising damp barriers where sealing is not necessary. In through-wall metal flashing provide expansion joints by mechanically interlocking and sealing joints 38 mm (1-1/2 in.) or by lapping and sealing with a non-hardening sealant. Extend flashing at least 100 mm (6 in.) beyond sills and loose lintels and provide end dams at least 50 mm (2 in.) high in mortar head joints. Provide end dams at every longitudinal termination of flashing. Ensure that flashing is continuous around corners. Extend the interior edge of flashing up at least 200 mm (8 in.) and into the bed joint of the interior wythe or into a reglet. Turn up flashing at interior edge to form selvage. Provide a plastic insulator between dissimilar metals to prevent electrolytic corrosion.

Flashing materials should be described in the specifications. The generic term "flashing" should be used on drawings.

Specify sheet copper, stainless steel, copper clad stainless steel, or terne coated stainless steel for exposed or through wall flashing.

Provide weep holes at wall face immediately above flashing and a vent at the top of the cavity. Vents and weep holes may be voids left in a head joint or a corrosion resistant ventilator placed in an void head joint. Place weep holes and vents horizontally at nominally 600 mm. (24 in.) o. c. for nominal 8 in. (200 mm) and 300 mm (12 in.) stretcher lengths and at 800 mm (32 in.) o c for nominal stretcher lengths of 400 mm (16 in.). Do not specify weep hole tubes, because they clog with mortar easily. Cotton sash cord at least 150 mm (12 in.) long may be used at a spacing of nominally 200 mm (16 in.).

PARAPETS AND CURBS

Roof curbs project above the roof 150 mm. (6 in.) or less. Parapets extend above the roof more than 150 mm (6 in.). Protect the tops of curbs and parapets, and flash the joint with the roof.

Where coping extends beyond the face of the wall and provides an adequate drip, flashing may stop at the wall surface. However, where the coping is flush with the wall face, extend the flashing out beyond the wall face at least 13 mm (1/2 in.) on both sides and turn it down to form a drip.

The end joints of prefabricated metal copings and curb covers are assembled with the manufacturer's fittings. Shop formed metal copings and curb covers may be lapped, joined with a standing seam, or butted and either covered with a plate or provided with a concealed gutter plate. Expansion joints are required at suitable intervals depending on the type and gauge of metal (*Architectural*...1953). Treat the tops of piers and pilasters similarly. Slope the tops of all copings and projections. If the exterior wythe of the parapet is not supported at roof level, an expansion joint is necessary immediately below the coping at the top of the exterior wythe.

Shop formed metal copings and curbs may be installed over pressure treated wood, anchored to masonry with 13 mm (1/2 in.) stainless steel or galvanized steel bolts.

Do not specify brick masonry for copings or sills. In exterior walls where the driving rain index (Grimm 1982) is greater than two, do not use sand finished brick.

For concrete masonry exterior walls where the driving rain index is greater than three, provide durable, water resistant, and vapor permeable exterior surface coating, e g stucco. Where the driving rain index is three or less, a water cement or latex paint is adequat Clear coatings can temporarily reduce water permeance, but they do not prevent water permeance and are not durable.

CONNECTORS

Connectors include anchors, ties, and fasteners. Use stainless steel wire ties conforming to ASTM 580, Type 304. Alternatively, use steel wire ties which conform to ASTM A 82, hot dip galvanized after fabrication in compliance with ASTM A 153, Type B-2. Do not juxtapose dissimilar metals.

Do not specify drip wall ties. Drips reduce strength, and there is no published test data to indicate that drip ties reduce water permeance. See references (*Building*...1995, *Specifications*...1995, Wall...1987) for tie embedment, cover, and corrosion resistance requirements.

When both wythes of a cavity wall are built simultaneously and when bed joints in both wythes occur at the same vertical interval as tie spacing, use bed joint reinforcement to tie the wythes together. As an alternate use rigid individual ties in which case tie placement is more difficult to control.

If both wythes are built concurrently from one side of the wall, masonry units on the other side must be laid "over hand." i e the mason does not face and can not clearly see the opposite face of the wall. This may affect wall appearance.

To provide early enclosure, the two wythes are often built at different times, in which case scaffolding must be provided on both sides of the wall. The interior wythe is built first, in which case rigid individual ties or bed joint reinforcement extending out of the interior wythe interferes with construction of the exterior wythe. Do not permit ties to be bent out of the way. Accordingly, specify the use of two piece adjustable ties or joint reinforcement with adjustable ties.

When walls are not designed so that the bed joints in both wythes occur at the same level at appropriate intervals, the two pieces of adjustable ties are vertically offset. The vertical distance between the two pieces is called eccentricity. Building codes (*Building Code*...1995) permit the use of adjustable ties having a maximum eccentricity of 32 mm (1-1/4 in.). An eccentricity of 32 mm. (1-1/4 in) reduces adjustable tie strength 90% and increases flexibility 500 times. If cavity walls do not 'course out', the use of eccentrically loaded adjustable ties could result in walls which are weaker and more subject to cracking which permits rain penetration, tie corrosion, and the other ill effects of excessive water. Tie eccentricity is entirely unnecessary, when bed joints in both wythes occur at the same vertical interval as tie spacing. Modular masonry design facilitates the use of adjustable ties with no eccentricity. Design cavity walls to 'course out'. Design adjustable ties with no eccentricity and specify mechanical play of not more than 1.2 mm (0.05 in.) (*Wall*... 1987, Grimm 1993).

MOVEMENT JOINTS

Movement joints in structures include building joints, expansion joints, control joints, and construction joints. To avoid very serious error, do not use the terms for the four types of joints interchangeably and show joint details. Masonry movement joints include expansion joints and control joints.

Building joints transverse the entire structure and are positioned to accommodate gross differential movement in the building, including especially differential settlement. Such joints are less frequent and wider than other movement joints in masonry.

Expansion joints close to relieve expansion of clay masonry due to heat, moisture, and freezing. Although shrinkage of concrete masonry usually exceeds its thermal expansion, this may not be true for dark colored concrete masonry. Although masonry expansion joints open to adjust to contraction as masonry cools or dries, their net movement is one of closure, because clay brick masonry has irreversible expansion due to moisture and freezing. Expansion joints should be entirely free of joint reinforcement, mortar, and debris. Expansion joint filler is not necessary, but its use will ensure that the joint is not bridged by mortar during construction. If a joint filler is used in an expansion joint, a force of no more than 69 kPa (10 psi) should compress the filler at least 50%.

Clay masonry expands. Structural frames contract due to elastic deformation, cooling, and creep. Accommodate differential movement between walls and frames by horizontal expansion joints between the soffit of spandrel beams and the top of masonry walls infilled in structural frames. A horizontal expansion joint placed between the top of a masonry wall and a flexural member above should ensure that deflection and column contraction do not load the wall. Provide horizontal expansion joints below shelf angles.

The thickness of those expansion joints depends on the anticipated differential movement, sealant joint compressibility, and acceptable risk of failure (Grimm and Yura 1989). The code (*Building Code*...1995) limits the deflection of beams supporting unreinforced masonry to 1/600th of the span. Horizontal expansion joint width can be reduced by limiting deflection of flexural members over non-bearing walls to 1/1000th of the span. The probability of a given differential movement between walls and frames is a function of materials types (Grimm and Yura 1989).

For example, if a clay masonry wythe is infilled in a concrete frame, the probability is 95% that the differential strain will not exceed 0.00207 mm/mm of wythe height (Grimm and Yura 1989). If the wythe height is 3.05 m (120 in., 10 ft.), the differential movement is 0.00207 mm/mm x 3050 mm = 6.3 mm (0.25 in.). If the spandrel beam deflects 3 mm (1/8 in., 0.125 in.), and shelf angle deflection is 1 mm (0.04 in.), then the total differential movement is 6.3 mm + 3 mm + 1 mm = 10.3 mm (0.41 in.). If the compressibility of the joint filler is 50%, the required expansion joint thickness is 10.3/0.5 = 20.6 mm (0.81) in.

Place vertical expansion joints in clay brick masonry: 1. at horizontal intervals of about 6.1 m (25 ft.); 2. at changes in wall height or thickness; 3. at pilasters, recesses, and chases; 4. at or near corners and wall openings; and 5. at wall intersections and where brick masonry abuts columns.

Control joints are placed in concrete masonry walls to accommodate CMU shrinkage. Place vertical control joints in concrete masonry walls at appropriate horizontal intervals and where expansion joints should occur in clay brick masonry as described above.

Design sealant joints in accordance with ASTM C 962. Where backer rods are not feasible, bond breaking tape can be used. Since the water permeance of the facade is dependent on sealants which have a mean life expectancy of seven years, advise the owner that frequent maintenance may be necessary.

AIR/VAPOR RETARDERS

Vapor retarders are not required in cavity walls in most building types in the 48 contiguous states. However, they are required where the average interior relative humidity exceeds 50% or where glazed brick is used if the weathering index (ASTM C 216) exceeds 50. Examples of building types in which the need for vapor retarders should be investigated include laundries, indoor swimming pools, hockey rinks, cold storage facilities, locker rooms, computer rooms, conservatories, and portions of hospitals. When required, a vapor retarder should be placed on that side of the insulation which is warmer for most of the year. Vapor permeance of a nominal 100 mm (4 in.) wythe of brick masonry is about 0.8 perm (gr/h-sq ft-in. Hg). Vapor permeance of a nominal 200 mm. (8 in) wythe of hollow CMU (limestone aggregate) is about 2.4 perm.

Air leakage is usually more important to condensation control than vapor diffusion. When an air pressure differential occurs across a wall, air may pass through or around the wall. A pressure differential may be caused by wind, fan pressure, or stack effect. In winter when warm air rises in a tall building, a positive pressure is created in the upper stories and a negative pressure in the lower stories. Air supply by mechanical ventilation may increase air pressure. Exhaust fans may reduce air pressure. A windward facade experiences pressure and a leeward encounters suction. These phenomena may create a significant pressure differential across the wall.

In winter if interior pressure is greater, air may exfiltrate to a cooler part of the wall where condensation can form. Condensed water can be just as damaging as wind driven rain. In hot-humid climates during summer warm moist exterior air may infiltrate and cause interstitial condensation. If the interior surface material becomes moist, mold growth may flourish (*Mold*...1991). An air barrier should be placed on that side of the insulation which is warmer most of the year.

An air retarder would limit air leakage and, thus mitigate the problem. The air retarder should be continuous, durable, impermeable, and structurally capable of sustaining the air pressure differential. A perfect air retarder is not attainable. Complete control of air and vapor flow is not feasible (*ASHRAE*...1989). For that reason and because of the permeance of masonry to wind driven rain, corrosion protection for metal connectors in masonry is an important design consideration.

For additional information on air and vapor retarders refer to references (Moisture...1988, *ASHRAE*...1989a, *ASHRAE*...1989b).

SHELF ANGLES

The exterior wythe of a non-bearing cavity wall is usually supported by a shelf angle attached to the structural frame. Support at least two thirds of the exterior wythe thickness on the shelf angle. If the wythe thickness is 75 mm (3 in.), that leaves 25 mm (1 in.) for installation of a sealant joint.

The exterior face of the exterior wythe is generally required to remain in the same plane as the exterior face of the wall below. A concrete structural frame may be out of plumb 10 mm (3/8 in.) in a story height, in which case a single shelf angle would have to move to the exterior by 10 mm (3/8 in.), leaving only 16 mm (5/8 in.) for a sealant joint. The resultant depth would preclude the use of a backer rod, and a bond breaker tape would be required.

Structural frames have greater allowable construction tolerances than masonry. The exterior face of walls are usually required to be in one plane. Construction tolerances for structural frames and masonry walls may result in dimensional incompatibility. Such problems should be anticipated in the design. Field adjustments are expensive.

Provide construction details which accommodate the construction tolerances permitted by the specifications. One solution is to use a shorter horizontal leg shelf angle and bolt a plate to it with slotted holes to permit adjustability. The structural design of shelf angles is described by Grimm and Yura 1989.

FINISHED GRADE

Slope finished grade adjacent to exterior walls away from the wall at a minimum grade of 5% for not less than 10 ft (3 m). Place the bottom of the cavity at least 200 mm (8 in.) above finished grade.

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