Essential Elements of Durable Exterior Masonry Walls

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INTRODUCTION

Masonry materials have been used by mankind for thousands of years. Typically defined as relatively small units of substantial material bonded together, masonry is one of civilization's oldest construction systems. It has evolved from the very simple prehistoric stone and mud wall, to today's high-performance, pressure-equalized rain screen.

Throughout its history, masonry has proven to be durable, easily constructible, and adaptable. However, modern masonry exterior walls are prone to many design, material, and workmanship deficiencies that can significantly impact their durability.

HISTORY OF MASONRY WALLS

Until the early 20th century, masonry buildings in the United States were typically constructed with solid, load-bearing masonry walls. These walls were constructed with several wythes of stone or brick and were designed to resist structural loads as well as provide weather resistance for the building envelope. While these walls were commonly referred to as "barrier walls," solid masonry walls were not impervious to water penetration. Their ability to resist water penetration was directly related to their overall thickness, mass, and ability to absorb significant amounts of moisture.

Materials used in early solid masonry walls were very porous. This allowed walls to absorb substantial amounts of water penetrating through cracks and other defects in exterior wall surfaces. Water would not reach the interior face of the solid walls until they were completely saturated. Freeze-thaw protection of the saturated porous materials was provided by the thermal mass of the walls. Thick, solid masonry walls retained heat, significantly limiting freeze-thaw cycles and thus limiting freeze-thaw degradation.

Solid masonry walls are still being constructed today, but they are far more susceptible to water penetration. Increased labor costs and demand for lighter and higher building structures required engineers, architects, and manufacturers to develop more cost-effective designs in order to keep masonry a viable building component option. The primary means of reducing cost and weight was to reduce the thickness of the solid walls. This required much higher quality masonry materials for two reasons. First, greater strengths were necessary to carry the same loads that thicker walls carried. Second, the reduction in thermal mass of the walls (due to reduced thickness and the use of hollow masonry units) increased the need for more freeze/thaw-resistant materials. The higher quality masonry units and mortar used today are far more impervious than the materials used in early solid masonry walls and absorb far less moisture. Therefore, water penetrating the surface of an exterior wall through cracks or other defects is forced to continue through the wall instead of being absorbed in the wall materials and will reach the interior surface much quicker *(Photo 1)*.

Photo 1: Water penetrating to interior surface of CMU wythe of solid masonry wall.

Due to obvious limitations of solid masonry walls, cavity walls have been used extensively for the past 50 to 60 years. Cavity walls consist of two wythes of masonry separated by an air space. Typically, the inner wythe of a cavity wall consists of concrete masonry units (CMU), while the outer wythe consists of clay brick masonry. Another form of cavity wall commonly used consists of a clay brick exterior wythe in conjunction with a back-up wall made of metal studs and an exterior sheathing.

Cavity wall design recognizes that water penetration into masonry walls is inevitable and provides the necessary means to manage the water. Properly designed, detailed, and constructed cavity walls can prevent water penetration through the system. Unfortunately, masonry walls are not always properly designed, detailed, or constructed. It is these deficiencies in design, detailing, and construction of the modern cavity wall system that significantly reduce its durability, reliability, and effectiveness.

DESIGN DEFICIENCIES

Durability of masonry walls begins with good design. The two primary factors that most affect the durability of modern masonry walls (and that must be thoroughly understood by the design professional) are movement and moisture control.

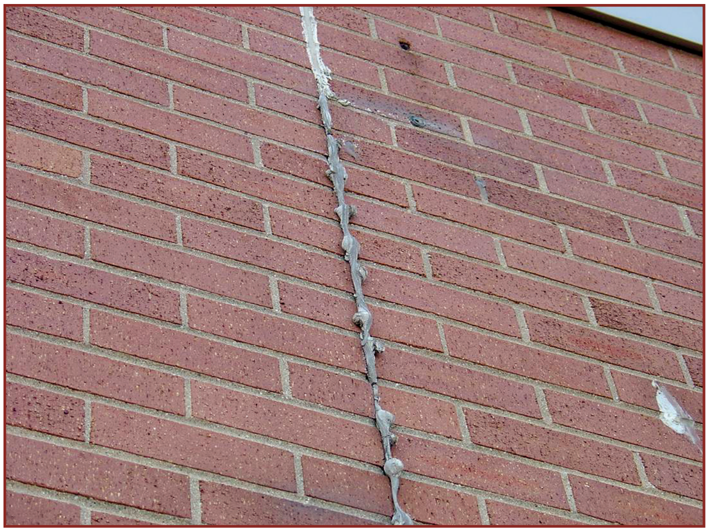


Photo 2: Sealant compressed out of improperly sized vertical expansion joint.

Movement Control

Movement in masonry walls is typically caused by changes in moisture content and temperature. Clay brick masonry units are their driest and smallest when they are removed from the kiln. From that point forward, they continually absorb moisture and irreversibly expand in size. Conversely, typical concrete masonry units are their largest at the time of casting and irreversibly shrink with time. The rate of clay masonry expansion and concrete masonry shrinkage slows over time. In addition to their initial moisture-related movements, masonry materials also expand and contract with changes in temperature.

Thermal and moisture expansion of clay masonry units require both vertical and horizontal expansion joints in masonry walls. Long lengths of unrestrained walls without vertical expansion joints will increase in length and displace adjacent walls away from their back-up materials. This displacement typically results in cracking at building corners and at discontinuities along the lengths of walls. Long lengths of restrained walls without vertical expansion joints will build up compressive stresses until the wall buckles.

Horizontal expansion joints must accommodate vertical expansion of masonry walls. These joints are usually placed immediately beneath shelf angles, which are typically supported by the building frame at each floor line. If clay masonry is installed tightly to the bottom of the shelf angles, the wall will likely buckle since vertical expansion will be restrained. Placing shelf angles at every other or every third floor will increase the accumulated movements in the exterior wythe and exacerbate the effects of improperly constructed horizontal expansion joints. In addition, placement of shelf angles at every other floor can create problems at window lintels and intermediate floor lines if details are not provided to accommodate wall movement.

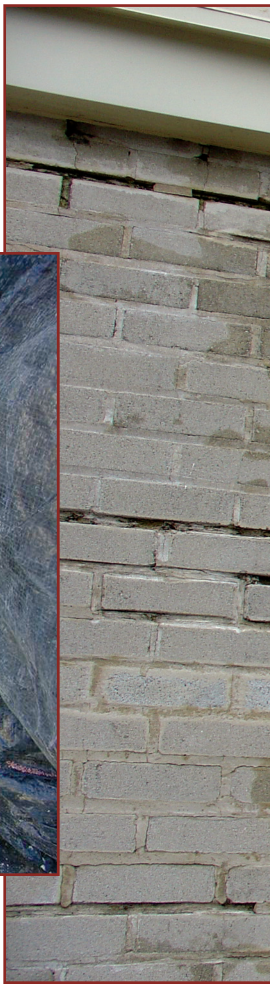
Shrinkage of concrete masonry requires adequately spaced vertical control joints to minimize cracks along the length of the wall. Similar horizontal control joints are necessary at the top of non-loadbearing walls to accommodate shortening without opening up gaps between the top of the walls and structural or architectural elements above.

Photo 3: Narrow wall cavity difficult to keep clean during construction.

Location of control and expansion joints and sizing of expansion joints are critical to minimize cracking and displacement of masonry. Expansion joints that are too narrow will close and begin to cause cracking and displacement as if the joints were never present *(Photo 2)*. Improperly spaced or located control and expansion joints will do the same.

Many problems associated with movement of masonry walls are due to the use of clay and concrete masonry units in the same wall system. The expansion of clay and shrinkage of concrete result in differential movement between the two materials. Improperly incorporating these two materials together in the same or separate wythes will typically cause unwanted cracking, bowing, and displacement.

Even if these materials are separated, as in cavity walls, the differential movement still needs to be accommodated. The exterior wythe of brick is required to be tied to the interior CMU wythe at regular vertical and horizontal spacing, as specified in Section 6.2.2.5 of the ACI 530 Building Code Requirements for Masonry Structures. This is usually accomplished with individual ties or continuous horizontal reinforcement. In either case, flexibility is necessary to allow horizontal



and vertical differential movements between the two wythes. For instance, continuous truss-type reinforcing will not allow horizontal movement between two wythes due to its inherent rigidity in the horizontal direction. Ladder-type reinforcing must be used if continuous horizontal reinforcement is specified.

Another type of movement that needs to be addressed in the design of masonry walls is lateral deflection. Exterior wythes of cavity or veneer walls are usually not designed to resist wind loads. Wind loads are typically transferred to interior wythes or stud walls through the ties. Those back-up elements must provide enough stiffness to prevent excessive deflection, and thus cracking, of the exterior masonry. This should be a significant consideration when designing masonry cavity wall systems with a metal stud back-up, since metal stud back-up systems are typically much less rigid than masonry back-up systems. Although ACI 530 does not provide any specific limitations on deflection of backup materials, the Brick Industry Association recommends that the lateral deflection of metal stud back-up systems be limited to L/600, where L is the unsupported length of the stud. For a 10-foot, unsupported wall height, the limiting deflection would be 0.2 inches.

Moisture Control and Water Management

The primary purpose of exterior masonry walls is to protect the interior of buildings from the environment. If water migrates to the interior of the building, the exterior walls have failed to perform their intended function. As previously indicated, modern solid masonry walls have little tolerance for deficiencies. Defects in exterior wall surfaces will lead to nearly instant water penetration. If not handled by the internal water management system, such water penetration can manifest as leaks inside the building.

On the other hand, properly designed, detailed, and constructed cavity walls can accommodate some exterior wythe defects without allowing water to penetrate to interior surfaces. For these walls to function as intended, they must be designed with a minimum 2-inch wide cavity. This dimen-

Photo 4: Freeze-thaw deteriorated mortar joints.

sion is considered the minimum width necessary, as recommended by the Brick Industry Association (BIA), to prevent the cavity from being bridged by mortar or other materials and allow water to cross over to the interior wythe. Narrower cavities are typically more difficult to keep clear during construction *(Photo 3)*. However, it should be noted that mortar bridging can still occur with a wider cavity if the masons do not exercise care to keep the cavity clear during construction.

Another requirement for cavity walls is a system to remove water from the wall. Flashing and weeps at the base of the wall and at all penetrations are typically used for this purpose. The flashing must be continuous, terminated properly at the interior wythe, extended past the face of the exterior wythe, and terminated at its ends with end dams. The joint above the flashing is where water exits the wall system. Weeps should be placed at no more than 24 inches apart at this level, and the joint should be filled with mortar instead of sealant.

Another method to improve the moisture resistance of masonry cavity walls with a CMU back-up is to coat the outside face of the back-up with a dampproofing material. While dampproofing does not provide any substantial protection against water intrusion, it will minimize the moisture absorption of the CMU when bridging occurs. Even if the cavity is kept completely clear, the masonry ties can bridge the gap and allow the water that runs down the inside face of the exterior wythe to reach the outside face of the interior wythe. Application of dampproofing requires careful consideration to ensure that moisture vapor transmission characteristics of the wall assembly are not adversely impacted.

In cavity wall construction with metal stud and sheathing back-up, a weather-resistive barrier (WRB) should be provided to minimize water penetration through the sheathing.

Lastly, proper design details should be conveyed to the masonry contractor in the design documents. In the authors' opinion, it is not uncommon to see a set of drawings for complicated masonry construction without adequate detailing of the water management system within the walls. During the design phase, the designers should consider all installation conditions and develop an appropriate detail for each condition.

MATERIAL DEFICIENCIES

Materials used in the construction of masonry walls have a major impact on their sustainability. The primary component materials include the masonry units, mortar, flashing, and metal supports.

Masonry units must have the appropriate physical properties to withstand the service conditions in which they will be placed. Poor freeze/thaw-resistant brick will quickly deteriorate in severe weathering regions. Excessive coefficients of thermal and moisture expansion will likely cause expansion of walls to exceed that anticipated by the designer, causing cracking and displacement the walls.

Similarly, mortar must have appropriate physical properties for the intended service conditions. Strength, workability, and freeze/thaw resistance are all important properties to consider when specifying mortar *(Photo 4)*. The mortar must also be compatible with the masonry units to ensure proper bond.

Durable flashing materials are necessary for durable masonry walls. Flashing that can be easily punctured, extrudes under the weight of the brick wall, is difficult to seal at its seams, and is UV degradable, will increase the likelihood that water will penetrate beyond the flashing to the interior surfaces of the masonry wall system.

Metal supports include ties and shelf angles. These components are subject to far more water in masonry walls today than they were in early masonry walls, primarily due to their design but also due to workmanship. As a result, metal components in masonry walls will corrode more quickly.

Selection of metal components should consider the expected service life of the wall system. Most masonry wall systems are expected to last far more than 50 years. Yet the use of corrosive metals within the walls will significantly lower their life expectancy. Corrosion of metals in masonry walls can lead to many problems, including cracking and bowing. Correction of such deficiencies requires costly and extensive rehabilitation. As such, durable metals should be used in conjunction with masonry wall construction. At a minimum, ties and bolts should be made of galvanized steel. In many cases, the use of stainless steel ties and bolts can be justified when considering the life cycle costs of the system. In the authors' opinion, shelf angles and lintels used in modern masonry construction should be hot-dipped galvanized after fabrication. If galvanizing cannot be justified, shelf angles and lintels should be coated with high performance, corrosion-inhibiting coating systems to achieve a service life that is compatible with the expected service life of the wall system. In most cases, life cycle costs for these items are very small in comparison with the cost to replace them part of the way through the design life of the wall system.

Photo 5: Mortar improperly placed in horizontal mortar joint and brick not properly supported on shelf angle.

WORKMANSHIP DEFICIENCIES

The final step to achieving sustainable masonry walls is assuring good workmanship during installation. Properly designed and detailed walls with carefully specified materials will still be subject to accelerated deterioration if good workmanship is not provided during installation.

The various components of masonry walls are as follows:

- The air space between the exterior and interior masonry wythes must be kept clean. Partial-height mortar nets are not sufficient since they still allow mortar to bridge between the two wythes at the top of the mortar net. The use of full-height mortar nets or drainage boards is gaining more popularity to ensure an open cavity for drainage.
- Vertical and horizontal expansion joints must be kept clean to allow them to function as intended *(Photo 5)*. Obstructions over only a portion of these joints can still cause cracking and displacement of adjacent masonry.
- Flashing must be carefully installed to ensure that it will be watertight. Open seams, punctures, and other damage to the flashing must be avoided, end dams must be installed, and flashing must not be trimmed back too close to the face of the wall *(Photo 6)*. Since most through-wall flashing materials degrade rapidly when exposed to UV, stainless steel drip edges are typically incorporated into the flashing system to extend beyond the face

ROOF KNOWLEDGE ASSESSMENT

Test your knowledge of roofing with the following questions, developed by Donald E. Bush Sr., RRC, FRCI, chairman of the RRC Examination Development Committee. These wind-related questions are based on the information contained in RCI's Wind and Drainage class.

1. **At normal temperature and pressure, what is the density of air?**
2. **Velocity pressure, q, is a function of wind speed, v. If wind speed is 100 mph, what is the velocity pressure?**
3. **What is Bernoulli's Equation?**
4. **The protective effect of a parapet at least 3 feet high is to reduce the corner pressure. When should this protective effect be considered?**

Answers on page 18

ROOF KNOWLEDGE ASSESSMENT

Answers from page 17:

1. **Nearly 0.0765 pounds per ft^3.**
2. **q = 0.00256(100)^2 = 25.6 psf**
3. **Bernoulli's Equation is the application of the Law of Conservation to a fluid (liquid or gas) in motion. When applied to air, this equation states that the pressure at any point in the air [which is in steady state (nonturbulent) motion], is constant. This pressure has two components: (a) a static pressure, which is the ambient atmospheric pressure, and (b) velocity pressure, which is the kenetic energy of air (total air pressure equals atmospheric pressure plus velocity pressure).**
4. **Only when the parapet has been designed to withstand peak wind loads.**

of the masonry.

- Materials must be supplied and installed as specified by the design professional. Use of poor quality mortar materials, poor quality brick, and non-corrosion-resistant metal cannot be allowed. In addition, steps should be taken to avoid exposing freshly placed masonry materials to hot or cold conditions. ACI 530.1 provides excellent guidelines for hot and cold weather masonry construction.
- Shelf angles must be installed so they provide continuous support around corners and are properly anchored. Their connections to the building frame should be constructed to minimize deflections when subjected to the weight of the masonry above. Shelf angles must also be protected from corrosion.

CONCLUSIONS

Masonry can be as durable as any other building material. We know this because of all of the buildings with masonry components that are still performing centuries after construction. However, without the essential elements of good design, material specifications, and workmanship, masonry building components will deteriorate far faster than they should.

Photo 6: Improperly sealed flashing seam.

For the long-term durability and effectiveness of exterior masonry walls, it is critical that the design process consider wall movement, moisture penetration, and water management. Masonry materials specified and used must be suitable for their intended environment. Finally, the walls must be constructed as designed and specified. Ensuring these essential elements in exterior masonry projects will result in serviceable walls for the anticipated life of the building.

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