FACTORS THAT DIMINISH THE SUSTAINABILITY OF MASONRY WALLS

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Introduction

Masonry materials have been used by mankind for many thousand 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, adaptable, and thus, sustainable. However, modern masonry exterior wall assemblies are prone to many design, material, and workmanship deficiencies that can significantly impact their sustainability.

History of Masonry walls

Up 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 resists 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 their 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 are far more susceptible to water penetration. Increasing 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.

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 consisting 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 wall system. Unfortunately, masonry walls are not always properly designed, detailed, or constructed. It is the deficiencies in the design, detailing and construction of the modern cavity wall system that significantly reduces its sustainability and reliability.

Design deficiencies

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

Movement Control

Movement in masonry walls is typically caused by changes in moisture content and temperature. Clay 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 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 irreversible moisture expansion of clay masonry units requires 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 out away from their backup materials. This displacement nearly always results in cracking at the corners of buildings and at discontinuities along the lengths of walls. Long lengths of restrained walls without vertical expansion joints will build up compressive stresses within the wall 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 tight 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 also 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 shrinkage 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.

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 there. 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 almost always cause unwanted cracking, bowing, and displacement.

Even if these materials are separated, as in cavity walls, the differential movements still need 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 which 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. Although ACI 530 does not provide any specific limitations on deflection of backup materials, the Brick Industry Association recommends that the deflection of metal stud back-up systems be limited to L/600.

Moisture Control and Water Management

The primary purpose of exterior masonry walls is to protect the interior of buildings from the environment. If water finds its way 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 dimension is considered the minimum width necessary to prevent the cavity from being bridged by mortar or other materials and allowing water to cross over to the interior wythe. Narrower cavities are typically more difficult to keep clear during construction. 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, is typically used for this purpose. The flashing must be continuous, properly terminated 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 design 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. Higher than normal coefficients of thermal and moisture expansion will likely cause expansion of walls to exceed the design expansion, cracking and displacing 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. 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 degradeable will increase the likelihood that water will penetrate beyond the flashing and through 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 corrodible 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 partway through the design life of the wall system.

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 which are carefully detailed and specified by design professionals must be correctly supplied and installed during construction.

- 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.

- Flashing must be carefully installed to ensure it is 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. Since most through-wall flashing materials degrade rapidly when exposed to UV, stainless steel sheet metal drip edges are typically incorporated into the flashing system to extend beyond the face 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 sustainable as any other building material. We know this because of all of the buildings with masonry components that are still performing their intended function, centuries after construction. However, without good design, material specifications, and workmanship, masonry building components will deteriorate far faster than they should.