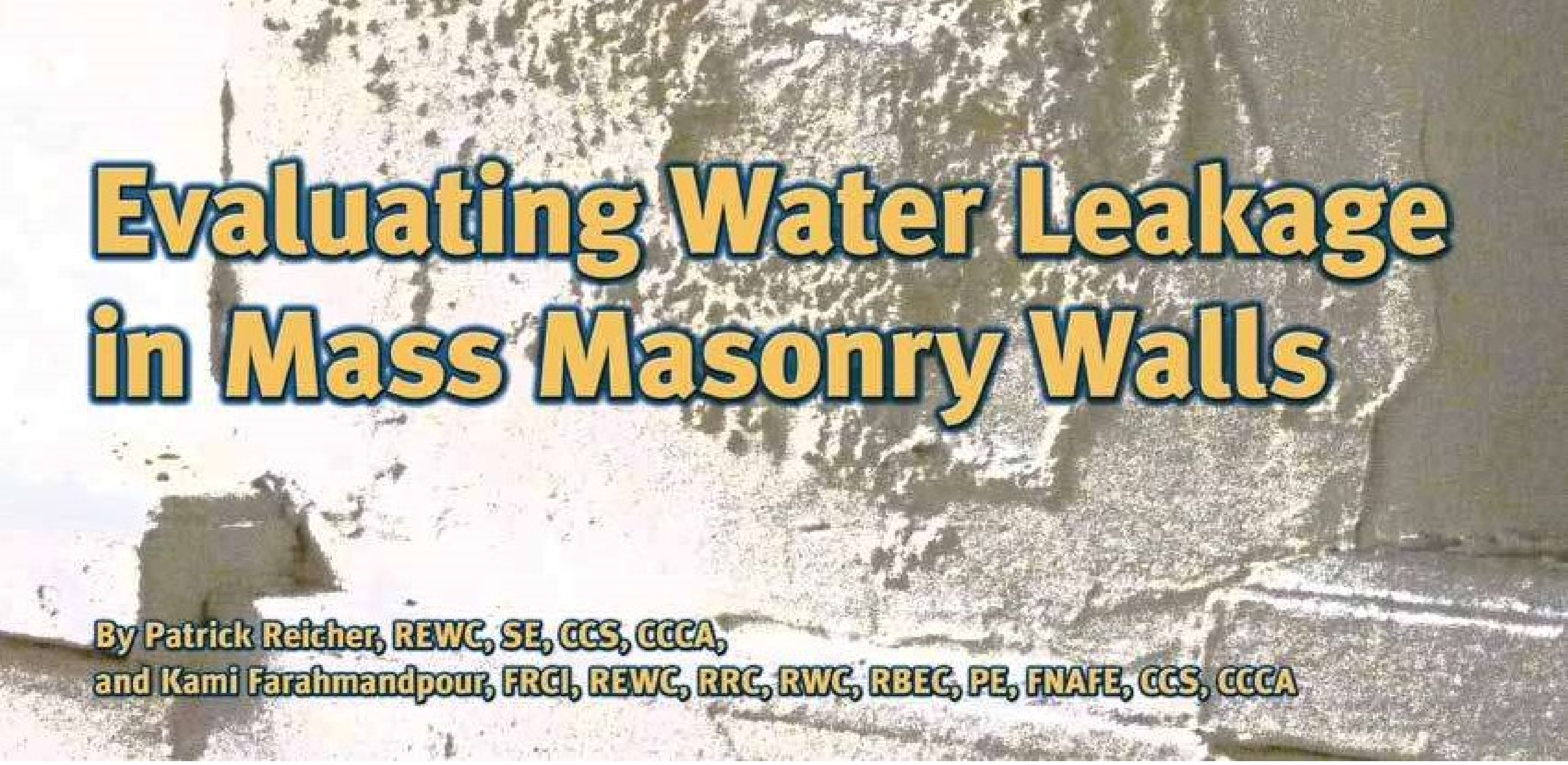


Evaluating Water Leakage in Mass Masonry Walls

By Patrick Reicher, REWC, SE, CCS, CCCA,
and Kami Farahmandpour, FRCI, REWC, RRC, RWC, RBEC, PE, FNAFE, CCS, CCCA

INTRODUCTION

Prior to the 1950s, many buildings were constructed using multi-wythe mass masonry walls. Such walls typically did not include air barriers, weather-resistive barriers, vapor retarders, or thermal barriers, as do modern wall assemblies.

Buildings consisting of mass masonry are highly dependent on the thickness of their walls and the quality of masonry units and mortar joints within the walls to control water leakage. Over time, such buildings will inevitably exhibit water leakage or will have components that exhibit deterioration due to excess moisture accumulation within the walls. Prior to implementing a repair program to address such issues and to extend the building's useful life, a systematic condition assessment and water leakage evaluation should be performed. This article describes a methodology for performing water leakage evaluations for mass masonry walls.

MASONRY WALL TYPES

Prior to the 1950s, multi-wythe mass masonry wall systems consisting of solid masonry for their entire thickness were commonly used. Newer and lighter masonry walls were developed after that time. By the 1980s, masonry cavity walls incorporating a water management system were widely used. These walls utilize a drainage cavity, including through-wall flashing and weeps to divert water that penetrates through the single-wythe masonry veneer to the exterior. Ideally, masonry cavity walls are designed and constructed with a weather-resistive barrier installed on the exterior face of the back-up wall to prevent water within the drainage cavity from penetrating further into the wall. Cavity wall construction also typically includes insulation on either the interior or exterior side of the backup wall.

Both mass masonry walls and masonry cavity walls rely on the bond between mortar and masonry units to limit water penetration beyond the exterior wythe of the wall or the veneer. Aside from this similarity, mass masonry walls function entirely differently than modern cavity walls. Mass masonry walls rely on their large mass to absorb water that inevitably penetrates beyond the exterior face of the wall. This water is stored within the masonry until it can evaporate to the exterior environment or into the building. Since no insulation was typically used on the interior of the walls, interior paint was highly permeable, and interior spaces were not air-conditioned prior to the mid-1900s, moisture evaporation to the interior did not typically pose significant issues. Additionally, the interior finish on mass masonry walls was often constructed of cement plaster, which was not susceptible to moisture damage like gypsum plaster. Lack of insulation and the large thermal mass of the masonry also helped keep mass masonry walls relatively warm and reduced temperature fluctuations.

Mass masonry walls can be either load-bearing or non-load-bearing. Most buildings with load-bearing walls have been limited to approximately four stories in height, though several such buildings are much taller. Most mid-rise and high-rise buildings included non-load-bearing mass walls constructed with masonry infill between floor slabs. In some instances, the structural concrete frame was exposed to the exterior, with mass masonry infill walls constructed between structural frame elements. In other buildings, the structural frame was completely concealed by the exterior wythe of masonry. In these cases, the exterior wythe of masonry was often supported by shelf angles anchored to concrete slab edges. The remaining wythes of masonry were typically supported directly on the floor slabs. The confinement of the masonry infill walls by the building frame causes several issues due to differential movement between the frame and the masonry. For example, deflection of floor slabs that support the masonry can cause cracking. Additionally, the irreversible expansion of the masonry infill can cause stresses to build up within the infill walls, sometimes resulting in bowing.

In both load-bearing and non-load-bearing masonry mass walls, the individual masonry wythes were typically connected using masonry header courses.

WATER PENETRATION THROUGH MASS MASONRY WALLS

Mass masonry walls are susceptible to water penetration due to several factors.

Photo 1 – Open mortar joint between limestone and brick masonry provides a path for water penetration beyond the exterior wythe of masonry.

Photo 2 – Parapet wall lateral displacement due to inadequate accommodation of irreversible expansion of the brick masonry.

These factors include the following:

1. The condition of mortar joints on the exterior face of the walls greatly impacts the quantity of water that is shed versus that absorbed into the walls. Mortar joints that bond well to masonry units typically serve to reject most of the water that contacts the exterior face of the walls. However, cracked and/or open mortar joints will provide a path for water penetration beyond the exterior wythe of masonry (*Photo 1*). For several reasons, the mortar and masonry units cannot be made completely watertight.
2. Mass masonry walls were typically not designed with movement joints to accommodate irreversible expansion of brick masonry, building frame movements, and movements associated with temperature and moisture. Lack of movement joints can result in stress buildup. Such stresses can cause cracking, localized displacement (*Photo 2*), failure of headers, and/or bowing. The cracks will provide a direct path for water penetration beyond the exterior wythe of masonry.
3. Brick masonry headers were typically used to connect the exterior wythe to the remainder of the wall. Over time, these headers can fracture due to shear stresses, deterioration, or other means. Shear stresses can build up due to differential thermal, frame, or irreversible moisture movements between

Photo 3 – Leak location at wall section reduced from four- to two-brick masonry wythes to accommodate internal drain pipe.

Photo 4 – Use of hollow clay tile units as backup wythes reduces the mass of masonry that can absorb and retain moisture.

the exterior wythe and inner wythes. Where headers fail, the exterior wythe of masonry can move independently of the interior wythes, typically manifesting as bowing. Cracks in the mortar joints and/or masonry will inevitably develop due to this movement, allowing for water penetration beyond the exterior wythe.

4. Embedded shelf angles were often constructed without sufficient protection to inhibit corrosion. As the steel corrodes and expands to several times its original size, cracks will develop, allowing water penetration. Steel corrosion can also cause shear stresses that can lead to failure of brick headers.
5. If the walls are not sufficiently thick to provide a large mass to absorb moisture, they can transmit free moisture through their thickness far sooner than more massive walls. In our experience, walls less than four wythes thick are particularly susceptible to occasional water leakage. Where portions of walls become less than four wythes thick at specific locations, they will also be more susceptible to leaks (*Photo 3*). Similarly, the use of hollow units, such as hollow clay tiles, in lieu of solid masonry units as backup wythes, reduces the mass of masonry that can absorb

and retain moisture, thus increasing susceptibility of water leakage (*Photo 4*).

6. The exterior and interior surfaces of mass masonry walls dry out faster than the center wythe(s) due to their exposure to the environment. As such, thick walls will retain moisture for a long duration, and deterioration of mortar and masonry within the walls is expected (*Photo 5*). Such deterioration reduces the ability of the walls to absorb and retain additional moisture, leading to more susceptibility to leaks. In many cases, such deterioration goes unnoticed since it is not visible without first removing masonry from the face of the wall.
7. Inadequate workmanship or use of substandard materials during original construction can result in voids within the walls or weak mortar joints that are susceptible to freeze/thaw deterioration. This reduces the ability of the walls to absorb and retain moisture and provides paths through the wall for water penetration.
8. Mass masonry walls were typically constructed with cement plaster directly applied to their interior face as a finish. Properly applied, the cement plaster provided for another line of defense against moisture intrusion. However, more importantly, the cement plaster was not susceptible to degradation when exposed to moisture. Over time, many mass masonry wall

Photo 5 – Deterioration of masonry and mortar within the exterior wall.

Photo 6 – Deterioration of interior gypsum-based plaster finishes.

interior finishes have been repaired using gypsum plaster or alternative products such as gypsum sheathing. These materials are far more susceptible to degradation due to exposure to moisture. As such, it is not uncommon to encounter mass masonry walls with gypsum-based interior finishes that exhibit ongoing plaster deterioration (*Photo 6*).

EVALUATING LEAKS IN MASS MASONRY WALLS

ASTM E2128, *Standard Guide for Evaluating Water Leakage of Building Walls*, describes methods for evaluating causes of water leakage of exterior walls. The recommended sequence of activities for an exterior wall leak evaluation program is summarized as follows, with steps listed in parenthesis:

1. Background review (review of project documents, evaluation of design concept, determination of service history)
2. Field investigation (visual inspection, investigative testing, exploratory openings, laboratory testing)
3. Analysis and reporting (analysis, report preparation)

The recommended protocol established by ASTM E2128 can be used as the basis for an exterior wall leak evaluation, regardless of wall system or material. With specific regard to mass masonry walls, the following items should be considered.

Review of Project Documents

Documents that may be helpful for the investigator include original design documents, codes and standards referenced in the original design documents, submittals, shop drawings, construction photographs and field reports, project closeout documents, and records pertaining to prior repairs.

An accurate set of record drawings can be particularly useful. These documents, taken as a whole, can provide the investigator with a considerably detailed description of the wall construction.

Unfortunately, original design documents for buildings constructed in the late 19th and early 20th centuries usually consisted of only a few sheets of drawings describing the materials and work required for construction. More detailed forms of project documents were not consistently used until after World War II.[1]

Because document reproduction was once a time-consuming and potentially cost-prohibitive undertaking, only a few copies of the original design documents may have been developed. In many cases, the original design documents may have been misplaced or inadvertently destroyed, and thus unavailable to the investigator. In cases where the original design documents are available, they may not be legible. In many cases, none of the original construction documents or records related to prior repairs have survived changes in building management and ownership.

Nonetheless, investigators should make every effort to obtain pertinent project documents and glean as much information from them as possible. For most projects, however, the investigator will need to document existing and as-built conditions during a field investigation.

Evaluation of Design Concept

Understanding the moisture management scheme used for a wall is a critical component of the investigation. Misunderstanding of how the wall system was intended to manage moisture can lead to improper investigation techniques and false conclusions.

Mass masonry walls were not designed with explicit water-resistance performance requirements in mind. Rather, these walls were designed and constructed of sufficient thickness and mass to allow the walls to absorb and store water until it could evaporate under favorable conditions.

Understanding the structural behavior of the wall is also important. For load-bearing walls, wall thicknesses were typically governed using empirical methods. For non-load-bearing walls, exterior wythes of brick were typically designed to be supported on shelf angles. Details for such systems must provide for the interfacing and integration of components so that each one can perform individually and so that the components can perform collectively as a system.

Determination of Service History

Prior to recommending a field investigation protocol, an investigator should perform a cursory visual evaluation of areas with known leaks, interview building occupants and maintenance personnel, and review leak records. Patterns of the reported leakage and visible damage will provide hypotheses as to the causes. In some cases, obtaining historic weather records near the building can also be useful.

Except under the most severe conditions, leaks through mass masonry wall systems are unlikely to manifest immediately after a rain event. Typically, leaks due to precipitation manifest after long periods of rain, once the walls have become saturated. As such, leaks reported shortly after rain commences should be treated with

Photo 7 – Calibrated spray rack testing performed on mass masonry wall with adjacent window opening masked to isolate the masonry.

caution. The investigator should consider whether water infiltration could be due to some other mechanism or source (condensation, change in interior relative humidity, piping systems, etc.), or through some other building component (fenestration, window perimeter sealant, wall penetrations, roofing system base flashing, etc.).

Buildings that exhibit water leakage may have been previously repaired on one or more occasions. Although well intended, these previous repairs may be contributing to the current leakage. It will be necessary to distinguish between original construction and attempted repairs during subsequent phases of a systematic evaluation.

Visual Inspection

The major objectives of a visual inspection program are to determine as-built conditions, document apparent water damage and potential water leakage paths, and formulate hypotheses about the cause(s) of water leakage. When a visual inspection of the entire building façade is not practical due to access limitations, inspected areas should include both typical and unusual conditions and properly performing and non-performing wall sections. A sufficient number of inspection locations on the interior and exterior of the building must be selected to accomplish these objectives. Other components, such as fenestrations and perimeter sealant around windows and doors, should also be reviewed during this stage.

Since project documents for mass masonry buildings will often not be thorough enough to provide the investigator with adequate background information, more inspection locations may be required than are typically needed for newer buildings. Information lacking in the design documents must be generated from observations, measurements, and exploratory openings in the field. However, such exterior exploratory openings should not typically be made until after investigative testing is performed to allow the wall to be tested in its current "as-found" condition.

Investigative Testing

The primary objectives of investigative testing are to recreate leaks that are known to occur, trace internal leak paths under controlled and reproducible conditions, and correlate test results with observed damage. Regardless of wall type, best practices for investigative testing include the following:

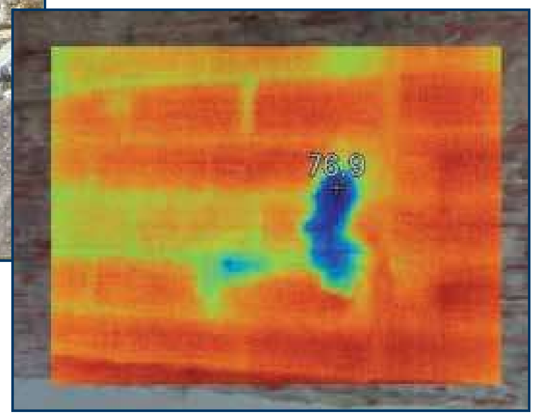
1. For diagnostic purposes, a wall should be tested in its current as-found condition.
2. Effective diagnostic testing should result in the identification of entry points by isolating adjacent wall components during testing. Where there are windows or other penetrations adjacent to the masonry being tested, they must be masked such that deficiencies in adjacent components or systems cannot contribute to observed water penetration. Those components should also be tested separately by isolating them from the adjacent masonry.
3. Testing of isolated areas should begin at the bottom of the test area and progress vertically to the top.
4. Once testing produces a leak, the entry point and the path followed by the water within and through the wall must be traced.
5. Interior finishes must be removed in the vicinity of the water testing to readily observe water penetration. However, in the case of interior cement plaster finishes, the removal should be limited to the interior paint to facilitate observation of wetting patterns. Complete removal of the interior plaster can also yield misleading results.
6. Testing conditions should replicate those that resulted in leaks as closely as possible.

While item numbers 1 through 5 above can be readily accomplished during a testing program, replicating the actual conditions under which leakage occurs is not always possible when testing mass masonry walls. Additionally, there are no widely accepted diagnostic test methods that have been specifically developed for evaluating leakage through mass masonry walls. Fortunately, ASTM E2128 allows diagnostic test methods to be adapted from existing test methods and procedures to meet specific objectives for a particular building. Based on our experience, we have found the following test methods appropriate for use when diagnosing leaks through mass masonry walls.

1. **Calibrated Spray Rack Testing.** Procedures similar to those for ASTM E1105, *Standard Test Method for Field Determination of Water Penetration of Installed Exterior Windows, Skylights, Doors, and Curtain Walls by Uniform or Cyclic Static Air Pressure Difference*, can be utilized. This test is performed by wetting a wall area with a matrix of uniformly spaced spray nozzles that deposit a film of water to the wall's exterior surface, typically at a rate of 5 gallons per square foot per hour (*Photo 7*).

Photo 8 – Chamber securely anchored to masonry wall during an ASTM C1601 test.

Photo 9 – Extent of saturation detected on the interior of the building using infrared thermography during a calibrated spray rack test.



Although ASTM E1105 utilizes an air pressure differential between the interior and exterior, tests performed on mass masonry walls are typically performed without differential pressure. Due to the many different air paths through the walls, use of a localized chamber to induce an air pressure difference across the wall thickness is typically impractical. If a nominal air pressure differential is desired by the investigator, use of a blower door apparatus can be considered.

During the test, water flowing down the face of a wall by gravity is capable of causing leaks under some circumstances, even without differential pressure. We have found these tests, which simulate surface flow alone and without differential pressure, are a useful first test. However, unless differential pressure is applied across the wall assembly, the time for the leaks to manifest on the interior of the building can be much longer than the standard test duration of 15 minutes.

2. **Calibrated Spray Nozzle Testing.** Procedures similar to those for the American Architectural Manufacturers Association's *Quality Assurance and Diagnostic Leakage Field Check of Installed Storefronts, Curtain Walls, and Sloped Glazing Systems* (AAMA 501.2) can be used. This test is performed by spraying water through a designated nozzle at a pressure of 30 to 35 psi while holding the nozzle approximately 1 foot from the tested wall surface.

This test is suited only for small areas suspected to be problematic (penetrations, cracked masonry, etc.). This test can also be performed at interfaces with dissimilar materials or systems, provided that the masonry is isolated from adjacent construction. However, the authors discourage the use of this test method for diagnosing leaks through the field of the masonry walls, as it is primarily intended for glazing systems. During the test, the nozzle can be moved slowly across the interface between the mass masonry wall surface and adjacent components, moving from low to high areas. As with calibrated spray nozzle testing, the time for the leaks to manifest on the interior of the building can be substantial.

3. **Chamber Testing.** Chamber testing (with differential pressure) can be performed in general accordance with ASTM C1601, *Standard Test Method for Field Determination of Water Penetration of Masonry Wall Surfaces.* Typically, such tests are performed using a chamber pressurized to 10 pounds per square foot (psf), and a water flow rate of 3.4 gallons per square foot per hour. The test methodology includes provisions to modify water flow rates and differential pressure based on actual in-service conditions that resulted in leaks.

While this test method was originally developed to measure water penetration through the exterior surface of the wall, the method can be adapted to mass masonry walls (*Photo 8*). In addition to providing for a quantitative measure of water penetration through the exterior face of the wall, this test method also replicates wind-driven rain far more accurately than the tests discussed above.

The following tools can be used during water testing to assist in interpretation of the results:

1. Infrared thermography can be used to monitor water penetration and extent of saturation on interior wall surfaces in the vicinity of water testing. Surface evaporation at water penetration sites or damp areas results in lower surface temperatures that can be detected using an infrared imager (*Photo 9*).
2. High internal building pressures commonly caused by the mechanical systems or stack effect can make it difficult to recreate leaks that occur under wind-driven rain conditions. As such, differential air pressure measurements should be made during water testing to evaluate contributions of internal building pressure to interior water leakage. These differential pressure measurements are made using a digital micromanometer by extending a plastic tube from the micromanometer to the exterior of the building.

In many cases, fenestrations will need to be tested as part of a comprehensive testing program. There are several standard test methods that can used for such purposes. As an example, sill dam tests can be performed in general accordance with AAMA 511. Water testing can also be performed in accordance with ASTM E1105 or AAMA 501.2. Similarly, test methods may be utilized to evaluate the roof membrane, base flashing, and/or roof drains if reported leaks are located near the top of the building.

Exploratory Openings

Exploratory openings involve the progressive removal of wall materials to reveal underlying, concealed conditions. Exploratory openings are made to evaluate the extent, significance, and cause of observed deterioration and hidden deficiencies that may be allowing water leakage into interior areas.

A masonry restoration contractor will typically be required to provide access and to make and temporarily repair exploratory openings. In many cases, the existing original masonry will be damaged and cannot be reinstalled. As such, new masonry should be procured prior to the start of the field investigation. The building owner should be forewarned that it may not be possible to match the new masonry to the existing masonry in size, color, and texture. As an example, pre-1950 masonry walls were typically constructed using nonmodular, standard-size units (8 inches wide). Modern brick is typically constructed in modular sizes (7⅝ inches wide).

It is imperative that the investigator observe the exploratory opening as it progresses. Sometimes, damage to brick headers can result from the removal process. Carefully watching the removal process will help an experienced investigator to evaluate what caused the damage.

Exploratory openings also provide for an opportunity to observe potential water travel paths (*Photo 10*). In solid masonry walls, dirt deposits within the wall are typical indications of prolonged water travel. When examining fractures, dirt deposits within the fracture plane also help the investigator evaluate if the fracture is fresh (i.e., a result of the removal process) or old.

Photo 10 – Staining on backup brick masonry indicates water travel path through wood windowsill into masonry wall.

Material samples can be taken from exploratory openings for subsequent laboratory testing.

Laboratory Testing

There are numerous laboratory-testing methods that can be used to evaluate the quality of materials within a solid masonry wall or to assess deterioration mechanisms. A complete review of these test methods is beyond the scope of this article.

Some of the most common tests employed as part of investigating older masonry walls are petrographic examination and chemical testing of mortar materials. These tests provide valuable information regarding mortar constituents and proportions. Such information is important when specifying repair mortars for repointing or reconstruction of the masonry.

Analysis and Report

A comprehensive diagnostic program should result in an explanation for most, if not all, aspects of the leaks and interior damage. The investigator is expected to establish a cause-and-effect relationship between wall characteristics and observed leakage.

It is imperative that conclusions are made based solely on the facts and that false conclusions are not made. Unfortunately, for mass masonry wall systems, it may not always be possible to extrapolate field investigation findings to the remainder of the building without performing an all-encompassing and likely cost-prohibitive field investigation. Such limitations and disclaimers must be clearly enumerated. The report can also include recommendations for additional investigation and/or recommendations for repair.

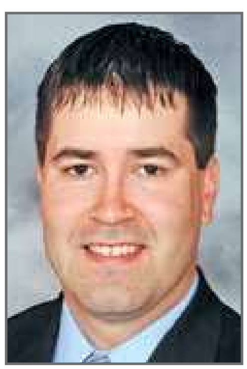
SUMMARY

Evaluating water leakage issues in mass masonry walls should start with an understanding of their water management characteristics.

Due to limited or nonexistent documentation of original construction, lack of obviously clear leakage paths, and potentially insufficient industry standards for guidance, evaluation of mass masonry exterior walls for water leakage can seem like a daunting task. However, experienced investigators can develop exterior wall evaluation protocols specifically for mass masonry walls by following the methodology outlined in ASTM E2128. Results obtained from a well-implemented program can then be used as the basis for repair design.

REFERENCES

1. The Construction Specification Institute (CSI) was formed in 1948, in part to address the growing need in the design and construction industries for a standard approach to project documentation.



Patrick Reicher,
REWC, SE, CCS, CCCA

Patrick Reicher is a senior structural engineer with Building Technology Consultants, PC, a forensic engineering firm in Arlington Heights, Illinois. Reicher is a licensed structural engineer in the State of Illinois and has over 10 years of specialized experience in the evaluation and repair design of many types of buildings, from recently constructed to historic structures. He is also a Registered Exterior Wall Consultant (REWC), Certified Construction Specifier (CCS), and Certified Construction Contract Administrator (CCCA).

Kami Farahmandpour,
FRCI, REWC, RRC,
RTWC, RBEC, PE,
FNAFE, CCS, CCCA

Kami Farahmandpour is the principal of Building Technology Consultants, PC, a forensic engineering firm in Arlington Heights, Illinois. Farahmandpour has been involved in the evaluation, testing, and repair of construction materials and building envelope performance since 1984. Kami is a Fellow of RCI, Inc., and a Fellow of the National Academy of Forensic Engineers. He has served as an expert on several cases involving defects in construction, design, and maintenance of building envelope systems.