

Water Penetration Tests of Masonry Walls

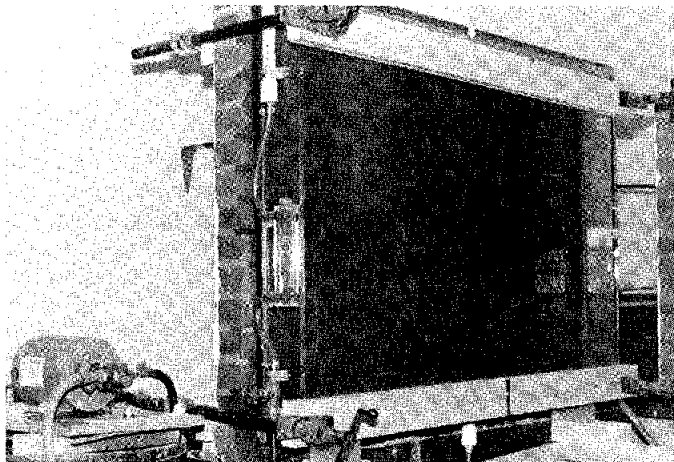
For many years, owners, tenants, builders, and designers have voiced concern over rain penetration through masonry walls. Considerable effort has been expended in field investigations and laboratory research to resolve the problem.

History of Testing

Since the early 1930's, many test methods have been used to measure water passing through various masonry wall assemblies. Early tests were conducted using masonry boxes or simply by spraying water on walls. In the 1930's and 1940's the U.S. National Bureau of Standards conducted numerous tests to identify the factors contributing to water penetration of masonry. Several reports were published during this period. Then, after many years of research inactivity, a small-panel method for investigating water penetration was developed.⁽¹⁾

Current testing is in accordance with American Society for Testing and Materials (ASTM) Designation E514, Standard Method of Test for Water Penetration of Masonry. As an ASTM standard with an E designation, this test method includes no specification limits. Acceptance-rejection criteria for a test wall must be established by the person requesting this test or using the test data.

This report summarizes findings of much research, including work by the Construction Technology Laboratories (CTL) that considered the many factors affecting the weather resistance of masonry structures.^(2,3,4,5,6) Earlier CTL investigations were sponsored by the Masonry Cement Research and Education Group. More recent work was sponsored by the Portland Cement Association.



Test chamber for E514 water penetration test

Factors Affecting Water Penetration

The research reported in References 2 and 3 emphasizes the fact that design, materials, workmanship, and maintenance interact to affect the weather resistance of masonry structures. The work also stresses the difficulty of selecting any one of these factors as the sole cause of leakage in masonry walls. The following discussion summarizes the effect of these factors on water penetration of masonry.

Design

There are many options for wall design, including singlewythe walls, solid walls, solid grouted walls, and cavity walls. For each of these, the wall thickness, the degree to which the wall is solid or voided (hollow), and the age of the wall will influence its resistance to water penetration. Recommendations for the design and detailing of masonry walls are set forth in *Building Weather-Resistant Masonry Walls* (PCA publication IS220M).

Materials

Each construction material used — cement, sand, water, and admixture in the mortar, as well as the masonry unit, reinforcement, and flashing — should meet the requirements of a product specification.

The performance characteristics of masonry mortars can be altered by the selection of component materials. For general masonry construction, masonry cement provides a convenient combination of cementitious materials for mortar.

The aggregate (sand) used in masonry mortar affects mortar water demand, which may influence shrinkage of mortar, depending upon the masonry unit and climatic conditions. Fine sands yield more workable mortars, but risk more volume change. Coarser sands are less workable, but cause less shrinkage. Aggregates that conform to ASTM Designation C144, Standard Specification for Aggregate for Masonry Mortar, or Canadian Standards Association (CSA) Standard A82.56M, Aggregates for Masonry Mortar, produce the most desirable mortar characteristics.

As long as the water for the mortar is clean and potable, its quality is not critical to performance. However, controlling the amount of water used during mortar mixing and during curing must not be overlooked.

ASTM and CSA standards caution against the indiscriminate use of admixtures in masonry mortar. For more information, see *Masonry Cement Mortars* (PCA publication IS181M).

Workmanship

Although difficult to assess, workmanship is a significant factor influencing the ability of a masonry wall to resist water penetration. Quality workmanship is especially important during the operations described below.

Proper materials handling is critical during cold weather. Handling of weather-sensitive mortar-making materials should ensure the protection of the "as received" material prior to mortar preparation.

Mortar preparation that consistently and properly proportions the individual materials will optimize the performance of the masonry mortar. Batch-to-batch variations in aggregate-cement ratio, mixing time, mortar temperature, and air content can be minimized by good quality control.

Flashing that is installed improperly or punctured during installation will result in a water penetration problem.

Individual masonry units should be placed on a full fresh bed of mortar that will wet all contact surfaces and allow final positioning.

Mortar droppings (or spillage) that close or fill the voids in cavity walls are no doubt responsible for many water permeance problems. Masons must be careful to maintain cavities free of mortar.

Joint tooling that produces a well-compacted, closed surface on the mortar joint without any horizontal ledges will help achieve weather-resistant joints.

Washing and cleaning of the completed wall should be kept to a minimum or avoided completely. Acid washing frequently is accompanied by acid consumption of the mortar, which can contribute to wall permeability.

Maintenance

Drainage, repair of caulking and cracks, and weather-proof coatings are aspects of maintenance that will prevent water penetration related problems such as efflorescence.

Two types of efflorescence, temporary and permanent, can indicate moisture within the masonry wall. Temporary efflorescence usually occurs shortly after construction is completed and results in a whitish deposit on masonry surfaces. The most common cause is construction water leaving the walls, evaporating at the surface, and depositing water-soluble alkalies on the wall surface. The deposits, which occur frequently, are easily removed by scrubbing the walls with water or washing them with a high-velocity water spray.

Permanent efflorescence indicates water penetration into the masonry. When it appears near the bottom of the wall, efflorescence can indicate that flashing was not installed to prevent water from migrating upward from the ground into the masonry. At the top, flashing improperly installed at the roof-wall anchorage allows water from the roof to find its way down into the masonry.

Providing adequate drainage and keeping drains clear of obstructions can prevent water accumulations on roofs that may overflow into walls and cause leaks.

Caulking that cracks or separates from the bonded surfaces will allow the passage of water. Recaulking requires joint cleanout and refilling with a quality product.

The causes of cracks in masonry walls should be eliminated. For example, volume-change cracks due to temperature extremes can be corrected by use of expansion joints. Tuckpointing can then restore original esthetics and weather resistance.

Coated masonry should be inspected periodically, as coatings will lose their effectiveness with age and exposure to aggressive environments.

Laboratory Research

There have been several research programs conducted at CTL to investigate the water penetration of masonry walls. The specific objectives of the research reported in References 4 and 5 were to establish the effects of the following factors on masonry wall permeance: mortar water content, mortar cementitious materials content, masonry unit physical properties, storage (curing) of masonry, exposure conditions (varying water quantity and pressure) during test, and prolonged outdoor exposure (aging).

Mortar formulations were of the M, S, and N types, as specified in Table 2 of ASTM C270. A 12-in. thick (300-mm) wall made of 8-in. (200-mm) concrete block and 4-in. (100-mm) clay face brick, with a 3/4-in. (20-mm) solid collar joint, was selected as representative of walls commonly designed and built. Sixty-six wall test specimens measuring 48x48 in. (1220x1220 mm) were fabricated. Wall test specimens were cured and stored under the prescribed limits of ASTM E514. They were moved from storage to the test area 28 days after fabrication.

More recent research reported in Reference 6 focused on the performance of single wythe brick masonry walls constructed with masonry cement mortars. Twenty different masonry cements were selected to represent the range of products available in various parts of the country. Wall assemblies were tested using standard procedures of E514. In addition to the standard size (48x48 in. or 1220x1220 mm) E514 wall assemblies, comparative tests were made on smaller size (32x32 in. or 810x810 mm) assemblies. Water penetration tests were performed at 14 and 28 days after fabrication.

In addition to the stated objectives, these research programs provided insight into the effect of mortar air content, bond strength of prisms, and specimen fabrication on water penetration of masonry walls.

Findings

Mortar water content

A well-documented and researched theory states that increased mortar water content helps increase "wetting out" of the masonry unit's contact face and consequently improves adhesion between the mortar and the masonry unit. Excessively high mortar water content, however, may increase a wall's water permeance by increasing absorption and shrinkage in the mortar.

In phase I of the research reported in Reference 4, the mortar water content was varied and its effect on water penetration measured. The basic mortar water content was gauged by the mason to produce "medium" mortar of essentially uniform wetness or workability. For comparison to the "medium" mortar, drier (low-water-content) and wetter (high-water-content) mortars were prepared.

The evaluation of wall performance indicated that mortars with medium or high water content displayed greater resistance to water penetration than did low-water-content mortars.

Mortar air content

The use of air entrainment in masonry mortar has been a subject of much discussion and controversy. While it is generally understood that air entrained mortars provide advantages of improved workability and resistance to freeze-thaw deterioration, the concern is sometimes expressed that this is achieved at the cost of reduced performance of the masonry wall in terms of resistance to water penetration. However, CTL research reports on water penetration clearly indicate that the air content of masonry mortars has no significant influence on the water permeance of masonry walls.

Tests reported in Reference 4 included both masonry cement mortars and portland cement-lime mortars. Air content of these mortars ranged from 1% to 17%. The data indicated that mortar air contents in this range did not significantly affect the water penetration resistance of masonry walls. Tests reported in Reference 6 contained mortars made with 20 different masonry cements of varying air content. Once again, results indicated that there is no relationship between the air content of the mortar and the water penetration of masonry walls. This conclusion is supported by the experimental data and observations of a majority of published research, as noted in Reference 3.

Cementitious material content

The "Property Specifications" section of ASTM C270 allows aggregates to be proportioned in a range from 2-1/4 to 3-1/2 times the volume of cementitious materials. Reference 4 included tests to study the effect of varying the ratio of aggregate to cementitious materials over the permitted range of values on the water permeance of masonry walls. The test data indicated that all mortars, regardless of cementitious material content, showed good resistance to water penetration.

Bond strength

It is sometimes claimed that there is a link between the higher bond strength of masonry prisms and improved resistance to water penetration of masonry walls. However, the test results from these CTL studies do not support that claim. Examination of the data from Reference 4 provides no indication of a relationship of bond strength to water permeance. This observation is supported by data from reference 6 where regression analysis of the data yields a low coefficient of correlation between measured bond strengths of prisms and water penetration of masonry assemblies. As noted in that report, since most water penetration occurred through the head joints, testing the bond strength of bed joints of masonry prisms cannot be considered a viable tool for assessing potential water penetration of masonry walls.

Masonry unit physical properties

The initial rate of absorption (IRA) of brick units was the variable studied in Reference 4 to establish the effect of the masonry unit on the water penetration of masonry. Test specimens made with a brick of slightly lower IRA than used in phase I were built using medium-water-content mortar (see above). Although a reduction in IRA from 14 to 10 g/30 sq. in./minute resulted in a slight improvement in resisting water penetration, the range overlapped, and no conclusion could be drawn.

Fabrication

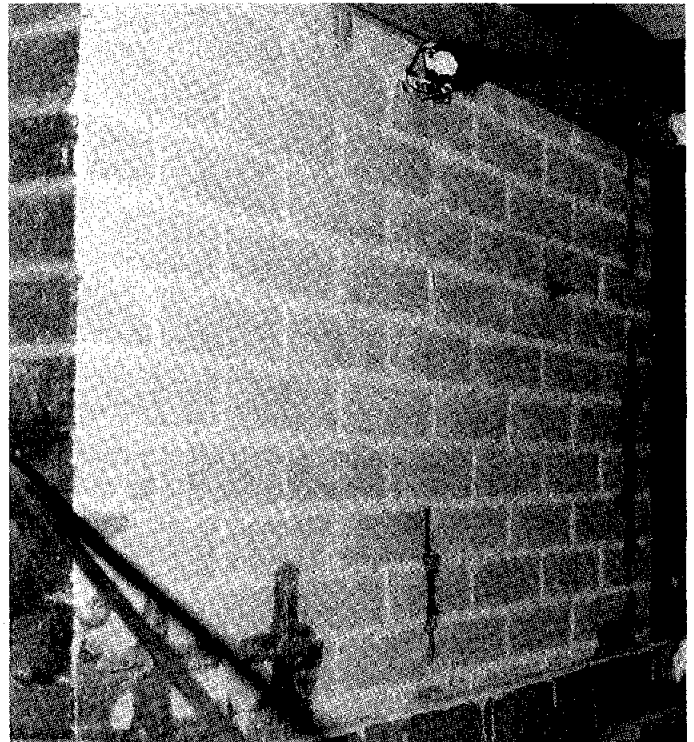
It has already been noted that workmanship is a significant factor influencing the ability of a masonry wall to resist water penetration. That fact was evident in the CTL studies from the observed pattern of moisture migration through wall assemblies during testing. In these studies most of the visible dampness occurred along the vertical edge of masonry panels. It was observed that this dampness generally occurred where initial mortar unit contact had been disrupted for necessary alignment and adjustment of units or where joints had been repointed during the tooling operation. The significance of these findings is the indication that E514 is often more a measure of the workmanship involved in the fabrication of masonry test specimens than a measure of the performance potential of the masonry materials.

Storage and curing

The 1974 revision of ASTM E514 stipulated air storage (temperature and humidity ranges specified) of test assemblies after fabrication. Phase VI tests from Reference 4 investigated how the curing of mortar affects masonry permeance. The lack of strength gain or slow strength gain of mortar cubes stored in air highlights the detrimental effect of a lack of curing moisture.

The test walls were subjected to a moist curing environment by being either (1) completely enveloped in a plastic cover, or (2) covered with water-saturated burlap and wrapped in a plastic cover. Walls covered with wet burlap exhibited some improvement in resisting water penetration when compared to their air-stored counterparts.

As a result of these tests, curing requirements of E514 were modified in the 1986 revision to incorporate improved control of this variable. The current edition of E514 requires that specimens be constructed in a laboratory



Backside of water penetration specimen during testing. Water penetration occurring at perimeter and head joints.

and immediately wrapped with a plastic cover for 7 days of "self curing". After 7 days the plastic is removed and the assembly cured in laboratory air for at least 7 more days.

Exposure conditions

The ASTM test method for water penetration of masonry subjects test panels to severe exposure conditions. Conditions are equivalent to 5.5 in. (140 mm) of rain per hour driven by a 62.5-mph (100-km/hr) wind. The 1974 revision of E514 required that these exposure conditions be maintained until a rating was obtained, or for a maximum period of 3 days.

Once again the research reported in Reference 4 led to improvements in the control of test conditions set by E514. In phase V of the research program, walls were subjected to water quantities less than the test method guidelines and to incremental increases in air pressure. Under these varied exposure conditions, test walls stored in air performed extremely well. When exposure to water was cycled, walls resisted water penetration regardless of simulated wind velocity. As a result of this work, a four hour minimum exposure period was established, with provisions for optional retesting and reevaluation.

It is still difficult to relate ASTM E514 test conditions to reality, as such conditions rarely occur in nature. The test permits comparative testing of laboratory specimens, but the results do not necessarily predict field performance accurately.

Prolonged outdoor exposure (aging)

It became apparent during the research reported in Reference 4 that wall specimens often showed a tendency toward decreased water penetration during the test procedure. To investigate the effects of prolonged outdoor exposure on water permeance, the specimens were placed in outdoor storage for about nine months (including one winter's exposure) with the top of each wall protected with a plastic cover. The specimens were then returned to the laboratory, permitted to revert to ambient conditions of the storage area, and retested.

As indicated in Reference 5, regardless of the amount of water leakage that occurred during the first test period, all walls had substantially less leakage when tested at the age of 11 months.

Conclusion

The results of these CTL research programs show that design and workmanship affect water permeance far more than materials do. Indeed, the effect of workmanship is so critical that testing by E514 is more a measure of the fabrication techniques used in assembling test specimens than it is a measure of the performance potential of masonry materials. Mortar air content, variation in aggregate to cementitious material ratios ranging from 2-1/4 to 3-1/2, mortar type, mortar composition, and bond strength of prisms had no significant influence on resistance of masonry walls to water penetration in these studies.

An enormous amount of effort has been expended on the study of masonry. Errors of the past have been identified, the chemistry of the materials is known, the engineering performance of masonry walls has been established, and the mechanism of rain penetration through masonry is understood. If masonry walls were constructed in accordance with the recommendations of the research cited in this report, it is unlikely that rainwater penetration would be a continuing problem.

References

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