# WATER PENETRATION THROUGH MASONRY WALLS LABORATORY AND FIELD INVESTIGATIONS

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## ABSTRACT

Several mortar joint profiles and thicknesses are used in contemporary masonry walls. However, the 3/8" thick tooled concave joint has long been assumed by the masonry industry to give the most water resistant wall. An extensive review of the literature revealed that the above assumption has not been based upon any scientific investigation but on an intuitive understanding of the mechanism of rainwater penetration through masonry walls. An experimental investigation to determine the influence of mortar joint thickness and profiles was undertaken at the University of Texas at Arlington during the Summer of 1990. The results of this study, reported in detail elsewhere, are summarized in the introduction part of this paper.

Upon completion of the above study, the author accepted a position with the Engineering\Design Services Section of the Physical Plant Division of Texas A&M University, College Station, Texas. As with many universities in the United States, the over 4500 acres of the main campus has many brick veneer clad buildings. Resulting from many complaints of rain penetration through these buildings, a systematic investigation was conducted to record the causes of water penetrations before proceeding with repair. The (field) investigations as to the cause of leakages with actual buildings and in the test walls constructed earlier for laboratory investigations have shown close similarities. The details are reported below.

## INTRODUCTION

Experimental work at the University of Texas at Arlington resulted in data giving the rateability of mortar joint profiles in clay masonry of various commonly used joint profiles in resisting the penetration of water through the walls. The tests were conducted using ASTM E 514-86: "Standard Test Method for Water Penetration and Leakage Through Masonry Walls" (American Society for Testing and Materials, 1986). The materials used in the walls conformed to appropriate ASTM standard specifications; the mortar contained no admixtures. Tests confirmed the masonry industry's long-held recommendation that a concave joint is the most water resistant joint. More specifically, the work yielded the following rating of joint profiles in order of decreasing performance: concave joint, weather joint, vee joint, and raked joint, Figure 1.

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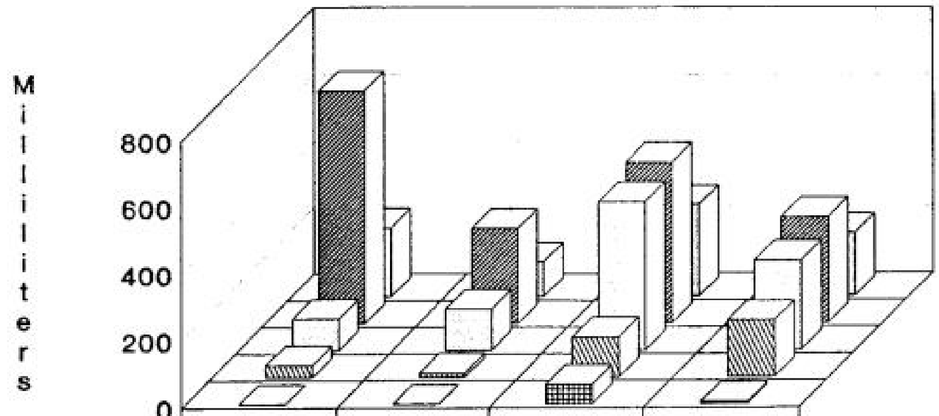


| THICKNESS | 10mm(3/8") | 10mm(3/8") | 20mm(3/4") | 20mm(3/4") |
|---|---|---|---|---|
| AVERAGE | 207.5 | 105 | 277.25 | 190.25 |
| RAKED | 701 | 286 | 485 | 319 |
| VEE | 94 | 122 | 446 | 268 |
| WEATHER | 35 | 12 | 120 | 168 |
| CONCAVE | 0 | 0 | 58 | 6 |
| JOINT TYPES | 14 DAYS | 28 DAYS | 14 DAYS | 28 DAYS |

Figure 1 - Relative performance of various joints at 14 and 28 days of age

Although tooled concave joints gave the best average performance, leakages occurred in several walls built with the joint. In some instances, much larger quantities of water passed through the concave joints than through walls with other joint profiles. To investigate the reasons for this phenomenon, prisms containing leaky joints were removed from the walls. Joint compositions were investigated by removing portions of the brick and mortar thus exposing the interior joints.

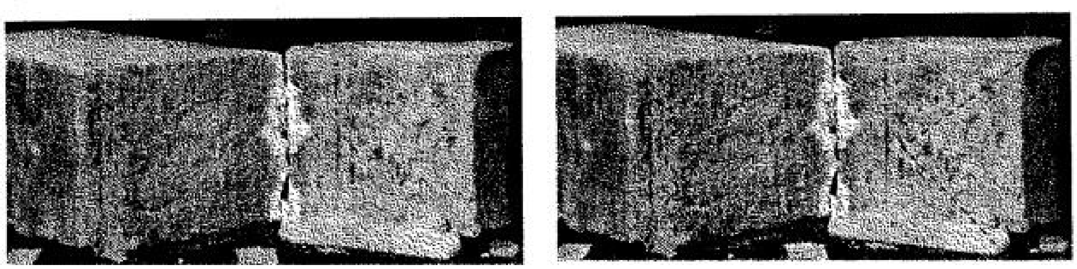

Figure 2 - Interior of a joint showing the leak hole and change of mortar profile

Visual and physical examination of the interiors provided insight into the details of the workmanship and the bond between the individual bricks on either side of the joint and mortar components. Figure 2 shows one such interior. The area to the right of the (<) in this figure indicates new mortar added to the tapped open joint. The line with a profile (<) is the intersection of the new mortar and water path. Dark areas in the figure indicate crystal growth that was apparently interrupted when the brick unit was moved and the joint opened, resulting in the loss of bond between the brick and the mortar.

Figure 3 - Rear of unit showing position of the leak hole

Examination of the joint interiors yielded overwhelming evidence to indicate that even a tooled concave joint will leak when used with bricks with a high initial rate of absorption, (IRA), values and/or poor workmanship, particularly the latter. This conclusion has been supported by the author's personal observations of the techniques used by the two masons employed to build the walls. Their consistent tendency to move or tap the bricks after their initial placement resulting in pulling the mortar off the bricks and creating holes in the joints, Figure 3. Specific details and additional conclusions from this study have been reported elsewhere (Hines, 1991, Hines and Mehta, 1991). The above study was conducted in partial fulfillment of the Master of Architecture degree at the University of Texas at Arlington.

Upon arriving at Texas A&M University, the author was charged with the responsibility of facilitating and directing the repairs of leaky buildings. The author decided to investigate and record his observations as to the probable cause of leakages before proceeding with repair. In every case, this study was done by cutting prisms out of the suspected portions of the walls and isolating the mortar joints. Similarities between the experimental data obtained from the above study and the observations from the field at Texas A&M University are conclusive to make final recommendations to the masonry industry and presented in this paper..

**ADDITION TO DUNCAN DINING HALL, TEXAS A&M UNIVERSITY**

The addition to Duncan Dining Hall was completed in 1988. The original building is a load-bearing masonry wall structure but the addition has been constructed with a brick veneer facade to harmonize with the existing building. The new bricks are tumble bricks with tooled concave joints of varying widths varying from 10mm (3/8"0to 20 mm (3/4"), simulating an aged appearance of the masonry on the existing building. Since completion of the addition leaking through the building's new entry parapet expansion joints is an ongoing occurrence.

Figure 4 shows a head joint cut from a portion of the wall of the new building. The ease with which the bricks from either side of the joint came apart showed the lack of bond between the units and the mortar. Such would be caused either by the brick's high IRA value and/or the poor quality of the mortar used. Note also the depressions on the surface of the mortar which indicates that the brick was either moved from its initial position and (possibly) additional mortar added to the joint or the mason did not use proper brick laying technique by exerting adequate pressure to yield a tight head joint.

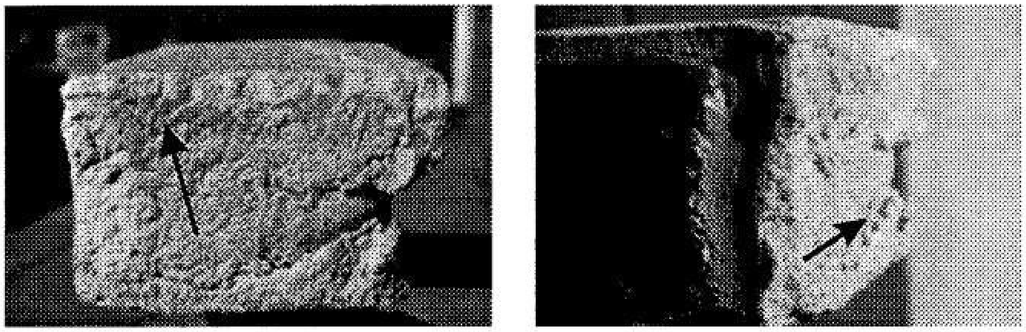

Figure 4 - Sample of brick removed from Duncan Dining Hall

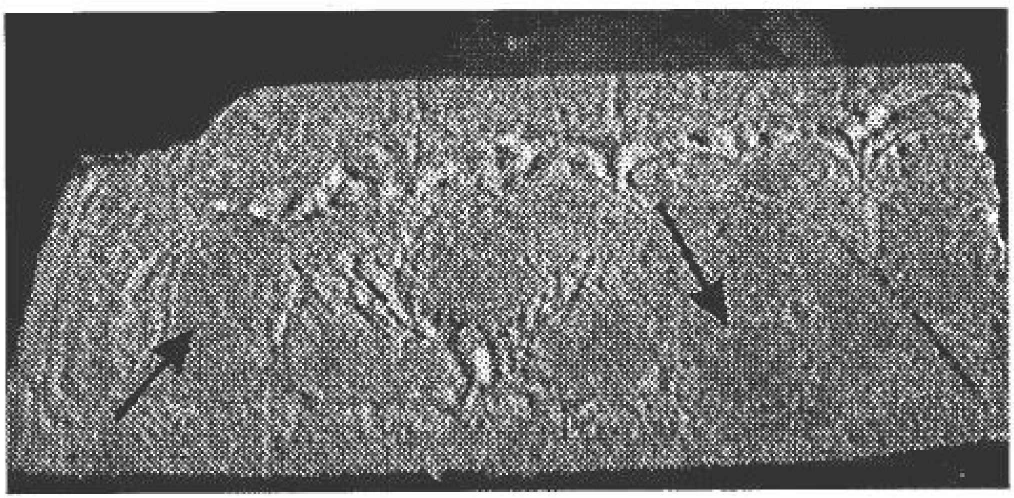

Figure 5 - Sample showing the bed joint. Note the color contrast indicated by the arrows. The shading indicates the location of crystals.

Figure 5 shows a bed joint extracted from another location in the same wall, indicating the same deficiencies as in the previous head joint. In a few other joints, the mortar was so deficient in quality that it powdered when rubbed with fingers. Investigations of the flashings indicated that the counter flashings incorrectly installed, Figure 6, and on the east side of the entry, the weep holes omitted.

At this stage, the original specifications of the project were examined. Such called for the following items: (i) conduct IRA tests; IRA value not to exceed 30 grams per 194 $cm^2$ (30 $in^2$) of brick face; (ii) if the IRA values exceed the above, the stack of bricks is to be appropriately moistened; (iii) Type 'S' mortar is to be used; (iv) sample walls are to be built for approval; (v) conduct mortar tests from approved batches with continuous inspection. Records of the project form the University Systems' Contracting Office indicates no testing of either the bricks or the mortar. The sample panels were approved only for color and texture. No records exist as to the observations of the inspection of the masonry during construction.

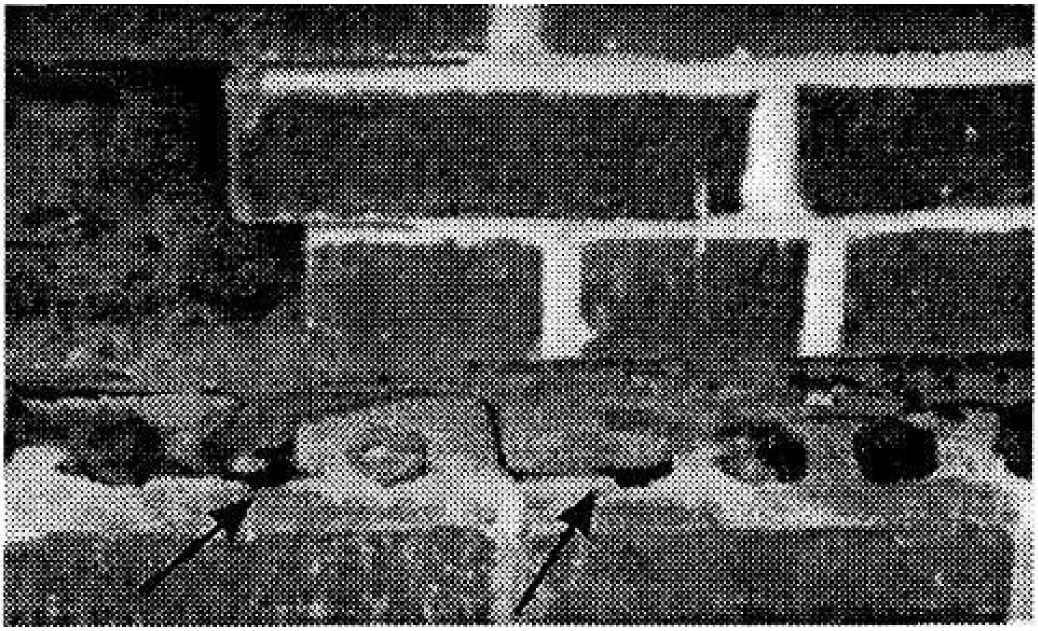

Figure 6 - Opening in the parapet wall showing flshings, brick and the mortar interface.

The University Physical Plant's estimate of the remedial work (Hines, 1992) is nearly $250,000.00 dollars. The work would include total removal and proper installation of all the masonry work.

**BIOSCIENCES/BIOPHYSICS BUILDING, TEXAS A&M UNIVERSITY.**

In the Fall of 1990, one year after completion, reports were received by Physical Plant regarding rainwater penetration through the second-floor glazing assembly of the Biosciences/Biophysics Building - a brick veneer clad facility. Several investigations were undertaken to find the cause of the problem. High pressure water tests on the glazing revealed defects in the brick veneer close to the glazing assembly. Subsequently samples of brick prisms were removed and revealed the following defects: (i) the flashing at the lintel level was poorly installed and (ii) the cavity space between veneer and the back-up was full of mortar droppings of up to one-half to three-quarters the height of the soldier course, blocking the escape of rain water through the weep holes. Figure 7 shows a removed masonry prism revealing poor workmanship similar to that of Duncan Dining Hall Addition.

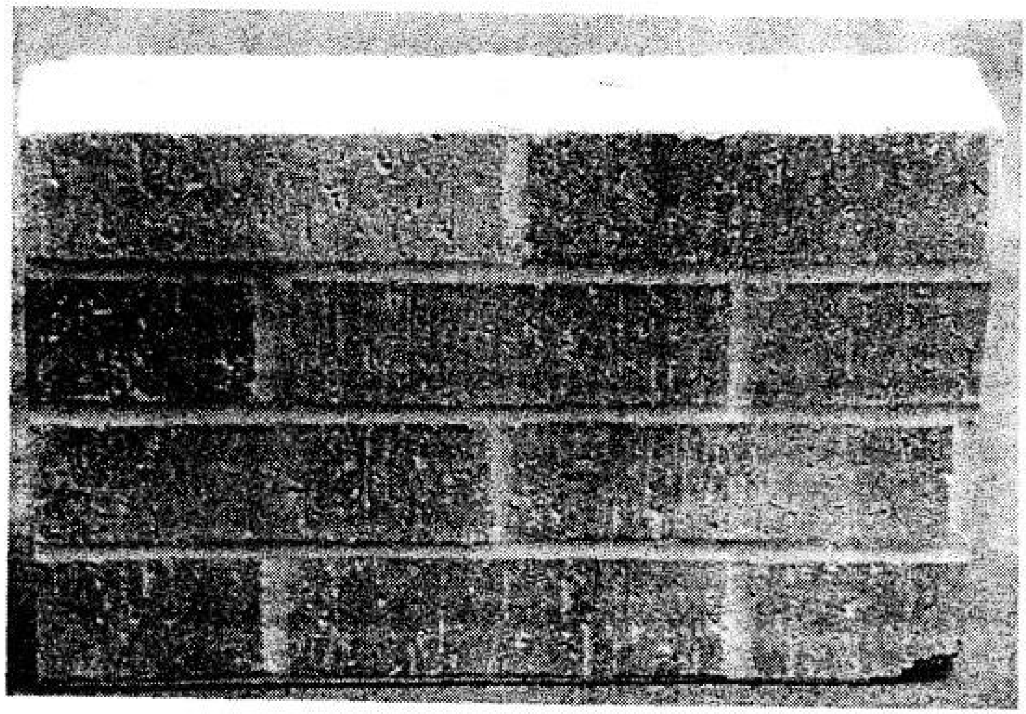

Figure 7 - Brick veneer prism removed from Bioscience/Biophysics exterior.

The prism shows voids in the head joints, Figure 8 and several boat shaped depressions in the bed joints, Figure 9. In view of these findings, the Physical Plant is considering an impulse radar scan, (Abrams and Matthys, 1991) of the entire building to locate areas of probable future leakage so that all necessary repairs may be undertaken at one time. Repairs include complete removal and proper construction of all the masonry work. The total estimated cost is US $750,000.00 (Hines, 1992).

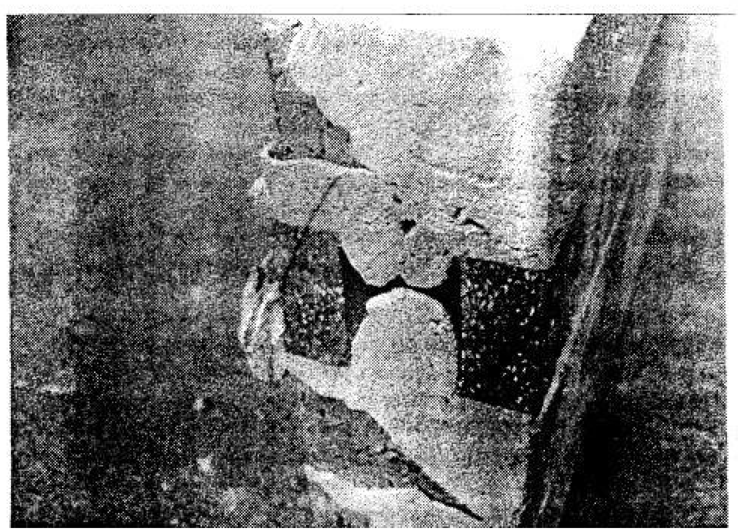

Figure 8 - Rotated exposed head joint showing separation between the mortar and the brick.

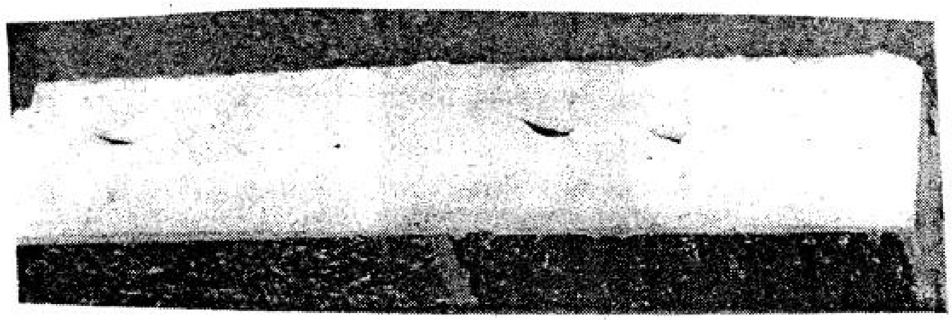

Figure 9 - Bed joint showing boat-shaped leakage holes

**DAVIS-GARY DORMITORY, TEXAS A&M UNIVERSITY**

September 1990, one year after the completion of the interior and exterior restoration work on the facility, the Physical Plant received reports of scaling and separation of the acrylic wall coating from the interior plaster facing covering the exterior masonry walls. Such consist of brick veneer with clay structural tile and back-up and a (3/4") plaster finish over the tile. During the restoration, an applied acrylic coating placed over the plaster.

An examination of the specifications for the project revealed that the restoration contractor was required to thoroughly clean, repoint and seal all the masonry and stonework; clean and clear all the weep holes; clean, prime and paint all steel brick angles; and seal the interface of the lintels and the masonry. University records and Physical Plant's inspection of the completed work, indicated that the mortar joints not adequately repointed; holes in the mortar joints not filled, steel lintels and the construction joints not addressed. The restoration work was not performed in accordance with the specifications.

Further examination showed that the original construction did not provide for insulation or vapor barriers in the wall cavities. When the original building was air-conditioned, such was never considered. It is now clear that one of the reasons for the release of the acrylic coating from the plaster walls would be moisture intrusion from the cavity space into the interior of the building. Moisture in the cavity results from leaky mortar joints and clogged weep holes as well as condensation. The details for the correction of the problem are currently being worked out and include repointing of all the mortar joints, cleaning, and clearing of all the weep holes, installing proper flashings and insulation, sealing of the masonry and all to be performed under continuous inspection.

**CONCLUSION**

The laboratory and field investigations of water penetration through masonry walls reported in this paper establish the following facts:

1. Should the workmanship, detailing and the quality control of masonry materials be of good quality, then a tooled concave joint helps to provide the most water resistant joint. Although this fact was recognized by the masonry industry prior to

this study, there was no conclusive scientific supporting evidence. The results of the experimental work done at the University at Texas at Arlington has filled the gap

2. The field investigations conducted at Texas A&M University, College Station, supports the view that if the workmanship and the detailing of masonry are substandard, the masonry work will leak regardless of the quality of materials and the joint profiles used. Workmanship is the single most crucial factor in obtaining water-resistant walls. Several other researchers have reported this fact. The destructive testing of samples of the leaky portions of the masonry obtained from laboratory samples and the actual buildings adds scientific evidence to the already existing knowledge.

3. Satisfactory workmanship can only be obtained through a collaborative effort between the design professional (architect and/or engineer) and the builder. Strict adherence to the specifications and continuous inspection of the masonry must be required in all project types.

4. Proper bricklaying techniques, masonry detailing and proper specifications for good practice, are fairly well established. What is lacking is the realization of its importance among the design community and to some extent the masonry contracting community. This gap can be bridged through an aggressive strategy to educate architects and engineers so that wasteful and costly but entirely avoidable errors, such as those in this paper, are eliminated.

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