ACCELERATED FIELD TEST METHOD FOR WATER PENETRATION OF MASONRY

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Summary

Since water leakage through masonry is a common defect that can cause costly repairs, an effective method for determining the rate of water penetration into a joint under wind driven conditions is an essential necessity in evaluation of masonry joint condition, or effectiveness of repairs.

In-situ resistance of masonry against wind driven rain can be evaluated using a test apparatus developed by the authors. The portable device allows field testing of masonry from swing stage scaffolds and other access equipment. Quantitative measurements of permeability of masonry joints can be obtained in as little as 10 minutes by driving a known volume of water through the joint under constant pressure. This method provides the means for evaluation of existing masonry structures, quality control of repaired areas at selected locations, and evaluation of the effectiveness of masonry sealers and repairs on masonry walls. The test method is non-destructive with the exception of two small holes drilled in the joints to secure the apparatus on the masonry.

A laboratory study was conducted to correlate the test results with the quality of the joints. A criteria for acceptance of a joint was established using the laboratory test results.

The results of the laboratory tests performed on two test panels indicated that localized flaws otherwise not detected by the standard laboratory test (ASTM E 514-86), can be identified by the CTL method. Furthermore, quantitative values can be established which can be used as acceptance criteria for masonry joints.

The results of the laboratory tests also verified the capability of CTL's accelerated field test to quantitatively identify improvements in test panels' resistance to water penetration after the application of a penetrating masonry sealer.

It was also demonstrated that small differences existed between results of tests using CTL's accelerated field penetration method, and the standard laboratory procedure (ASTM E 514-86). These differences are attributed to water leakage into the masonry, rather than through the masonry. This type of leakage is considered a potential cause of deterioration and can only be detected by the CTL method.

Introduction

Water leakage through masonry facades is a common defect in masonry construction. It is often caused by poor bond between masonry units and mortar, or lack thereof, as well as flaws in workmanship. The most obvious result is usually penetration of water, especially wind driven rain, which can cause deterioration of interior finishes, jeopardize integrity of masonry ties and anchors, and in severe cases, cause deterioration of the masonry. In the case of highrise buildings it often reaches critical proportions. Therefore, evaluation of masonry permeability and early detection of the problem areas of building facades is critical in preventing costly repairs later on.

The authors, at Construction Technology Laboratories, Inc. (CTL), have developed a test apparatus that allows rapid assessment of the wall's resistance against water penetration while eliminating some of the drawbacks of existing methods.

Overview of Existing Test Methods

Currently, most widely used methods for measuring water penetration in the field include RILEM Test Method No. 11.4 (RILEM Tube) and a modified laboratory procedure (ASTM E 514-86). Both methods have disadvantages.

The modified ASTM method examines an area of 3 ft. by 4 ft. using a test chamber anchored to the wall. Test exposure conditions simulate 5.5 in. of rain per hour accompanied by 62.5 mph wind. Water is pumped from a calibrated tank at ground level into the chamber and sprayed across the face of the wall. The wall is preconditioned for 1/2 hour so it is saturated with water. Then the water level in tank is recorded. Water is sprayed on the wall for at least 4 hours and no more than 8 hours. Tank water level is recorded every 1/2 hour. The test is stopped when two consecutive

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readings are the same. If this never occurs, the test is stopped after 8 hours. The quantity of water lost from the tank in the last hour of the test is measured as the water leakage rate. If the leakage rate is less than 1/2 gallon per hour, the materials, bond, and workmanship are considered good. Materials and workmanship may be questionable if the leakage rate is 1/2 to 1 gallon per hour. A leakage rate greater than 1 gallon per hour indicates serious problems with materials or workmanship. One test is performed per day and preparation time is 2 to 3 hours. Principal difference between this procedure and a laboratory test is that water penetration is assessed by measuring the amount of water entering through the face of the wall rather than exiting from the back of the wall. The main disadvantage of this test is that during one test period it offers only localized assessment of wall quality. Also, masonry quality criteria cited above are, in the author's opinion, too liberal.

RILEM method employs a graduated tube that has a flat circular brim at the bottom. The tube is attached to the substrate with putty and filled with water. The water level is checked at 5 minute intervals for the first 30 minutes and then at 60 minutes. Readings are plotted comparing the volume of water absorbed with time required to absorb it. The slower the water absorption, the less permeable the wall. The main disadvantage of the RILEM tube method lies in its variable pressure which is caused by the reduction of the static head of water in the test tube during the test and limited availability of the tubes which must be imported from Europe.

Significance of the CTL Method

Unlike the methods described above, the CTL procedure measures the elapsed time required to drive a known volume of water through a selected portion of masonry surface under constant pressure. The method allows a small area (approximately 6 in.^{2}), such as a head joint, a bed joint segment, or a junction of joints to be isolated for testing. This nondestructive procedure identifies joints with poor bond or workmanship flaws, thus providing a rapid condition assessment of the building facades.

The following are some of the advantages of the CTL test :

- Field testing of facades from swing stage scaffolds and other access equipment is possible since the equipment is portable.
- A complete test can be performed in as little as 10 minutes. Therefore, a number of tests can be conducted, at various locations throughout the structure, in a day.
- The method provides a quantitative measurement of permeability of the masonry surface at specific locations.
- The effectiveness of masonry sealers on masonry walls can be evaluated in the laboratory or in the field.
- The method can be used to evaluate the effectiveness of repairs, such as tuckpointing or Manchester grouting.
- Quality control tests can be performed on repairs, using this method, by comparing test results on control samples with results on actual repairs.

Functional Description of Test Apparatus

As shown in Figure 1, the test apparatus consists of a pressure chamber with an integrated graduated cylinder, and a pressure tank.

The pressure tank is manually pumped to the desired test pressure (typically 5, 10, or 15 psi). A pressure gauge mounted on the pressure tank can monitor the internal pressure of the tank. The pressure tank has sufficient volume to maintain relatively constant pressure during each test. A 3-way valve, mounted on the pressure tank, is connected to the atmosphere on one side, the pressure tank on another side, and the pressure chamber on the other.

The pressure tank and pressure chamber are connected by plastic tubing with quick couplers on both sides for easy assembly in the field.

The pressure chamber has an integrated graduated cylinder on the top. The pressure line from the pressure chamber is connected to the top of the graduated cylinder. At the bottom, the pressure chamber is equipped with a bleeding valve to facilitate filling and draining of the pressure chamber. A special sponge gasket seals the interface of the pressure chamber and masonry.

Test Procedure

In order to determine the permeability at a joint location, the pressure chamber must be installed onto the wall. First, a desired location for the test is marked on the wall. Then two 3/8 in. holes are drilled in a bed joint or head joint adjacent to the test location. Two 1/4 in. expandable anchors are installed to hold clamps. The clamps are used to secure the pressure chamber on the test surface applying sufficient pressure to seal the interface between the pressure chamber and the surface of masonry. In some cases where the convex shape of the joint dictates, additional sealers such as putty are used to fill the depressions.

Once the pressure chamber is secured on the joint, it is filled with water through the bleeding valve located at the bottom of the chamber. The water rises through the graduated cylinder on the pressure chamber to its zero position. A period of one to two minutes is allowed for the absorption of the joint mortar and brick, after which time the pressure chamber is refilled to its zero mark, and bleeding valve shut. Meanwhile, the pressure tank is manually pumped to the test pressure. The pressure within the tank can be monitored using the pressure gauge mounted on the tank.

Pressure is then applied by opening the three-way valve mounted on the pressure tank. As the three-way valve is opened, the time required for 25 cc of water (capacity of the chamber) to penetrate the joint is measured using a stop watch. The actual test pressure is also monitored by the pressure gauge mounted on the pressure chamber. The actual test pressure and the tank pressure should theoretically be equal. However, losses within the plastic tubing, and differential pressure heads due to different heights of the tank and chamber can cause small variations.

Common Types of Defects and Deterioration of Masonry

Some of the most commonly encountered defects of masonry joints are schematically presented in Figure 2.

Figure 2a shows a sound mortar joint with properly tooled surface and fully bonded interface between brick and mortar. A joint with the lack of bond is schematically shown in Figure 2b. Marginal bond, or complete lack of bond could be caused by a variety of reasons, such as incompatibility between brick and mortar, dirty bedding surfaces of the units, use of sand-molded brick, as well as unintentional dislodgement of units during construction process. Figure 2c shows partially debonded interface at the bottom of the joint. Partially debonded interfaces at the top or bottom of the joints could be caused by any of the above cited reasons and also by the intentional disruption of bond for the purposes of alignment.

All of the above cited defects routinely occur in masonry construction. In most instances they remain unnoticed and could greatly contribute to water infiltration and subsequent deterioration of the masonry.

CORRELATION OF TEST RESULTS WITH JOINT CONDITION

In order to correlate results obtained by CTL's accelerated field test with the actual condition of the joints, a laboratory program was established.

The laboratory program consisted of performing several tests on walls approximately 5 ft x 5 ft. Two walls (Panel 1 and Panel 2) were constructed using locally purchased face brick and type S masonry mortar. The walls were single wythe and were constructed by a local commercial mason. Panel 1 was constructed with some intended flaws in craftsmanship that could affect joint performance.

Each wall was tested at several locations. For the sake of simplicity, most tests were performed on bed joints. A limited number of tests were performed on junctions of bed joints and head joints in panel 2. Figures 3 and 4 reflect the locations of tests performed on Panels 1 and 2, respectively.

Each location was evaluated using different test pressures, starting with zero (0) and increasing at approximately 5 psi increments to a limit of 15 psi. Hence, each location was tested at four (4) test pressures, 0, 5, 10, and 15 psi. The actual pressures recorded from the pressure gauge mounted on pressure chamber were recorded.

It must be noted that each test pressure corresponds to the pressure applied by the pressure tank (P_t) only. The pressure that drives water into the joint is the sum of pressures applied by the tank (P_t) and the hydrostatic head applied by the column of water in the graduated cylinder (P_h).

$$P_d = P_t + P_h$$

Equation 1

where:
P_d = actual driving pressure

Therefore, zero test pressure corresponds to an actual test pressure equal to P_h. The hydrostatic head P_h is a variable pressure ranging from 0.21 psi to 0.07 psi and is insignificant compared to test pressures of 5, 10, and 15 psi. However, the average value of P_h during each test grossly represents the 90 mph wind pressures that drive rain water into masonry walls.

In order to correlate results of CTL's accelerated field test and the laboratory test, several locations were tested at various test pressures on panel 1. The results of these tests are plotted on Figures 5 and 6 where the rate of water penetration into the tested portion of the joint is plotted versus the test pressure P_t. The rate of water penetration into the tested portion of the joint Q_w is calculated as follows:

$$Q_w = V_w / t$$

Equation 2

Where:
V_w = Total volume of water penetrated into the joint
Q_w = Rate of water penetration into the joint
t = Elapsed time

Figure 5 represents results performed on joints with no induced flaws in workmanship while Figure 6 represents results of those tests performed on joints with intentionally induced flaws in workmanship, that produced leaks in the laboratory test. As shown on Figures 5 and 6 a consistent correlation exists between quality of the joints and the rate of water penetration at various test pressures. An average water penetration curve may be derived for joints with acceptable quality, and those with flaws in workmanship as shown on Figure 7.

To demonstrate potential applications of CTL's accelerated field test, panel 2 was tested before and after application of a penetrating masonry sealer. The average results of the tests performed on panel 2 are reflected in Figures 8 and 9. As shown, a significant improvement of the masonry's resistance to water penetration was achieved after the application of the sealer particularly at the junctions of head and bed joints. This improvement was confirmed by performing the standard laboratory procedure (ASTM E 514-86) on test panel 2, before and after the application of the sealer. Results of the standard laboratory tests indicated an average 75% improvement in the test panel's resistance to water penetration after application of the sealer, while results of CTL's accelerated field tests indicated an average improvement of approximately 50% at all test pressure levels.

Differences between the results of standard laboratory tests and CTL's accelerated field tests, are attributed to water leakage into the masonry. As mentioned previously, this leakage can only be detected by the accelerated field test. The standard laboratory test cannot detect such defects.

Furthermore, results of accelerated tests performed on panel 2 indicate higher values of water penetration at locations where junctions of bed joints and head joints were tested (Figure 9). Standard laboratory test (ASTM E 514-86) performed on panel 2 revealed leakage of water through some junctions of joints including test locations 18 and 19, reflected in Figure 9. Therefore, localized defects can be detected using the accelerated field test method.

CONCLUSION

The results of tests performed on test panel 1 indicate that localized flaws can be identified by the CTL method. Furthermore, quantitative values can be established which can be used as acceptance criteria for masonry joints.

The results of tests performed on panel 2 verify the capability of CTL's accelerated field test to quantitatively identify improvements in test panels' resistance to water penetration after the application of a masonry sealer.

It has been demonstrated that small differences exist between results of tests using CTL's accelerated field penetration method, and the standard laboratory procedure (ASTM E514-86). These differences are attributed to water leakage into the masonry. This type of leakage is considered a potential cause of deterioration and can only be detected by the CTL method.

It is also shown that localized leakages in areas such as junctions of head joints and bed joints can be quantitatively identified using the accelerated field test.

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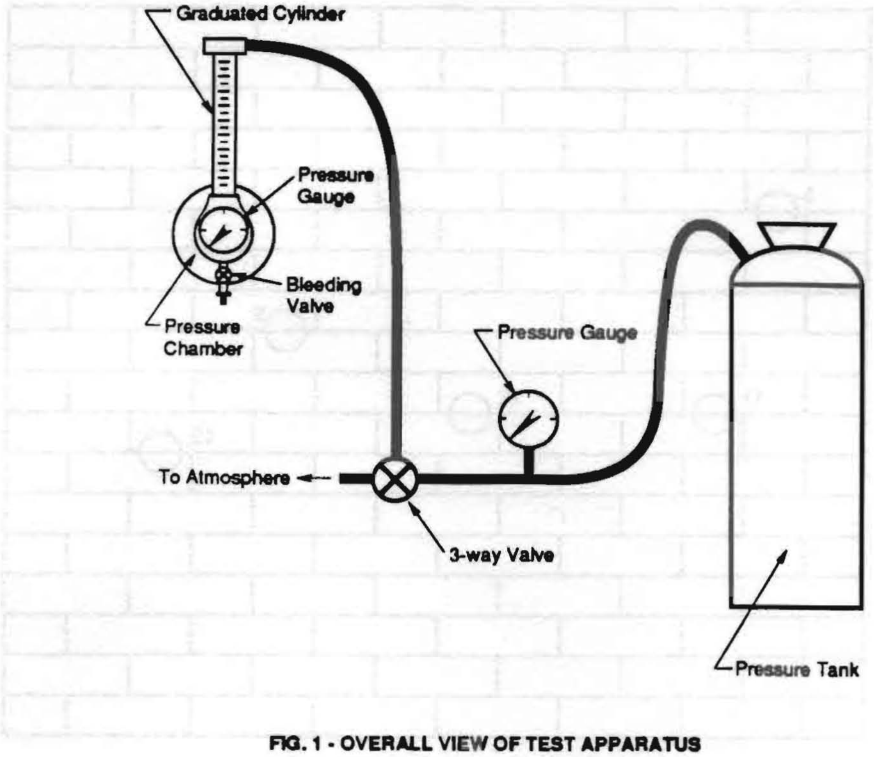

FIG. 1 - OVERALL VIEW OF TEST APPARATUS

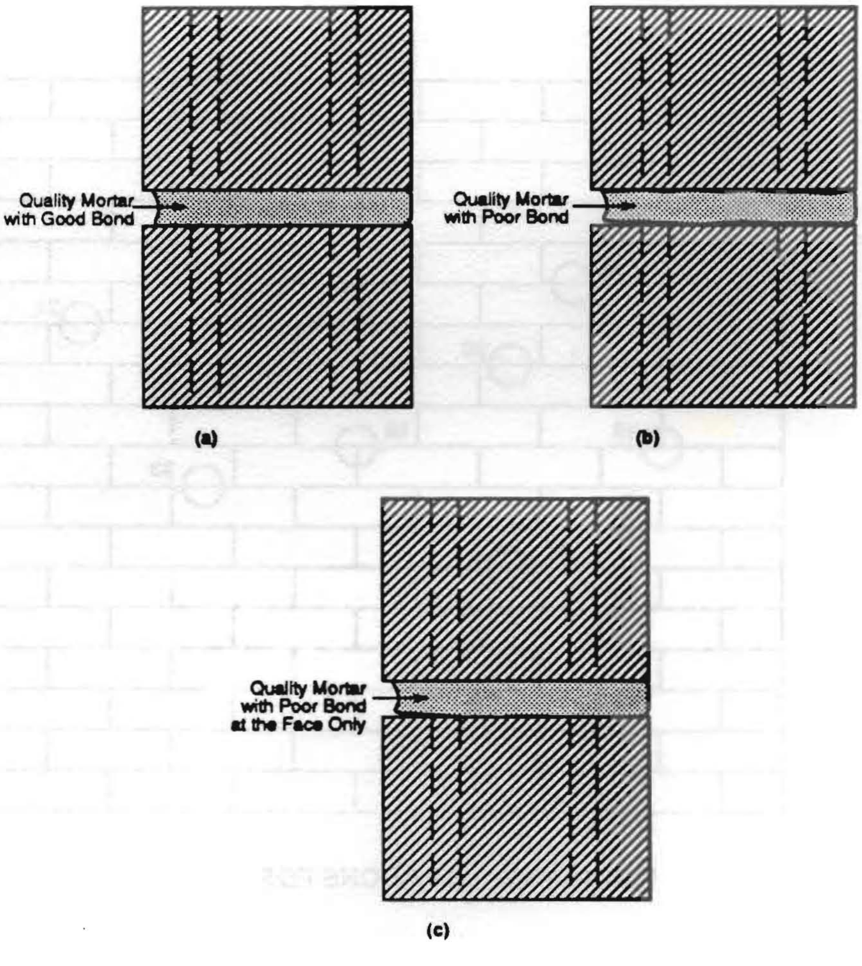

FIG. 2 - MOST COMMON DEFECTS OF MASONRY JOINTS

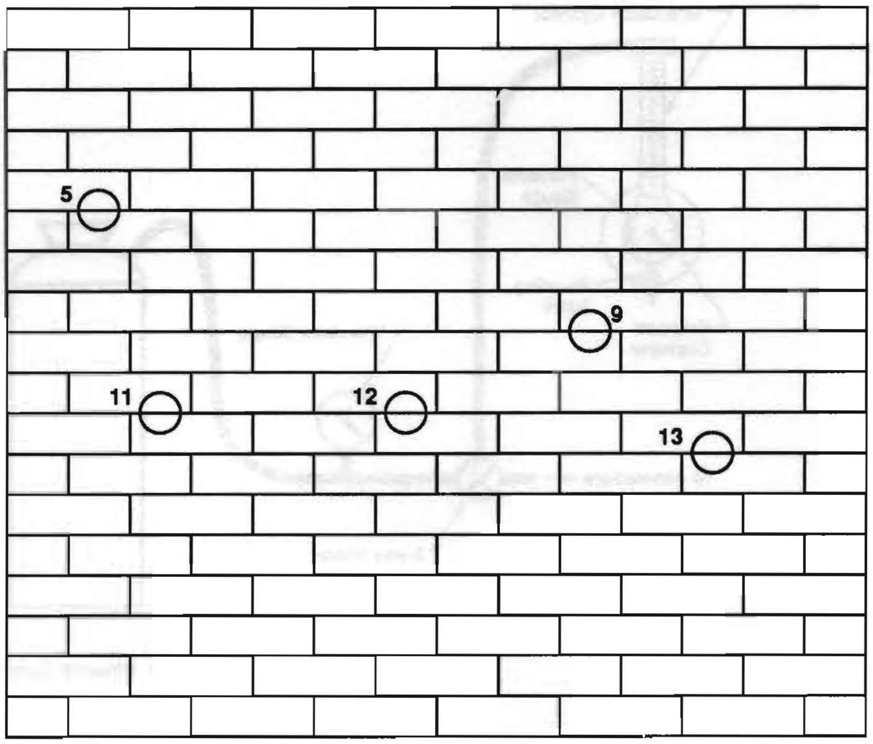

FIG. 3 - TEST LOCATIONS FOR PANEL #1

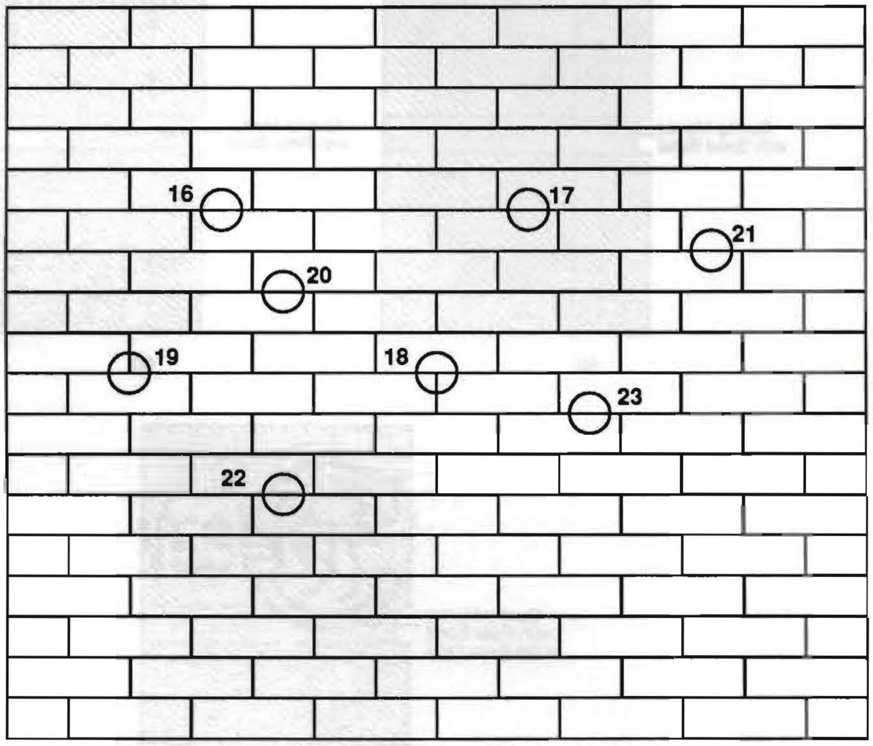

FIG. 4 - TEST LOCATIONS FOR PANEL #2

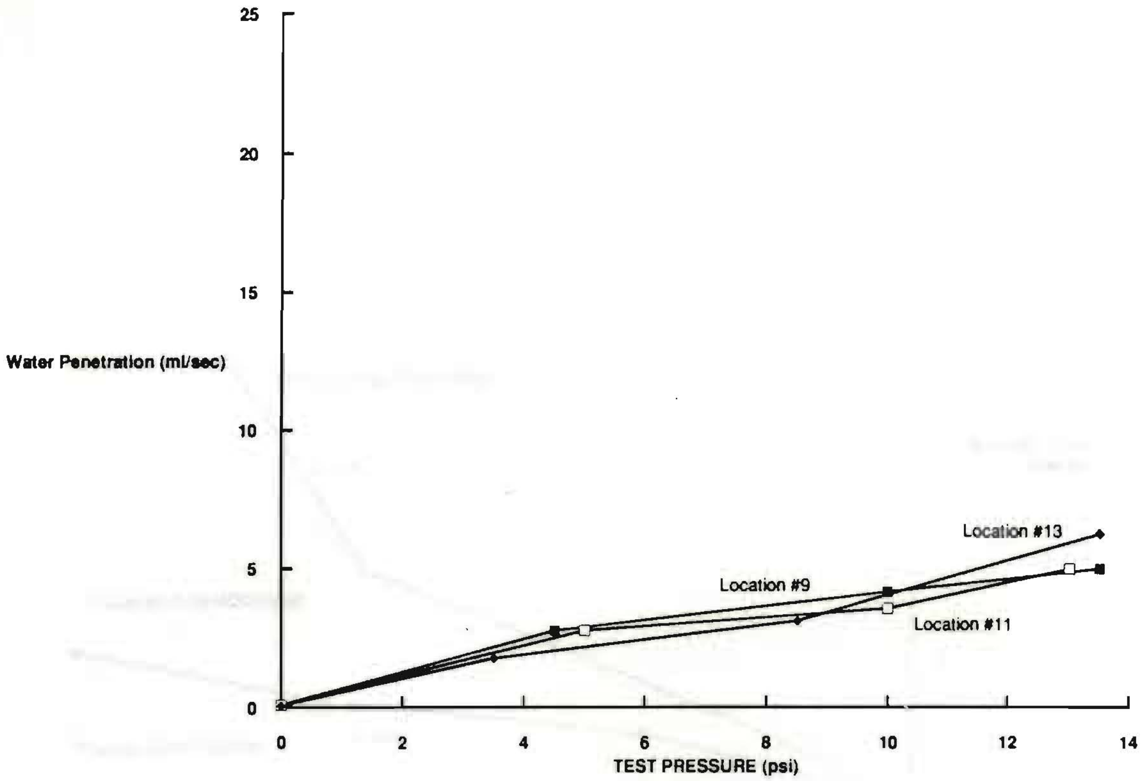

FIG 5 - TEST RESULTS OF PANEL #1 PERFORMED ON JOINTS WITH NO FLAWS

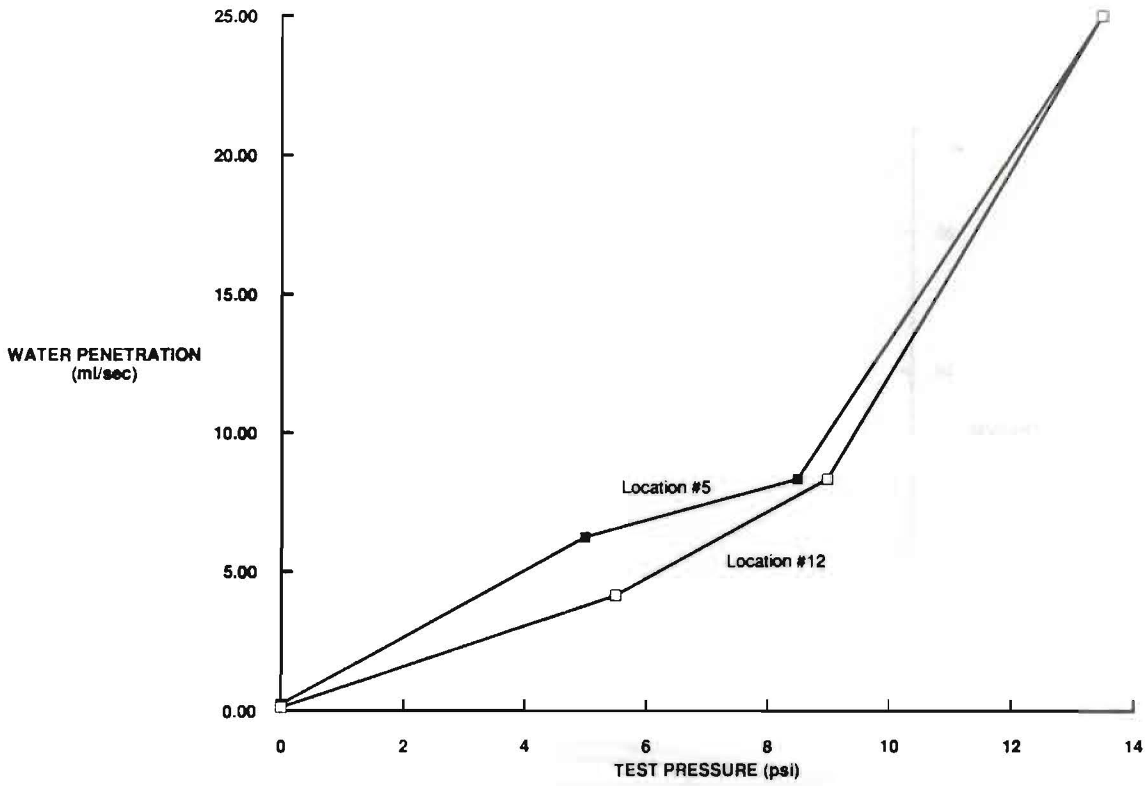

FIG. 6 - TEST RESULTS OF PANEL #1 WITH INTENTIONALLY INTRODUCED FLAWS

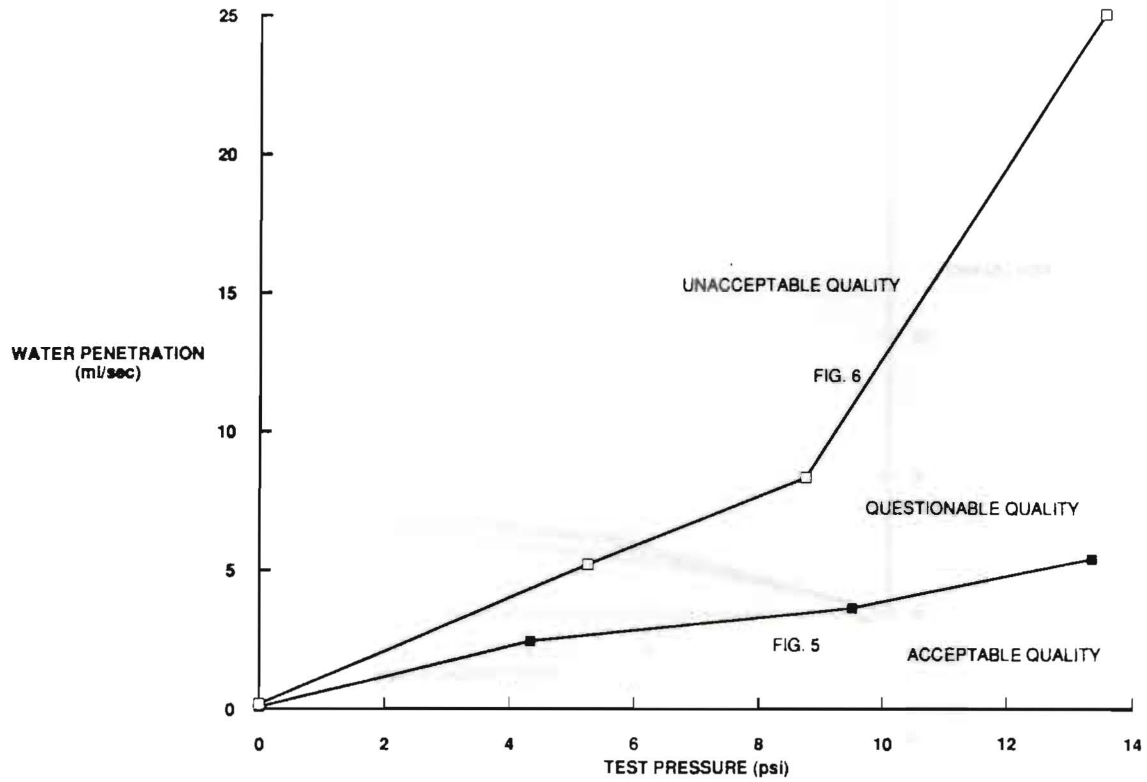

FIG. 7 - TEST RESULTS OF PANEL #1 - AVERAGES OF FIGS. 5 AND 6

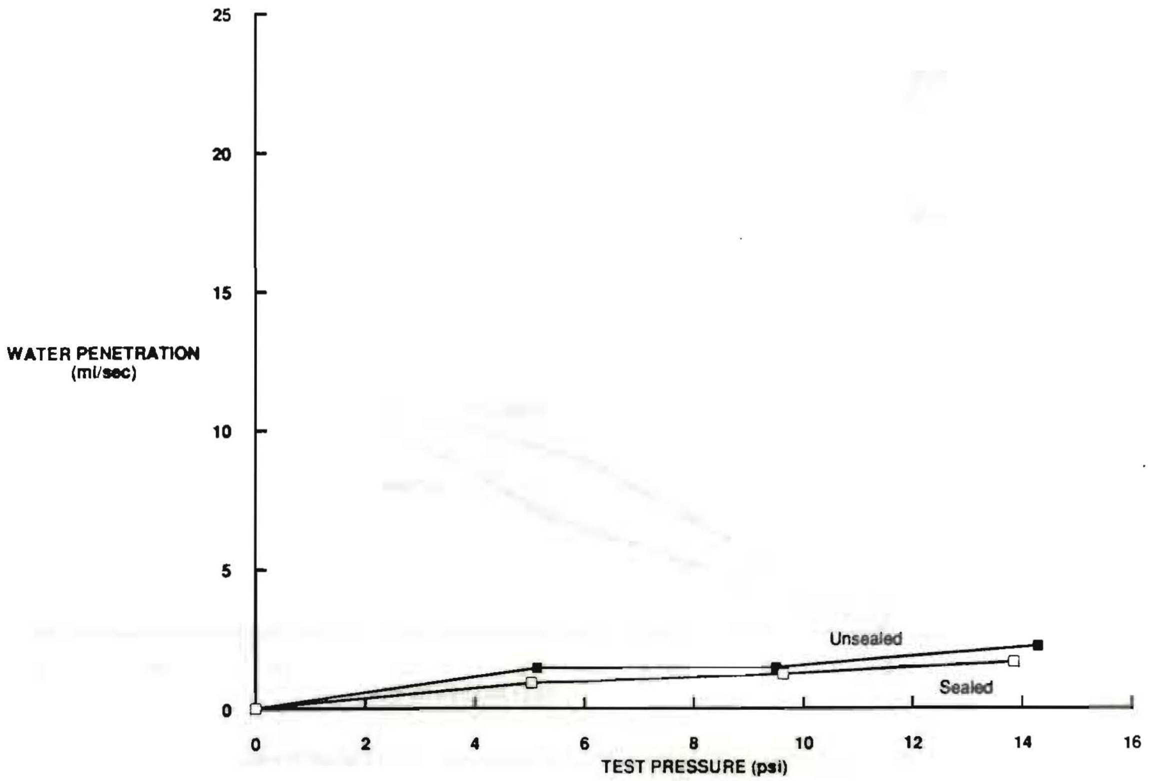

FIG. 8 - AVERAGE TEST RESULTS AT BED JOINT LOCATIONS

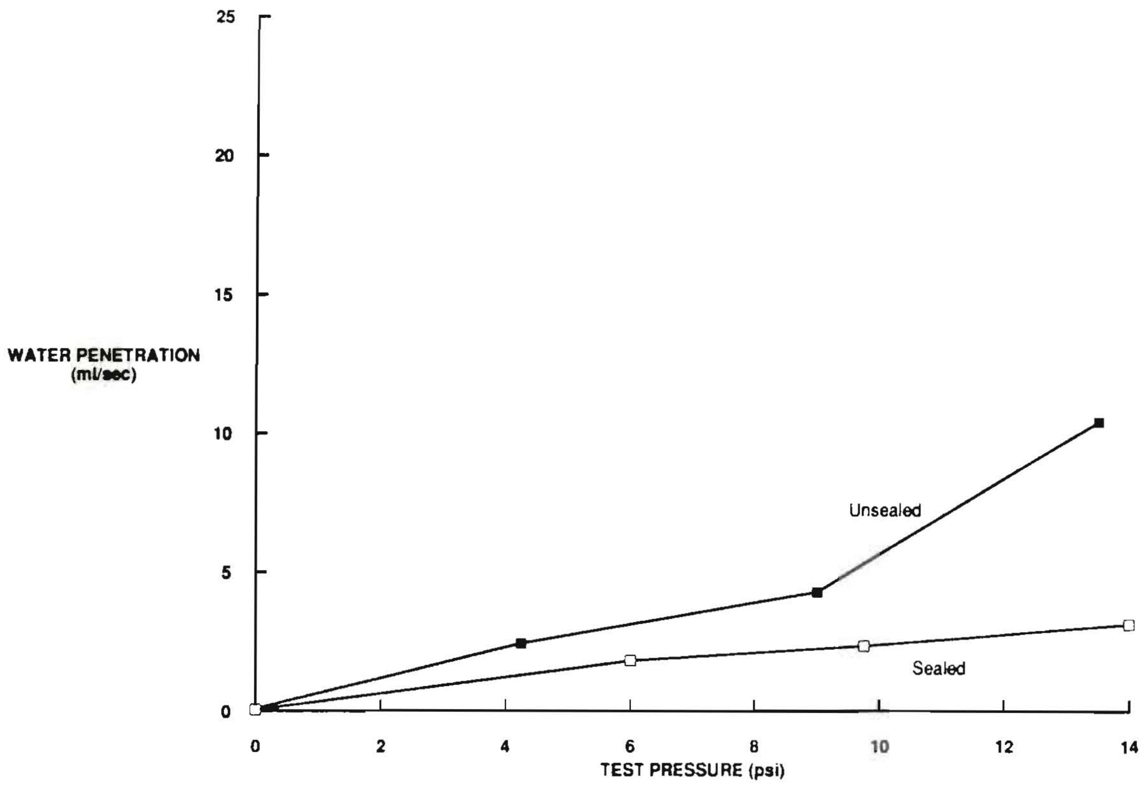

FIG. 9 - AVERAGE TEST RESULTS AT "JUNCTION OF THE JOINT" LOCATIONS