Technical Notes 39B - Testing for Engineered Brick Masonry - Quality Control
March 1988

Abstract: Testing prior to and during the construction of engineered brick masonry may be required to provide a means of quality assurance. Testing may cover materials, to determine compliance with the project requirements, assemblies, to determine the properties of the masonry as constructed or to establish the properties of masonry in existing structures. The extent of testing required must be determined by the engineering or architectural firm responsible for the project design and will depend upon the complexity and importance of the project. This *Technical Notes* describes quality assurance procedures applicable to brick masonry assemblies; other issues in this series address testing of component materials and testing to establish allowable design stresses.

Key Words: **brick**, **bond strength**, **diagonal tension**, engineered brick masonry, grout, masonry testing, mortar, **prism testing**, **quality assurance**, shear, **testing**.

INTRODUCTION

Engineered brick masonry design is a rational design procedure based on material properties and fundamental engineering analysis principles. This type of approach, as opposed to an empirical approach, permits the designer to retain the aesthetic qualities of brick masonry and make efficient use of brick masonry's structural properties.

Since engineered brick masonry design is dependent on material properties, minimum material strength requirements are determined in the preliminary design phase. Materials (brick, mortar and grout) are selected and may be tested to determine allowable design stresses for the combination of materials selected (see *Technical Notes* 39A). Quality assurance testing is then performed during construction to evaluate the properties of constructed masonry. The results of these tests are then used to determine if the constructed masonry is acceptable.

This *Technical Notes* discusses standards developed by the American Society for Testing and Materials (ASTM) that may be used for quality assurance testing of engineered brick masonry. This *Technical Notes* is not intended to replace applicable ASTM standards, but to supplement them.

The purpose of this *Technical Notes* is to serve as an aid in selecting, applying and interpreting tests. The engineer, architect or other responsible person must use judgment in selecting and applying these test methods, but it is hoped that this *Technical Notes* will aid in that process.

PURPOSE OF QUALITY ASSURANCE TESTING

Several standards are used in the United States for the design of brick masonry structures. These standards are referenced in most building codes and contain some type of requirement for testing of materials and assemblages to evaluate material properties, design parameters or as a means of quality assurance. Quality assurance testing is specifically performed to determine that the materials, construction and workmanship meet the project specifications.

The BIA Standard (*Building Code Requirements for Engineered Brick Masonry*, Brick Institute of America, McLean, Virginia, August 1969), for example, requires inspection and testing in order for the designer to make use of higher allowable design stresses. Allowable stress values under the BIA Standard are divided into two categories: "With Inspection" and "Without Inspection". If no inspection is provided, the design allowables for "Without Inspection" are used and represent a thirty-three percent reduction in magnitude, as compared to the values permitted for "With Inspection". Therefore, it is advantageous to implement quality assurance measures in some cases to permit higher allowable stress values.

The type of inspection required in the BIA Standard typically consists of an inspector (the engineer, architect or other responsible party) and some type of testing. The tests outlined in this *Technical Notes* are those that are most commonly performed to satisfy the requirements of the BIA Standard.

TESTING METHODS

The ASTM standards commonly used for quality assurance testing of brick masonry materials and assemblies are contained in the Annual Book of ASTM Standards. Current copies of applicable standards should be readily available to laboratory personnel, individuals involved in field sampling and testing, and individuals involved in interpreting test results. The applicable ASTM standards are:

Component Materials

Clay Masonry Units

ASTM C 67, Standard Method of Sampling and Testing Brick and Structural Clay Tile.

Mortar

ASTM C 270, Standard Specification for Mortar for Unit Masonry.

ASTM C 109, Standard Test Method for Compressive Strength of Hydraulic Cement Mortars (using 2-in. or 50-mm Cube Specimens).

ASTM C 780, Standard Method for Preconstruction and Construction Evaluation of Mortars for Plain and Reinforced Unit Masonry.

Grout

ASTM C 476, Standard Specification for Grout for Masonry.

ASTM C 1019, Standard Method for Sampling and Testing Grout.

Assemblies

Masonry Compressive

ASTM E 447, Standard Test Methods Strength for Compressive Strength of Masonry Prisms.

Flexural Bond Strength

ASTM E 518, Standard Test Methods for Flexural Bond Strength of Masonry.

ASTM C 1072, Standard Test Method for Measurement of Flexural Bond Strength.

In addition to the preceding standards, other standards, while not generally used for quality assurance testing, may be performed in conjunction with compressive and/or flexural bond strength tests to establish a relationship between test methods for quality assurance purposes. These methods listed below are discussed in detail in *Technical Notes* 39A.

Flexural Tensile Strength

ASTM E 72, Standard Methods of Conducting Strength Test of Panels for Building Construction.

Shear Strength Diagonal Tension (Shear)

ASTM E 519, Standard Test Method for Diagonal Tension (Shear) in Masonry Assemblages.

Typically, ASTM standards provide clear and concise explanations of the procedures involved in sampling and testing; however, for the novice, some areas may be confusing. *Technical Notes* 39 Revised presents a complete discussion of the preceding standards for testing component materials.

The standards are listed here for the sake of completeness only. The remaining standards relating to the testing of masonry assemblages are the subject of this *Technical Notes.*

LABORATORY SELECTION

A laboratory selected to perform masonry testing should be properly staffed and be experienced in masonry testing. The equipment available at a laboratory will directly affect the types of tests that can be performed, and the specimens that can be tested. As a minimum, a laboratory will require a curing room with controlled temperature and humidity, and a compression testing machine with a minimum capacity of 300,000 lb and a 15-in. stroke to perform prism tests. Other test methods described in this *Technical Notes* require more specialized equipment that may not be available at some laboratories.

EVALUATION OF MASONRY STRENGTH

Compressive Strength

General. Masonry assembly compressive strength should be determined by prism tests in accordance with ASTM E 447, Method B (see Figure 1).

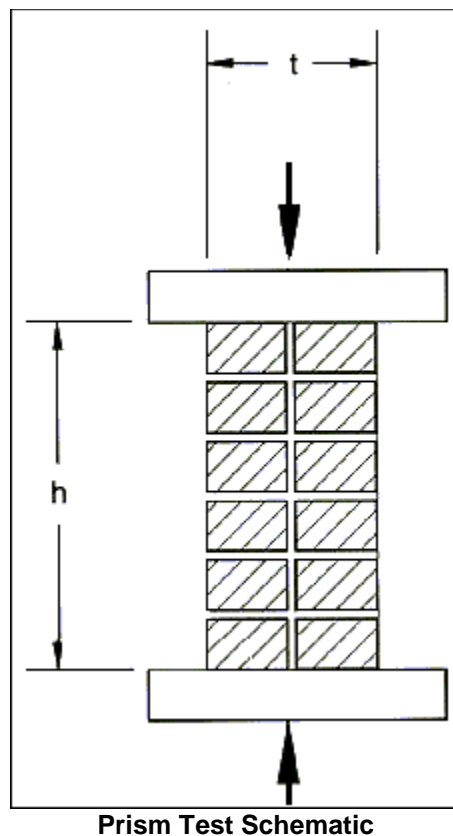

Prism Test Schematic

FIG. 1

Specimens. A minimum of three prisms should be constructed, using the same materials and workmanship as used in the project. The mortar bedding, joint thickness, joint tooling, bonding arrangement and grouting pattern should be the same as that in the project. No structural reinforcement should be included; however, metal wall ties may be included if used in the project. Prisms should not be grouted unless all hollow cells and spaces in the actual construction are to be grouted.

The prism thickness should be the same as that of the actual construction. The prism length should be equal to or greater than the prism thickness. The height of the prism should be at least twice the prism thickness or a minimum of 15 in. (375 mm).

Handling and Curing. Prisms should be constructed on the jobsite in an area where they will not be disturbed or damaged. Prisms should be subjected to atmospheric conditions similar to those of the masonry they represent for a period of 48 hr prior to being prepared for transportation to the testing laboratory. Prisms should be secured and transported in such a manner so as not to damage them.

After prisms are delivered to the laboratory, they should be cured in laboratory air, free of drafts, at 75 deg F +/- 15 deg F (24 deg C +/- 8 deg C), with a relative humidity between 30 and 70% for a period of 26 additional days.

Capping. Proper capping of prisms cannot be over-emphasized. Brick units are not perfectly formed and their bearing surfaces may not be parallel and free from surface irregularities. The purpose of capping the bearing surfaces is to assure reasonably parallel and smooth bearing planes. This reduces the likelihood of uneven bearing and stress concentrations that can result in premature prism failure. The capping material itself should have a compressive strength in excess of that expected of the prism to insure that the capping material does not fail before the prism.

Laboratory personnel responsible for capping prisms should be knowledgeable of the capping procedures prescribed in ASTM C 67 and C 140. Poor capping techniques and inappropriate capping materials can result in erratic test results and lower apparent prism compressive strengths.

Testing. Prisms should be centered under the spherical upper bearing block of the testing machine so that the resulting load will be applied through the center of gravity of each specimen. This is extremely important since the introduction of an eccentric load, if the specimen is not properly centered, can result in lower apparent prism compressive strength.

The speed of testing specified in ASTM E 447 should be followed to obtain consistent results. Past experience on the effect of the loading rate on compressive strength has shown that, as the loading rate increases, there may be a significant increase in apparent compressive strength. The prescribed loading rate provides a moderate rate of loading that produces more consistent results and more accurately represents the true prism compressive strength.

Calculation and Report. The ultimate compressive strength of a prism is calculated by dividing the maximum compressive load by the cross-sectional area of the prism. For prisms constructed with solid units (ASTM C 216 or ASTM C 62), or units grouted solid, the gross cross-sectional area is used to calculate compressive strength. For prisms constructed with ungrouted hollow units (ASTM C 652), the net cross-sectional area (determined by the procedure described in ASTM C 67) is used in the calculation. When brick masonry prisms with height-to-thickness ratios (h/t) of less than 5 are tested, the ultimate compressive strength, as calculated above, must be multiplied by the factors given in Table 1 to correct for slenderness effects.

The report should contain the prism dimensions, prism age, description of materials, maximum compressive load for each prism, cross-sectional area of each prism, compressive strength of each prism, average compressive strength of the specimens, standard deviation and coefficient of variation.

TABLE 1[a]

Slenderness Ratio[b]	2.0	2.5	3.0	3.5	4.0	4.5	5.0
Correction Factor[c]	0.82	0.85	0.88	0.91	0.94	0.97	1.00

[a]These values are different from those now given in the August 1969 BIA Building Code Requirements for Engineered Brick Masonry. They are based on subsequent research and more nearly reflect the masonry behavior in prisms with h/t less than 5.

[b]Height to thickness (h/t).

Recommendations and Evaluation. When prism tests are used as a means of quality assurance for the BIA Standard, not less than 3 prisms should be constructed for each 5000 sq ft of wall area or each story height, whichever is more frequent. Additional test prisms may be constructed at the discretion of the engineer or architect.

Often it is desirable to establish strength relationships for prisms cured less than 28 days to prisms cured for 28 days. This may be established by testing one set of 3 prisms (5 prisms preferred), constructed for each curing period. The prisms should be cured at the site for 24 hr and transported to the laboratory and stored with an ambient temperature and humidity as prescribed in ASTM E 447 for the remainder of the curing period. One set of prisms should be tested at 28 days and the other set tested at the desired age level, typically, 3 or 7 days. From this data, strength relationships between shorter curing periods and 28-day curing periods may be developed.

It is desirable to establish the relationship between early prism strengths to 28-day strengths by testing. However, if this relationship is not or cannot be established, an approximate method may be used to predict the 28-day prism compressive strengths.

The work represented by the quality assurance specimens may be deemed acceptable if the average 28-day compressive strengths or the projected average 28-day compressive strengths are not less than the specified design compressive strength.

Diagonal Tension (Shear) Strength

General. Under certain circumstance, it is sometimes necessary to directly establish design shear stresses more accurately than values established as a function of compressive strength (see allowable shear stresses in the BIA Standard). When this is the case, the methods outlined in ASTM E 519 or ASTM E 72 are used to establish design values (see *Technical Notes* 39A). These test methods require large masonry specimens and cannot be used practically as quality assurance tests. However, these tests may be performed with companion compressive test specimens to develop a relationship between shear and compressive test results. This permits testing of smaller compressive specimens as a means of quality assurance.

Companion Specimens. Compressive test prisms should be constructed and tested as outlined in *Technical Notes* 39A. A minimum of 3 prisms (preferably 5 prisms) should be constructed and tested. The data collected from the compressive prism tests and diagonal tension tests can be used to establish a relationship between prism compressive strength and design shear strength. When this relationship is established, tests can then be conducted by ASTM E 447, in lieu of ASTM E 72 and E 519.
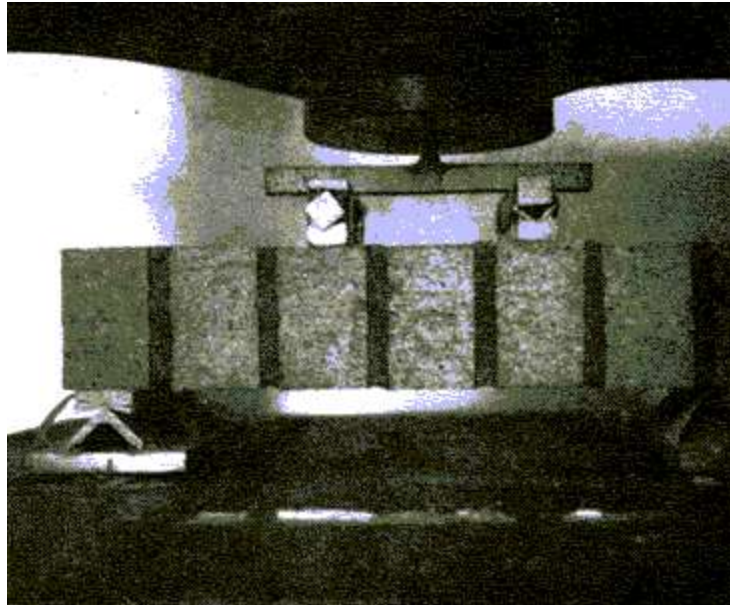
FLEXURAL BOND STRENGTH

General. ASTM E 518 or C 1072 may be used as quality assurance tests to measure the flexural bond strength between masonry units and mortar. These tests are not intended for use in establishing design stresses. Design stresses should be established through ASTM E 72, as described in *Technical Notes* 39A.

Companion Specimens. A relationship between the flexural bond strength obtained by ASTM E 518 or ASTM C 1072 and the transverse strength of ASTM E 72 may be developed by testing companion specimens. This requires that ASTM E 72 transverse load tests be performed and that companion specimens, as prescribed in ASTM E 518 or ASTM C 1072 be constructed and tested using the same units, mortar and workmanship as the E 72 tests. The data from these tests can then be used to establish the relationship between the transverse flexural strength and the flexural bond strength.
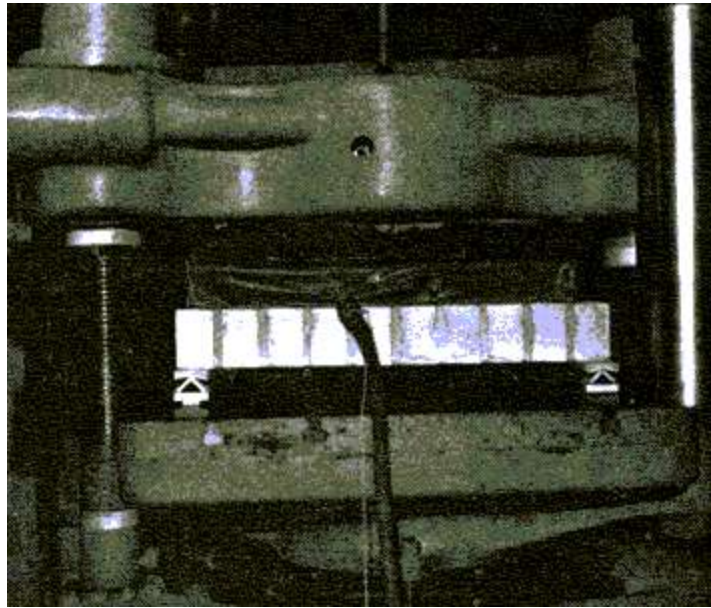
Once this relationship has been established, ASTM E 72 tests need not be conducted. Quality assurance tests can then be made by ASTM E 518 or ASTM C 1072.

ASTM E 518 Test. E 518 provides two methods for performing tests on flexural beams. Method A uses concentrated loads at 1/3 points of the span (see Fig. 2). Method B uses a uniform loading over the entire span (see Fig. 3) applied by an air bag.
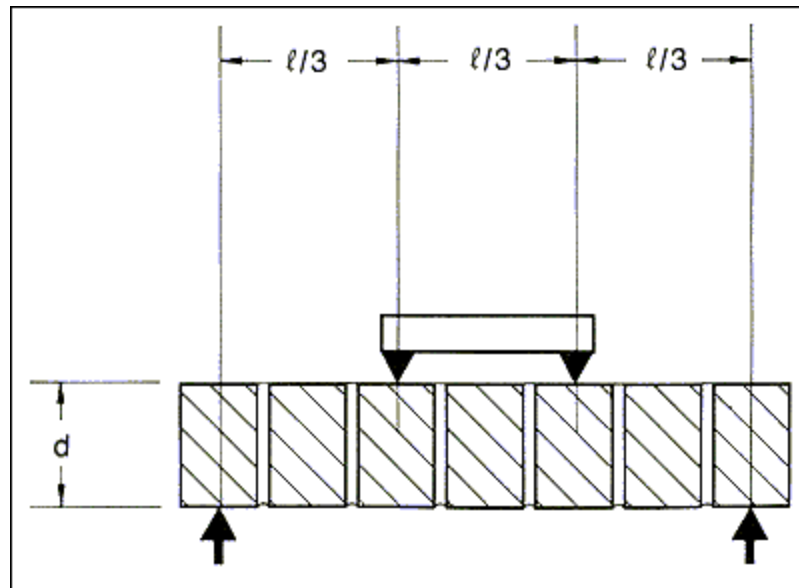
E518 Method A Test

FIG. 2

E518 Method B Test

FIG. 3

Specimens - Prisms should be built at the jobsite with the same materials and workmanship as the actual construction.
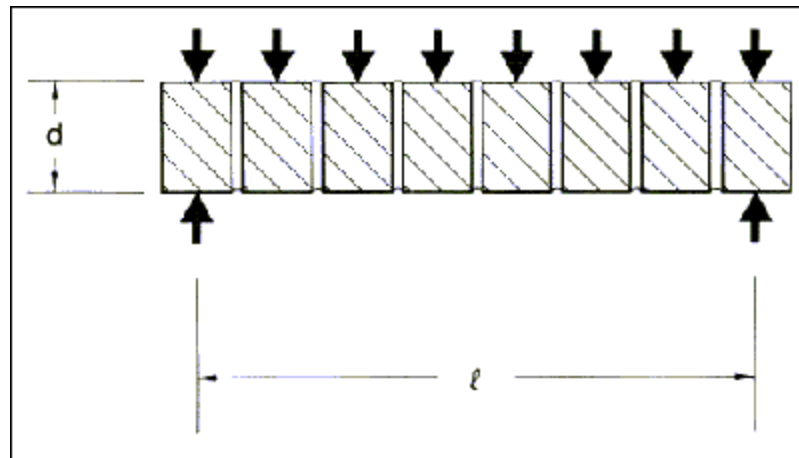
Prisms constructed in the field for quality assurance testing should be protected from damage, but exposed to the same atmospheric conditions as the constructed masonry. These prisms should be stored at the jobsite until the testing date.

Testing - While ASTM E 518 does not specify the orientation of the specimens, specimens for both Method A and Method B (see Figs. 4 and 5) should be placed with the tooled joints downward; that is, loads should be applied to the unfinished face. This provides a more standardized test and allows a more accurate comparison of results.

E518 Method A Setup

FIG. 4

E518 Method B Setup

FIG. 5

If Method A is used and failure of any specimen occurs outside of the middle third of the specimen, the test results for that specimen should be discarded.

Calculation and Report - After testing is completed, the gross area modulus of rupture (tensile bond strength) can be calculated using one of the following formulae:

Method A test: specimen made of solid masonry units.

$$R = \frac{(P + 0.75P_s)l}{bd^2} \qquad\qquad (Eq.1)$$

where:

R = gross area modulus of rupture, psi (Mpa)

P = maximum machine-applied load, lb (N)

P_s = weight of specimen, lb (N)

l = span, in. (mm)

b = average width of specimen, in. (mm)

d = average depth of specimen, in. (mm)

Method B test: specimen made of solid masonry units.

$$R = \frac{0.75(P + P_s)l}{bd^2} \qquad\qquad (Eq.2)$$

Method A test: specimen made of hollow masonry units.

$$R = \frac{(0.167P + 0.125P_s)l}{S} \qquad\qquad (Eq.3)$$

where:

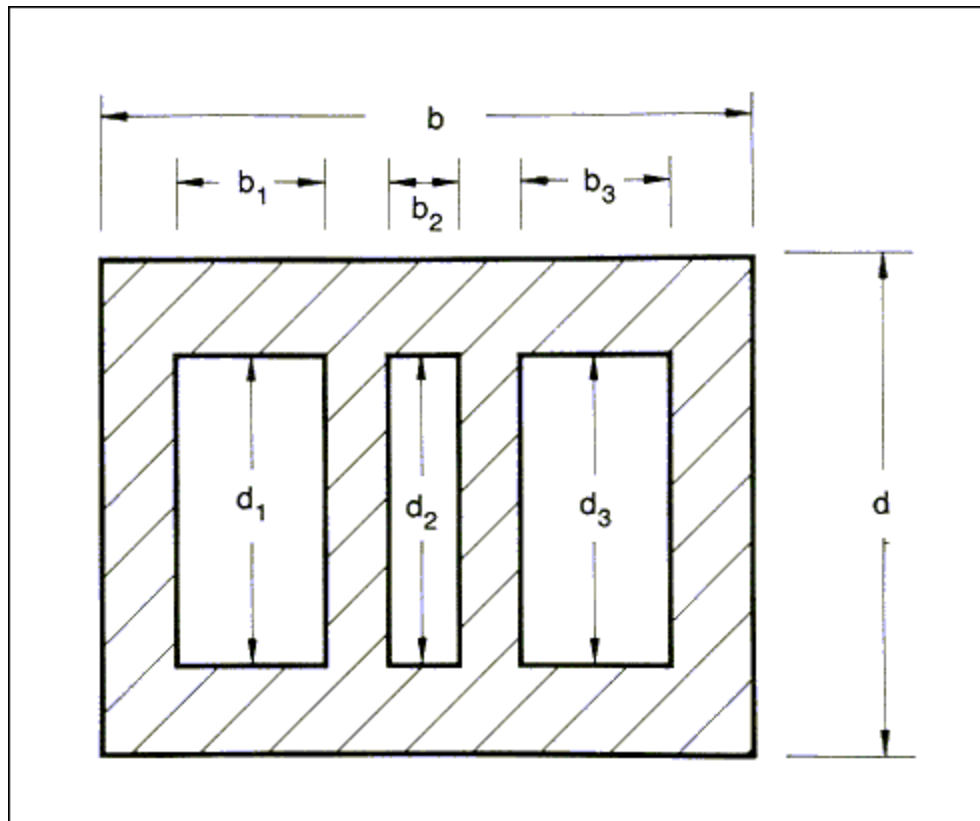S = section modulus of actual net bedded area, in.^{3} (mm^3)

Method B test: specimen made of hollow masonry units.

$$R = \frac{0.125(P + P_s)l}{S} \qquad\qquad (Eq.4)$$

For calculation of the section modulus based on the net bedded areas of hollow units, the following formulae may be used:

Fully bedded hollow units; (see Fig. 6).

Cross Section-Full Bedded Hollow Unit
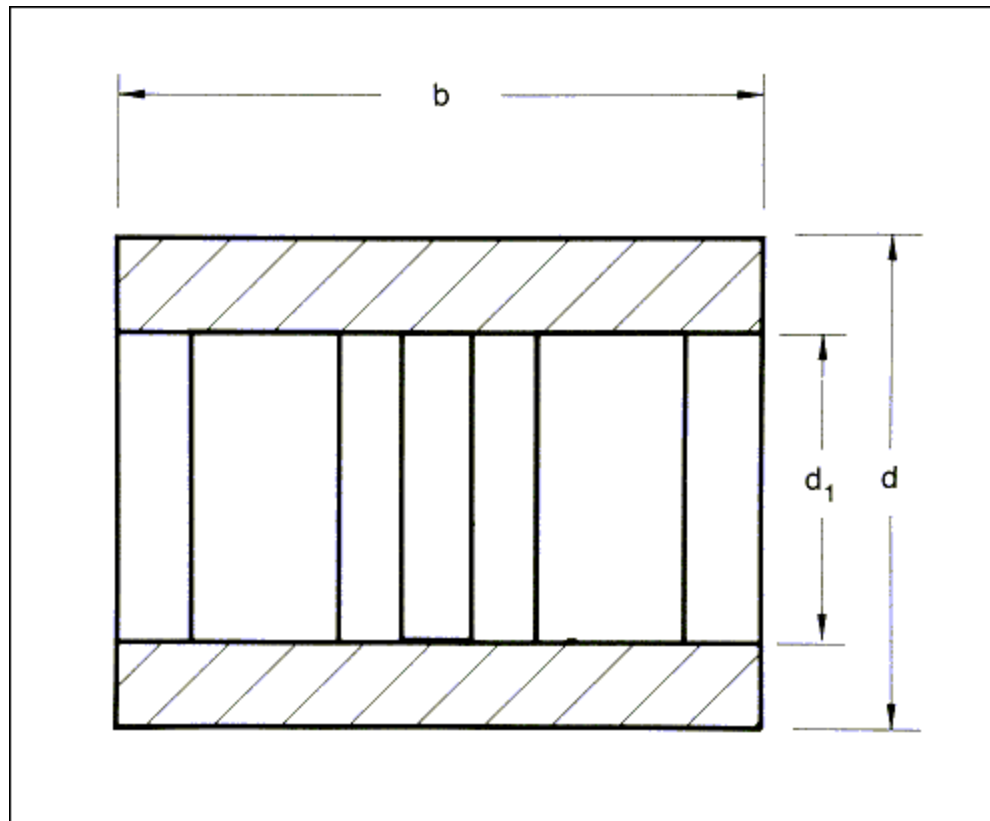
FIG. 6

$$S = \frac{bd^3 - \left(b_1 d_1^3 + b_2 d_2^3 + b_3 d_3^3 \ldots b_n d_n^3\right)}{6d} \qquad (Eq.5)$$

where:

b_1 = width of cores, in. (mm)

d_1 = depth of cores, in. (mm)

Face shell bedded hollow units: (see Fig. 7)

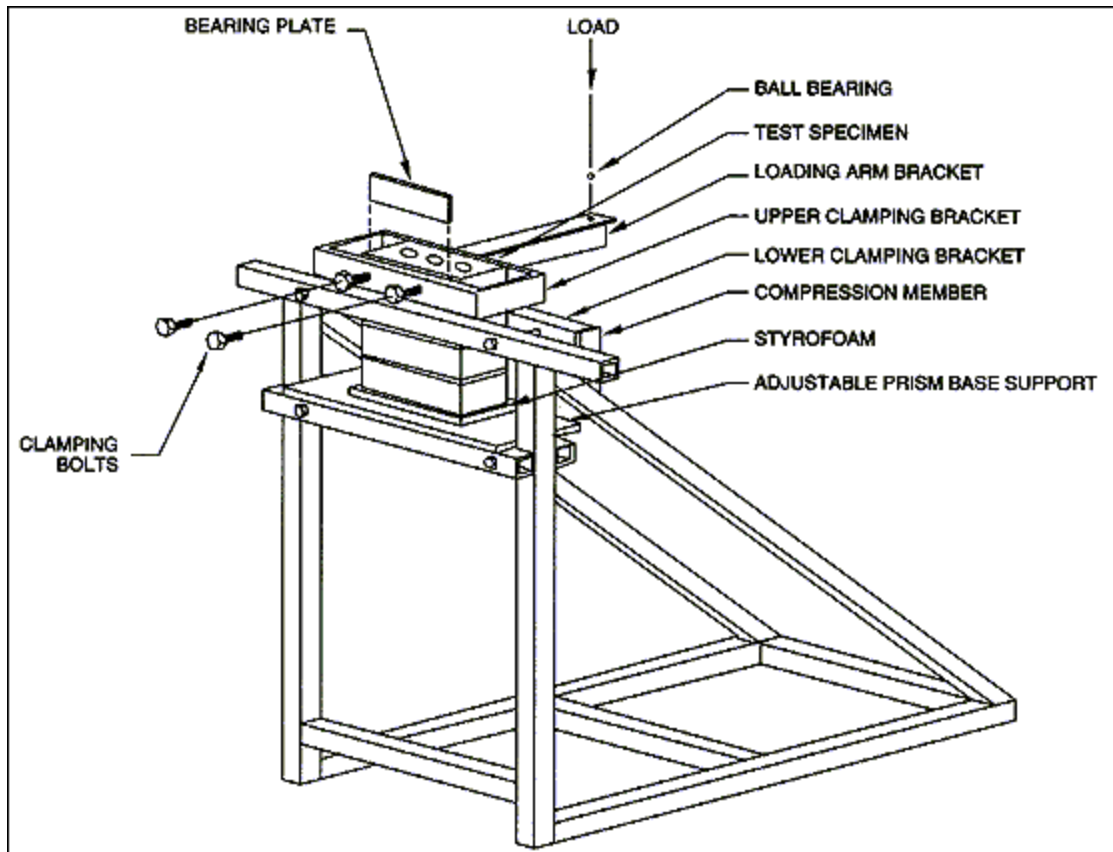**Cross Section-Face Shell Bedded Hollow Unit**

FIG. 7

$$S = \frac{b\left(d^3 - d_1^{\,3}\right)}{6d}$$ (Eq.6)

ASTM C 1072 Test. ASTM C 1072, commonly known as the "bond wrench test", permits individual mortar joints to be tested for flexural bond strength by applying an eccentric load to a single joint in a prism (see Fig. 8). This method has several advantages over the ASTM E 518 test method in that: 1) More data is collected from each prism. 2) The data gathered is more representative since each joint in a specimen is tested instead of the weakest joint in the specimen. 3) It may be used to test specimens extracted from existing structures. 4) Joints remaining after testing by the ASTM E 518 method may be tested and the results of the two methods compared.

Specimens- Prisms should be constructed at the jobsite with the same materials and workmanship used in the actual construction. Prisms should be constructed in a location where they will not be disturbed or damaged, but be subjected to atmospheric conditions similar to those of the actual masonry.

Prisms should be a minimum of 2 units in height, with a minimum width of 4 in. (200 mm). It is recommended that the prisms be a full unit in width. Joints should be 3/8 in. ± 1/16 in. (9.4 mm ± 1.6 mm) in thickness. One face of each prism should be tooled to match the tooling of the project. Prisms should be stored at the jobsite until the testing date. As a minimum, 5 joints should be tested.

Testing- Prisms should be placed in the support frame so that the tooled joints face the clamping bolts in the loading arm and are subjected to flexural tension (see Fig. 8). Prisms should be positioned vertically such that a single brick projects above the lower clamping bracket. A soft bearing material a minimum of 1/2 in. (13 mm) in thickness should be placed between the bottom of the prism and the adjustable prism support base. The loading arm clamping bolts should be tightened using a torque of not more than 20 lb-in. (2.3 N-m). Loading should be applied at a uniform rate such that the total load is applied in not less than 1 min. nor more than 3 min.

Bond Wrench Test Apparatus

FIG. 8

Calculation and Report- After testing is completed, the flexural bond strength can be calculated as:

Specimens made of solid masonry units

$$Fg = \frac{6(PL + P_1L_1)}{bd^2} - \frac{(P + P_1)}{bd} \qquad (Eq.7)$$

where:

        Fg = gross area flexural tensile strength, psi (MPa),

        P = maximum machine applied load, lb (N),

        P_1 = weight of loading arm, lb (N) (See Appendix X1 in ASTM C 1072)

        L = distance from center of prism to loading point, in. (mm),

            L_1 = distance from center of prism to centroid of loading arm, in. (mm) (See Appendix X1 in ASTM C 1072)

        b = average width of the cross-section of failure surface, in. (mm),

d = average thickness of cross-section of failure surface, in. (mm)

Specimens made of hollow masonry units

$$F_n = \frac{(PL + P_1L_1)}{S} - \frac{(P + P_1)}{A}$$

(Eq.8)

where:

F_n = net area flexural tensile strength, psi (MPa),

S = section modulus of actual net bedded area, in.^{3} (mm^3),

A = net bedded area, in.^{2} (mm^2).

For calculation of section modulus, see Eqs. 5 and 6 and Figs. 6 and 7. The net bedded area may be calculated as:

Fully bedded hollow units; (see Fig. 6)

$$A = bd - (b_1d_1 - b_2d_2 + b_3d_3 \ldots b_nd_n)$$

(Eq.9)

Face shell bedded hollow units; (see Fig. 7)

$$A = b(d - d_1)$$

(Eq.10)

EVALUATION OF TEST RESULTS

General

In most cases, strength levels are established by testing or by the selection of design values. Evaluation then becomes a simple matter of comparing the results of the quality assurance tests with the desired strength levels.

Unsatisfactory Test Results

Examination of Procedures. Several alternatives are available when test results fall below the required level. If backup specimens are not available for testing, then close examination should be made of the method of prism construction, the handling of the specimens during transportation and storage and of the laboratory facilities and test procedures. Actual stresses should be checked to determine if the lower strength will provide structural stability. After the above observations and calculations are completed, some judgments should then be made. They are:

1. Did mortar proportions or properties change?

2. Did brick properties change?

3. Were there unusual curing conditions?

4.Were specimens damaged during transit or storage?

5. Were specimens properly constructed?

6. Were test procedures properly followed?

7. Were calculations correctly performed?

As a result of these questions, the possible cause of low test results may be determined.

Alternate Test Procedure. If no immediate solution is evident and reduced strengths result in safety factors below an acceptable level, prisms may be cut from the area in question and tested as described previously.

After specimens are cut from the wall, they should be transported to the lab for testing. If specimens are cut by a water-cooled saw, they should be allowed to dry prior to testing.

Exercise of Judgment. If the test results are still low, then a judgment is required. If the field-cut specimen tests result in strengths that lower the factor of safety below an acceptable level, then removal of the masonry in question must be considered. Obviously, this is the last resort after all other possibilities have been closely examined.

SUMMARY

This *Technical Notes* has discussed quality assurance testing based on procedures developed by ASTM. Testing agencies using these ASTM test methods should be fully aware of their procedures and limitations, so that improper application and erroneous results are avoided.

While the testing procedures outlined in this *Technical Notes* are primarily for engineered brick masonry under the BIA Standard, they may also be used for non-structural masonry testing and quality assurance testing under other standards. Excessive testing can add unnecessary cost to the project. It is important that care be exercised to avoid excessive testing.

It should also be pointed out that, while strengths are important properties of masonry, they are not the only desirable properties. Strengths should not become so important that other desirable properties of masonry are sacrificed. It is still important that masonry be resistant to water penetration, provide sound control and be properly detailed. Quality assurance testing is just one tool to provide assurance that all of the desirable properties of brick masonry are obtained.

Testing procedures described in this *Technical Notes* may involve the use of hazardous materials, operations and/or equipment. This *Technical Notes* does not purport to address all of the safety practices associated with the use of these test methods. It is the responsibility of the user of this *Technical Notes* to establish appropriate safety and health practices and determine the applicability or regulatory limits prior to the use of the test methods described.

The information contained in this *Technical Notes* is based on the available data and experience of the technical staff of the Brick Industry Association. The information should be recognized as recommendations which, if followed with judgment, should prove beneficial to the performance of masonry construction.

Final decisions on the use of information, details and materials as discussed in this *Technical Notes* are not within the purview of the Brick Industry Association and must rest with the product designer, owner or both.