MASONRY EVALUATION USING THE FLATJACK METHOD

October 1991

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PREFACE

This report represents a compilation of three recent publications pertaining to the evaluation of masonry structures using the flatjack method. The first article has been reprinted from the proceedings of the recent conference on "Nondestructive Evaluation of Civil Structures and Materials". This paper was presented by Atkinson-Noland & Associates at the conference in October, 1990, and provides a brief overview of the procedures used to conduct flatjack tests as well as typical test results. A complete description of equipment and procedures necessary for flatjack testing is provided in ASTM standards pertaining to the flatjack method. Reprints of these standards are included here.

THE FOLLOWING PAPER
HAS-BEEN REPRINTED FROM:

PROCEEDINGS

NONDESTRUCTIVE EVALUATION OF CIVIL STRUCTURES AND MATERIALS

Sponsored in part by
The National Science Foundation
Grant No. MSM 9005818

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University of Colorado
Boulder, Colorado
October 1990

A REVIEW OF THE FLATJACK MEETHOD
FOR
NONDESTRUCTIVE EVALUATION

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ABSTRACT

The application of flatjack testing to the nondestructive evaluation of unreinforced, solid-unit masonry is presented. The flatjack method provides a direct measure of the state of compressive stress, deformabifity, and compressive strength. Laboratory test results have shown that the flatjack method provides an accurate estimate of masonry properties insitu. Procedures related to both the in-situ stress test and the in-situ deformability test are discussed, including flatjack design and calibration. Results from flatjack tests conducted on several old masonry buildings are included.

SUMMARY

The flatjack test is a very useful tool for the nondestructive evaluation (NDE) of structural properties of masonry. Under the proper conditions, flatjack testing can provide information on the in-situ state of stress at virtually any point in a masonry structure, a measure of the deformability of the masonry materials, and in some cases a direct measure of masonry compressive strength. Flatjack testing is based upon methods which originated in the field of geomechanics. The technique was first suggested for use with masonry by Italian researchers Rossi and Binda. Atkinson-Noland & Associates has been engaged in the evaluation of flatjack testing since 1985 under sponsorship by the National Science Foundation for use in the evaluation of existing older brick masonry buildings in the United States. Flatjack testing standards have been developed for RILEM and are currently under development in ASTM.

INTRODUCTION

Engineers faced with the repair or retrofit of existing masonry buildings require knowledge of strength and deformability properties of the masonry, as well as the state of compressive stress in the masonry. NDE techniques such as ultrasonic pulse velocity or hardness testing may be able to locate flaws or provide a comparative survey of masonry quality, but they can not provide the quantitative data required for engineering evaluation and analysis. The flatjack method is unique in that it provides a direct measure of masonry strength and modulus parameters.

This paper presents an overview of both the in-situ stress test and the in-situ deformability test, including the design of typical flatjacks, calibration, laboratory results, and field results. The development of ASTM standards for the use of flatjacks to measure compressive stress in-situ and to measure masonry deformability in-situ is reviewed.

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BACKGROUND

Flatjack techniques are well established in the field of rock mechanics for determining stresses and material deformability in the rock structure of tunnels and mines [2, 4, 5]. The technology of the flatjack test has been modified and adapted to the purpose of evaluation of brick and stone masonry structures in Italy by P.P. Rossi and others [3, 7, 9, 10]. Rossi developed initial specifications for the optimum size and placement of flatjacks, techniques for measuring deformations, the proper calibration of flatjacks, and post-test analysis of data. Several researchers, including the authors, have conducted further experimental work on the application of flatjacks to masonry evaluation problems [1, 6, 12]. Abdunur [1] experimented with very small semi-circular flatjacks, and conducted idealized photoelastic stress analyses on plastic models. Wang and Wang [12] developed a relatively thick flatjack with large displacement capabilities for use on very soft masonry materials typically found in China.

Analytical studies have been done in support of the experimental results. Sachhi-Landriani et. al. [I I] conducted extensive nonlinear finite element analyses of both the single and double flat jack tests in masonry materials. They found their numerical models to be generally in support of experimental evidence, and offered some insight concerning the effect of certain assumptions on the accuracy of the results. For example, the accuracy of the in-situ deformation test is compromised because of the restraining effects of the vertical boundaries of the "in-situ prism". Based on their analytical work, they recommend that if the two flatjack test is carried out to failure of the masonry, the failure stress should be reduced by 20% to yield the unrestrained compressive strength. Similarly, the in-situ stress test may overestimate the actual state of stress by as much as 10% according to their models.

Standards governing flatjack testing have been developed in Europe for RILEM by Committee 76LUM (Arnold Hendry, Chair). Procedures for the two flatjack methods have been submitted to ASTM Task Group C15.04.6 (In-situ Masonry Evaluation), as a basis for developing an ASTM standard.

With some modifications, the flatjack test has been successfully adapted for use in the United States. Certain characteristics of existing unreinforced brick masonry buildings in the U.S., most of which were built prior to the early 1930s, have required modification of procedures and flatjack configuration from those used in Italy. Typical complications include thin (1/4 inch) mortar joints used for face brick, the use of weak sand-lime mortar mixes, the presence of brick "frogs" and voids in the masonry, and incomplete filling of head and collar joints.

DESCRIPTION OF FLATJACK TESTING

Flatjacks may be made in many shapes and sizes as illustrated in Figure 1. The shape and thickness of a flatjack is determined by its function and the nature of the

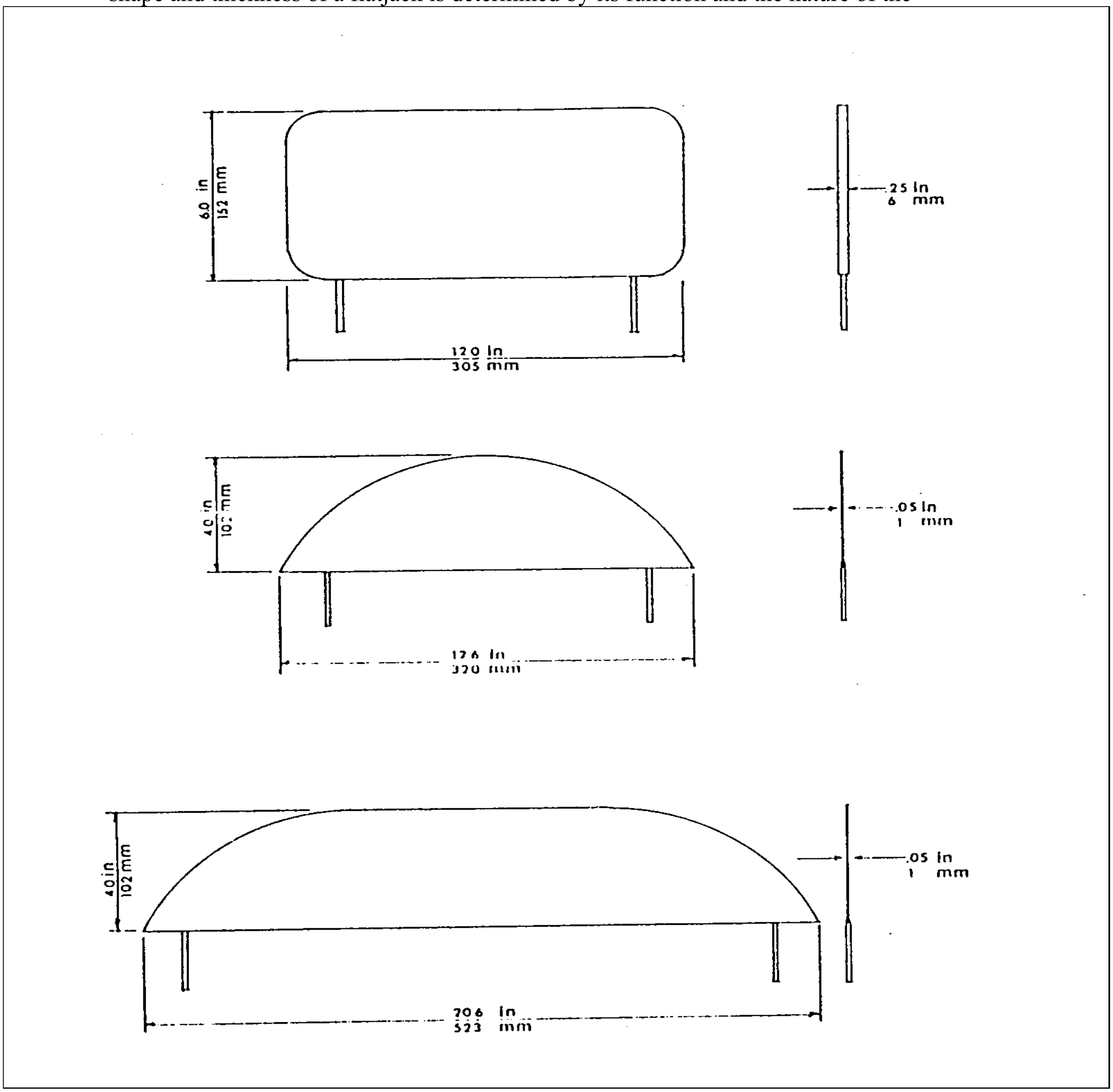

Figure 1. An example of typical flatjack configurations.

masonry materials being evaluated; the shapes represented in Figure I have proven to be satisfactory for many applications. Flatjacks with curved edges are designed to fit in a slot cut by a circular saw, and rectangular jacks are used where mortar must be removed by hand or with a drill. Semi-circular jacks are suitable for in-situ stress measurement but are not large enough to be used in the two-flatjack test; rectangular or semi-rectangular flatjacks with a length equal to or greater than that of two masonry units should be used.

Regardless of shape, flatjacks developed in this research consist of two thin sheets of steel welded at the edges (see Figure 1). Overall flatjack thickness can vary from a minimum of 0. 05 inches to a maximum of 0. 5 inches.

The thickness of the flatjack is determined by its specific function: the ideal flatjack will completely fill the slot in the mortar joint or shims may be used together with the flatjack to completely fill the slot thickness.

Calibration of the flatjacks is of utmost importance and is accomplished by measuring the stress provided by the flatjack for various levels of internal pressure. Ideally, the flatjack should be calibrated in a servo-controlled testing machine using thick bearing plates. It is imperative that the flatjack be kept at a constant thickness during the entire calibration process.

When there are significant voids or impressions (such as "frogs") in the masonry surface against which the flatjack is placed, measures must be taken to ensure that the flatjack makes complete contact over the surface, and that the flatjack will not extrude into the voids. Large deformations in the testing flatjack will cause inaccuracies in the test results and will make it difficult to remove the flatjack without causing excessive damage to the wall. Several techniques for providing a uniform stress distribution over the area of the flatjack have been investigated, including the use of single-piece and multiple-piece metal shims, and grouting of the area surrounding the flatjack. The most successful solution involves the use of one or more thin flatjacks inserted adjacent to the working flatjack. These "fluid cushion shims" are initially pressurized and allowed to deform plastically into voids and irregularities. This allows for the best possible uniform application of pressure by the working flatjack to uneven masonry surfaces.

In-Situ Stress Test

The in-situ stress test is a simple problem of stress relief, which involves measurement of deformations around a slot cut in the masonry. The test setup is depicted in Figure 2. Before the slot is cut, metal gage points are affixed to the surface of the masonry above and below the location where the flatjack will be inserted. An initial reference measurement is taken of the distance between the gage points, using a removable dial gage (Wittemore Gage). A slot of the exact shape and size as the flatjack is then formed by either drilling or cutting of the mortar joint with a circular saw. It is essential that all mortar be removed and the slot be thoroughly cleaned to provide a uniform bearing surface for the flatjack. The working flatjack is inserted into the slot, along with any flatjacks used as shims, if required, to provide a "snug" fit. The fluid cushion shims are "seated" into the slot by initially pressurizing them to 200 to 300 psi, allowing them to deform into any voids or irregularities. Pressure is then relieved, and an initial displacement reading is taken. The working flatjack is pressurized, with displacement readings being taken every 25 to 50 psi. The test is completed when the distance between gage points are restored to the position before the slot was cut. The pressure in the working flatjack, modified by calibration constants to account for the flatjack stiffness and the area of the slot, is equivalent to the original compressive stress in the masonry. Additional cycles are helpful in verifying the cancellation pressure

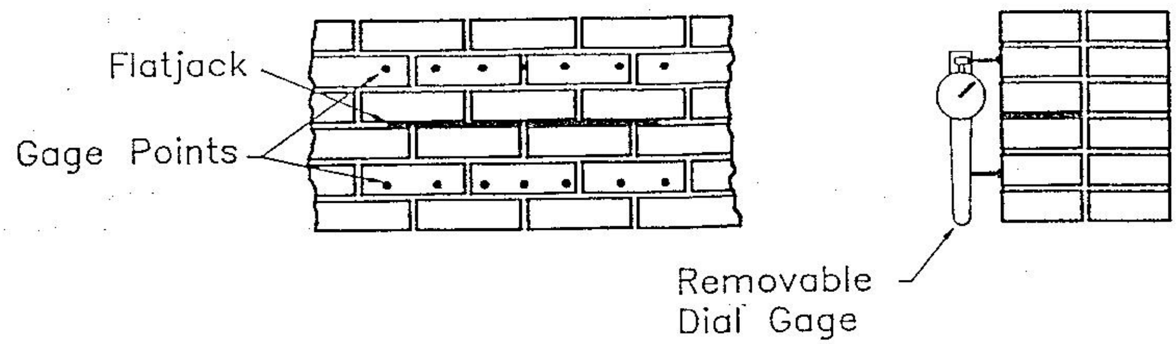

Figure 2. Setup for the in-situ stress test.

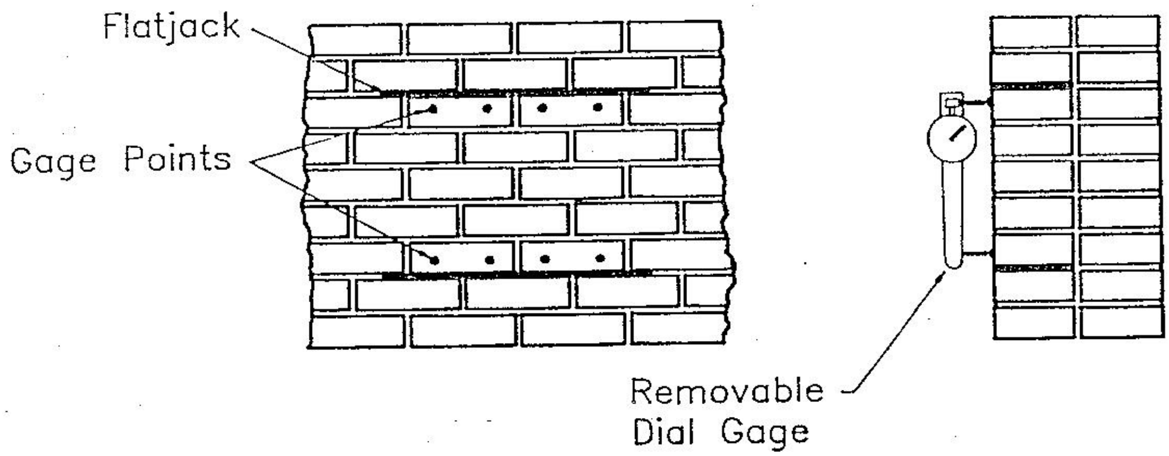

Figure 3. Setup for the in-situ deformability test.

In-Situ Deformability Test

Two identical flatjacks are used for the in-situ deformability test, as shown in Figure 3. The slots for the flatjacks should be parallel and separated by at least 5 courses of brick masonry. Dial gages or electronic displacement transducers are mounted on the surface of the masonry between the two slots to measure deformations of the masonry. The two working jacks are pressurized equally during testing, and deformations of the masonry between the flatjacks are measured at small increments of pressure. The jack pressure, modified by the flatjack calibration factor and the slot area factor, provides a measure of the magnitude of stress applied to the masonry. An in-situ stress-strain curve may be plotted, using the measured deformations and the modified flatjack pressures.

Because these tests are not strictly nondestructive, a small amount of repair work is needed. Following either of the tests the flatjacks are removed, being careful not to damage the surrounding masonry. The masonry is returned to its original condition by repainting mortar into the flatjack slot.

APPLICATION

The flatjack tests described herein are among the most useful and informative nondestructive tests available for the evaluation of masonry structural properties. Unlike other nondestructive tests, the flatjack method provides a direct physical measurement of engineering material characteristics needed for structural analysis and evaluation; there is no reliance on correlations to laboratory tests.

The in-situ stress test provides a direct measure of the vertical stress at a point in a structure, and thus gives an indication of the factor of safety of the structure in terms of compressive loads. Stress measurement tests can be used on either side of a masonry wall to determine the presence of stress gradients caused by bending moments. The measurement of in-situ stress can also provide a gauge of the accuracy of structural analyses in predicting the effects of gravity loads.

The in-situ deformability test produces a direct measure of the compression modulus which can be used for calculation of deflections, or for input into finite element analysis programs. The test may optionally be carried out to failure of the masonry to determine the in-situ masonry strength, if such damage to the structure is acceptable.

EXAMPLE RESULTS

The flatjack method was developed for use in the United States through a series of laboratory experiments on masonry walls and small masonry prisms. Results from a typical in-situ stress test are shown in Figure 4, which plots deformations around the flatjack slot for various levels of flatjack pressure. This particular test was conducted in the laboratory on a wall constructed using weak mortar and reclaimed old clay bricks. The test wall was built in a simple load frame and subjected to a uniform stress of 250 psi . A stress of 280 psi was measured during this test, which is reasonably close to the applied stress of 250 psi.

In-situ deformability tests were also conducted on the test walls and provided similarly favorable results. The masonry modulus has been measured with a least squares approximation, fitting a straight line to the initial linear portion of the curve. For this particular specimen, the masonry modulus was measured as 433 ksi during loading of the test wall and 439 ksi by testing prisms constructed with the test wall. A cyclic stressstrain curve obtained from the in-situ deforinability test (Figure 5) gives an average modulus of 445 ksi. Tests on other wall specimens show similar accuracy, generally within 10% of the masonry prism modulus.

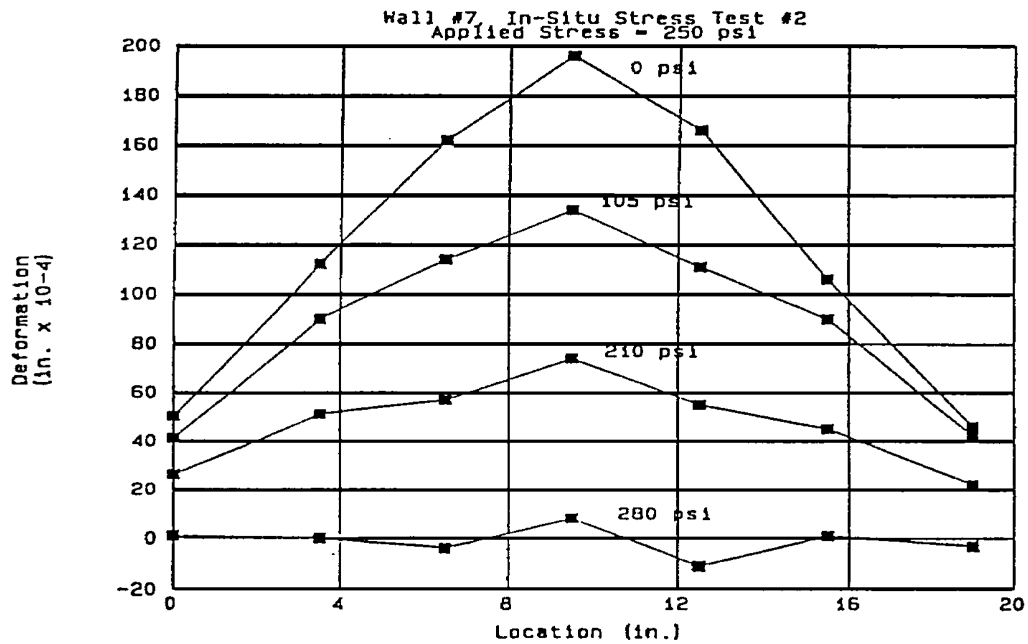

Figure 4. Deformations around flatjack slot during an in-situ stress test.

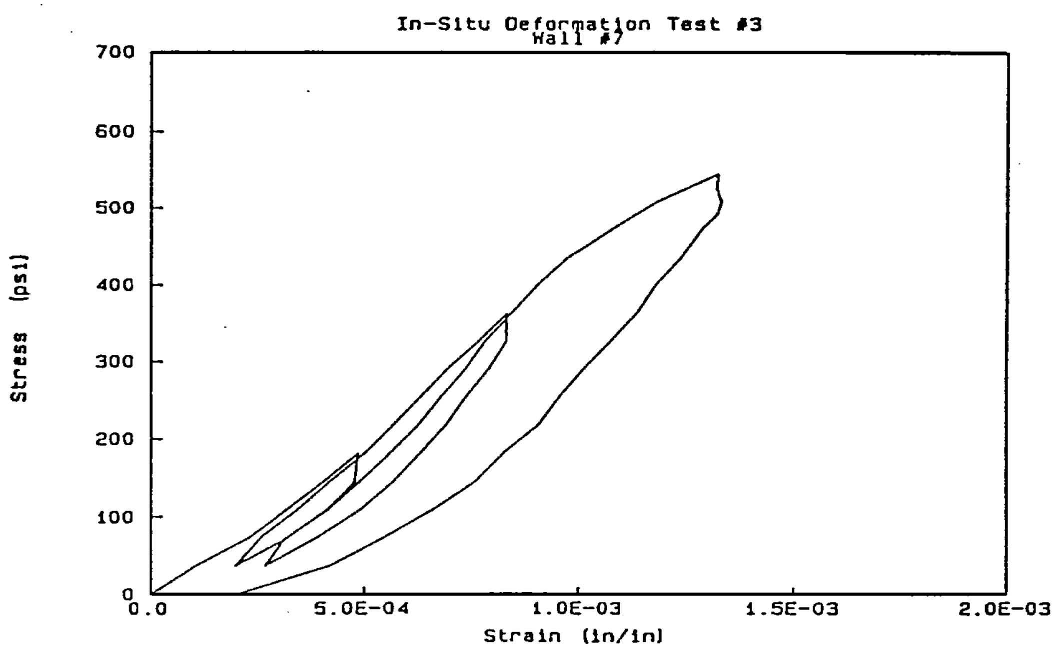

Figure 5. A stress-strain curve obtained during a cyclic in-situ deformability test.

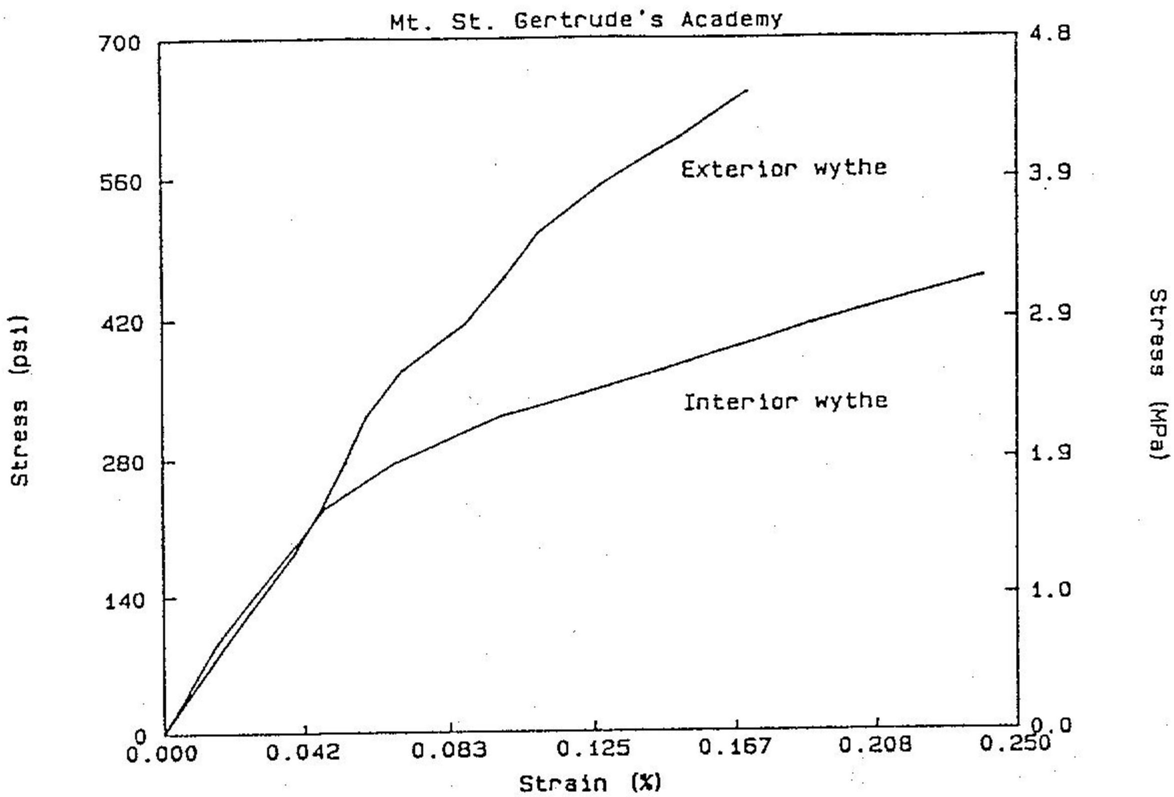

Figure 6. In-situ deformability test results from Mt. St. Gertrude's Academy, Boulder, Colorado. Note the drop in modulus of the load-bearing interior wythe at about 225 psi.

The flatjack method was evaluated for field use through testing of several old masonry buildings. In many older masonry buildings, the outer wythe is a single layer of high quality "face" brick, behind which are one or more interior wythes of **"common"** brick. Because appearance is not of importance in the interior wythes, the.common brick is a lesser quality unit, often set in thick mortar joints. Figure 6 shows the results of deformability tests on Mt. St. Gertrude's Academy in Boulder, Colorado, a three-story load-bearing masonry school building constructed in 1892. Two stress-strain curves are shown in Figure 6, one from the exterior wythe, and one from an interior wythe. Even though the initial stiffness of the two wythes is nearly identical, they are obviously of different quality. The elastic modulus has been estimated by fitting a fine to the linear portion of the curves after the initial segment and has been calculated as 383 ksi for the exterior wythe and 115 ksi for the interior wythe. The exterior veneer is clearly of superior quality than the interior, load-bearing wythe.

A similar curve is shown in Figure 7, obtained during a flatjack test prior to restoration of the Raybon House in Colonial Williamsburg, Virginia. The Raybon house is over 200 years old and was constructed with hand-molded bricks and soft mortar. The modulus estimated from this test was 380 ksi.

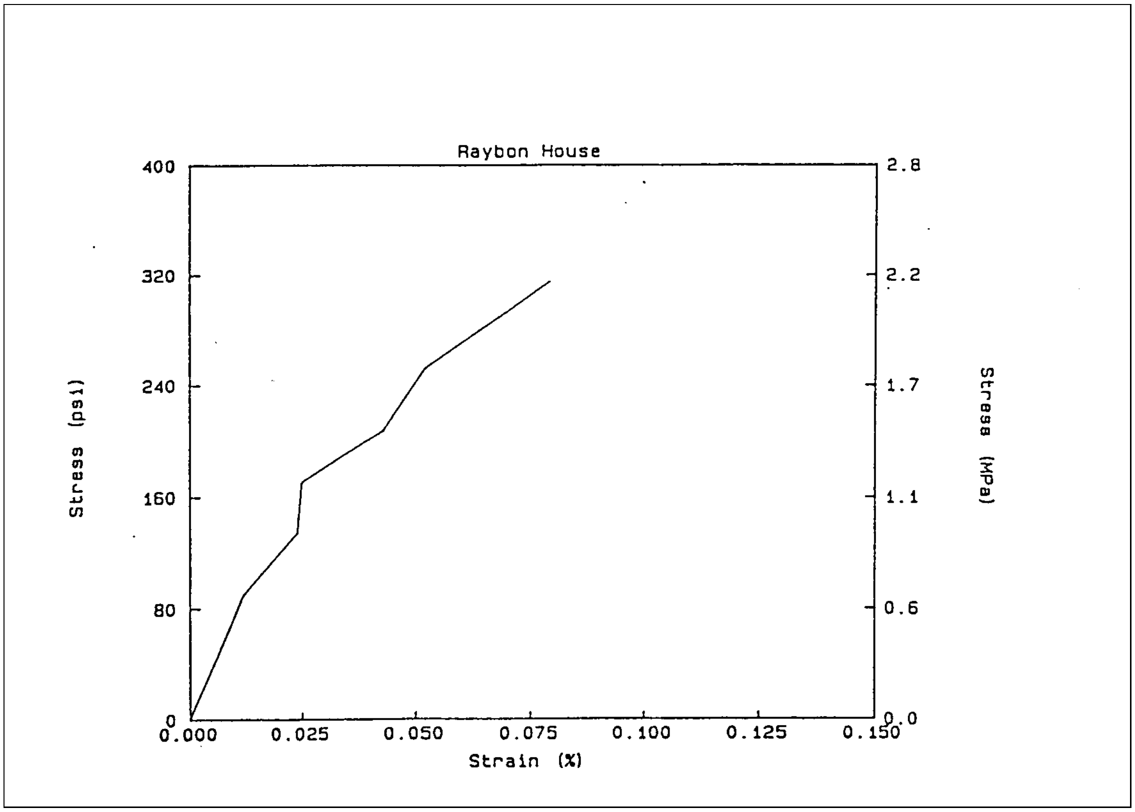

Figure 7. In-situ deformability tests results obtained for the Raybon House, Colonial Williamsburg, Virginia.

Flatjack tests have recently been used in the assessment of several old masonry buildings in southern California as part of a seismic upgrade program. The results of tests on two of these buildings are presented here. Both buildings were constructed using fired clay brick and soft, sand-lime mortar. The first plot, shown in Figure 8, is from an in-situ deformability test conducted on a circa 1900 building in Pasadena, California by Specialized Testing and Inspection of Redondo Beach, California. This structure consisted of masonry insitu in a steel frame, covered by a plaster coating. A masonry modulus of 100 ksi was calculated as the average of three tests. Similar results are shown in Figure 9 for a deformability test conducted on an old cathedral in Los Angeles, California. The cathedral was constructed as a reinforced concrete frame structure, with a 3-wythe thick masonry infill. Four tests were conducted on the structure by Materials Engineering Consultants of Glendale, California. An average masonry modulus of 67 ksi was recorded. The masonry stiffness values obtained during these tests are recognized as being extremely low and are thought to reflect not only deterioration of the constituent materials, but also the poor construction practices and weak masonry materials typical of the turn of the century.

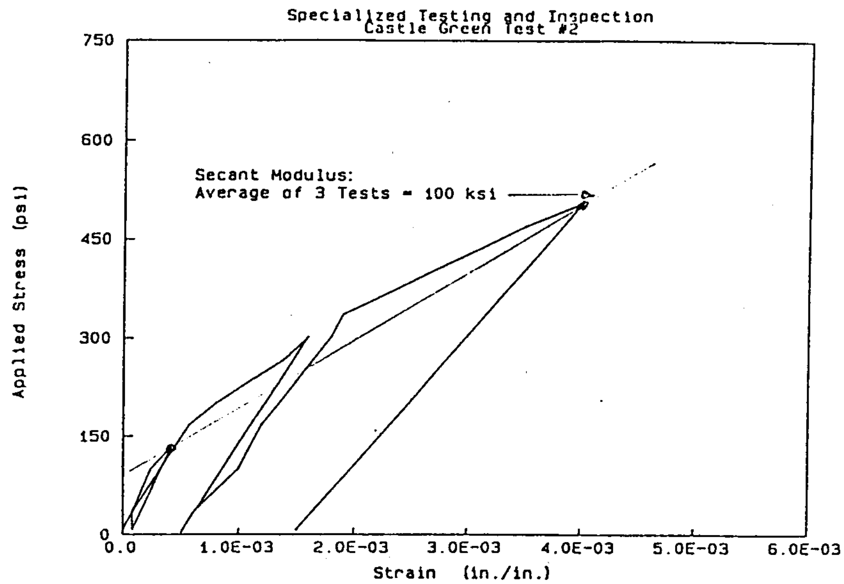

Figure 8. In-situ deformability test conducted on a circa 1900 masonry structure in Pasadena, California.

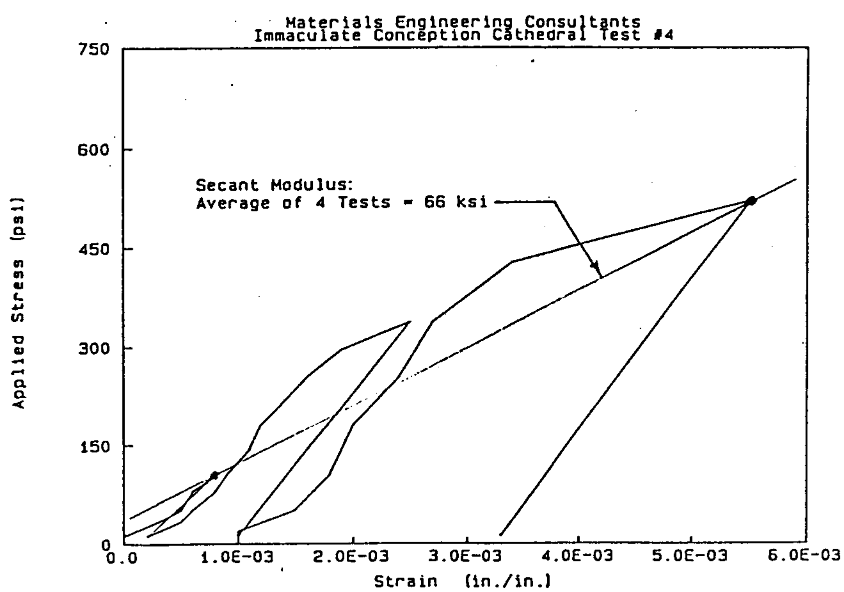

Figure 9. In-situ deformability test conducted on a masonry cathedral in Los Angeles.

DEVELOPMENT OF ASTM STANDARDS FOR FLATJACK TESTS

Standard methods for conducting in-situ compressive stress measurements and insitu deformability measurements are being developed by ASTM. The standards Will include a description of flatjack calibration procedures as well as in-situ testing procedures using flatjacks. The development is under the auspices of Task Group C15.04.06 of ASTM Committee C 1 5. Dr. John Matthys is the chair of the Task Group.

The standards for both applications have been reviewed by Task Group members. The standard for in-situ compressive stress measurement has been reviewed and balloted. Resolution of negative comments has been completed and the standard will be reballoted. The standard for in-situ deformation measurements is currently in the balloting process.

CONCLUSIONS

The flatjack method provides a relatively straightforward technique for the in-situ measurement of masonry compressive stress and deformability. No other nondestructive test method offers direct physical measurement of material and structural properties without reliance on empirical correlations. The degree of accuracy is generally compatible with the needs of analysis for typical retrofit projects. Equipment needed for flatjack testing is simple to operate, completely portable, and relatively inexpensive.

The test requires some skill and care, particularly in dealing with the problems of voids or frogs in the mortar joints. Not only will significant innaccuracies be introduced if voids are not properly spanned, but the flatjack may inadvertently become a permanent part of the structure. Also, care must be taken not to damage the structure during cutting of slots.

Current test procedures provide for testing of only a single exterior wythe, which may have properties significantly different from the interior wythes. Techniques need to be developed for the application of fl@tiack tests to interior wythes of masonry with a minimum of disruption to the visible structure.

Flatjack tests may easily be integrated into the structural evaluation process, and provide data that is complimentary to other nondestructive tests. Information concerning the states of stress at various points throughout the structure can be helpful in the interpretation of data from the in-place shear test and both ultrasoific and mechanical pulse tests. Data on the elastic modulus and strength of masonry obtained from the two-flatjack test may be used for correlation to Schmidt Hammer, pulse velocity, or pull-out tests. Flatjacks may also be used in conjunction with the in-situ bed joint shear test to provide a measure of mortar joint shear strength under various magnitudes of compressive stress.

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