APPLICATION OF NDE TO MASONRY STRUCTURES; CURRENT TECHNOLOGY AND FUTURE NEEDS

R. H. Atkinson,
J. L. Noland and
G. R. Kingsley

Atkinson-Noland and Associates, Inc.
2619 Spruce Street
Boulder, Colorado 80302

INTRODUCTION

A large inventory of unreinforced masonry buildings exists in the United States many of which may be structurally marginal or inadequate for their present or proposed use. Recent advances in seismic hazard mapping have resulted in more stringent design requirements in many parts of the country. Changed functional use of masonry structures can also impose increased design loadings.

A critical element in the any repair or upgrading project is the need to assess the condition of the structure. This assessment is needed to establish the existing condition of the structure and to plan for its repair. Secondly, means to assess in real time the progress of the repair are required especially when techniques such as grouting are being used. Finally, an assessment of the modified structure is required to assure that the repairs have provided the needed upgrade in structural capacity.

Current practice is to determine masonry condition by cutting prisms or cores from the building for destructive laboratory tests. For statistical significance a large number of specimens must be tested. The removal of a large number of test specimens from the structure will significantly disfigure the structure and in cases of historic structures may not be allowed. The development of nondestructive test methods for masonry structure evaluation is clearly needed.

EVALUATION FACTORS

A structural engineer faced with the problem of evaluating the condition of an existing masonry structure requires quantitative material data in terms of peak strength, strain at peak strength, and modulus of rupture. The engineer also needs to know the location and extent of all flaws in the structure including cracks, bed joint delaminations, zones of deterioration due to environmental effects and zones of

Review of Progress in Quantitative Nondestructive Evaluation, Vol. 9
Edited by D.O. Thompson and D.E. Chimenti
Plenum Press, New York, 1990

internal voids and poor construction practice. Finally, the level of existing stress in structure should be determined to assess overall margins of safety under present or future loadings.

REVIEW OF CURRENT EVALUATION METHODS

The development of NDE techniques for masonry has generally involved an application of methods used for the NDE of concrete [1,2] or of rock masses[3,4]. A recent study [5] has developed and evaluated a number of NDE techniques for application to masonry. These include:

Ultrasonic Pulse

Perhaps the most common application of nondestructive testing methods to masonry has been with ultrasonic pulse velocity (UPV) techniques similar to those used for concrete. Figure 1 presents a comparison of masonry prism strength versus wave velocity in which a reasonable correlation is seen. This correlation is, however, dependent on materials and test technique and needs to be established for individual masonry constituents. Figure 2 shows the rapid attenuation of amplitude of a 54 kHz input signal with distance.

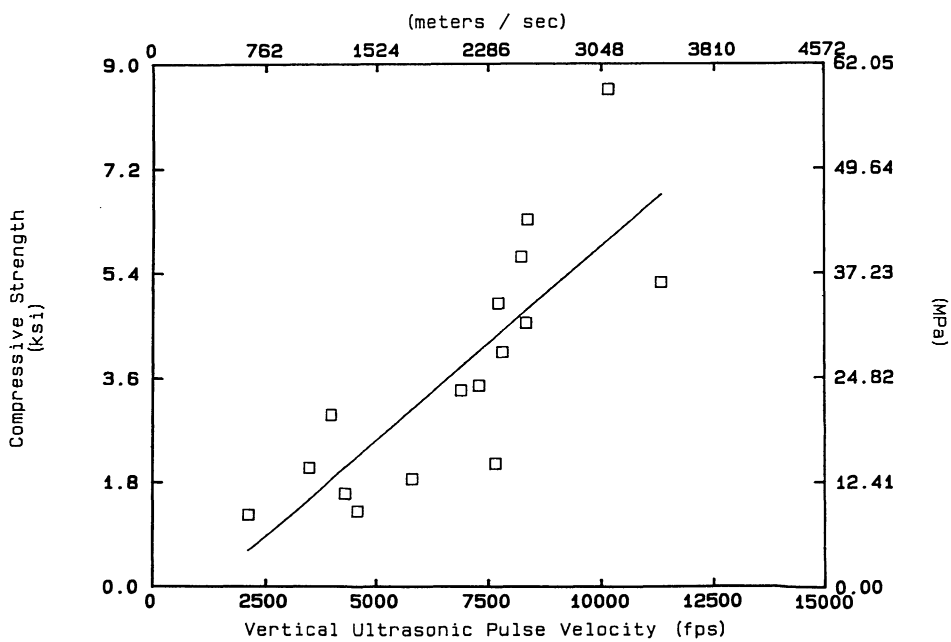

Figure 1. Correlation of Ultrasonic Pulse Velocity with Masonry Prism Compressive Strength.

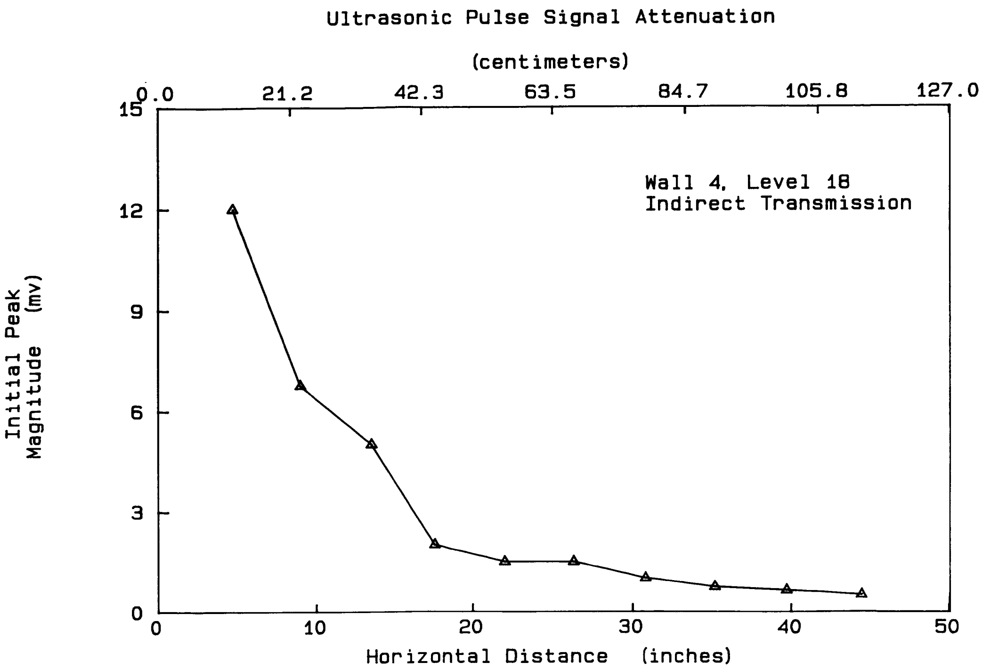

Figure 2. Ultrasonic Pulse Signal Attenuation.

Previous work [6,7,8] as well as the present study [5] point to several conclusions. First, while UPV measurements can be correlated to masonry prism compressive strength for specific materials, a generalized relationship between masonry compressive strength and ultrasonic velocity is not anticipated. Second, UPV techniques are well suited to the detection of flaws, but the signal strength deterioration limits their usefulness to modern materials and short transmission lengths. Third, studies to date have used the pulse velocity as the descriptive parameter. Attenuation or frequency analysis may reveal more about material condition than the velocity.

Mechanical Pulse

The mechanical pulse is generated by a surface impact and the pulse arrival is recorded with one or more accelerometers (Fig. 3). There has been much development of this technique (sometimes referred to as the "pulse-echo" technique) for concrete [9]. Because of the high amplitude and long wavelength of the input pulse, the technique is well suited to masonry field evaluations, and several researchers have used it for a variety of masonry applications [10,11]. While mechanical pulse velocity has some correlation with masonry prism compressive strength, it is better suited to the detection of flaws and irregularities (Fig. 3) [5].

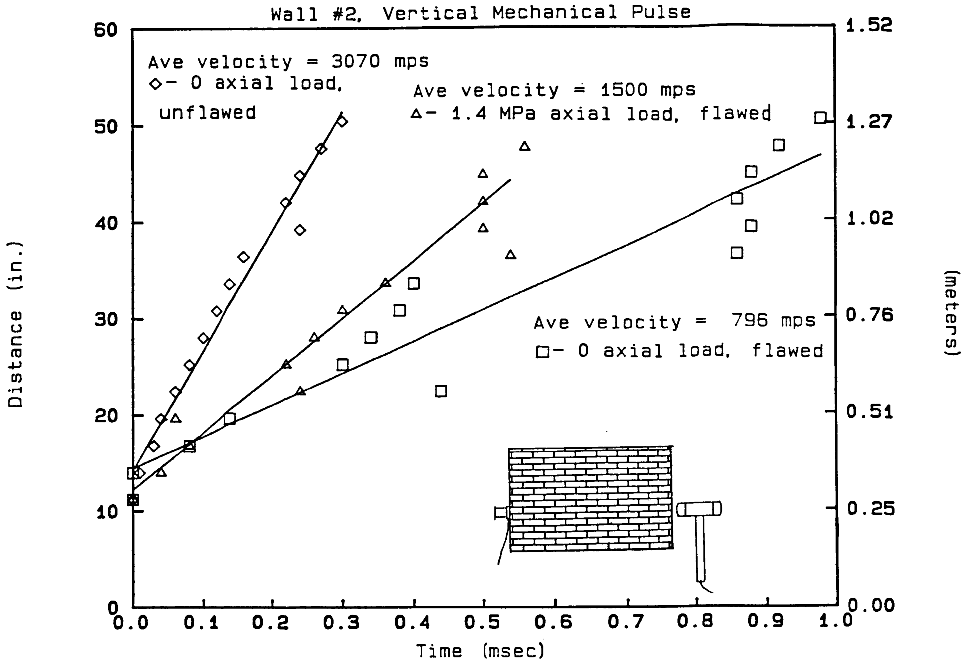

Figure 3. The Effect of Flaws and Compressive Stress on Mechanical Pulse Velocity.

Hardness

The Schmidt Hammer measurement of surface hardness [12] has been shown to have a reasonable to correlation masonry prism compressive strength [3]. While the quantitative prediction of masonry compressive strength based on Schmidt Hammer tests is not recommended without companion destructive tests, the method has good potential for the rapid and inexpensive evaluation of material uniformity in a structure.

Neutron Probe

The neutron probe [13] uses prompt gamma/neutron activation to determine elemental composition of a target material. Elements are identified by characteristic gamma rays emitted from the target material while it is being bombarded with neutrons. Neutron probe results can be useful in several types of building analysis: (1) determination of the composition of historic building materials, (2) location of contaminants such as water or soluble salts, and (3) location of voids. Although the neutron probe does not measure mechanical or structural properties, it can provide a useful complement to a structural evaluation [14].

Flatjack In-Situ Stress Measurement

A flatjack is a thin steel bladder that is pressurized with a fluid to apply a uniform stress over a small area. The use of large flatjacks to determine the in-situ state of stress and deformability of rock was modified for use in masonry structures by Rossi [4] and others [15,16].

Evaluation of in-situ compressive stress is a simple process of stress-relief induced by the removal of a portion of a mortar joint, followed by restoration of the original state of stress by pressurizing a flatjack inserted in the slot. When the mortar is removed from a horizontal joint, the release of the stress across the joint causes the slot to close by a small amount. The magnitude of this deformation is measured using a removable dial gauge between two or more points located symmetrically on either side of the slot. A flatjack is then inserted in the slot and pressurized until the original position of the measuring points is restored. At this point, the pressure in the flatjack is equivalent to the vertical compressive stress in the masonry.

Flatjack In-situ Deformability Measurement

The deformation properties of masonry may be directly evaluated by inserting two parallel flatjacks, one directly above the other separated by several courses of masonry, and pressurizing them equally, thus imposing a compressive load on the intervening masonry [4]. The deformations of the masonry between the flatjacks are then measured for several increments of load, and used to calculate the masonry stress-strain curve (Fig. 4) and deformability modulus. If some damage to the masonry is acceptable, the test may be carried out to ultimate stress. This technique is useful when a direct measure of material deformability is needed for stress analysis or deflection calculations. The two-flatjack test, like the single-flatjack test and the shove test may be considered nondestructive, because the mortar may be replaced leaving no evidence of testing.

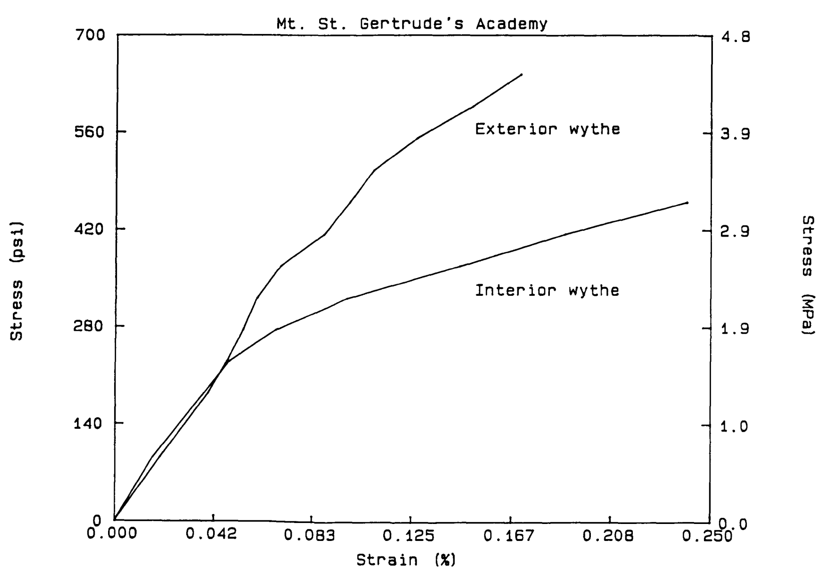

Figure 4. Example Stress-Strain Curves Obtained from Flatjack Tests on an Existing Masonry Structure.

In-place Shear (Shove) Test

The in-place shear test was designed to measure the in-situ bed joint shear resistance of masonry walls [17]; a parameter required for seismic hazard analysis. It requires the removal of a masonry unit and a head joint on either side of a test unit. The test unit is then displaced horizontally relative to the surrounding masonry using a hydraulic jack, and the horizontal force required to cause first movement of the test unit is recorded (Fig. 5). The test procedure has been modified in the present study [5] using flatjacks above and below the test unit to control normal stress. The test is repeated for several levels of normal stress permitting friction angle determination (Fig. 5).

Combination of Existing NDE Techniques

At the current level of development, the best application of NDE to masonry is to combine a number of complementary techniques. Rapid methods such as the Schmidt Hammer might be used to assess the condition of the entire structure, with pulse velocity methods used to map the variation in material condition in critical areas of the structure and direct measurements of material deformability and joint shear strength made using flatjack techniques in specific locations. Procedures and methods used would vary depending on individual building requirements. In all cases, experience and judgement in understanding the NDE techniques used and the nature of masonry is required for the accurate interpretation of results.

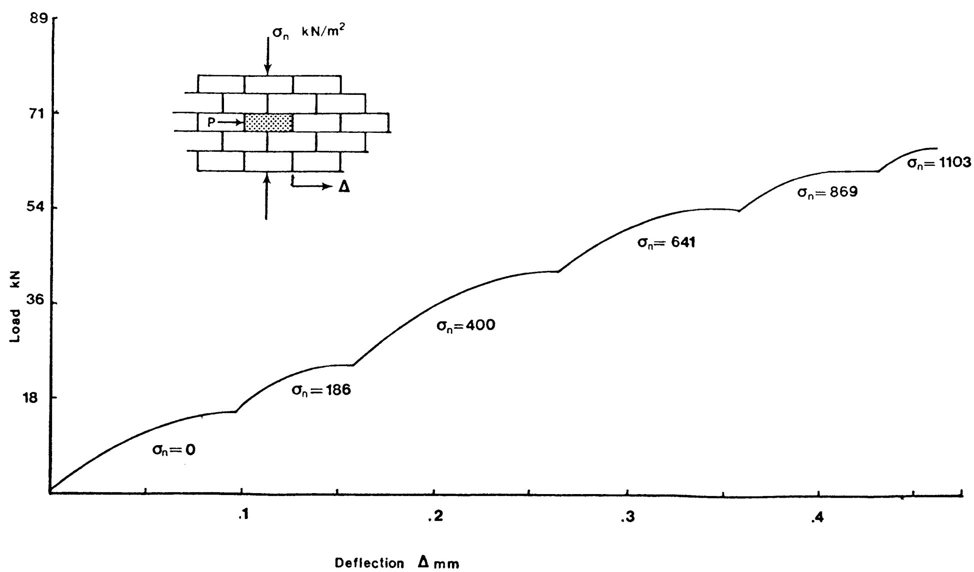

Figure 5. Typical Results from a Modified In-Place Shear Test.

ASSESSMENT OF CURRENT METHODS

Of the various methods described above only those employing the use of flatjacks or the shove test provide direct measures of the strength and stiffness of the masonry material in a quantitative form directly useful detailed structural analysis. At present these tests only evaluate the outer layer of a masonry wall with the result that inner layers which typically are composed of poorer quality materials are overlooked.

Most applications using ultrasonic or mechanical pulse have been limited to using velocity as the evaluation parameter. While relationships with strength and the ability to find flaws have been demonstrated, use of velocity data alone is inadequate to determine material properties or to locate flaws to the accuracy required for detailed structural evaluation.

POTENTIAL FOR FUTURE ADVANCEMENT IN MASONRY NDE

Development of NDE techniques for masonry have to date adopted or modified techniques from the areas of concrete and rock evaluation. In the meantime very considerable advances have been made in the application of quantitative NDE methods in the fields of medicine, aerospace structures, exploration seismology and manufacturing among others.

Several avenues of opportunity exist for the application of these techniques to masonry . The ultrasonic and mechanical pulse methods can be advanced through the use of signal conditioning and use of frequency domain analysis of data now being recorded. Application of multiple sensor arrays as used in seismic surveys [18] or in medical imaging together with advanced data reduction and analysis algorithms may have the potential to improve mapping of structural flaws.

Recent developments in use of ground penetrating radar [20] employing short pulse, video and synthetic pulse techniques together with time and frequency domain analysis may provide means for the rapid survey of masonry structures. Recent material developments in the aerospace industry [19] involving embedding of sensors in a material at its time of construction creating so-called "smart materials", could have application to newly constructed or renovated masonry buildings to locate internal flaws and to provide warnings of excessive stress and strain conditions.

REFERENCES

1. R.C. DeVekey, "Non-destructive Test Methods for Masonry Structures", Proc.of the 8th Int.Brick/Block Masonry Conf., Dublin, Sept.1988.
2. N.G. Zoldners, J.A. Soles, "An Annotated Bibliography on Nondestructive Testing of Concrete, 1975-1983," ACI SP 82-39, In-Situ Nondestructive Testing of Concrete, p. 745, 1984.
3. J.L. Noland, R.H. Atkinson, J.C. Baur, "An Investigation into Methods of Nondestructive Evaluation of Masonry Structures," Rpt. to the Nat. Science Foundation, Atkinson-Noland and Assoc., Boulder, Colorado, USA, 1982.

4. P.P. Rossi, "Flatjack Test for the Analysis of Mechanical Behavior of Brick Masonry Structures," Proc. 7th Int. Brick Masonry Conf., Melbourne, Vol. 1, 1985.
5. Final Report, NSF Grant ECE-8315924, "Further Development and Field Verification of Methods for Non-Destructive Evaluation of Masonry Structures", Atkinson-Noland & Assoc., Boulder, CO (in preparation).
6. B. Hobbs, S.J. Wright, "Ultrasonic Testing for Fault Detection in Brickwork and Blockwork", Proc. Int. Conf. on Struct. Faults and Repair, V. 1, London, July, 1987.
7. G.M. Calvi, "Correlation between Ultrasonic and Load Tests on Old Masonry Specimens", Proc. 8th Int. Brick/Block Masonry Conf., Dublin, Sept.1988.
8. M. Berra, et. al., "Ultrasonic Pulse Transmission: A Proposal to Evaluate the Efficiency of Masonry Strengthening by Grouting", Proc. 2nd Joint USA-Italy Workshop on Evaluation and Retrofit of Masonry Structures, Aug. 1987.
9. N.J. Carino, M. Sansalone, N.N. Hsu, "A Point Source-Point Receiver, Pulse-Echo Technique for Flaw Detection in Concrete," ACI Jour., Mar. 1986.
10. M.C. Forde, and A.J. Batchelor, "Low Frequency NDT Testing of Historic Structures," 3rd Eur. Conf. on NDT Testing, Florence, 1984.
11. G.R. Kingsley, J.L. Noland, R.H. Atkinson, "Nondestructive Evaluation of Masonry Structures Using Sonic and Ultrasonic Pulse Velocity Techniques," Proc. 4th N. Am. Mas. Conf., Univ. of Calif. Los Angeles, Aug., 1987.
12. Am. Soc. for Testing Materials, "Tentative Test Method for Rebound Number of Hardened Concrete," ASTM C805-75.
13. Livingston, et. al., "The Application of the Neutron Probe to the Nondestructive Evaluation of Building Condition", Proc. Int. Workshop on NDE for Performance of Civil Struct., USC, Feb. 1988.
14. G.R. Kingsley, "Nondestructive Evaluation of a Nineteenth Century Brick Smokehouse in Colonial Williamsburg, VA", Proc. 1st Int.Conf.on Structural Studies, Repairs and Maint. of Historical Blds, Florence, Apr. 1989.
15. G.R. Kingsley, J.L. Noland, "A Note on Obtaining In-situ Load-deformation Properties of Unreinforced Brick Masonry in the United States Using Flatjacks", Final Report of the Joint USA-Italy Workshop on Evaluation and Retrofit of Masonry Structures, 1988.
16. J.L. Noland, G.R. Kingsley, and R.H. Atkinson, "Utilization of Nondestructive Techniques in the Evaluation of Masonry," Proc. 8th Int. Brick/Block Masonry Conf., Dublin, Oct., 1988.
17. ABK, A Joint Venture, "Methodology for Mitigation of Seismic Hazards in Existing Unreinforced Masonry Buildings: Diaphragm Testing," Topical Rept 03, Dec. 1981.
18. E.A. Robinson, and T.S. Durrani, Geophysical Signal Processing, Prentice-Hall, 1986.
19. C.M. Dube, et. al., "Laboratory Feasibility Study of a Composite Embedded Fiber Optic Sensor for Measurement of Structural Vibrations," Dynamics Technology, Inc. Report DT 8723-01, Feb. 1988.
20. W.E. Pittman, R.H. Church, W.E. Webb, and Mclendon, "Ground Penetrating Radar - A Review of its Application in the Mining Industry," U.S. Bur.of Mines, IC-8964, 1984.