Evaluation of brick masonry by non-destructive methods

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Evaluation of Brick Masonry by Non-Destructive Methods

Evaluation de maçonnerie en briques à l'aide de méthodes non destructives

Bewertung von Backsteinmauerwerk mit Hilfe zerstörungsfreier Prüfverfahren

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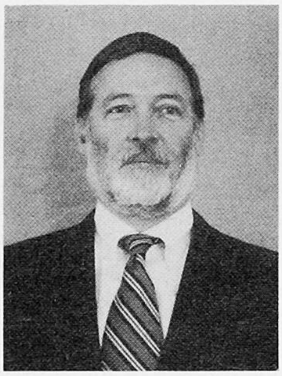
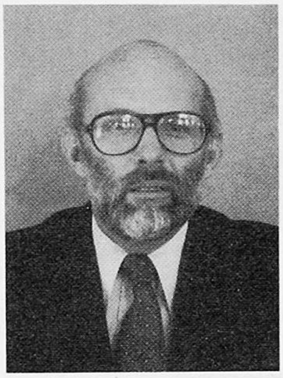


James L. Noland, born 1934, received his Ph.D. in structural engineering from the University of Colorado. He has been involved in research, development and design in many areas related to structures and structural materials with a special interest in masonry.



Richard Atkinson, born 1938, received his Ph.D. in geotechnical engineering from the University of Colorado. Application of rock mechanics techniques to mining problems and to structural masonry have been a major area of his work.

SUMMARY

The project reviews existing non-destructive evaluation methods, which have been applied to other materials, for their effectiveness as methods of strength and condition assessment of masonry. Results are briefly presented with the conclusion that certain methods appear to have potential as practical means of evaluating masonry.

RESUME

Le projet analyse l'application des méthodes non destructives, utilisées pour d'autres matériaux, à l'évaluation de la résistance et de l'état réel d'une structure en maçonnerie. Les résultats sont présentés brièvement. Il semblerait que certaines méthodes puissent être utilisées comme moyens pratiques d'évaluation des structures en maçonnerie.

ZUSAMMENFASSUNG

Der Beitrag untersucht verschiedene zerstörungsfreie Prüfmethoden (NDE-Verfahren) auf ihre Eignung zur Bestimmung der Festigkeit und Güte von Mauerwerk. Die Ergebnisse zeigen, dass sich lediglich gewisse Verfahren für die praktische Bewertung von Mauerwerk eignen.

1. INTRODUCTION

Evaluation of masonry structures in the USA to ascertain strength properties and general condition, i.e., presence of flaws and/or general deterioration, is primarily based on visual observations and destructive tests of specimens removed from the structures [9,31][1]. Visual examination can detect only gross defects while destructive tests of specimens removed from a structure may be time consuming, expensive, and may cause aesthetic or structural damage particularly if the number of destructive test specimens is sufficient to yield a satisfactory degree of statistical confidence.

The research reviewed herein was done to determine whether methods and equipment used for NDE of other materials, primarily rock and concrete [1,2,4,7,11,13,18, 21,26], could be, or have the potential to be, satisfactory NDE methods for structural masonry. The NDE methods evaluated in the research were chosen based on:

- availability and cost of equipment,
- potential for safe and ease of use in field conditions, and
- prior success of use for NDE of other materials.

2. REVIEW OF PREVIOUS NDE OF MASONRY IN THE USA

With the exception of two limited studies on full scale buildings [20,28], no systematic investigation had been conducted in the UDA into the application of NDE methods to masonry prior to the study discussed in this paper [30].

3. NON-DESTRUCTIVE EVALUATION METHODS CONSIDERED

3.1 Schmidt Rebound Hammer

The Schmidt Rebound Hammer is primarily a surface hardness test apparatus developed for concrete testing [13], but has also been used to evaluate rock [1,7] and to provide data used to predict performance of rock tunnel boring mechanics [27].

3.2 Mechanical Pulse Velocity

The mechanical pulse velocity method is based on the correlation of the velocity of an impact-generated stress wave in a material to the properties of that material. Wave velocity is primarily a function of elastic modulus, poisson's ratio, and density, however correlations have been found between strength properties of concrete and wave velocity [13,26]. Wave velocity is affected by flaws in a material [4,13] and was therefore considered potentially amenable to flaw detection in masonry.

3.3 Ultrasonic Pulse Velocity

The ultrasonic pulse velocity method operates on the same principle as the mechanical pulse velocity method. The stress waves are generated, however, by an electroacoustic transducer and are at a high frequency [13,26]. This method has been used to detect flaws in the collar joint of two-wythe masonry walls [29].

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[1] It should be noted that a form of destructive test, the "shove-test", is being used in parts of the USA for examination of older masonry buildings made using lime-sand mortar or mortars of very low cement content. Post-test repairs completely restore original appearance [30,31]. The "flat-jack" test used in Italy is also a test which temporarily damages the structure, but it can easily be restored to original condition [5,12,17].

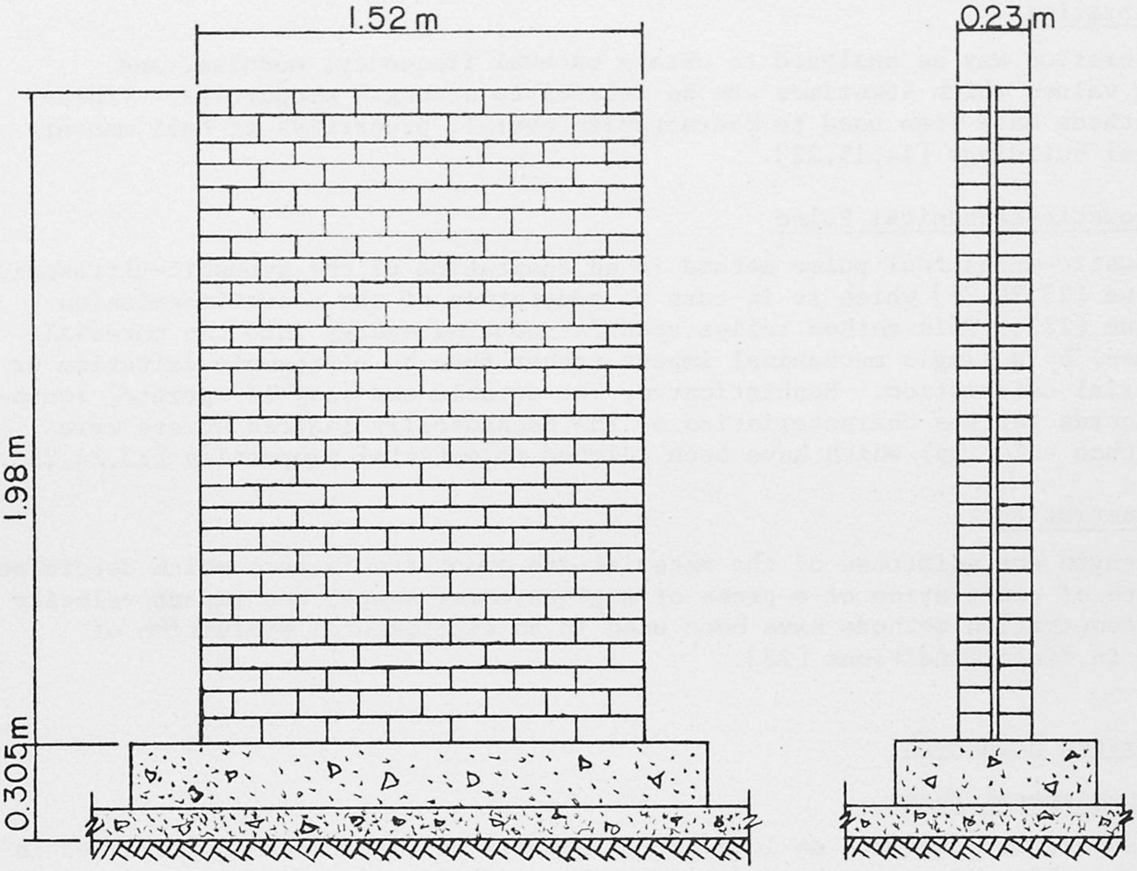

FIGURE 1 - BRICK MASONRY WALL SPECIMEN

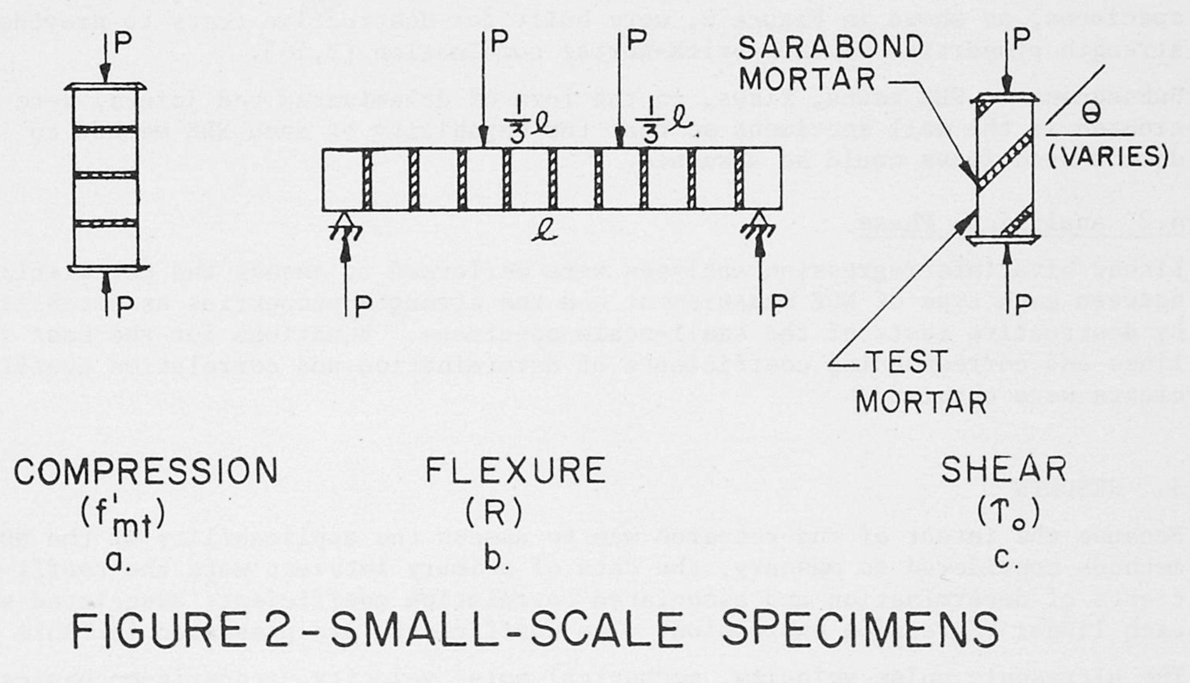

FIGURE 2 - SMALL-SCALE SPECIMENS

3.4 Vibration

Free vibration may be analyzed to obtain natural frequency, modulus, and damping values which sometimes can be related to strength properties. Vibration methods have been used to characterize overall properties of tall masonry and steel buildings [14,15,22].

3.5 Acoustic-Mechanical Pulse

The acoustic-mechanical pulse method is an adaptation of the acoustic-ultrasonic technique [23,24,25] which is in turn an adaptation of the acoustic-emission technique [11]. This method relies upon introducing energy into the material (specimen) by a single mechanical impact rather than by ultrasonic exitation or by material deformation. Sophisticated, but durable and easy-to-operate, equipment records various characteristics of the mechanically induced stress wave (other than velocity) which have been related to material properties [23,24,25].

3.6 Penetration

The strength and stiffness of the material are among the factors which determine the depth of penetration of a probe of a given mass, shape, and impact velocity [13]. Penetration methods have been used in an experimental evaluation of masonry in field conditions [28].

4. RESEARCH CONDUCTED

4.1 Experimental Phase

NDE measurements were made on large brick masonry wall specimens constructed in a laboratory in a cantilever condition as shown in Figure 1. A total of thirty walls were constructed of three types of brick each of a different compressive strength; walls of each kind of brick were built using each of five different mortars. This was done to provide a range of strength properties over which to evaluate the NDE methods considered. The wall specimens built and the NDE tests performed on each are summarized in Table A. Companion small-scale specimens, as shown in Figure 2, were built for destructive tests to provide strength properties of each brick-mortar combination [3,16].

Subsequent to NDE tests, flaws, in the form of delaminated bed joints, were created in the wall specimens so that the capability of each NDE method to detect such flaws could be assessed.

4.2 Analytical Phase

Linear bivariate regression analyses were performed to assess the correlation between each type of NDE measurement and the strength properties as established by destructive tests of the small-scale specimens. Equations for the best fit lines and corresponding coefficients of determination and correlation coefficients were obtained.

5. RESULTS

Because the intent of the research was to assess the applicability of the NDE methods considered to masonry, the data of primary interest were the coefficients of determination and associated correlation coefficients associated with each linear regression expression. The coefficients are presented in Table B.

The ultrasonic pulse velocity, mechanical pulse velocity, acoustic-mechanical pulse, and vibration methods yielded significantly different results when applied to walls with one or two delaminated bed joints. The pulse velocity methods appeared capable of locating the flawed joint, but the acoustic-mechanical pulse and vibration methods could not. The rebound hammer method did not show sensitivity to bed joint flaws.

6. CONCLUSIONS

NDE, at least for the type of masonry tested, appears to have potential for assessment of the strength and condition of masonry. Of the methods considered, the Schmidt Rebound Hammer results were the most closely correlated to compressive strength while the ultrasonic pulse velocity method yielded results most closely related to the modulus of rupture. None of the methods were able to provide results well correlated to joint shear strength.

7. RECOMMENDATIONS

Additional experiments are suggested to evaluate NDE on other forms of masonry. Combining NDE methods applied to masonry may provide better NDE measurement to strength property correlations [6,19].

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Table A

Wall Specimens*

Wall Series No.	Clay Unit Type	Mortar Type	Nondestructive Tests Performed
IA	A.R.	0:1:3	SH, V, UP, MP
IB	A.R.	0:1:3	SH, V, UP, MP
IC	A.R.	0:1:3	SH, V, UP, MP
ID	A.R.	0:1:3	SH, V, UP, MP, DP
IIA	A.R.	1:¼:3	SH, V, UP, MP
IIB	A.R.	1:¼:3	SH, V, UP, MP
IIC	A.R.	1:¼:3	SH, V, UP, MP
IID	A.R.	1:¼:3	SH, V, UP, DP
IIIA	A.R.	1:1:6	SH, V, UP, MP
IIIB	A.R.	1:1:6	SH, V, UP, MP
IIID	A.R.	1:1:6	SH, V, UP, MP
IVA	A.R.	1:2:9	SH, V, UP, MP, DP, AMP
IVB	A.R.	1:2:9	SH, V, UP, MP, AMP
IVC	A.R.	1:2:9	SH, V, UP, MP, AMP
IVD	A.R.	1:2:9	SH, V, UP, DP
X	A.R.	1:3:12	SH, V, UP, MP, DP
VA	I.S.	1:¼:3	V, UP, MP, DP
VB	I.S.	1:¼:3	V, UP, MP
VC	I.S.	1:¼:3	V, UP, MP
VIA	I.S.	1:1:6	SH, V, UP, MP, DP
VIB	I.S.	1:1:6	SH, V, UP, MP
VIC	I.S.	1:1:6	SH, V, UP, MP
VII	I.S.	1:2:9	SH, V, UP, MP, DP
VIII	I.S.	1:3:12	SH, V, UP, MP, DP
IX	I.S.	0:1:3	SH, V, UP, MP, DP
XI	H.P.	1:¼:3	SH, V, UP, MP, DP
XII	H.P.	1:1:6	SH, V, UP, MP, DP
XIII	H.P.	1:2:9	SH, V, UP, MP, DP
XIV	H.P.	1:3:12	SH, V, UP, MP, DP
XV	H.P.	0:1:3	SH, V, UP, MP, DP

*Code:

SH = Schmidt Hammer
V = Mechanical Vibration
UP = Ultrasonic Pulse Velocity
MP = Mechanical Pulse Velocity
DP = Densicon Penetrometer
AMP = Acoustic Mechanical Pulse
A.R. = Antique Rustic Brick (f_b = 86.1 MPa)
I.S. = Iron Spot Brick (f_b = 91.2 MPa)
H.P. = Hard Pressed Brick (f_b = 46.7 MPa)

Table B

Results of Destructive Tests on Small Specimens vs. NDE Measurements on Unflawed Wall Specimens

Dependent Variable y'	Independent* Variable x	Correlation Coefficient R	Coefficient of Determination R^2
Compressive Strength f'_{mt}	NR	.890	.792
	WD	.768	.590
	HUV	.772	.596
	VUV	.849	.721
	UV	.776	.603
	VMV	.703	.495
	HMV	.734	.539
	BP	.620	.390
	MP	.530	.280
Modulus of Rupture R	HUV	.690	.476
	VUV	.675	.455
	UV	.672	.452
	WD	.644	.415
	NR	.738	.545
	VMV	.447	.200
	HMV	.910	.828
Shear Strength τ_o	NR	.518	.268
	WD	.177	.031
	HUV	.257	.066
	VUV	.392	.154
	UV	.220	.049
	VMV	.340	.115
	HMV	.326	.106

Code:

NR = Rebound number
WD = Natural frequency of vibration
HUV = Ultrasonic velocity - horizontal direction
VUV = Ultrasonic velocity - vertical direction
UV = Ultrasonic velocity - thru wall
HMV = Mechanical pulse velocity - horizontal direction
VMV = Mechanical pulse velocity - vertical direction
BP = Penetration test - brick
MP = Penetration test - mortar
f'_{mt} = Compressive strength of prism
R = Modulus of rupture
τ_o = Shear strength as measured using the inclined bed joint specimen [16]