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Autor: Forde, Michael C. / Komeyli-Birjandi, F. / Batchelor, A.J.

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Monitoring of Masonry Bridge Abutments

Contrôle de butées en maçonnerie des ponts

Überwachung von Flügelmauern bei Mauerwerksbrücken

Michael C. FORDE
Dr., University of Edinburgh
Scotland

F. Komeyli-BIRJANDI
Dr., Westpile Ltd
Uxbridge
England

A.J. BATCHELOR
Mr., Holequest Ltd.
Civil Tech NDT Ltd
Galashiels - Scotland

Dr Forde obtained his Civil Engineering Degree from the University of Liverpool and his MSc and PhD from the University of Birmingham. He is the author of over 50 papers. Currently he is Senior Lecturer in Civil Engineering at the University of Edinburgh.

Dr. Komeyli-Birjandi is a graduate of the universities of Liverpool and Edinburgh. He is employed by Westpile Ltd.

Mr. A.J. Batchelor has specialised in Ground Engineering and Structural Investigation and Repair. He is a Director of Holequest Ltd and Civil Tech NDT Ltd.

SUMMARY

The paper describes the application of time and frequency domain techniques to the monitoring and assessment of the quality of masonry bridge abutments. Time delay techniques using digital instrumentation are outlined. The application of these techniques to the assessment of masonry quality and void detection are described. Case studies are used to illustrate the techniques.

RESUME

L'article décrit l'application des techniques en fonction du temps et de la fréquence pour contrôler et évaluer la qualité des butées en maçonnerie des ponts. Les techniques de retardement employant une instrumentation numérique sont exposées à grands traits. L'application de ces techniques à l'évaluation de la qualité de maçonnerie et à la détection de vides est décrite. Des exemples concrets ont été choisis pour illustrer ces techniques.

ZUSAMMENFASSUNG

Der Artikel beschreibt die Anwendung von Methoden im Zeit- und Frequenzbe- reich, um die Qualität von Flügelmauern bei Mauerwerksbrücken zu überwachen und zu beurteilen. Zeitverzögerungsmethoden mit Digitalinstrumentation werden vorgestellt. Die Anwendung dieser Methoden auf die Beuerteilung der Mauerwerksqualität und auf die Entdeckung von Hohlräumen werden beschrieben. Fallbeispiele dienen der weiteren Erklärung der angewendeten Techniken.

1. INTRODUCTION

In many parts of Europe up to 50% of a country's transportation infrastructure can comprise stone masonry bridges. In the U.K examples have been given [1] of regional authorities where in excess of 50% of the road bridges are stone masonry of approximately 100 years age. From this background it became clear to the NDT Bridge Research Group at Edinburgh University that cost effective investigation techniques are required prior to planning remedial measures.

The traditional method of investigating stone masonry bridges has been inspection by two means - visual inspection by a technician/engineer and coring by rotary core means. It is clear that rotary core drilling may permanently scar the structure and prove expensive due to the fact that scaffolding is almost inevitably required. In these circumstances the potential cost advantage of non-destructive testing is very substantial. The basic procedure would be that the structure could be rapidly assessed over its entirety prior to selective calibration of the quality of the structure by the conventional coring techniques.

When evaluating masonry bridges one of the key components of the structure is the abutments. Early papers [2,3] by the Edinburgh University NDT Research Group outlined a sonic transmission technique which was effectively used to obtain overall transmission velocities and to identify significant voids in masonry structures. More recently [4], work upon transient shock testing of masonry bridge abutments and piers has been reported.

The objective of the work reported herein is to present the findings of full-scale research upon masonry bridge abutments and other relevant structures using the techniques of time domain and frequency domain.

2. TIME DELAY TECHNIQUE

The scientific principles behind the sonic time delay technique were reported earlier [2]. The technique involves measuring the time from the initiation of a sonic pulse on one side of the structure to the transmission and reception of this pulse on the other side of the structure. The commencement of the propagation was measured by an accelerometer adjacent to the point of impact on one side of the structure. The reception of the signal on the other side of the structure was identified by another accelerometer at the other side - Fig. 1.

It was shown earlier [4] that the interpretation of results from such an investigation is basically that:

a) if no propagation is observed then voidage may well be present, or alternatively the structure may suffer leaf separation or discontinuity from a crack - assuming sufficient energy has been input to the structure to overcome signal attenuation/damping.

b) where propagation does exist the greater the velocity the higher the quality of the material and conversely the lower the velocity the poorer the quality of the material.

2.1 Developments in signal Processing: Time Domain

The early research [1,2 & 3] reported above employed an analogue storage oscilloscope with excitation using a conventional steel tipped hammer.

Permanent records were taken using a Polaroid oscilloscope camera. Whilst relatively effective, the technique is limited in terms of the potential for additional signal processing

The more recent work [4] has employed digital signal processing. Data was captured using a Nicolet 4094 digital oscilloscope with 12 bit A/D convertor and twin 360K disk drives. The analog signal recorded on the accelerometers following the hammer blow was digitised using the 12 bit convertor and the digitised signal then stored on a 5.25 inch floppy disk in one of the twin disk drives. The digital data was then available for subsequent detailed analysis in the laboratory. The Nicolet digital oscilloscope has a memory of 16K points and contains a 16 bit processor. The digital oscilloscope also features the powerful analytical tool of non destructive zoom of the trace.

In addition to using digital systems for data capture and analysis, a more sophisticated system of excitation has been used. An instrumented hammer containing a 2.5 tonne load cell with a frequency tuned plastic tip was employed.

3. TIME DOMAIN CASE STUDY: BARGOWER BRIDGE, SCOTLAND

In order to illustrate the power of the technique a full-scale investigation of Bargower Bridge, Ayrshire, Scotland is reported below.

The structure comprised a single 11 metre span masonry arch, which was to be load tested to failure by the Edinburgh University research group as part of the full-scale testing programme of the Transport and Road Research Laboratory, England.

The downstream elevation of the structure was marked out in a 1-metre grid and tested by the time delay technique as described in Section 2. above. The results of the transmission tests are summarised in Fig. 2, using the following coding - Table 2:

CODING	VELOCITY metre/sec	DESCRIPTION
A	>2000	VERY GOOD
B	1500 - 2000	GOOD
C	1000 - 1500	FAIR
D	500 - 1000	POOR
E	<500	VERY POOR
N	NO TRANSMISSION	

Table 1

The time delay technique can clearly be used to identify the shape of masonry abutments and springers by using the summary of data culled from a large number studies - see Section 4. below.

4. SUMMARY OF TRANSMISSION TEST RESULTS

From transmission test data compiled from extensive laboratory and full-scale testing the following table has been compiled based upon average velocities - Table 2.

MATERIAL	AVERAGE SONIC VELOCITY metres/sec	SOURCE	REFERENCE
Good Brickwork	3100	Birjandi et al, 1984	[3]
Poor Brickwork	2500 - 2700	Birjandi, 1986	[8]
Uncracked Reinforced Cavity	3500	Birjandi et al, 1984	[3]
Cracked Reinforced Cavity	2700 - 3000	Birjandi et al, 1984	[3]
Structural Concrete	>4500	Neville, 1975	[6]
Granite Masonry Pier No. 1	3450	Birjandi, 1986	[8]
Granite Masonry Pier No. 2	3370	Birjandi, 1986	[8]
Red Sandstone Masonry Pier	1970	Birjandi, 1986	[8]
Yellow Sandstone Masonry Pier	2040	Birjandi, 1986	[8]
Whinstone Masonry Pier	2500	Birjandi, 1986	[8]
White Sandstone Pier	1700	Birjandi, 1986	[8]
Steel - Rod	5100	Catchpool et al, 1949	[9]
Steel - Bulk	6100	Catchpool et al, 1949	[9]
Dry Sandy Top Soil	200 - 300	Clayton et al, 1982	[5]
Dry Sandy Clay	400 - 600	Clayton et al, 1982	[5]
Saturated Sandy Clay	1300 - 2400	Clayton et al, 1982	[5]
Water	1430 - 1680	Clayton et al, 1982	[5]
Limestone & Dolemite	4000 - 6000	Clayton et al, 1982	[5]

<u>TABLE 2</u>

5. FREQUENCY DOMAIN TECHNIQUE

This technique was used to test the face of the masonry abutments. The method of data collection involved mounting an accelerometer with built in charge amplifier on to the vertical surface of the abutment exposed above water level, followed by excitation of the structure using an instrumented hammer with a 2.5 tonne load cell. The consequent dynamic response of the abutment was then monitored by the accelerometer and transmitted to an FM high frequency tape recorder where the analog signal was recorded for subsequent analysis. The analysis of the recorded signals back in the laboratory involved playing the tape signals into a Bruel & Kjaer 2034 two channel dynamic signal analyser. The procedure involved converting the signal from analog to digital using a twelve bit A/D converter.

Basically two different analyses were undertaken upon the signals. The first analysis involved investigating the longitudinal vibrational response of the abutments (This analysis would have been undertaken until recently by mounting an electro dynamic shaker on the vertical surface and sweeping through a range of discrete frequencies using an exciter.) The analog signal recorded on the high frequency FM tape recorder was converted from the time domain to the frequency domain by undertaking a Fast Fourier Transform algorithm. The principle behind the analyses is that the intact thickness of the abutment is given by the expression below, based upon the physics of rods [7,8]

Intact thickness of abutment $L = Vm/(2x\Delta F)$.

Where L = intact thickness of abutment

Vm = velocity through the material

ΔF = the interval between resonant frequencies as indicated on the FFT frequency domain plot, after Davis and Dunn [7].

6. FREQUENCY DOMAIN CASE STUDY: HIGH BRIDGE, STRUIE, SCOTLAND

High Bridge, Struie, Highland Region, Scotland, comprised a single span stone masonry arch bridge.

The test procedure involved mounting an accelerometer on the surface of the abutment face and then exciting the structure adjacent to the accelerometer using an instrumented hammer with a built in 2.5 tonne load cell. The locations for the tests are given in Fig 3.

The method of assessing the data obtained from the West abutment, comprised analysing the signals recorded on the analog tape recorder. The force input from the hammer, and the response from the accelerometer were analysed using Fast Fourier Transform Algorithms on the 2 channel Bruel & Kjaer signal analyser with subsequent downloading onto a Hewlett-Packard 9816s micro computer for plotting on an ink spray graphics printer.

Before the results are summarised, consider the method of analysis outlined above, in relation to the West Abutment of High Bridge - Fig 4. In this case the fundamental frequency was identified as 220 Hz (i.e. cycles/second). The frequency interval F between resonances can be read off as 400 Hz. Thus assuming $L = 3\text{m}$, then:

$L = 3 = Vm/(2 \times \Delta F) = Vm/(2 \times 400)$

therefore $Vm = 3 \times (2 \times 400) = 2400$ m/s.

The next step in the interpretation relates to value of the fundamental frequency ("A" in Fig. 4) in relation to the interval between harmonics (ΔF in Fig. 4):

If "A" $= \Delta F$, then the structure is "FREE ENDED"

If "A" $= \Delta F/2$, then the structure is "FIXED ENDED"

Thus from Fig. 4, $A = 220$ and $\Delta F = 400$

i.e. $A = \Delta F/2$ approx. Therefore at this location the abutment is fixed against the fill/rock of the valley sides.

In order to obtain an overall engineering interpretation of the data from the many sets of points taken on the West Abutment face, the data was averaged over the number of blows per point times the number of blows per horizontal row on the abutment face. Thus on Fig 3 assuming a sonic velocity of 2000 metres per second it will be seen that the thicknesses of the masonry analysed using the transient shock vibration method were as follows:

LEVEL	THICKNESS OF MASONRY (metres)	FIXITY
L1	0.85	Free
L2	3.00	Fixed
L3	3.40	Fixed
L4	2.70	Fixed
L5	2.00	Fixed
L6	1.90	Fixed
L7	2.20	Fixed

Table 3

7. CONCLUSIONS

Two non-destructive investigation techniques have been described for the investigation of masonry bridge abutments - time domain and frequency domain.

In the time domain, the time delay technique has been shown to be a powerful tool to rank velocities through masonry abutments. It was stated that this could be further used to distinguish the shape of masonry abutments, differentiating between continuous masonry and soil fill.

Where only one face of an abutment was available, the transient shock (or frequency domain method) was shown to be capable of determining the thickness and fixity of an abutment.

8. ACKNOWLEDGEMENTS

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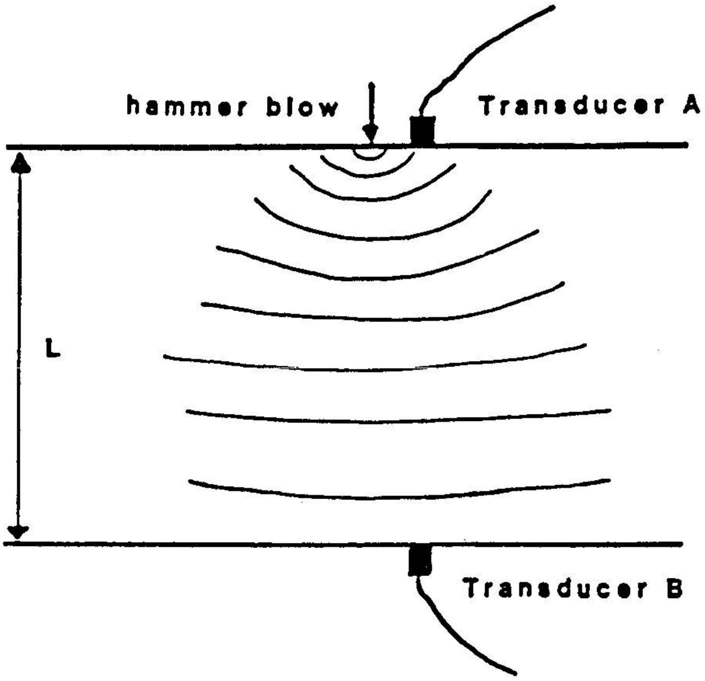

Fig. 1 Time Delay Technique

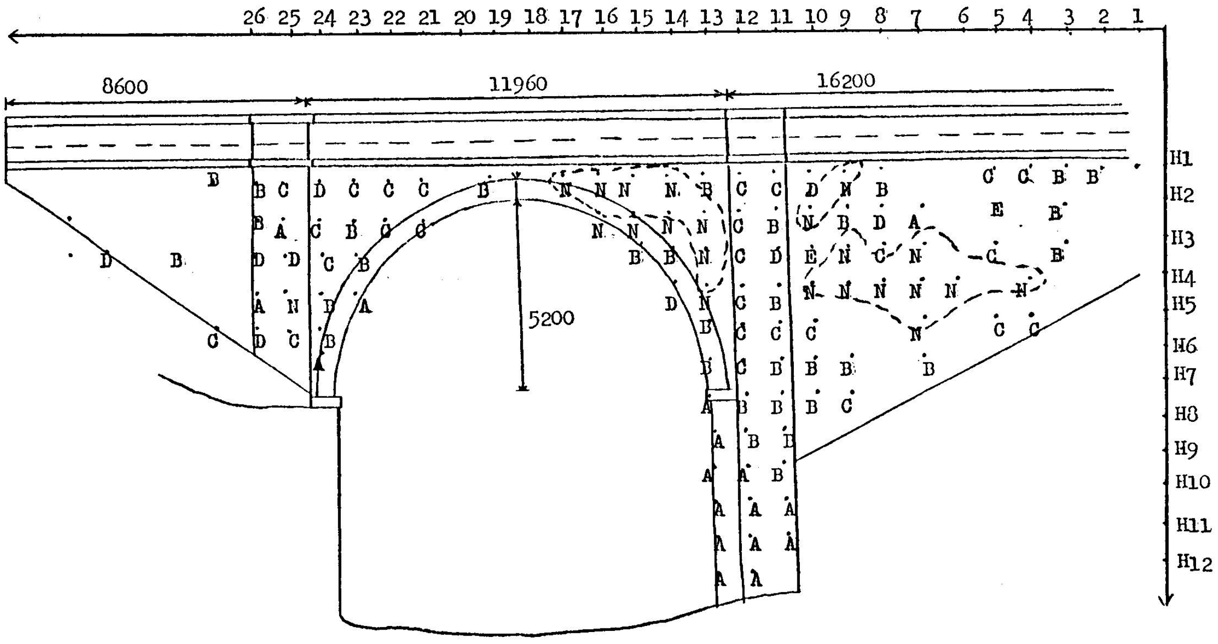

Fig. 2 Bargower Bridge, downstream face, transmission test results.

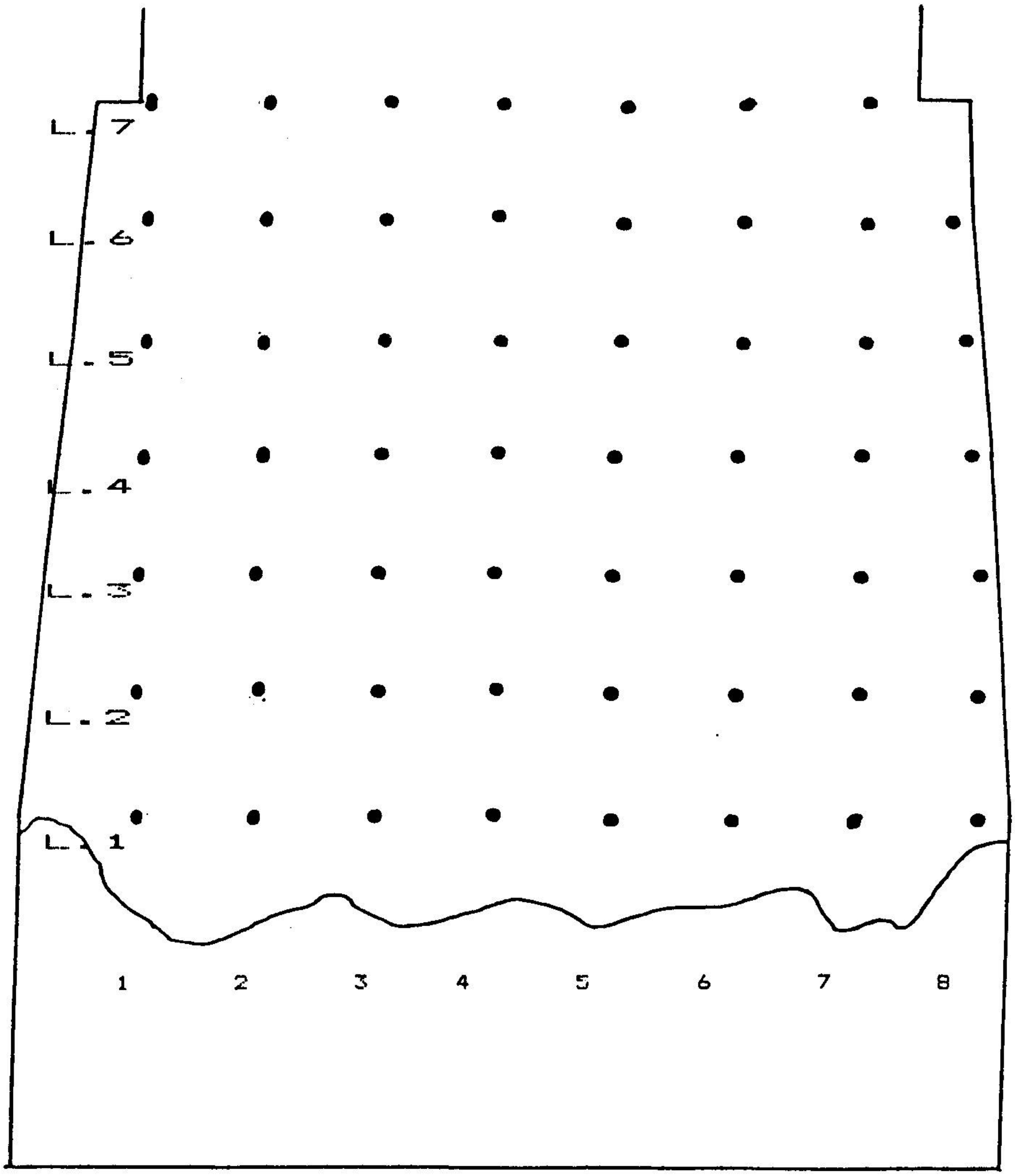

Fig. 3 High Bridge Struie, West Abutment - test locations.

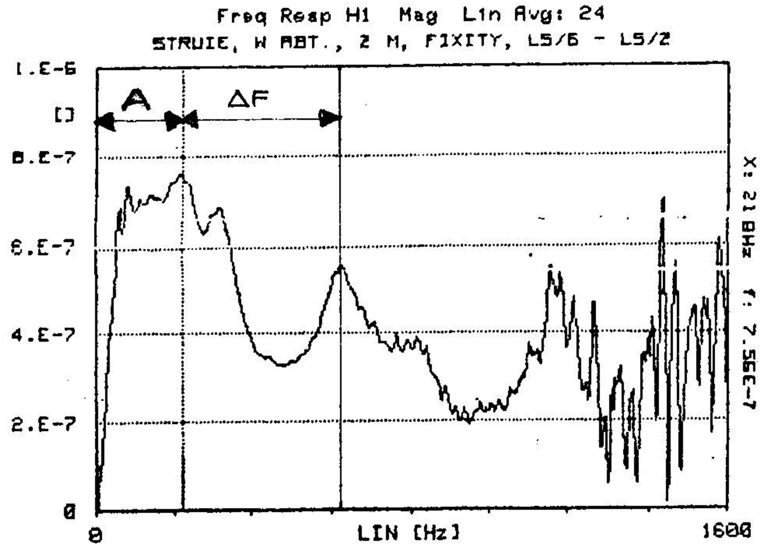

Fig. 4 High Bridge Struie, West Abutment - typical result.

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