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DYNAMIC TESTING OF MASONRY BY LONGITUDINAL VIBRATION AND ULTRASONIC PULSE VELOCITY METHODS

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ABSTRACT

Two dynamic test methods, which had been originally developed for measuring mechanical properties of concrete, have been adopted for masonry testing.

The Longitudinal Vibration Test Method (LVTM) uses a modified version of the Electro-Dynamic Materials Tester Emefco SCT/5. The original instrument complies with BS 1881:52 (longitudinal vibrations). This test is based on measuring the fundamental natural frequency of a regularly shaped brick or masonry specimen. An accurate oscillator operates a vibrator, which in turn excites the specimen clamped in the centre of its length. The oscillations are picked up by a piezo-electric crystal pick-up passed through an amplifier and the signal is displayed on an oscilloscope.

The Ultrasonic Pulse Velocity Method (UPVM) uses a standard measurement unit the CNS Portable Ultrasonic Non-destructive Digital Indicating Tester (PUNDIT). This test is based on measuring the velocity of ultrasonic pulses travelling in a solid material. PUNDIT generates ultrasonic pulses and indicates the time taken for the earliest part of the pulse to reach the receiving transducer accurately measured from the time it leaves the transmitting transducer when these transducers are placed at suitable points on the surface of the material. The distance, which the pulses travel in the material, is also measured and the velocity is determined from the ratio of the path length to the transit time.

Results of both these tests are compared to the results of the conventional uniaxial static test for several types of masonry. The ability of these tests to reflect such phenomenon as influence of the load frequency on the modulus of elasticity of masonry is discussed.

INTRODUCTION

Masonry is one of the oldest and still one of the most popular building materials. A large stock of unreinforced masonry buildings exists in Australia as well as in other countries. Many of these buildings were constructed before any standards for masonry were developed. Although it is likely that at the time of their construction the conservative approach was regarded as the safe one, this may not be the case from the today's engineering knowledge point of view. The probable reasons for this are: inadequate design, poor workmanship, accumulated damage, changes of working loads, and so on. The safety of existing buildings should be verified from time to time on the basis of the contemporary engineering knowledge and deficient buildings must be rehabilitated or demolished. The essential part of the evaluation of masonry buildings is the assessment of masonry condition and mechanical properties.

One of the parameters that have been identified as influencing the structural response of buildings is the dynamic modulus of elasticity of masonry. The major aim of this project was to find methods suitable for experimentally studying the dynamic modulus of elasticity of masonry and its dependency on the load frequency.

A number of non-destructive methods have been developed for evaluation of mechanical properties and assessment of condition of other than masonry materials. Some of these were latter studied for use with masonry. The most popular methods for masonry condition assessment are the ultrasonic pulse velocity method (UPVM) and the sonic pulse velocity, also known as the mechanic pulse test. The UPVM was first used for masonry assessment by Leeper et al. (1967). Pulse methods were also explored by Snell (1978), Noland et al. (1982), Senbu et al. (1986), Hobs (1986), Kingsley et al. (1987), Bocca (1988), Calvi (1988), de Vekey (1988), and Epperson et al. (1989). These studies have demonstrated that pulse measurements correlate with masonry strength and could be used to distinguish between various grades of masonry or to locate typical kinds of flaws. The authors also note the rapid attenuation of the signal over a long path length. The combination with other non-destructive was recommended because of the many factors influencing the wave velocity, including among others: mortar type and content, entrained air, moisture content, temperature, path of waves, presence of reinforcement.

The other present and potential techniques for the non-destructive evaluation of masonry structures were reviewed by Abrams et al. (1991) following presentations by noted professionals in this area during the Workshop (1990) at the University of Colorado. A number of these methods were used for evaluation of mechanical properties of masonry. The rebound hammer method, the probe penetrometr, the pull-out test, the flat-jack method, the in-place shear test, the bond wrench test, and the conventional tests of cores extracted from an in-situ masonry.

METHODS

Of the methods previously used for masonry testing, the flat-jack method and the laboratory compressive testing of extracted cores are recommended to determine the elastic modulus, but neither of them uses dynamic loading. The only methods that use dynamic pulses and theoretically suit for testing of the dynamic modulus of elasticity are the pulse velocity methods.

These tests are based on measuring the velocity of sonic or ultrasonic pulses travelling in a solid material. Test set-up for the UPVM is shown in Fig. 1. A testing apparatus generates pulses and indicates the time taken for the earliest part of the pulse to reach the receiving transducer accurately measured from the time it leaves the transmitting transducer when these transducers are placed at suitable points on the surface of the material. The distance, which the pulses travel in the material, is also measured and the velocity is determined from the ratio of the path length to the transit time.

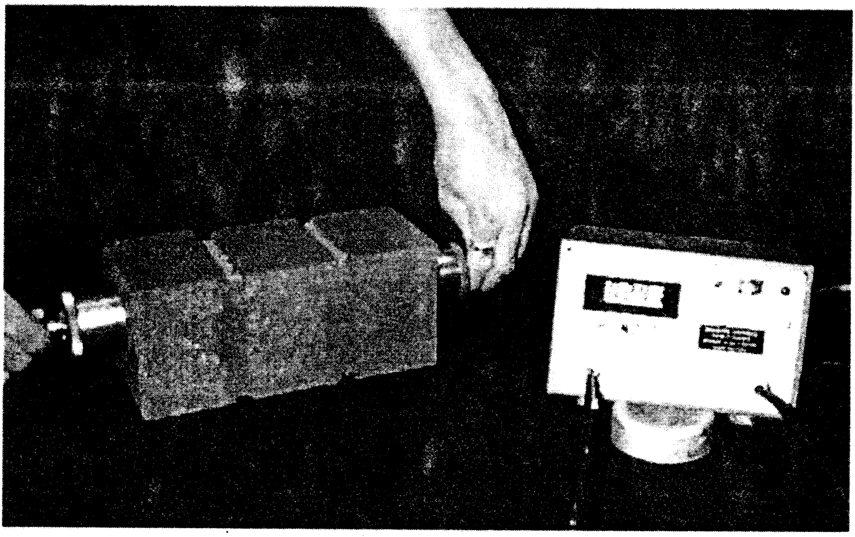

Figure 1. Experimental Set-up for the Ultrasonic Pulse Velocity Method

The velocity of pulses can be related to the dynamic modulus by a relationship of the form:

$$V = \sqrt{\frac{\widetilde{E}(1-\nu)}{\rho(1+\nu)(1-2\nu)}}\ , \tag{1}$$

where V is the velocity of pulses, E is the dynamic modulus of elasticity, ρ is the density of the material, and γ is the Poisson's ratio for the material.

There are several problems with using the pulse velocity methods for testing the dynamic modulus of elasticity. One is the rapid attenuation of the pulses. Another problem is that additional tests are required to determine the Poisson's ratio. A serious theoretical limitation is that Eq.1 only applies to homogeneous elastic materials. The major technical difficulty is that a testing machine normally has transducers with the constant frequency. This is insufficient for experimental study of the frequency dependence phenomena. The typical frequency range of testing machines (25 kHz to 1 MHz for ultrasonic and about 1 kHz for sonic testing) is also much higher then the practical range for masonry structures. Because of all these problems it was decided that pulse velocity method could only be used in conjunction with another method to study the dynamic modulus of elasticity.

A suitable technique has been found among the techniques used for evaluation of concrete structures. It is the Longitudinal Vibration Test Method (LVTM). This test is based on measuring the fundamental natural frequency of a regularly shaped brick or masonry specimen. Test set-up for the LVTM being used for testing a brick specimen is shown in Fig. 2. A very accurate oscillator operates a vibrator, which in turn excites the specimen clamped in the centre of its length. The oscillations are picked up by a piezo-electric crystal pick-up passed through an amplifier and the signal is displayed on an oscilloscope. The frequency of the input signal is increased until the first resonance of the output signal is observed. The resonance frequency is considered the fundamental natural frequency of the specimen.

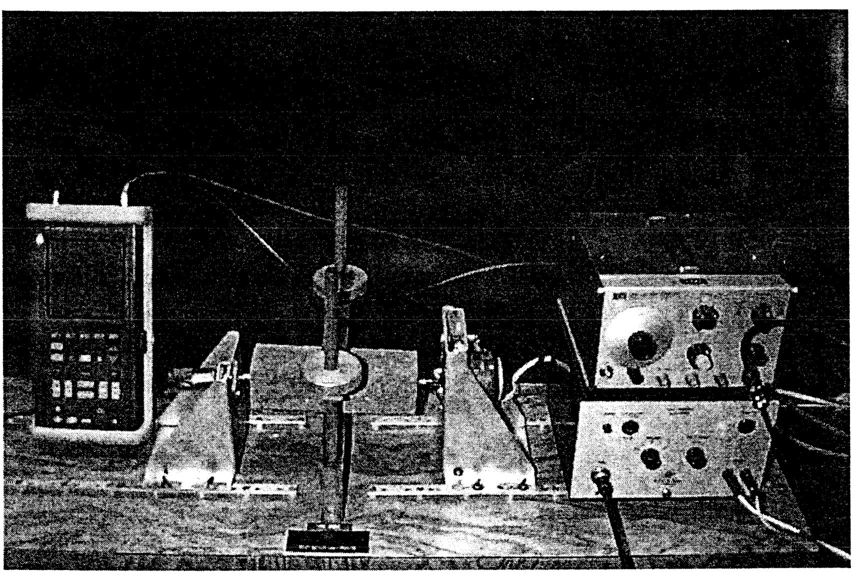

Figure 2. Experimental Set-up for the Longitudinal Vibration Test Method

The natural frequency can be related to the dynamic modulus by a relationship of the form:

$$f = \sqrt{\frac{\tilde{E}}{4L^2 \rho}} \, , \tag{2}$$

where f is the fundamental natural frequency, E is the dynamic modulus of elasticity, ρ is the density of the material, and L is the length of the specimen.

The LVTM has fewer problems comparing to the UPVM, as far as testing for the dynamic modulus of elasticity is concern. There is no need for additional tests. The Eq. 2 is derived from principles of structural dynamics and has more general application than Eq. 1. The typical frequency range of testing is 1 kHz to 10 kHz, which is also high, but closer to the practical range for masonry structures. The major advantage of this method for studying the dynamic modulus of elasticity is its ability to gradually vary the natural frequency of specimen by changing specimen's length or cross-section.

EXAMPLES

The LVTM and the UPVM were used to study the dynamic modulus of elasticity of masonry prisms. The Young's Modulus and the Poisson's Ratio (for use with the UPVM) of prisms was also determined using the quasi-static uniaxial compression tests.

Three stack high masonry prisms were constructed from five different brick types. Three pressed clay bricks designated by colour red, brown, and biscuit; one calcium-silicate and one concrete brick were used. A total of 44 prisms were manufactured for the test program. 10 of them were cut into half-prisms. Prisms were made using a mortar with the following ingredients: cement : lime : sand (1:1:6) by volume. The lime was in the form of lime putty that had been aged for two months.

The longitudinal vibration test method used a dynamic test rig that is a modified version of the Electrodynamics Standard Material Tester EMFCO SCT/5 (EMFCO, n.d.). This test rig is noted in the specification as to complying with BS 1881: 52 (Longitudinal Vibration). Specimens were saw cut from the prisms by sawing into two halves about the longitudinal axis. A Tektronix Function Generator FG501 with controlled frequency was used to generate the applied sinusoidal loading function. This signal was amplified using a Peavey Electronics Corp. XR400 Amplifier to feed the 3-Ohm coil on the test rig. Each specimen was clamped on the test rig using a jaw clamp at the midpoint. A piezo-electric crystal pick up detects the signal, which was monitored on a Tektronix Oscilloscope 7603 for peak amplitude. The frequencies used were in the range from 1 to 20 kHz. The critical areas in this type of experimental work are ensuring that the lowest resonant (with multiples) and not spurious frequencies are identified and that the results can be repeated. A steel cylindrical specimen was used as validation of the procedure.

The ultrasonic pulse vibration method uses a standard measurement unit. This method uses the CNS portable ultrasonic non-destructive tester (PUNDIT, 1978). A calibrating specimen is provided with the rig. Testing was at 50 MHz about the longitudinal axis of the specimen.

The quasi-static test uses uniaxial compression applied to the smaller end faces of the prisms with a Tinius Olsen 1800 kN Universal Testing Machine. A rectangular test rig capable of measuring the relative displacements about two axes was designed to provide a repeatable measurement protocol. The rig is similar to the standard cylindrical concrete test rig, only modified to also measure Poisson's Ratio. A photograph of the quasi-static test rig being used for testing brick units is shown in Figure 3.

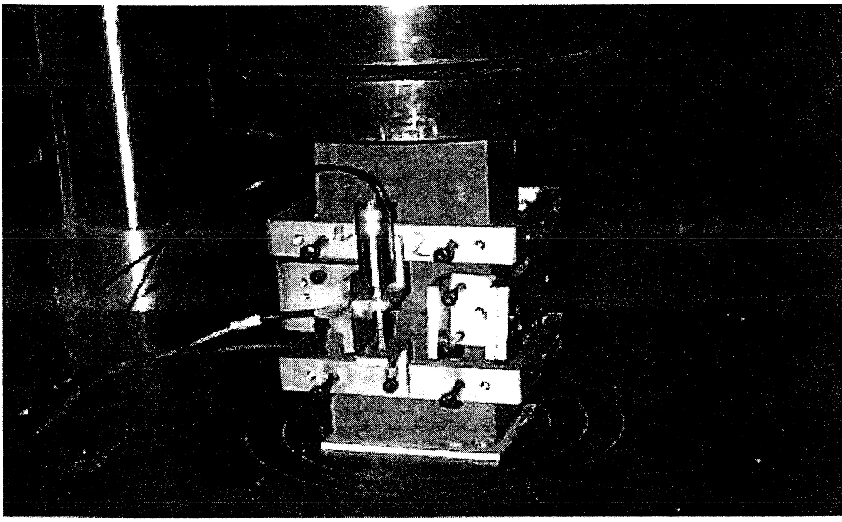

Figure 3. Experimental Set-up for the Quasi-Static Test Method

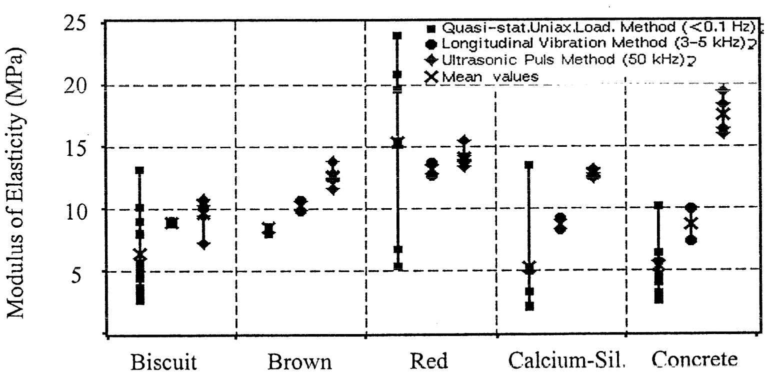

Figure 4. Modulus of Elasticity of Masonry

The results of all dynamic and static tests are presented in Fig. 4.

CONCLUSIONS

The UPVM and the LVTM are compared in Table 1.

Table 1. Comparison of the UPVM and the LVTM

Method	UPVM	LVTM
Non-destructive	Yes	Yes
Requires additional tests	Yes (Poisson's Ratio test)	No
In-situ testing	Yes (No for additional tests)	No (extracted cores testing)
Specimen preparation	No (Yes for additional tests)	Yes (Square prism/cylinder)
Frequency	Constant (25kHz to 1MHz)	Variable (1kHz to 10kHz)
Repeatability of results	Depends on the coupling material and the pressure applied to transducers	Independent
Scatter of results	Average	Low

From the conducted experimental study of the dynamic modulus of elasticity of masonry the following conclusions can be made regarding test methods:

- The Longitudinal Vibration Test Method has found to be suitable testing method for determination of the dynamic modulus of elasticity of masonry;
- The Longitudinal Vibration Test Method has found to be easier to use and more accurate comparing to the Ultrasonic Pulse Velocity Method;
- It is recommended to use both methods to study the frequency dependency of the dynamic modulus of elasticity of masonry, because having different range of working frequencies they compliment each other;
- It was found that the elastic modulus of masonry determined from quasi-static tests such as the uniaxial compression test of extracted masonry cores could be conservatively taken as the dynamic modulus of elasticity.

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