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Application of acoustic tests to mechanical characterization of masonry mortars

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ABSTRACT

Resonant acoustic tests appeared recently as an interesting nondestructive alternative that can be applied for the determination of elastic properties with low cost and accuracy. Besides, the same sample can be tested repeatedly if necessary, simplifying laboratorial procedures for long term monitoring. This paper presents an experimentally based evaluation of elastic modulus of general mortars specified in British standard for masonry through both conventional (destructive) and acoustic (nondestructive) tests. Four mortar mixes were produced and cylindrical specimens (50 mm × 100 mm) were cast. The specimens were subjected to uniaxial compression, allowing the determination of the static elastic modulus. Acoustic tests were performed prior to the static tests so that the dynamic elastic modulus was characterized. A very good correlation between dynamic and static elastic moduli was achieved so that the second can be easily estimated from the first. Additionally, the dynamic elastic modulus is better correlated to the compressive strength of mortars than the static elastic modulus.

1. Introduction

Mortar is one of the constituents of the composite anisotropic material denominated "masonry". Mortar is responsible for creating a uniform stress distribution, smoothing the irregularities of blocks and accommodating deformations associated to thermal expansions and shrinkage. It is well known that the influence of masonry mortars on compressive strength of masonry is reduced. Steil et al. [1] observed an increase of 8.8% in the compressive strength of masonry prisms when the compressive strength of mortar was increased 78%. In other study, Cunha et al. [2] increased the compressive strength of mortar by 400% to obtain an increase of 20% in the compressive strength of masonry. The compressive strength of mortar measured on cubes or cylinders presents a very low representativeness since mortar is confined in a masonry wall differently of the standard specimens [3]. On the other hand, mortar was found to play an important role in the bond strength properties at the unit–mortar interfaces [4–7]. It is well accepted that bond strength is dependent on the unit and mortar properties and also on the moisture content of the unit at time of laying. In addition to the bond strength, mortar has a high influence on deformability of masonry [8]. According to the results pointed out by Vasconcelos and Lourenço [9] the deformability of masonry is clearly influenced by the material at the bed joints. Very distinct pre-peak behavior was found by considering dry saw unit–mortar interfaces, rough dry joints, lime mortar or dry clay resulting from sieving granitic soil. Mohamad et al. [10] also studied the deformation properties of masonry composite through compressive tests in masonry prisms built with four distinct types of mortar. The authors concluded that mortar governs the non-linear behavior of masonry and have a large influence in the axial strain of masonry prisms.

Deformation properties and specially the elastic modulus of mortars have a large influence on the behavior of masonry structures. The experimental determination can be developed through the conventional static method described by ASTM C469 [11].

This procedure is well accepted for concrete specimens and at some extent applicable to mortar specimens. However, when compared to nondestructive tests the conventional static method has some limitations:

– the equipments are more expensive, with larger dimensions, or require more maintenance: loading machine, load cells and displacement transducers, and
– being a destructive test, there is no possibility of repeating the test with the same sample. If a problem occurs during the test and the sample is damaged, the test cannot be repeated. Besides this, for obvious reasons, the same sample cannot be used to follow continuously the development of elastic modulus with time.

On the other hand, the nondestructive Resonant Frequency Methods provide a low cost, simple, fast and accurate way of

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evaluation of elastic properties of materials. Malhotra and Sivasundaram [12] presented an interesting description of the development of such techniques, which is briefly shown here. In 1938, Powers [13] related the musical tones created by concrete specimens to the tones of calibrated orchestra bells. Subsequent researchers introduced electronic equipments to identify the resonant frequency of specimens subjected to an oscillating force based on the maximum amplitudes observed in the frequency range.

Nowadays, the most known method of implementation of these tests is described by ASTM C215 [14]: a variable frequency audio oscillator, an amplifier and a driving unit are responsible for applying controlled oscillating forces.

An alternative method, based on impact resonant acoustic spectroscopy was used in this paper, which is an inexpensive and practical nondestructive technique that can be implemented with portable equipment. This method was first described by Ito and Uomoto [15]. An impact is applied in some region of the sample to activate a specific mode of vibration (flexural, longitudinal or torsional) and the sound radiated by the sample surface at some location of interest is captured by a microphone. After processing the acquired data, the natural frequencies can be clearly identified and associated to the elastic properties of the material, in this case the elastic modulus of mortar. More details are given in Section 2.

2. Experimental program

The performance of distinct general mortar compositions specified by BS 5628-1 [16] was evaluated based on static and acoustic experimental tests. For this experimental characterization, an enlarged experimental program was designed.

2.1. Material properties

Portland cement, lime and sand were the materials used to prepare all mixes of mortars. The cement used was a Portland cement type II specified according to the classification of ASTM C150 [17]. The hydrated lime used is a commercial lime of class CH-III for masonry purposes, according to ABNT NBR 7175:2003 [18]. Four mixes of mortar were prepared keeping the same binder/aggregate ratio: 1:3 (Portland cement:sand), 1:0.5:4.5 (Portland cement:lime:sand), 1:1:6 (Portland cement:lime:sand) and 1:2:9 (Portland cement:lime:sand). The sand used in this study is graded as zone 1 with a maximum diameter of 0.60 mm and a fineness modulus of 1.74 according to ABNT NBR 7211:2009 [19], which specifies sand properties for load-bearing masonry (Fig. 1). Some physical properties of materials are indicated in Table 1.

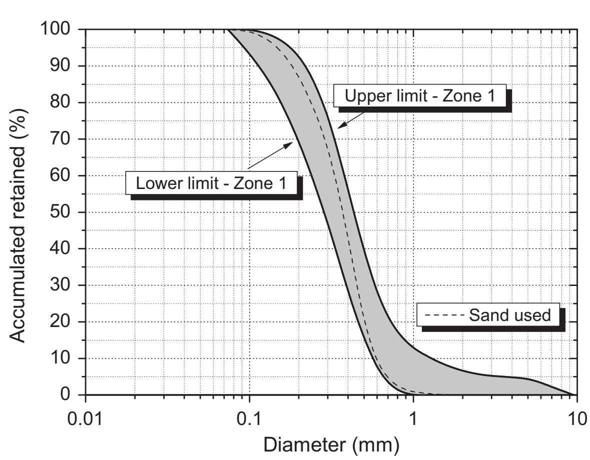

Fig. 1. Grading curve of sand.

Table 1
Properties of materials.

	Cement	Lime	Sand
Unit mass (kg/m^3)	1171	765	1665
Density (kg/m^3)	3070	2450	2611

2.2. Test specimens

Mixing of mortars was performed in accordance with the recommendations given in ABNT NBR 13276:2002 [20]. The cement, lime and fine aggregate were mixed without addition of water until they were thoroughly blended in a mixing pan of vertical axis. The water was added and the mortar was mixed until it became homogeneous in appearance and had the desired consistency. Flow table test was performed according to ASTM C1437 [21] and the flow value obtained to produce a satisfactory workability was equal to 250 mm. At least nine specimens of mortar were taken from each mortar mix. Specimens had 50 mm of diameter and 100 mm of height (height–diameter ratio of 2:1) according to ABNT NBR 13279:1995 [22]. The specimens were made in four layers of approximately equal volume and consolidated through rodding. Thirty strokes were used to compact each layer, in accordance with ABNT NBR 13279:1995 [22]. To prevent water evaporation from unhardened mortar, the specimens were covered immediately after molding with a non-absorptive and nonreactive plate and maintained in the laboratory for 2 days. After that, the molds were removed and the specimens were immediately stored in the moist chamber for curing until the age of testing. Static and acoustic tests were performed after 90 days of the construction of specimens.

2.3. Static tests

Static tests were performed according to ABNT NBR 13279:1995 [22] under displacement control at a rate of 0.01 mm/s. Two vertical LVDTs with an effective gauge length of 50 mm were located in the middle of samples (Fig. 2). The flatness and perpendicularity of top and bottom surfaces were obtained, rectifying all specimens.

Static elastic modulus was obtained in accordance with ASTM C469 [11] which describes a compressive test method for concrete. It stipulates a chord modulus between two points: the lower point corresponds to a longitudinal strain of 50×10^{-6} (to be free of possible irregularities in strain readings caused by seating of the testing machine platens and strain measuring devices) and the upper point corresponds to a stress equal to 40% of the compressive strength at the time of loading (near the upper end of the linear behavior).

2.4. Acoustic tests

Acoustic tests were performed as described schematically in Fig. 3. The specimen was supported by steel wires connected to a rigid frame in order to simulate free–free boundary conditions.

A specially designed hammer with a rubber handle and steel sphere head was used to apply the impact. The rubber handle was selected because its dynamic properties (high damping and very low natural frequencies) had not created interferences in the measurements. A steel sphere head was chosen because its first natural frequency is easily estimated as $136000/r$ (in Hertz, assuming $E=214$ GPa, $\nu=0.31$ and $\rho=7.85$ g/cm^3), where r is the sphere radius in centimeters [12]. The radius of the sphere was chosen so that its first natural frequency was above the expected