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Sensor and dimensions effects in ultrasonic pulse velocity measurements in mortar specimens

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Abstract

Ultrasonic Pulse Velocity (UPV) method is a very popular technique used in Non-Destructive Testing (NDT) in Civil Engineering. Major benefit of the method is its simplicity. UPV uses the concept of measuring time of a first arrival of ultrasonic wave from one side of the specimen to another. Moreover, UPV is an ASTM standard test method for concrete specimens. The standard specifies the applications of UPV as: assessment of relative quality of concrete, presence of imperfections (i.e. voids, cracks, and the effectiveness of its repairs). UPV can be also applied to monitoring changes in the condition of a specimen.
In spite of an easiness of the method the obtained results highly depend on the transducers used, the coupling quality, and the specimen dimensions. In this article the authors focus on the sensor and the dimensions effects. The results for UPV tests on 9 mortar specimens of different heights and diameters are presented. The specimens are tested with 54 kHz and 850 kHz resonant frequency (fc) transducers and the state-of-the-art laser vibrometer (response measurements).
The authors discuss the laser vibrometer readings and the influence of specimens' dimensions on the measured pulse velocities. Practical recommendations for the minimal dimensions of the test object in order to minimize the error in the UPV tests are proposed.

Keywords: Non-Destructive Testing, Ultrasonic Pulse Velocity, Laser Vibrometer, Size effects

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1. Introduction

Concrete is a popular structural material used in Civil Engineering applications. Condition of concrete may be affected by the quality of a design, manufacturing, loads applied to a structure, character of the loads, environmental deterioration, or aging. The condition of concrete is essential for the safety of a structure. Micro-defects may also be present in concrete before the loads are applied. One example of such are voids in the mortar matrix. The micro-defects may be a result of shrinkage, creep, bleeding, settlement of coarse aggregates etc. [1]. In this study mortar is used instead of concrete in order to test the material that is more homogeneous. In order to assess the condition of concrete/mortar non-destructive testing (NDT) methods may be applied. Two major groups of NDT techniques are electromagnetic and acoustic. In the first group the most popular are ground penetration radar, thermal imaging, electrical resistance testing, and radiography. Among the acoustic methods the impact echo, ultrasonic pulse velocity (UPV), and surface waves analysis can be distinguished [2,3]. The latest trends focuses more on attenuation of wave front [4,5] and more sensitive methods for detecting changes in velocity (e.g. Coda Wave Interfefometry [6,7,8]).

Wave velocity depends on the medium properties, therefore UPV method is a very popular technique used in NDT in Civil Engineering. Propagation velocity of the longitudinal (P-wave) through the material (v_P) can be calculated as:

$$v_P = \sqrt{\frac{E_d(1-\nu)}{\rho(1+\nu)(1-2\nu)}}, \tag{1}$$

where E_d is dynamic Young's modulus, ν is the Poisson's ratio, and ρ is the density. Major benefit of the UPV is its simplicity. The method is based on the concept of measuring time of a first arrival of ultrasonic wave from one side of the specimen to another. Moreover, UPV is an ASTM standard test method for concrete specimens [9]. The standard specifies the applications of UPV as: assessment of relative quality of concrete, presence of voids imperfections (i.e. voids, cracks, and the effectiveness of its repairs). UPV can be also applied to monitoring changes in the condition of specimen [9]. In spite of an easiness of the method obtained results depend highly on the transducers used, the coupling quality, and the specimen dimensions. In the paper authors discuss those factors by using three kinds of measuring equipment and different sizes of mortar specimens (length and diameter effects are discussed).

2. Laboratory Setup and Test Configuration

2.1. Specimens

In this study 9 mortar samples prepared by Berube [10] in 2008 are tested. During the preparation of mortar specimens a 3:1 sand-cement ratio was used. In order to reduce the volumetric change during curing a 0.64 water-cement by weight ratio was used [10]. The sand was prepares was sieved with two kinds of meshes (#100 (0.150 mm) and #16 (1.18 mm)) As a result small particles that may absorb too much water were removed with the first sieve. The second process removed large particles and therefore the samples are more homogeneous. All of the specimens were cast from the same batch in order to increase the accuracy of comparative tests. Specimens were left for 24 hours in open air. Additional wetting was performed. After that the moulds were removed and the specimens were placed in the moisture room for 28 days after casting. Finally the faces of each specimen were smoothed with a drill press with a coarse sand paper. Then the specimens were stored in NDT lab of the University of Waterloo for 8 years, which makes the specimens a unique testing set. A list of all the mortar specimens and their accurate measurements are presented in table 1 (the names correspond with the rounding of dimensions in cm).