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Strength estimation of concrete masonry units using stress-wave methods

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HIGHLIGHTS

- Nondestructive test (NDT) methods for CMU strength estimation are studied.
- Statistical methods are used to establish the reliability of each NDT method.
- Challenges in practical application of each method is discussed.
- Longitudinal resonant frequency based NDT is more reliable than UPV.

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ABSTRACT

Solid concrete masonry units (CMUs) are rapidly replacing burnt clay bricks in the construction industry, especially in the southern regions of Asia. In developing countries, the plants producing CMUs lack effective quality control for the fabricated units. They rely on destructive tests, such as those described by ASTM C140, to demonstrate compliance with compressive strength criteria. Such destructive testing is expensive and is, therefore, performed on a limited scale. A previous study concluded that a surface hardness based nondestructive test (NDT) method (rebound hammer test) is not reliable and that ultrasonic pulse velocity (UPV), which is a stress wave propagation based method, can be a useful tool for strength estimation of CMU (Sajid et al., 2016). This study compares the performance of the UPV test with that of the resonant frequency test, another stress wave propagation based method, to evaluate the compressive strength of concrete specimens. The specimens are made with materials, mixture proportions and compaction similar to those of solid CMUs. The statistical models show that the resonant frequency test is more reliable compared with the UPV test for evaluating strength of concrete for masonry units.

1. Introduction

Buildings with masonry construction are prevalent in developing as well as developed countries. In developed countries, masonry production is based on the latest technologies and often meet the requisite quality assurance parameters of building codes. However, in less developed countries with growing economies, the case is different. For instance in Pakistan, the demand for masonry construction has given rise to the use of concrete masonry units (CMUs), which are produced in local factories (Fig. 1). The lack of quality assurance testing for such construction materials is discussed by Sajid et al. [1]. Pakistan is located in a seismic prone region and CMUs are used in 3.3% of the country's built environment [2]. Because there is no efficient way to verify the quality of these CMUs, the buildings are vulnerable to inadequate performance during seismic events [2]. The country suffered through the major calamity of the October 08, 2005 earthquake in which damage to buildings made of concrete masonry units contributed greatly to the loss of human lives [3].

Currently, the test method used for strength evaluation of CMUs is as prescribed in ASTM C140 [4], which requires a universal testing machine (UTM). The UTM is an expensive piece of equipment and in addition, the high cost of testing of CMUs is a major impediment to frequent testing. Consequently the amount of testing is kept to a minimum. An efficient testing technique for strength evaluation of CMUs is, therefore, needed. Nondestructive test

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Fig. 1. CMU manufacturing operations in a small scale production facility.

(NDT) methods have proved to be good tools for in-place strength evaluation of concrete [5].

Among the many methods that are available, the rebound hammer test and ultrasonic pulse velocity (UPV) test are the most widely used NDT tests because of their low cost and simplicity of use. The former method measures surface hardness and the latter indirectly measures speed of a stress-wave propagating through the test specimen. Both are recommended for structural health monitoring and strength evaluation of concrete structures [6]. A previous study [1] reported the results of both these methods and concluded that the stress-wave propagation based technique is more reliable. This paper discusses a study of stress-wave propagation-based NDT techniques for concrete specimens with properties similar to those of solid CMUs. The methods studied and compared are UPV and resonant frequency measurements.

The main issue in using NDT methods to estimate strength is the reliability of the results. Most NDT methods measure a property related to compressive strength and pre-established correlations are needed to estimate strength from the NDT measurement. The accuracy of strength estimates is mainly related to the fact that concrete is a composite material, which can be made using numerous proportions of its constituent materials resulting in different compositions and properties. As a result, correlations will typically be concrete mixture dependent. A number of studies have investigated the reliability of results of UPV measurements of concrete [7]. Various researchers have reported on the issues in using UPV for strength evaluation of concrete [8,9]. Similarly, the use of resonant frequency testing for strength evaluation has been attempted by a number of researchers since 1945 [10]. In most of these studies of strength evaluation using resonant frequency, the underlying relationship has been between strength and dynamic modulus of elasticity. The dynamic modulus of elasticity is obtained from the resonant frequency and mass of a test specimens using the equations given by ASTM C215. Gudmarsson [11] reported the dependable use of resonant frequency tests for strength characterization of asphalt concrete specimens.

This research aims to investigate the prospects of using UPV and resonant frequency measurements on test specimens for estimating the compressive strength of hardened concrete with properties similar to that of CMUs used in the field.

2. Methodology

The methodology for this study is outlined in Fig. 2. Cylindrical specimens were fabricated using zero slump concrete as used for CMU production in factories. Fine aggregate (natural sand) had a fineness modulus of 2.78, an absorption of 1.1%, and a relative density of 2.53. While the coarse aggregate (crushed stone) had a nominal maximum size of 9.5 mm, an absorption of 0.9% and a relative density of 2.79. A total of 15 batches of concrete were made to obtain a range of compressive strengths from 7 MPa to 40 MPa. Table 1 shows the nominal mixture proportions, in terms of relative mass, for three strength levels. Different strengths were obtained by making small changes to the actual *w/c* values.

Standard, 150 mm by 300 mm cylindrical specimens were fabricated from the 15 batches. A total of 90 cylinders were made using materials, mixture proportions, slump, and mode of compaction similar to those used to make CMUs in small-scale factories. A vibrating table, which is operated by a motor rotating at 1450 rpm, was used for compaction. The specimens were cured under water in a tank for 28 days. Testing of the concrete cylinders was performed as described in Fig. 2.

3. Data processing and analysis

Regression analysis is used to explore empirical relationships between the NDT test results and the measured compressive strength. Examples of regression analysis performed are shown in Figs. 5, 9, 13, for resonant frequency, dynamic modulus of elasticity and UPV, respectively. Several types of equations were examined for each data set, and root mean square error (RMSE) for each equation is compared as shown in Table 2. A power correlation is selected from the comparative study of the correlations and the values of RMSE. In general, the important criteria for a good regression model are (a) to make the smallest possible errors, in practical terms, when predicting what will happen in the future, and (b) to derive useful inferences from the structure of the model and the estimated values of its parameters [15]. Once a curve is fitted, we want to make predictions from it and want to know how good our predictions are. The uncertainties in the predictions will be