Alexandria Engineering Journal (2012) 51, 193–203

Alexandria University

Alexandria Engineering Journal

www.elsevier.com/locate/aej
www.sciencedirect.com

ORIGINAL ARTICLE

Reliability of using nondestructive tests to estimate compressive strength of building stones and bricks

Ali Abd Elhakam Aliabdo, Abd Elmoaty Mohamed Abd Elmoaty *

Department of Construction, Faculty of Engineering, Alexandria University, Egypt

Received 19 July 2011; revised 22 May 2012; accepted 27 May 2012
Available online 26 June 2012

KEYWORDS

Stones;
Bricks;
Hardness;
Schmidt hammer;
Ultrasonic pulse velocity and statistical models

Abstract This study aims to investigate the relationships between Schmidt hardness rebound number (RN) and ultrasonic pulse velocity (UPV) versus compressive strength (fc) of stones and bricks. Four types of rocks (marble, pink lime stone, white lime stone and basalt) and two types of burned bricks and lime-sand bricks were studied. Linear and non-linear models were proposed. High correlations were found between RN and UPV versus compressive strength. Validation of proposed models was assessed using other specimens for each material. Linear models for each material showed good correlations than non-linear models. General model between RN and compressive strength of tested stones and bricks showed a high correlation with regression coefficient R^2 value of 0.94. Estimation of compressive strength for the studied stones and bricks using their rebound number and ultrasonic pulse velocity in a combined method was generally more reliable than using rebound number or ultrasonic pulse velocity only.

1. Introduction

The objective of nondestructive in-place tests of concrete structures is to estimate properties of concrete in the structures. Very often the desired property is the compressive strength. To make strength estimation, it is necessary to have a known relation between the results of in-place test and the strength of concrete. This relation is usually estimated in the laboratory. The accuracy of the strength prediction depends directly on the degree of correlation between the strength of concrete and the quantity of measured in-place tests [1].

Rebound measurement and ultrasonic pulse velocity (UPV) are among the most widely used NDT methods regarding concrete strength assessment, and a recent European standard provides a formal solution on how concrete strength can be estimated from in situ testing [9]. The development and validation of a methodology that would lead with an acceptable level of confidence to a reliable strength assessment remains a key issue. A main point is that of "calibration", i.e. that of building and using a reliable relationship between NDT values and strength [10].

If the concrete specimens is small, any movement under the impact will lower the rebound readings, as stated by the ACI MONOGRAPH Series. In such cases the specimen has to be

* Corresponding author.
E-mail address: Abduo76@yahoo.com (A.E.M.A. Elmoaty).

Peer review under responsibility of Faculty of Engineering, Alexandrian University.

Production and hosting by Elsevier

1110-0168 © 2012 Faculty of Engineering, Alexandria University. Production and hosting by Elsevier B.V. All rights reserved.
http://dx.doi.org/10.1016/j.aej.2012.05.004

fixed or backed up by a heavy mass. It is best to grip the specimen in the testing machine. It has been shown by Mitchell and Hoagland that the restaining load at which the rebound number remains constant appears to be about 15% of the ultimate strength of the specimen [12]. In the present study 25% of the ultimate strength of the rocks specimens were considered.

A common statement is that while neither UPV nor rebound are, when used individually, appropriate to predict an accurate estimation for concrete strength, the use of combined methods produces more trustworthy results that are closer to the true values when compared to the use of the above methods individually. The combined approach leads to contrasted results as it have provided marginal improvements. A large number of relationships have been proposed in order to estimate the strength from a couple of (UPV, rebound) values. It appears that there is not a unique relationship and that calibration remains a key issue, as it is the case for individual methods [11].

Prior to the use of reinforced concrete structures, stones like lime stone was the main building material for major construction [2]. Most of historical and ancient buildings were made using stones and bricks. For example, for ancient buildings in Egypt, the main structure element in the structure system of these buildings depended mainly on some columns with base made with a certain type of rocks like marble, basalt, granite or lime stone. The governments do not allow to perform cores to estimate the compressive strength of these rock materials. This operation is necessary during the repairing or rehabitation processes of these buildings. So, nondestructive tests are the only allowable method to estimate the compressive strength of these materials.

Some new constructions, the estimation of compressive strength by nondestructive method can be used to reduce the number of specimens for compressive strength test. For example, for refractory bricks ASTM C 133 suggested 10 bricks for each 1000 bricks must be tested to ensure the compressive strength of this type of brick. In some constructions these number of bricks are not enough due to the importance or the dangerous of these structures. Chimneys of power stations are an example of these constructions in which the quality of the used bricks is very important to achieve the safety of these structures. So, in this case number of specimens of compressive strength tests must be increased or the same number of specimens according to ASTM C 133 can be used to get a relation between compressive strength and other nondestructive in-place test to estimate the compressive strength for additional number of bricks without performing compressive strength test and these specimens can be used again in the structure.

The most famous nondestructive in-place tests for concrete structures are ultrasonic pulse velocity and surface hardness methods [3–5]. The ultrasonic pulse velocity method consists of measuring the travel time of pulse of longitudinal ultrasonic waves passing through the material. The travel times between the initial onset and reception of the pulse are measured electronically. The path length between transducers divided by the time of travel gives the average velocity of wave propagation. A suitable apparatus and standard procedures are described in ASTM C 597. The ultrasonic pulse velocity test has been pointed out by several authors as useful and reliable nondestructive tool of assessing the mechanical properties of concrete of existing concrete structures [6].

Surface hardness method consists of impacting a concrete surface with a given energy of impact and then measure the size of indentation or rebound number. The standard procedures for this test have been established and are described in details in ASTM C 805. The Schmidt hammer was initially developed for concrete, but extensive application of it has been performed as a preliminary estimation of the stone strength [7].

This paper presents the reliability of using ultrasonic pulse velocity and surface hardness methods to estimate compressive strength of some building stones and bricks.

2. Research significance

As mentioned before, reliable relations between concrete compressive strength and nondestructive in-place tests like ultrasonic pulse velocity and surface hardness were established. These relations were widely used to estimate concrete compressive strength of the existing concrete structures. In some cases, compressive strength of some members of ancient buildings or some new structures made with other building materials (other than concrete) shall be determined. There is a little information about the relations between nondestructive in-place tests and compressive strength of these building materials. This research work aims to construct reliable relations between ultrasonic pulse velocity and surface hardness (rebound number) and cube compressive strength of some building materials. This research work covers some famous used materials like marble, white lime stone, basalt, pink lime stone, lime-sand bricks and burned bricks.

3. Experimental work

Stones and bricks samples were collected from various locations. Marble, pink lime stone, white lime stone and basalt were chosen as famous types of stones in Egypt. Burned bricks and lime-sand bricks were also studied as two examples of bricks in Egypt. The experimental work included six steps to establish either the relation between ultrasonic pulse velocity or rebound number versus cube compressive strength. These steps are:

- *Step 1*: Collection of varies types of each material from different sources with different ages.
- *Step 2*: Preparing of specimens by sawing to satisfy the dimension limits of compressive strength test according to ASTM C 170 which includes cubes with minimum dimensions not less than 50.8 mm. The cubes were air dried until time of testing.
- *Step 3*: Ultrasonic pulse velocity according to ASTM C 597 for each specimen was measured.
- *Step 4*: Specimens from each building materials were put in the center of compression testing machine and loaded to about 25.0% of their ultimate compressive strength (this load was controlled to be constant for a certain time) and then rebound number of these specimens were measured. Fifteen readings were taken to estimate the average rebound number.
- *Step 5*: After reading the rebound number, the applied load was increased until failure and then cube compressive strength of each specimen was calculated.
- *Step 6*: Construct the relation between compressive strength and rebound number or ultrasonic pulse velocity of tested materials.