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Estimation of compressive strength of hollow concrete masonry prisms using artificial neural networks and adaptive neuro-fuzzy inference systems

Qiang Zhou [a], Fenglai Wang [a,b,*], Fei Zhu [a]

[a] School of Civil Engineering, Harbin Institute of Technology, Harbin 150090, China
[b] Key Lab of Structures Dynamic Behavior and Control of the Ministry of Education, Harbin Institute of Technology, Harbin 150090, China

HIGHLIGHTS

- ANN and ANFIS are used to predict compressive strength of hollow concrete block masonry prisms.
- ANN and ANFIS show excellent performance in fitting experimental data.
- ANFIS model performs slightly better than ANN model.
- ANN and ANFIS outperform empirical methods including masonry codes.

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ABSTRACT

This paper proposes the use of artificial neural networks and adaptive neuro-fuzzy inference systems for estimating the compressive strength of hollow concrete block masonry prisms. Three main influential parameters, namely the prisms' height-to-thickness ratio and the compressive strengths of hollow concrete blocks and mortars, were used as input to the models. The two models were trained and tested using 102 data sets obtained from the tests conducted by the authors as well as published technical literatures and then verified by comparison with other empirical calculation methods. The results showed that the proposed models have excellent prediction ability with insignificant error rates.

1. Introduction

In the design of masonry structures, the compressive strength of hollow concrete block masonry is regarded as one of the most essential mechanical parameters as it has considerable influence on the safety and economic assessment of the structure [1,2]. However, determining the compressive strength is a significant challenge because of the complex composite behavior caused by the masonry components (hollow concrete blocks and mortars) and their interfaces [3,4].

In the past decades, different theoretical investigations [5–8] have been carried out on the behavior and strength of masonry prisms under axial compression. Several analytical models have been established by postulating a series of assumptions about the mechanism and then developing the equilibrium and deformation compatibility equations to predict the compressive strength. In general, the forms of these models are complex and require a large number of parameters to describe the failure characteristics of the masonry. Furthermore, some empirical models, including those used in design codes, have been proposed on the basis of experimental studies [9–18], to predict the compressive strength. Most of these empirical expressions largely depend on the prisms' height-to-thickness ratio and the compressive strengths of hollow concrete blocks and mortars. However, the data used to construct the empirical equations have been limited, and when new test results are available, the predictive accuracy and reliability of these empirical models have to be re-evaluated.

Abbreviations: ANN, artificial neural network; ANFIS, adaptive neuro-fuzzy inference systems; BP, backpropagation; LMBP, Levenberg–Marquardt backpropagation; FIS, fuzzy inference systems; MSE, mean squared error; MAPE, mean absolute percentage error; IAE, integral absolute error; COV, coefficient of variation.

* Corresponding author at: No. 73 Road Huanghe, Harbin 150090, China.
E-mail address: fl-wang@hit.edu.cn (F. Wang).

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In recent years, the well-known artificial intelligence techniques of artificial neural networks (ANNs) and adaptive neuro-fuzzy inference systems (ANFIS) have been widely adopted to solve many civil engineering problems because of their adaptability and high accuracy. These two models have been successfully used in such applications as the estimation of compressive strength and elastic modulus of various types of concrete [19–26] and the analysis of concrete drying shrinkage [27] and durability [28]. However, very few studies have been conducted on the application of artificial intelligence techniques to predict masonry behavior. Zhang et al. [29] established a cellular automata model to determine the cracking patterns of vertically loaded masonry wallets, and Garzón-Roca et al. [30,31] estimated the compressive strength of brick masonry using both ANN and fuzzy logic models. Moreover, Plevris et al. [32] used an ANN model to approximate the masonry failure surface under biaxial compressive stress.

The objective of this study was to construct ANN and ANFIS models to predict the compressive strength of hollow concrete block masonry prisms. For this purpose, 102 experimental data sets, gathered from experiments conducted in this study and published technical literature, were used to develop and evaluate the aforementioned two models. Finally, the proposed models were compared with several empirical methods [33–36] in order to evaluate their reliability and predictability.

2. Experimental test and data collection

The first step in developing both the ANN and ANFIS models was to collect sufficient data for the training and testing samples, which were then used to identify the parameters for the models. To obtain the data for these models, a database was developed by collecting data sets from experiments conducted in this study and data sets from previous studies [9–18].

2.1. Experimental test

2.1.1. Material

A commonly used hollow concrete block having dimensions of 390 mm (long) × 190 mm (high) × 190 mm (thick) with two cells and a half-concrete block having dimensions of 190 mm (long) × 190 mm (high) × 190 mm (thick) with one cell were considered for the experimental program (Fig. 1). The volume of the vertical holes in the concrete blocks was approximately 46%. The average thickness of the face shells and end webs of the concrete blocks was approximately 32 mm. In this study, two grade blocks having different strengths were used. The compressive strength of the hollow concrete blocks was measured in accordance with Chinese Standard GB/T 4111 [37] on five blocks for each strength grade.

Fig. 1. Geometry of full block and half-concrete block. All masonry prisms were constructed using hollow concrete full and half blocks, the dimensions of the full and half blocks were 390 mm × 190 mm × 190 mm and 190 mm × 190 mm × 190 mm (length × height × thickness), respectively.

General cement mortar was used for manufacturing the hollow concrete masonry prisms. The compressive strength of the mortar was measured using cubical specimens (70.7 mm side) according to Chinese Standard JGJ/T 70 [38]. Three different grade of mortar were chosen for the present study, and the mix proportion by weight was 1:4.75:0.72, 1:4.32:0.65, and 1:3.96:0.60 for cement, sand, and water, respectively. For each mix proportion, three specimens were prepared during the construction of the masonry prisms. The mortar cubical specimens were cured in a climatic chamber at a temperature of 20 °C and a relative humidity of 90% for 28 days before testing.

2.1.2. Construction of masonry prisms

Considering the influence of the height-to-thickness ratio (h/t), unit compressive strength (f_b), and mortar compressive strength (f_m) of the prisms on their compressive strength, two types of masonry prisms having six different block/mortar combinations were prepared in this study. The dimensions of the masonry prisms

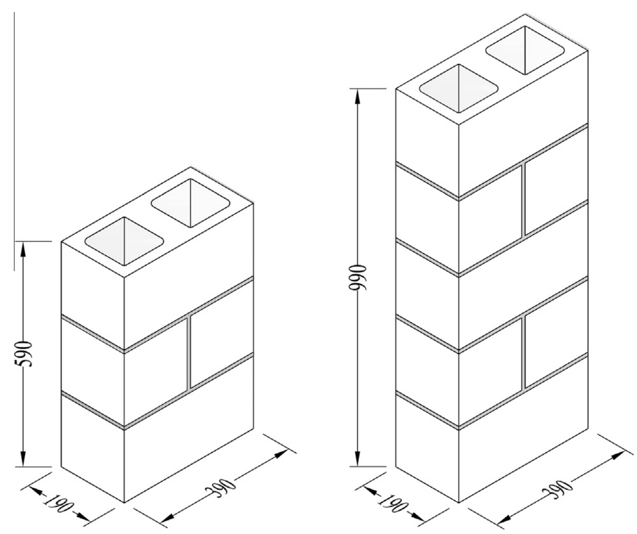

Fig. 2. Geometry of the tested specimens (dimensions in mm). Two types of specimens were constructed in running bond with full bedding, the dimensions of the specimens were 390 mm × 590 mm × 190 mm and 390 mm × 990 mm × 190 mm (length × height × thickness), respectively.

Fig. 3. Test set-up. Photograph illustration of the experimental test set-up.