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Research Review and Modeling of Concrete Compressive Strength Using Artificial Neural Networks

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ABSTRACT

As the construction industry is flourishing day by day, modelling techniques are becoming more and more important in making predictions. Artificial neural network is one of the techniques through which these predictions can be made with limited errors. This research paper deals with the prediction of the compressive strength of concrete using artificial neural network (ANN). The parameters under consideration were different grades of concrete (M-20 and M-30), different curing techniques that are commonly used during the construction of a building (sprinkling, ponding etc.), duration of curing and ageing of the concrete block samples (cubes and cylinders). These parameters were given as input to train the network for the output compressive strength obtained experimentally. Different weights were obtained for the network layer which were used for getting the target value. The network formed was validated for the compressive strength of concrete for the required sample by giving inputs and obtaining the desired output. The network formed can help in estimating the in situ compressive strength of concrete and thus can help designers in designing appropriate structural elements.

Keywords: Artificial neural network, compressive strength, curing, ageing, concrete grade

INTRODUCTION

In this paper artificial neural networks (ANN) model has been successfully used for establishing the relationship of compressive strength of concrete with different curing methods, grade of concrete and the age of the concrete cubes and cylinders. There are many factors that influence the compressive strength of concrete of which we used some to draw our results. The presented approaches enable to practically predict the in-situ compressive strength of concrete without using any type of destructive or non-destructive testing methods. Using this method site engineers can easily calculate the compressive strength of concrete by giving the general inputs. This method also helps in decreasing the computational time of compressive strength of concrete without much error in the accuracy.

Curing

Curing is an important part of construction activities as it help in decreasing the excessive internal energy produced inside the concrete due to various chemical reactions. These internal energies have to be dealt with or there will be a risk of cracks being formed in the concrete which in turn reduces the compressive strength of the concrete. Different types of curing methods are

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used in different situations depending on the nature of work and the climatic conditions. The compressive strength attained by concrete depends on the type of curing method adopted. In this experimental study the types of curing methods used are:

- Sprinkling: This is the most primitive type of curing in which the concrete is sprinkled with water at regular intervals to keep the concrete structures cool.
- Ponding: This method is normally used during the setting of large concrete slabs where a pool of water can be created. This is the best way of curing without the use of any chemicals as there is a layer of water above the slabs at all times.
- Covering using a gunny bag or a cloth: This method is generally used for columns and beams as a pool of water cannot be created above them. In this experimental study cloths of different colours such as red, yellow, blue, black and white were used for curing.

LITERATURE REVIEW

There are several non-destructive tests available that are used in calculation of the compressive strength of the concrete such as UPV, rebound hammer test, Windsor's probe method. Dias WPS and Pooliyadda SP (Neural networks for predicting properties of concretes with Admixtures. Journal of Construction and Building Materials, 2001) used analytical equations in modelling the effect of parameters on which compressive strength of

concrete depends and doing a regression analysis on the experimental data to obtain the value of the unknown coefficients. Vijay Pal Singh and Yogesh Chandra Kotiyal (Prediction of compressive strength using artificial neural network, 2003) used various NDT methods such as rebound hammer method, Windsor's probe method and ultrasonic pulse velocity method to predict the compressive strength of concrete cubes and then finally used the compressive testing machine to find the compressive strength of the cubes. 350 cubes with different mix designs were used to maintain variation of the compressive strength. All the cubes were cured under controlled temperature and were tested after 28 days. It is seen that if only one NDT is being used for the determination then rebound hammer method should be used as it gives results with the least amount of error. A combined model in ANN comprising inputs from rebound hammer as well as penetration method gives a much more accurate value of compressive strength than that by an ANN model using only a single input. UPV inputs when used singly gives the worst relationship between the predicted and the actual compressive strength and should never be used alone. Razon Domingo and Sorichi Hirose in their paper titled "Correlation between Concrete Strength and Combined Non-destructive Tests for Concrete Using High-Early Strength Cement" took three different samples of varying water- cement ratios ranging from 0.4 to 0.5 to assist in slump design. Specimens were then tested after 1, 3, 7 and 14 days for UPV values, rebound number, flexural and compressive strength to know the correlation among them. After performing the desired regression analysis, Domingo and Hirose formed two equations of correlations with high values of R^2. Kim JI, Kim DK, Feng MQ, Yazdani F (Application of neural networks for concrete strength. Journal of Materials in Civil Engineering, 2004) showed the application of neural network for predicting the strength of concrete.

Estimation of concrete strength in already existing buildings cannot be done using any destructive test and the data of the grade of concrete used and the type of curing may not be available at that point of time. In situations such as this certain NDT such as the Schimdt hammer can be used. (2010) Ferhat Ayidin and Mehmet Saribiyik in their paper "Correlation between Schmidt Hammer and destructive compressions testing for concretes in existing buildings" used Schmidt hammer test as a non-destructive test method and checked the compressive strength of the concrete using destructive methods. The tests were conducted on at least 24 samples of each kind i.e. 28 days, 90 days and in-situ core. Linear regression was performed on the data sets to obtain a regression equation with R^2 value of more than 0.85 in each case. The study had showed that different values of rebound numbers came up for the same compressive strength in the case of 28-90 days and core in-situ testing. As a result the author suggested that Schmidt Hammet test results can be influenced by many factors; such as the characteristics of the mixture, surface carbonation, moisture condition, rate of hardening and the curing type.

EXPERIMENTAL STUDY

A total of 461 samples have been taken for analysis. The samples included the concrete mix designs of M30, M20 and M40 of standard cubes and cylinders. We have used the data set for

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5 different variables as input variables with compressive strength as the output variable. The five variables used in our analysis are type of curing, time of curing, ageing, grade of concrete and shape of the sample. The ageing of the samples varies from 7 days up to 365 days. The values of compressive strength of M20 grade concrete ranges from 7.882 N/mm^2 to 35.707 N/mm^2 with a standard deviation of 7.026. The compressive strength of M30 grade concrete has the range from 6.115 N/mm^2 to 55.834 N/mm^2 with a standard deviation of 10.719. The types of curing used in the experiment are Sprinkling, Ponding with samples covered with wet cloth of red, blue, black, yellow and white colours. The time of curing has been kept limited to 3 and 7 days for convenience. Artificial Neural Network has been deployed to determine the correlation between the set of input variables and the compressive strength.

A non-linear relationship has been found between the input and the output variables using ANN analysis. A typical multi-layer feed-forward Artificial Neural Networks consist of an input layer, one hidden layer and an output layer. As per the problem statement The Levenberg-Marquardt network (LM) has been used in the analysis. The experimental data was stored in a computer file with .xls extension which was later converted to .mat to be used as our input data. The data was later divided to training (85%), validation (5%) and testing (10%). The data was later normalized to minimize the mean square error (MSE) using ANN.

RESULTS AND DISCUSSIONS

The neural network with one hidden layer consisting of 10 hidden neurons has been selected to minimize the mean square error (10.992e-0) and maximised R which came out to be 0.94285. The best validation performance was found out to be 6.3677 at epoch 40. There was found to be fluctuating mean square errors which is justified in the case of back propagation algorithm.

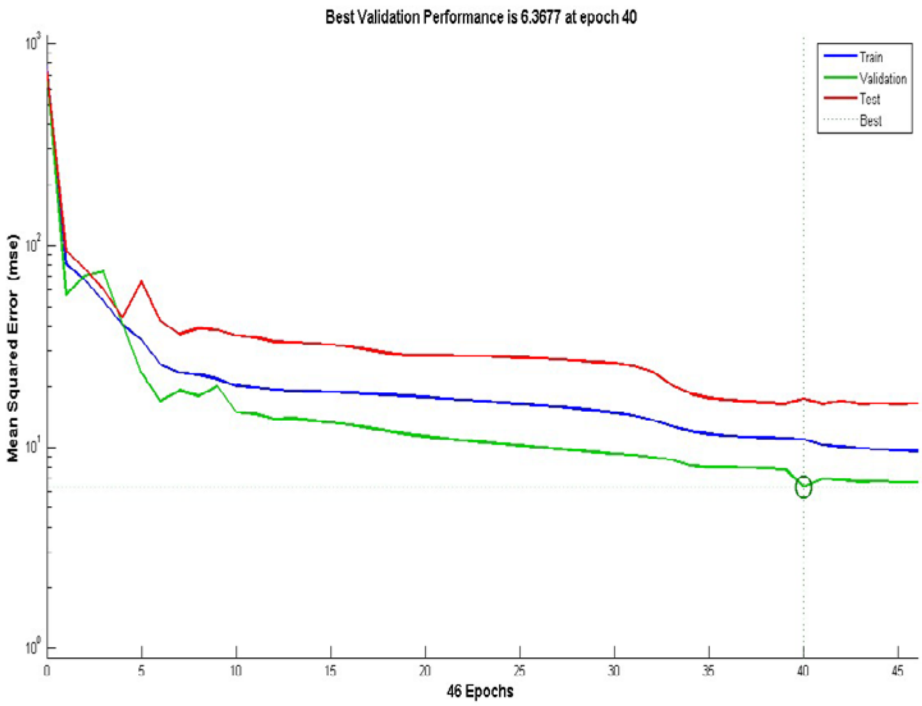

Figure 1. The performance of LM network

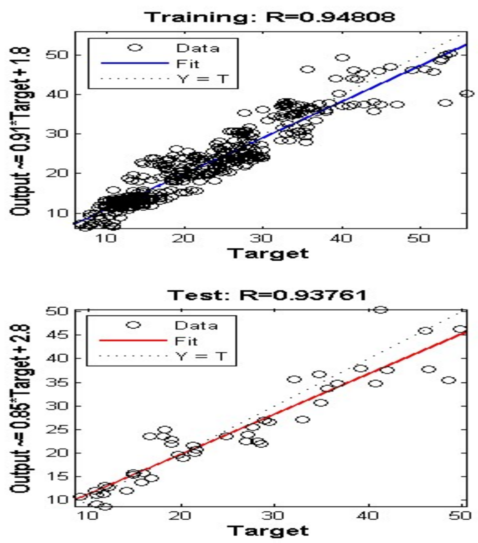

Figure 2. The regression of LM network

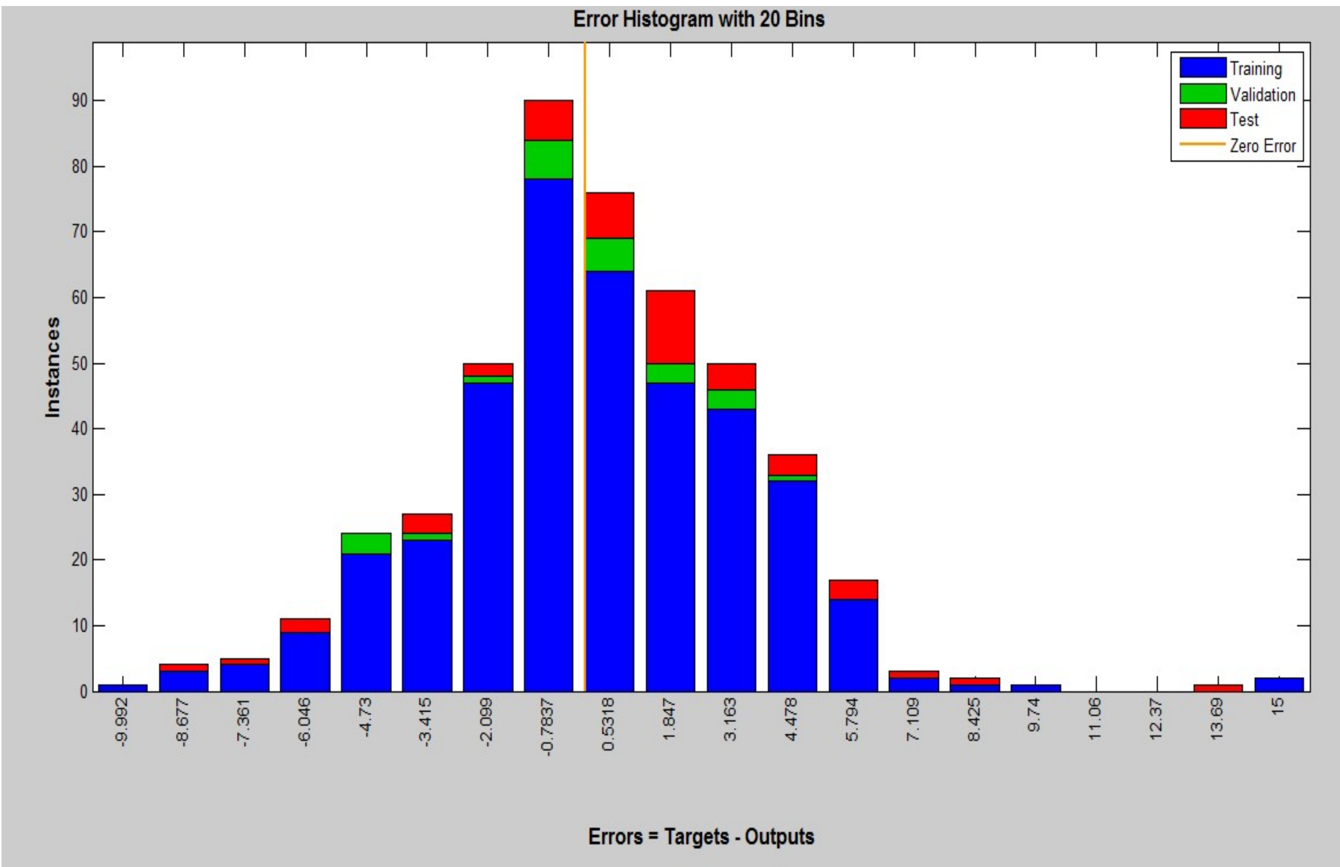

Figure 3. Error Histogram of LM Network

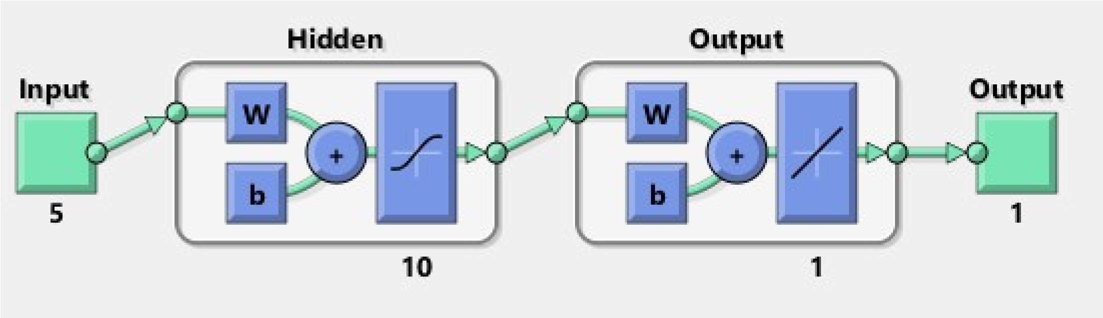

Figure 4. The network diagram

The respective weights for the 10 neurons from the input variable have been shown in table 2 and the weights from these 10 hidden neurons to the output variable have been depicted in table 1.

1.9832
1.4978
0.18007
0.2868
-0.22703
-0.46598
3.3296
-0.08146
0.21031
0.26619

Table 1: Weights from hidden neurons to output variable

3.1920	-0.8306	-3.5725	-0.0700	-2.0849
5.3417	0.7344	-10.0221	0.0205	-0.3158
0.1419	-0.0908	0.1621	2.8247	-1.1500
-0.0643	-0.0517	0.2273	1.9361	-1.5324
0.5337	1.3416	0.1919	1.2570	1.3843
-5.5013	-0.2918	-1.0706	0.0876	0.2526
-2.6790	0.0593	2.8817	0.0014	0.7849
3.6490	0.2728	-0.3138	-1.7040	3.4625
-1.0448	4.7949	-0.3942	-1.0848	1.4197
-0.1839	-0.3446	-0.3568	-4.6193	3.4022

Table 2: Weights from input variables to hidden neurons

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