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Estimating of Compressive Strength of Concrete with Artificial Neural Network According to Concrete Mixture Ratio and Age

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Abstract: Compressive strength of concrete is one of the most important elements for an existing building and a new structure to be built. While obtaining the desired compressive strength of concrete with an appropriate mix and curing conditions for a new structure, with non-destructive testing methods for an existing structure or by taking core samples the concrete compressive strength are determined. One of the most important factors that affects the concrete compressive strength is age of concrete. In this study, it is attempted to estimate compressive strength, modelling Artificial Neural Networks (ANN) and using different mixture ratios and compressive strength of concrete samples at different ages. In accordance with obtained data's in the estimation of concrete compressive strength, ANN could be used safely.

Keywords: *Concrete strength, Prediction, Artificial neural networks.*

1. Introduction

Cement, water, aggregate and concrete which is obtained by shuffling with some additives when it is required, is the most common and most popular building material being used in many large and small structures [1, 2]. The reason of this arises from the superiority of concrete compared to other building materials.

According to the results of scientific research; one of the most important of those errors that cause cracking and collapse structure are the poor quality of concrete produced in structures, inadequate water / cement ratio, curing conditions and inadequate concrete forming mixture in suitable proportions of the materials used can be considered.

There are many features that are expected from both fresh concrete and hardened concrete. Fresh concrete must have adequate workability. That uniform can be easily shuffled, moved, placed, compressible and its surface can be corrected easily. Placed fresh concert should have as little as possible transpiration (water intake), and setting (hardening) should be appropriate to the duration of use. The hardened concrete should have sufficient strength and volume stability within the required time. Concrete that can provide these features should be achieved in the most economical manner. Properties of concrete, firstly, depends on the amounts used and the properties of the material forming the concrete mix. Furthermore, applied shuffling, transportation, placement, compaction and surface correction processing, and also applied to fresh concrete curing method and curing time are very important other factors that affect the properties of concrete [3].

Concrete such as many other building materials is a material that its compressive strength is high and the tensile strength is low. Because of the very low tensile strength of concrete is not usually taken into account, the focus of the important feature is the compression strength. The standard compressive strength of concrete is defined as axial pressure strength o cylindrical samples of which diameter is 15 cm nnd height is 30 cm stored under water for 28 days. Expressed in terms of tensile strength, is obtained by divided the breaking load to the area of the cylinder [4].

The concrete compressive strength is a quite nonlinear function that changes depend on the materials used in the concrete and the time [5]. Concrete compressive strength in many scientific laboratory, by being waited at different curing environment of the concrete samples prepared using different mixtures, and by being broken at specific time slots prepared concrete samples are trying to achieve the desired level of concrete strength [5-7]. For such researches, time, materials and labor are required.

Artificial Neural networks (ANN) are computer systems which can derive new information by way of learning which is the characteristics of the human brain, its exploring and creating new knowledge abilities have been developed with the aim of performing automatically without any assistance [8]. ANN without the need for a mathematical model, they try to create a relationship between inputs and outputs. Thus, solutions are produced making generalizations on the properties exposed through samples that will occur later or the cases which have not been came across [8-10].

In this study, by being developed ANN models which was previously used as artificial different data of test results, concrete strengths were determined for different mixtures. Thus, by saving power from time, material and work labour, determination of Artificial Neural Network aimed to determine in a very short period of time.

2. Materials and Methods

2.1. Artifical Neural Networks

ANN is the generalization of human perception and mathematical

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models of biological neuron. ANN is composed by the combination of inspiration from biological nerve cells in neural cell development. Being able to model non-linear structure, parallel distributed structure, learning and generalization ability, to have adaptability and fault tolerance for different problems are one of the most important features of ANN [11].

ANN does not require any prior knowledge between input and output variables. By giving network input information and output information corresponding to the information, its learning of the relationship between the input-output network variables is provided [12]. This learning process is called as supervised learning. In solving of the available problem, back-propagation algorithm from supervised learning method has been used. The learning of a neural network with back-propagation algorithm; consists of two steps as forward and backward calculation. In forward calculation processing, input values which enter to the network with weight matrix output value are calculated. Then, based on minimizing the error value between the actual value and the output value generated by the network, network weights are rearranged. This process continues until the time when the network has produced the desired output [8, 9, 11, 12].

In this study, ANN network structure which has a hidden layer given in Figure 1.

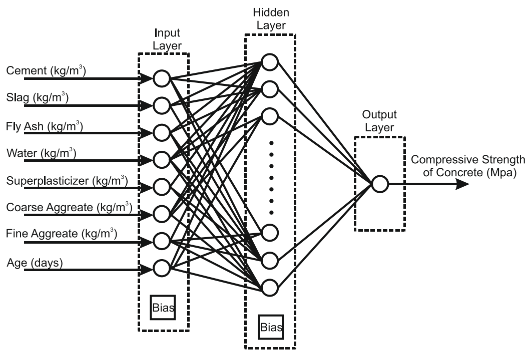

Figure 1. Developed ANN Structure

Table 1. Parameters of used ann model

Number of hidden layer	1
Number of input	8
Number of output	1
Activation function of output layer	Purelin
Learning Rate	0,01
Momentum constant	0,9
Performance goal	0
Minimum performance gradient	0,5

2.2. Dataset

In this study, concrete compressive strength data set of Professor ChenYeh from Chung-Hua University has been used [13]. Prof. I-Chen Yeh has used experiment results that he measured concrete compressive strength after being waited the obtained concrete between 1 and 365 days that he obtained from mixing differently of 8 different materials to measure how concrete compressive strength will change according to the used materials [13]. There are a total of 1030 data used in the dataset. . Including 8 of these are input data; the others are cement (kg/m^3), slag (kg/m^3), fly ash (kg/m^3), water (kg/m^3), superplasticizer (kg/m^3), coarse aggregate (kg/m^3), fine aggregate (kg/m^3) and age (days). The output data is the concrete compressive strength (Mpa). In figure 2, the properties used in concrete compressive strength, scatter plot of concrete compressive strength is given.

In ANN, undeterioration of the relationship between variables, accuracy of the analysis and the entire dataset of network to show an active performance were normalized using the equation 1 in the range of [0,1]

$$X_i = \frac{X_i - X_{\min}}{X_{\max} - X_{\min}} \quad (1)$$

In the next stage for training of the network, to be able to make verification with the trained network and testing can be done, all data set 80% has been allocated as training and 20% has been allocated as the test data randomly.

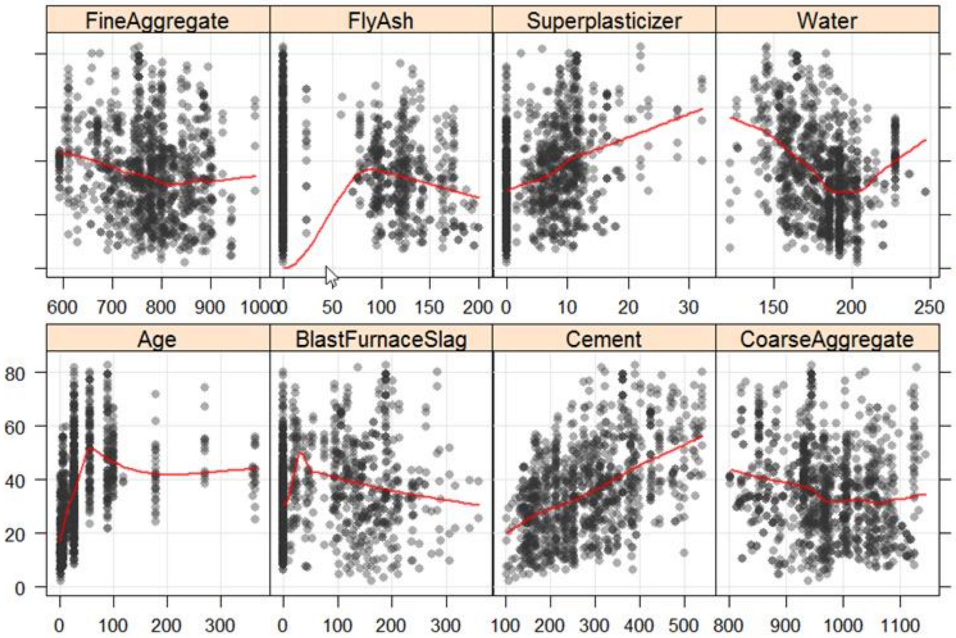

Figure 2. The distribution of the concrete pressure changes and properties used in estimation

The properties of the a estimation of concrete compressive strength has been given in Table 1.

3. Results

In the measurement of the accuracy of the estimation results obtained by ANN, utilized from RMSE (square root of error mean square) MAE (mean absolute error) and MSA (mean square average).techniques. Statistical expression of the measurements are given in equation 2, 3 and 4, respectively.

$$RMSE = \sqrt{\frac{\sum (y_t - \hat{y}_t)^2}{T}} \qquad (2)$$

$$MAE = \frac{1}{n}\sum_{t=1}^{n}\left| y_t - \hat{y}_t \right| \qquad (3)$$

$$MSE = \frac{\sum \left(y_t - \hat{y}_t \right)^2}{T} \qquad (4)$$

MATLAB 7.0 Neural Network Toolbox software has been used for estimation of the concrete compressive strength. To find the best ANN structure, training of network with different training algorithms has been made. The number of neurons in the hidden layer is maximum 50 for each training algorithm. Each ANN structure has been tested for 50 different neurons. The obtained structure of the ANN model and MSE, RMSE, MAE values are given in Table 2.

Table 2. Created ANN architecture and MS, RMSE, MAE values

ANN Model	Learning method	Number of neurons in hidden layer	Hidden layer transfer function	MSE	RMSE	MAE
1	GDX	9	Logsig	0,008436	0,091849	0,071200
2	BR	31	Logsig	0,001378	0,037126	0,023863
3	GD	46	Logsig	0,024588	0,156807	0,127096
4	SCG	44	Logsig	0,002179	0,046685	0,034014
5	LM	28	Logsig	0,001347	0,036712	0,024211
6	B	27	Logsig	0,019915	0,141121	0,114868
7	GD	12	Tansig	0,025743	0,160447	0,126697
8	**LM**	**27**	**Tansig**	**0,001247**	**0,035314**	**0,022824**
9	BR	49	Tansig	0,001526	0,039064	0,022034
10	GDX	9	Tansig	0,006009	0,077521	0,059355
11	SCG	49	Tansig	0,001824	0,042710	0,030492
12	B	15	Tansig	0,019933	0,141185	0,111363

B: batch training with weight and bias learning rules; BR: Bayesian regularization backpropagation; GDX: gradient descent with momentum and adaptive learning rule back propagation; LM: Levenberg–Marquardt back propagation; SCG: scaled conjugate gradient back propagation; GD : . Gradient descent backpropagation

As seen from Table 2, the best estimation has been obtained with Levenberg-Marquardt back propagation learning algorithm which is the number 8 model of ANN with 27 neurons in the hidden layer. R^2 value has been found as 0.99031 for the training phase, as 0.97106 has been found for the test phase (Figure 3).

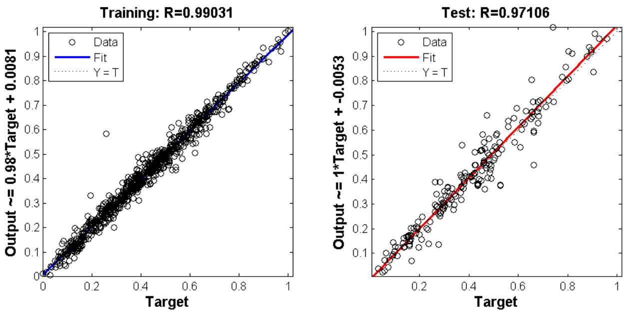

Figure 3. Comparison with the estimated ANN value of concrete compressive strength

Because of the nature of the mathematical description derived from limited empirical observations, estimation skills are limited. This ensures the fore of the ANN. Because ANN can produce results without the need for differential equations in the complex structure. The reason of ANN can be applied to a large number different problems is nonlinear property of transfer function. ANN approach does not require a previously defined functional structure. Because it can be directly adapted to the structure of problem [22].

In obtained ANN model, for test data which has not been attended to training, comparison of ANN estimation values with the experimental concrete compressive strength values have been given in Figure 4.

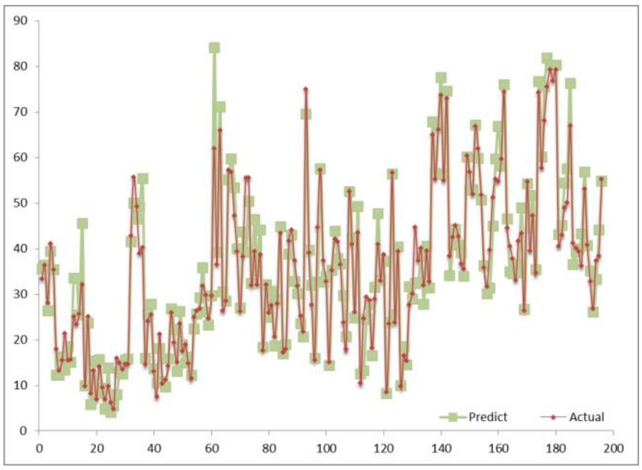

Figure 4. Comparison of the results of the concrete compressive strength with ANN results

Compared with the results of the concrete compressive strength, it is clearly seen estimation results of ANN have very close proximity to each other.

Thus, concrete compressive strength for various mixtures have been determined without the need for any experiment using different ANN algorithms with the help of data including compressive strength obtained from the prepared concrete samples in laboratory which have been prepared with the rate of different water, cement ratio, cement batching, superplasticizer, additives and silica fume rates. With the use of obtained model, required mix amount could be achieved to obtain the desired level of concrete compressive strength.

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