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Estimating the Behavior of Ferrocement Strengthened RC Columns Using Artificial Neural Networks

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Abstract

In this paper the behavior of reinforced concrete columns strengthened with Ferrocement was estimated by using Artificial Neural Network (ANN) simulation. 98 experimental results were selected for training of multilayer feed forward neural network to estimate the ultimate loads of ferrocement strengthened reinforced columns. The ANN mode was tested by using another 25 experimental data and also compared with theoretical and finite element methods. The comparative analysis of the results showed that the ultimate loads which estimated by the ANN predictive model is very close to the experimental results and finite element method than theoretical method.

Keywords: Artificial neural network, Ferrocement, Strengthened RC Columns, ultimate load.

INTRODUCTION

The method of strengthening concrete columns with Ferrocement is a common and important method do to the technique is easy and also low cost of used materials comparison with other types of strengthening [1,2]. Using ferrocement strengthened reinforced concrete Columns FSRC lead to increase the parameters (number of layers, compressive strength of concrete and mortar, yield strength, mortar thickness … etc.) to estimate the behavior of FSRC. The approximate theoretical methods (as suggested in ACI-318 code) [3] neglect many of variables, which effect on the behavior of FSRC as shown in several studies [4,5]. In this study, Artificial neural networks ANN was used to consider large number of variables to estimate the ultimate load of FSRC. Several researches showed that the ANN method is capable to estimate the results of many civil engineering works [6,7,8,9]. IN 2008, Topcu and Saridemir[10] are used ANN to Predict the compressive strength of concrete containing fly ash. In 2016, Gayathri et al.[11], used ANN for predicting compressive strength, split tensile strength and flexural strength of high performance concrete. In 2016, Manju et al.[12], are used ANN to predict the mechanical properties of self compacting concrete (SCC). All previous papers are shown good results when compared with experimental results.

ARTIFICIAL NEURAL NETWORK (ANN)

Artificial Neural Network (ANN) is an efficient computing system whose central theme is borrowed from the analogy of biological neural networks. ANN acquires a large collection of units that are interconnected in some pattern to allow communication between the units or nodes called neurons. These neurons, are simple processors which operate in parallel. Every neuron is connected with another neuron through a connecting link. Each connection link is associated with a weight that has information about the input signal. This is the most useful information for neurons solve a particular problem because the weight usually excites or inhibits the signal that is being communicated. Each neuron has an internal state, which is called an activation signal. Output signals, which are produced after combining the input signals and activation rule [13].

The artificial neural network can be divided into three parts called layers. The first layer is called the input layer responsible for receiving the data (parameters) which collected from the experimental results. The second part is called Hidden Layers which are responsible for finding patterns of correlation between input parameters. These layers perform the most internal processing of a network. The final part is called an output layer which is responsible for displaying the final network outputs depending on the processing performed by the neurons in the previous layers[14].

Many structures of ANN which depends on the neuron arrangement and the layers interconnected and composed. The present study depends on Multiple-Layer Feedforward Architectures as shown in Fig.1.

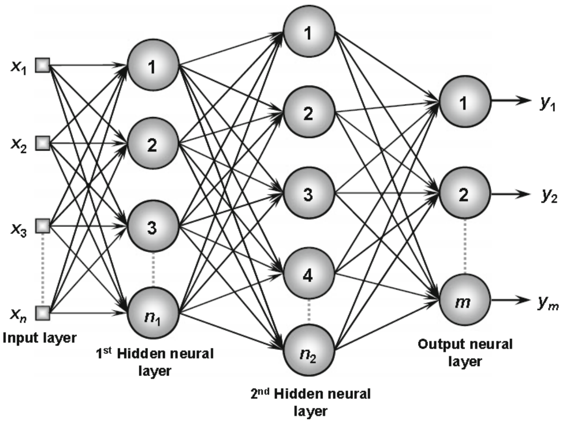

Figure 1. Feedforward network with multiple layers [14]

In Multiple-Layer Feedforward Architectures, the data is transferred to the processing from the input layer to the output layer to obtain the results through the hidden layers. Where all the neurons in the input layer are connected with all the neurons in the first hidden layer and all the neurons in the first hidden layer are also connected to all the neurons in the second hidden layer, and finally all the neurons in the second hidden layer are collated to produce the resulting nerve cells. Each contact between two neurons has a numerical force called the weight.

One of the most important features of artificial neural networks is their ability to learn from the input data of samples with corresponding outputs. Thus, after the network has learned the relationship between inputs and outputs, solutions can be generalized, meaning that the network can produce the output and is close to the expected (or required) output of any given input values. Fig.2 shows the general model of ANN.

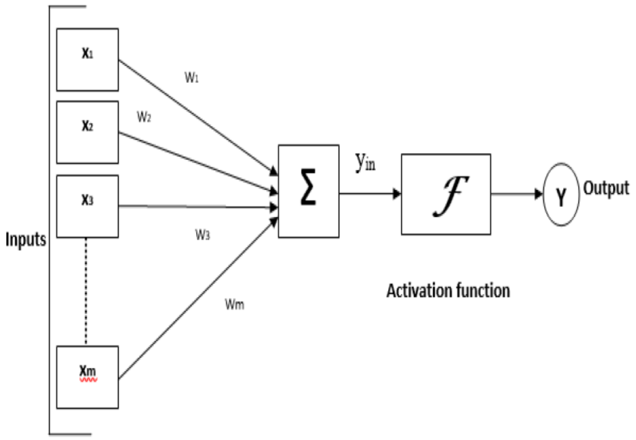

Figure 2. General model of ANN[13]

The net input can be calculated as follows:

$$y_{in} = x_1 w_1 + x_2 w_2 + x_3 w_3 + \ldots\ldots + x_m w_m$$

The output can be calculated by applying the activation function over the net input.

$$y = F(y_{in})$$

ARTIFICIAL NEURAL NETWORK MODELING

A total of 98 experimental tests were compiled for ferrocement strengthened reinforced concrete Columns FSRC. These experimental results were distributed on nine studies for different researchers, Sayan et al [15], AL-Sulyfani et al [16], Shinde and Bhusari [17], Shaheen and Hassanen [18], Tarkhan [19], Malhotra [20], Salih and Arunkumar [21], Anagha and Varghese [22], and Soman [23]. The input parameters were arranged to be general and have logical effect relationship on specimens. Twelve parameters (concrete cress section area, slenderness ratio, concrete strength, steel yield strength, steel area, ratio of steel stirrup area to spacing between them, stirrup yield strength, thickness of mortar, mortar strength, steel mesh yield strength, ratio of steel mesh area to spacing between them and number of mesh layers) are used as input neurons, Fig.3 shows typical cress section of FSRC.

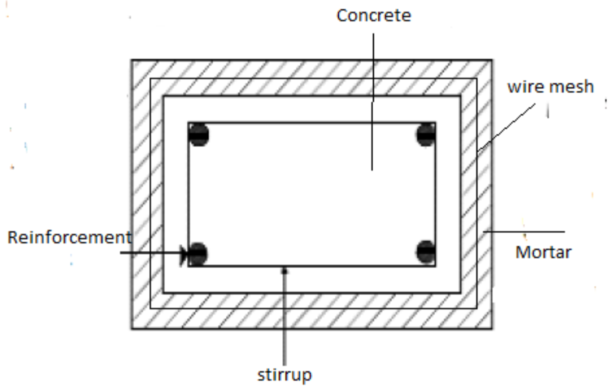

Figure 3. Cross Section of Strengthened Column

The ultimate load of strengthened reinforced concrete Columns FSRC are obtained as output neurons. These data are used for learning and testing the ANN model.

the mean square error (MSE) is represented as a criterion for the ANN for the training to reach to the best output prediction. Equation 1 shows the mean square error.

$$MSE = \frac{1}{n}\sum_{i=1}^{n}(F_i - y_i)^2 \qquad Eq.1$$

where, n is the total number of the data, F is the experimental (target) value, and y is the output ANN value.

After 240 iterations for training ANN, the model confirmed by the coefficient of determination the best performance (MSE) as shown if Fig.4 and with best regression coefficient R for training, validation and test data as shown in Figs.5,6 and 7. The regression coefficient that achieved by comparing the experimental values of the ultimate load for the data of FSRC (targets) with the values that predicted by ANN (output) with 80%, 10% and 10% for training, validation and test data of FSRC respectively.

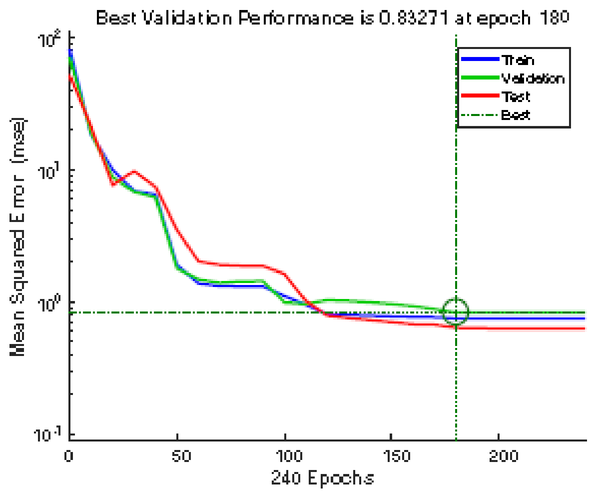

Figure 4. Best Performance for Training Data

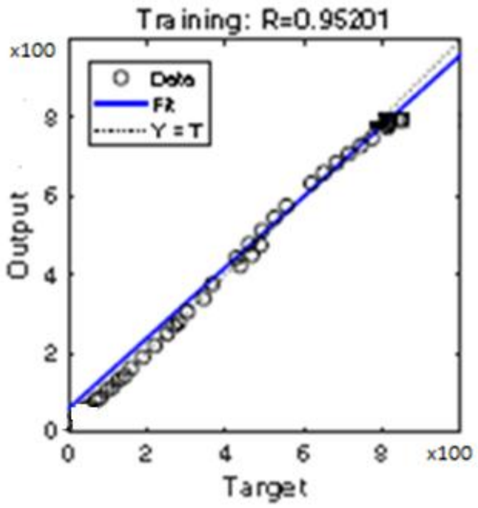

Figure 5. Predicted output Vs. target for training data

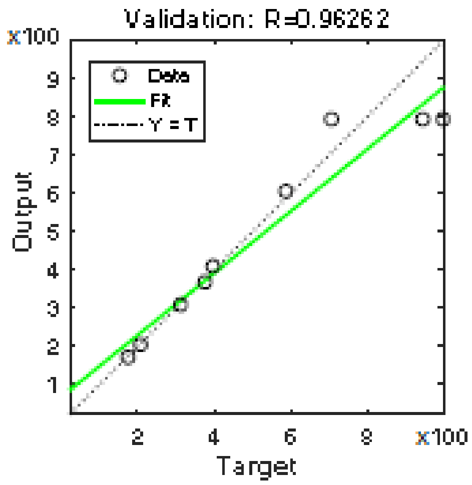

Figure 6. Predicted output Vs. target for validation of training data

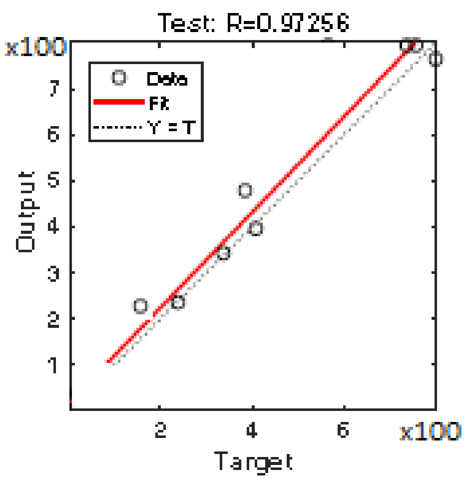

Figure 7. Predicted output Vs. target for testing of training data

RESULTS AND DISCUSSION

The results shown that the trained ANN model can be used to estimate the ultimate load of FSRC with consider several parameters. ANN model is testing by other experimental data (not used in training ANN model), Sikder [24], and also compared with theoretical results that obtained from ACI-318 Equation [3] which modified by adding the effect of ferrocement strengthened as shown in Equation 2. The comparison is shown in Table 1.

$$Pu = 0.85 f_c' A_c + A_s f_y + P_f \qquad Eq.2$$

Where:

Pu = ultimate load of column.

f_c' =Concrete compressive strength.

f_y = Yield strength of steel.

A_c = Gross area of concrete

P_f = Axial load carrying capacity of ferrocement overlay including confinement effect and can be expressed as.

$P_f = 0.053 A_{cf}\, f_{cf}'$ [25]

A_{cf} = Area of ferrocement mortar

f_{cf}' = Compressive strength of ferrocement mortar

Table 1. The comparison between ANN, ACI Eq. and experimental results.

Col. No.	ANN	ACI	EXP	ANN /EXP	ACI /EXP
1	532.2	431.5	538.2	0.99	0.80
2	531.9	480.4	547.1	0.97	0.88
3	548.1	507.1	560.5	0.98	0.90
4	429.4	431.5	440.4	0.98	0.98
5	500.3	431.5	507.1	0.99	0.85
6	528.6	489.3	551.6	0.96	0.89
7	467.8	418.1	484.9	0.96	0.86

Also the ANN model results are compared with experimental and finite element method results that obtained from Jaafer[26], as shown it Table 2.

Table 2. The comparison between ANN, FEM and experimental results.

Col. No.	ANN	FEM	EXP	ANN /EXP	FEM /EXP
1	734.5	715.6	743	0.99	0.96
2	438.6	475.3	463	0.95	1.03
3	621.7	632.6	636.1	0.98	0.99
4	1097.3	1162.4	1115.3	0.98	1.04
5	1529.3	1592.8	1570.8	0.97	1.01
6	510.6	475.7	489.5	1.04	0.97
7	511.3	590.2	538.9	0.95	1.10
8	686.5	715.6	705.9	0.97	1.01
9	842.3	876.4	821.7	1.03	1.07
10	730.2	749.2	749.2	0.97	1.00
11	1202	1272.4	1222.1	0.98	1.04
12	1582.4	1731.1	1665.05	0.95	1.04
13	187.2	189.7	180.5	1.04	1.05
14	178.2	166.7	177.33	1.00	0.94
15	420.3	387.4	405.5	1.04	0.96
16	385.2	388.6	390.3	0.99	1.00
17	368.3	398.2	388.7	0.95	1.02
18	682.4	712.6	703.4	0.97	1.01

The main variables considered in these tested studies were (number of layers, compressive strength of concrete and mortar, slenderness ratio, mortar thickness, reinforcement area, and wire mesh diameter). The results are shown that the ANN model exhibit good performance in prediction of ultimate load of FSRC.

CONCLUSION

Artificial neural networks ANN technique is used to estimate the behavior of ferrocement strengthened of reinforced concrete columns by predicting the ultimate load of FSRC by considering variable parameters. 98 specimens were used as input data to get performance ANN model and then examine the ANN model with 25 experimental results. The results showed that the ANN mode is very powerful method to estimate the ultimate load of FSRC compared with experimental results and the accuracy is very close to FEM values and also the ANN more accuracy than modified ACI equation.

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