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Model-Based Analysis for Ultimate Axial Load of Circular CFST Columns Using Artificial Neural Network

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1. Introduction

Concrete-filled steel tube (CFST) columns, which are formed by the filling of a hollow steel tube and concrete, are increasing due to the composite reaction of concrete and steel in many engineering structures. Not only do these sections have many advantages in construction, but they also significantly improve the mechanical properties of the structural components compared to reinforced concrete elements.

Generally, the design codes and ordinary process-based linear analysis of designs for considering the effects of steel tube and reinforcing concrete are ignored in the composite reaction (steel-concrete interaction) in CFST columns. One of the major drawbacks of the empirical models and arithmetic design codes is to apply the limited number of experimental samples to regress the ultimate capacity relations of CFST columns. Therefore, the application of proposed models does not have a wider range of acceptable accuracy. As a result, existing forecasting models may not be able to predict the behavior of these types of structures accurately. On the other hand, the effects of steel yield stress, concrete compressive strength, diameter to thickness ratio, and the ratio of height to diameter on the behavior of CFST columns have not been clearly interpreted in previous studies.

In this research, Artificial Neural Network (ANN) multi-layer has been applied to predict the ultimate strength and to examine the effects of different input variables on the behavior of CFST columns. Nonlinear ANN model based on 70% experimental data consisting of 1168 CFST circles using input variables such as geometric properties of samples (sample diameter, height and thickness of steel tube) and mechanical properties of steel and concrete (steel tube yield stress and concrete compressive strength) have been considered, and 30% of the experimental samples are used for verifying and comparing the eight experimental models and the EC4 code. The results suggest that the successful application of ANN and the high performance of this method have been shown to be more reliable in terms of accuracy and more adaptable to circular column experimental data compared to empirical modes and design codes.

2. Data analysis

In order to evaluate the ultimate strength models of the CFST circular columns, the laboratory data derived from references containing 1168 columns is used in the modeling structure. In the test specimens, steel tube yield stress is different ranging from 166 to 853 MPa; concrete compressive strength varies form 15 to 193 MPa; the range of outer diameter variations and steel tube thickness vary from 47 to 1020 mm and 0.70 to 30.13 mm.

3. Artificial Neural Network Perceptron Multi- layer (MLPNN)

Artificial neural networks have been inspired by the behavior of the human brain's biological neurons. Simplicity, low cost of computing, and high performance for estimation, have made this computing tool considerably popular. In MLPNN, a nonlinear connection between inputs and outputs can be created. A three-layer network, including input, hidden neurons, and output layers, is shown in figure 1 showing the input of each hidden neuron is the total weight of input variables with a bias, which can be expressed as follows:

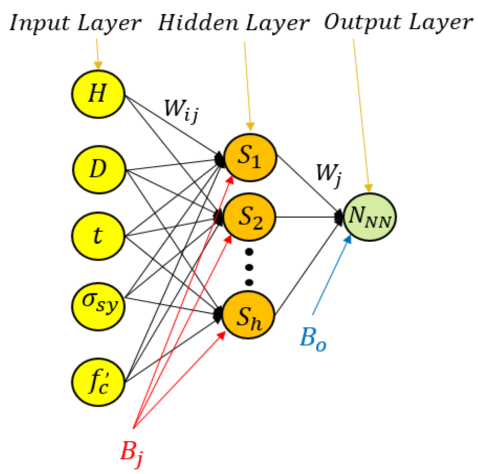

Fig. 1. Three-layer perceptron neural network structure with five input variables, one hidden layer and one output neuron

$$s_j = \sum_{i=1}^{n}(W_{ij}X_i) + B_j \, , \; j = 1,2,\ldots,h \qquad (1)$$

where n is the number of the input nodes, *Wij* shows the connection weight from the *i*th node in the input layer to the *j*th node in the hidden layer, *Bj* is the bias (threshold) of the *j*th hidden node, and *Xi* indicates the ith input. The output of each hidden node is calculated as follows:

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$$S_j = \frac{1}{(1+\exp(-s_j))}, j = 1,2,\ldots,h \quad (2)$$

After calculating the outputs of hidden nodes, the final outputs are defined as follows:

$$N_{NN} = \sum_{j=1}^{h}(W_j S_j) + B_0 \quad (3)$$

Where Wj is the connection weight from the jth hidden node to the *k*th output node, and B_0 is the bias (threshold) of the *k*th output node.

In this study, in order to predict the ultimate axial strength and investigate the effect of different variables on the behavior of columns of CFST columns, a three-layer neural network with 5 input neurons in the first layer, 11 neurons in the hidden layer and one output neuron in the third layer using the conjugate gradient Polak- Ribiere (CGP) method are used for network training with the number of replicates of 3000 epoch.

4. Validity of prediction models

The confined index of absolute error ration of the studied models and ANN predicted results are presented in Fig. 2. The model with highest d/MAE has superior performances in the prediction of ultimate axial load compared to others.

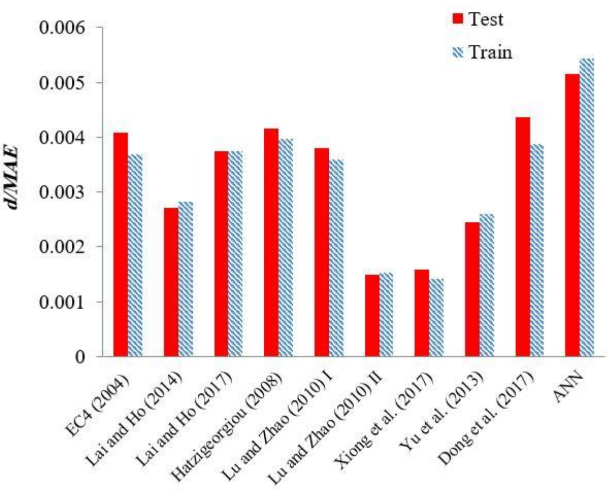

Fig. 2. d-to-MAE ratio for train and test data

According to the results of Fig. 2, the experimental models presented by Lai and Ho (2017) and Hatzigeorgiou and Dong *et al.*, Lu and Zhao (2010) I and EC4 cod show the best performances in terms of accuracy compared to other prediction empirical models. However, the ANN model provides the superior performance among other approaches in train and test phases.

By comparing the aspect ratio (D/t) on the axilla behavior of CFST columns showed in Fig. 3, it can be concluded that the axial forces are reduced by the increase of aspect ratios due to the decrease in the effect of the confinement steel. However, this decreasing capacity of the columns for different f'c has provided nonlinear relations.

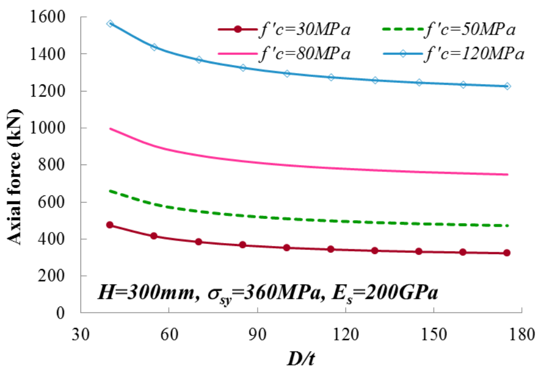

Fig. 3. Effect of D/t for different f'_c on the axial force

5. Conclusion

Based on the predicted results for ultimate strength of the concrete steel filled steel columns, the following observation can be extracted.

1- ANN model with correlation coefficient of 0.992 provides the best fitness compared to experimental empirical models and EC4 code. The ANN improves the RMSE about 100% in the training phase and 45% in the testing phase compared to the best empirical model.

2- By applying ANN model, a nonlinear relationship between concrete strength and ultimate axial strength is observed for high strength concrete with compressive stress more than 100 MPa.

3- By increasing the aspect ratio, the capacity of the columns is reduced.

4- Nonlinear behavior for the CFST columns are conducted with respect to the diameter of the thickness of the steel pipe ratio as well as the compressive strength of concrete.