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Potential of adaptive neuro fuzzy inference system for evaluating the factors affecting steel-concrete composite beam's shear strength

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Abstract. Structural design of a composite beam is influenced by two main factors, strength and ductility. For the design to be effective for a composite beam, say an RC slab and a steel I beam, the shear strength of the composite beam and ductility have to carefully estimate with the help of displacements between the two members. In this investigation the shear strengths of steel-concrete composite beams was analyzed based on the respective variable parameters. The methodology used by ANFIS (Adaptive Neuro Fuzzy Inference System) has been adopted for this purpose. The detection of the predominant factors affecting the shear strength steel-concrete composite beam was achieved by use of ANFIS process for variable selection. The results show that concrete compression strength has the highest influence on the shear strength capacity of composite beam.

Keywords: ANFIS; forecasting; steel-concrete composite beam; shear capacity

1. Introduction

Currently the behavior of composite beams is evaluated by shear capacity and load-displacement relations and is limited to the results from push-out or full scale testing (Viest *et al.* 1952, Slutter 1963, Bailey *et al.* 1999, Maleki and Bagheri 2008, Dong and Prasad 2009, Shariati *et al.* 2010, Shariati *et al.* 2011a, b, c, d, Mohammadhassani *et al.* 2013a, b, 2014a, b, Toghroli *et al.* 2014).

To investigate the ductility and shear strength of the steel-concrete composite beams, sophisticated equipment, lengthy experimental procedures are required, which consumes a significant amount of time and resources. Parametric studies with the aid of finite element procedures (Queiroz *et al.* 2007, Wang and Chung 2008, Liew and Xiong 2009) and neural network methods (Hakim *et al.* 2011, Mohammadhassani *et al.* 2013a, b, Toghroli *et al.* 2014) were carried out.

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A lot of mathematical models have been proposed for modelling the shear strength of composite beams. This study adopts the soft computing method to investigate the shear strength of composite beams. Non-linearity is the main issue while adopting the existing models, the main aim of this research is to overcome that by adopting simplified modelling. These analytical approaches can be replaced by ANN. The advantage of use of ANN over other procedures is that there is no requirement of the system parameters to be known and simpler solutions can be adopted for multivariable problems.

A specific sub-branch of ANN family named adaptive neuro-fuzzy inference system (ANFIS) was used in this investigation (Jang 1993). ANFIS was used to select the most influential parameters for the shear strength of composite beams. ANFIS is very efficient in learning and forecasting, which increases its capability to minimize the uncertainties encountered in a system. ANFIS has been used by researchers in various engineering systems as a hybrid intelligent system to improve the ability automatically learning and adapting (Lo and Lin 2005, Tian and Collins 2005, İnal 2008, Khajeh *et al*. 2009, Kurnaz *et al*. 2010, Ekici and Aksoy 2011, Petković *et al*. 2012).

2. Methodology

2.1 Testing program

Both the full scale test and push-out test specimens focused on the beam strength and its ductility and investigate their behavior in this matter. The test specimens comprise of steel I beam with a reinforced concrete slab connected to this beam using shear connectors.

Researchers have been discussed in different test results as output, but the results typically consist of a load slip relationship which shows the beam's strength and ductility, and failure modes of the beam. The push-out testing is more convenient and economic than the full scale tests and it has been verified to be able to provide the relevant properties for composite beam with acceptable accuracy. For this purpose, the finite element results of both the push-out and full scale tests using finite element analysis methods were used.

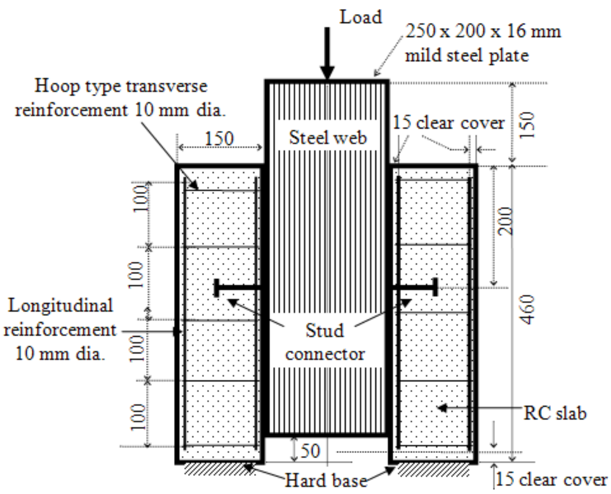

Fig. 1 Setup for the push-out test (Prakash *et al*. 2012)

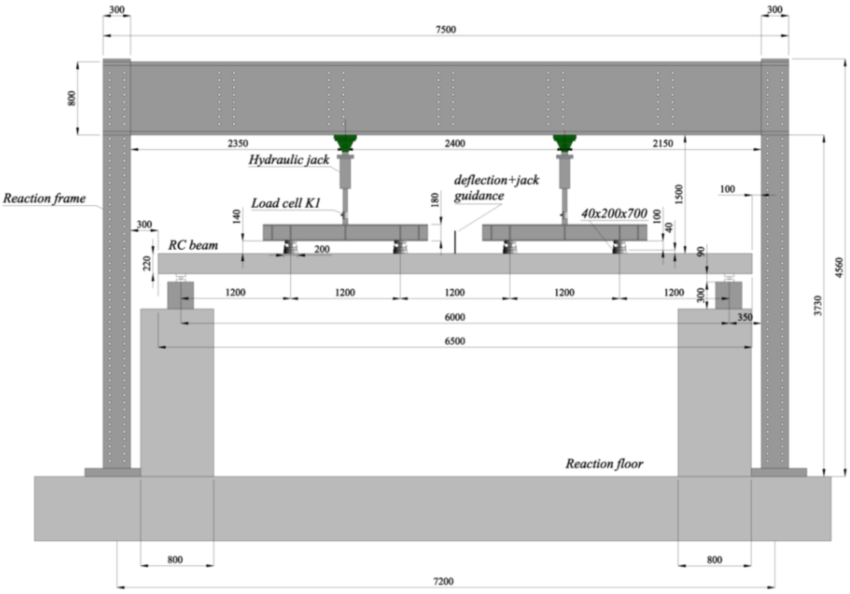

Fig. 2 Set up for full scale test (Michels *et al*. 2014)

Some experimental test using mentioned push-out tests (Maleki and Bagheri 2008, Maleki and Mahoutian 2009, Shariati *et al*. 2011a, b, c, d, Prakash *et al*. 2012, Shariati *et al*. 2012a, b, c, d, e, 2013, 2014) have been conducted on the behaviour of shear connector. A schematic view of push-out test setup is shown below in Fig. 1.

Some full scale tests on the behaviour of steel-concrete composite beam were conducted as well with the schematic view shown in Fig. 2.

In this study, a comprehensive nonlinear finite element method is used to model the steel-concrete composite beam for both the full scale and push out tests, and the input and output results to be used for soft computing scheme adaptive neuro-fuzzy inference system (ANFIS) have been extracted from those analyses.

In order to simulate the composite action in a beam, shear connectors must be used. The connectors have the ability to transfer shear forces even when faced with severe load reversals. To simulate monotonic loading, the load was increased until failure. Usually, the results of the experimental tests are presented with the load slip curve as shown in Fig. 3.

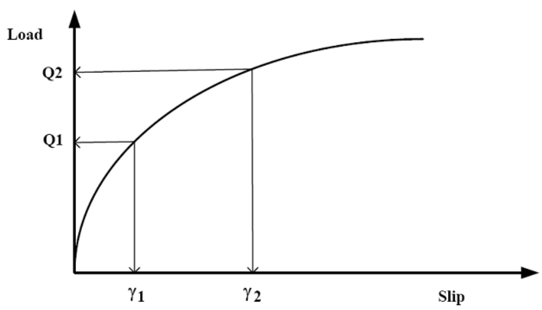

Fig. 3 Typical experimental test results for steel concrete composite beam (Duan *et al*. 2010)

2.2 Statistical data

The output parameters are shown in Table 1, which are used for this investigation. All percentage numbers are converted in decimal numbers during the ANFIS training procedure.

2.3 ANFIS methodology

MATLAB was employed to use fuzzy inference system for the training and evaluation of ANFIS. An ANFIS network for 2 input variables is shown in Fig. 4.

Takagi and Sugeno's class's IF-THEN fuzzy rules are used along with two inputs for the first order Sugeno are used for this study

$$\text{if } x \text{ is } A \text{ and } y \text{ is } C \text{ then } f_1 = p_1 x + q_1 y + r_1 \tag{1}$$

Input parameters make the first layer of MFs, and it is used to provide the input values to the next layer. Every node is carefully selected as an adaptive node with a node function

Each node here is considered an adaptive node having a node function $O = \mu_{AB}(x)$ and $O = \mu_{CD}(x)$ where $\mu_{AB}(x)$ and $\mu_{CD}(x)$ are called membership functions. Bell-shaped membership functions have the maximum value (1.0) and the minimum value (0.0) and are selected, such as

$$\mu(x) = bell(x; a_i, b_i, c_i, d_i) = \frac{1}{1 + \left[\left(\frac{x - c_i}{a_i}\right)^2\right]^{b_i}} \tag{2}$$

Table 1 Input and output parameters

Inputs	Parameters description
Input 1	t_w (Web thickness)
Input 2	t_s (Slab thickness)
Input 3	t_f (Flange thickness)
Input 4	f_c (Concrete Compression strength)
Input 5	L_c (Connector length)
Output	L Shear strength capacity of composite beam

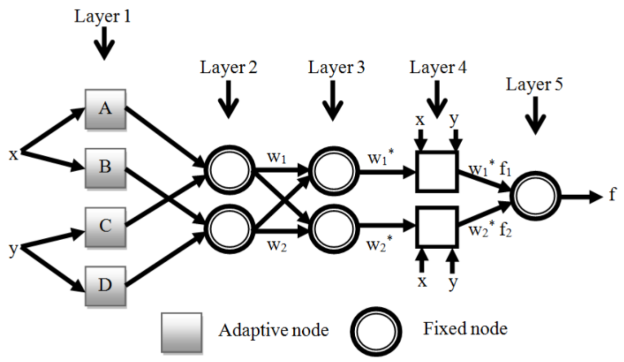

Fig. 4 ANFIS structure

where $\{a_i,\ b_i,\ c_i,\ d_i\}$ is the set of parameters set. This layer's parameters are assigned as premise parameters. The inputs to nodes are x and y.

The second layer is membership layer. This layer searches the weights of every membership function. The signal from previous layer is received to this layer as a signal, which later acts as a membership function to represent the fuzzy sets of each input layer. Nodes of Second layer are non-adaptive. This layer multiplies the received signal and the outcome is sent to $w_i = \mu_{AB}(x) * \mu_{CD}(y)$ form. Each and every output node exhibits the firing strength of a rule.

The third layer is called as rule layer. The neurons here act as the pre-condition to match the fuzzy rules. The level of activation of each rule is calculated and the quantity of layers determine the number of fuzzy. Every node computes the normalized weights. The nodes of 3rd layer are not influenced or trained, so they are considered as non-adaptable. The firing strength is computed as a value and is computed by each layer $w_i^* = \frac{w_i}{w_1+w_2}$, $i = 1, 2.$ The outcomes are called normalized firing strengths.

The output is controlled by the 4th layer. The output is provided as values as a result of inference rulde. The 4th layer is also known as the defuzzification layer. Now, each 4th layer node is again adaptable node with $O_i^4 = w_i^* xf = w_i^*(p_i x + q_i y + r_i)$. The set of layers in this layer is $\{p_i,\ q_i,\ r\}$. The variable set is designated as the consequent parameters.

Finally, the output layer is the 5th layer. In this layer all the received inputs from previous layers are added. Thereafter, it converts the fuzzy classification outcomes into a binary (crisp). Again the single node of the 5th layer is considered not adaptable. This node calculates the total output as the complete sum of all receiving signals

$$O_i^5 = \sum_i w_i^* xf = \frac{\sum_i w_i f}{\sum_i w_i} \tag{3}$$

While using the ANFIS for identifying variables, the algorithms employed were hybrid learning algorithms. The functions are propagated as signals up to the 4th layer where the hybrid learning algorithm passes. Least squares estimation is used to find the consequent variables. In the backward pass, the error rates circulate backwards and the premise variables are sychornized through the gradient decline order.

3. Results

3.1. Evaluating accuracy indices

The proposed model was presented by its forecasting performances as root means square error (RMSE), Coefficient of determination (R^2) and Pearson coefficient (r). These statistics are defined as follows:

(1) root-mean-square error (RMSE)

$$RMSE = \sqrt{\frac{\sum_{i=1}^{n}(P_i - O_i)^2}{n}} \tag{4}$$

(2) Pearson correlation coefficient (r)

$$r = \frac{n\left(\sum_{i=1}^{n} O_i \cdot P_i\right) - \left(\sum_{i=1}^{n} O_i\right)\cdot\left(\sum_{i=1}^{n} P_i\right)}{\sqrt{\left(n\sum_{i=1}^{n} O_i^2 - \left(\sum_{i=1}^{n} O_i\right)^2\right)\cdot\left(n\sum_{i=1}^{n} P_i^2 - \left(\sum_{i=1}^{n} P_i\right)^2\right)}} \tag{5}$$

(3) coefficient of determination (R^2)

$$R^2 = \frac{\left[\sum_{i=1}^{n} (O_i - \overline{O}_i)\cdot(P_i - \overline{P})\right]^2}{\sum_{i=1}^{n} (O_i - \overline{O}_i)\cdot\sum_{i=1}^{n} (P_i - \overline{P})} \tag{6}$$

where P_i is the experimental and O_i is the forecast value, respectively, while n is the number of test data.

3.2 ANFIS results

A comprehensive investigation was conducted to find the ultimate optimal combination inputs (Table 1) for the inputs with the most effective output parameters, which in this case, is the shear strength capacity of composite beam. An ANFIS model is based on the functions for each combination of parameters which are then trained for a single. Resultantly, the performance achieved is reported. From the output, the input with the most impact in forecasting the output was identified as shown in Fig. 5. The inputs with the lowest training error are the most relevant regarding. The left-most input variables have the lowest number of errors and most relevance to the outcome (the shear strength capacity of composite beam). According to Fig. 5 the input parameter 4 has the highest influence on the shear strength capacity of composite beam since the input 4 has the smallest RMSE.

The numerical results for all the single parameters and their influence on the shear strength capacity of the composite beam is shown in table. Also the two and three input combinations influence the shear strength capacity of composite beam.

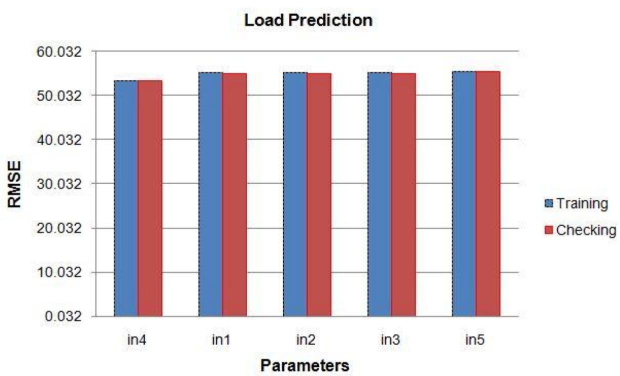

Fig. 5 Every input parameter’s influence on the shear strength capacity of composite beam

Table 2 Input parameters influence on forecasting of the shear strength capacity of composite beam

One input	Two inputs
ANFIS model 1: in1 → trn = 55.0905, chk = 54.9007	ANFIS model 1: in1 in2 → trn = 55.0905, chk = 54.9007
ANFIS model 2: in2 → trn = 55.0905, chk = 54.9007	ANFIS model 2: in1 in3 → trn = 55.0905, chk = 54.9007
ANFIS model 3: in3 → trn = 55.0905, chk = 54.9007	ANFIS model 3: in1 in4 → trn = 53.4032, chk = 53.2440
ANFIS model 4: in4 → trn = 53.4032, chk = 53.2440	ANFIS model 4: in1 in5 → trn = 52.3946, chk = 52.5326
ANFIS model 5: in5 → trn = 55.3081, chk = 55.4586	ANFIS model 5: in2 in3 → trn = 55.0905, chk = 54.9007
	ANFIS model 6: in2 in4 → trn = 53.4032, chk = 53.2440
	ANFIS model 7: in2 in5 → trn = 52.3946, chk = 52.5326
	ANFIS model 8: in3 in4 → trn = 53.4032, chk = 53.2440
	ANFIS model 9: in3 in5 → trn = 52.3946, chk = 52.5326
	ANFIS model 10: in4 in5 → trn = 48.9401, chk = 49.1513

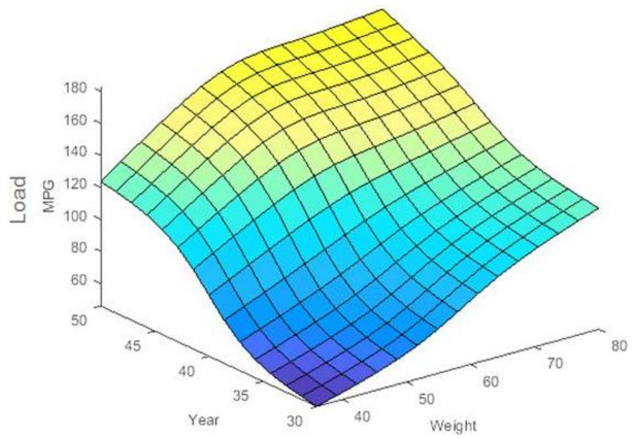

Fig. 6 ANFIS forecasted relationship

To facilitate the ANFIS process in finding the right inputs fast, the used function for al variables only trains it for a single epoch. After the selection and extraction of the combinations, the 100 epochs, which are the total number of epoch on the ANFIS training for the input, in order to track the overfitting between training and checking data. Fig. 6 shows the ANFIS relationship of the selected inputs and output parameter.

4. Conclusions

Forecasting of the shear strength capacity of composite beam is complicated because of the many indicators and factors influencing the shear strength capacity of composite beam. Therefore the research was presented as a new approach to overcome the difficulties faced in forecasting the shear capacity of the composite beams by the removal of the parameters which are not required.

The most effective parameters in evaluating the shear capacity of the composite beam forecasting by the methodology was studied in a systematic way. The ANFIS is used to minimize the vagueness in the shear strength capacity of composite beam and improves the forecasting substantially. The proposed ANFIS model transforms the complicated multiple performance characteristics into simpler single multi response performance index. Resultantly, the forecasting methodology developed in this research is useful for improving the multiple performances characterizing in the shear strength capacity of composite beam analyzed.

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