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Optimization of shear connectors with high strength nano concrete using soft computing techniques

Yadollah Sedghi[1], Yosef Zandi*[2], Masoud Paknahad[3],
Hamid Assilzadeh[4] and Mohamed Amine Khadimallah[5,6]

[1]Department of Civil Engineering, Islamic Azad University, Qeshm International Campus, Qeshm, Iran
[2]Department of Civil Engineering,Tabriz Branch, Islamic Azad University, Tabriz, Iran
[3]Faculty of Engineering, Mahallat Institute of Higher Education, Mahallat, Iran
[4]Institute of Research and Development, Duy Tan University, Da Nang 550000, Viet Nam
[5]Prince Sattam Bin Abdulaziz University, College of Engineering, Civil Engineering Department, Al-Kharj, 16273, Saudi Arabia
[6]Laboratory of Systems and Applied Mechanics, Polytechnic School of Tunisia, University of Carthage, Tunis, Tunisia

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Abstract. This paper conducted mainly for forecasting the behavior of the shear connectors in steel-concrete composite beams based on the different factors. The main goal was to analyze the influence of variable parameters on the shear strength of C-shaped and L-shaped angle shear connectors. The method of ANFIS (adaptive neuro fuzzy inference system) was applied to the data in order to select the most influential factors for the mentioned shear strength forecasting. Five inputs are considered: height, length, thickness of shear connectors together with concrete strength and respective slip of the shear connectors after testing. The ANFIS process for variable selection was also implemented in order to detect the predominant factors affecting the forecasting of the shear strength of C-shaped and L-shaped angle shear connectors. The results show that the forecasting methodology developed in this research is useful for enhancing the multiple performances characterizing in the shear strength prediction of C and L shaped angle shear connectors analyzing.

Keywords: ANFIS; composite beams; C-shaped angle; forecasting; L-shaped angle; monotonic loading; push-out test; shear connectors

1. Introduction

In recent decades, different types of structural elements have been studied experimentally and numerically (Wang *et al*. 2019, Xu *et al*. 2020a, b, Deng *et al*. 2021, Zhu *et al*. 2021b). For example, many forms of shear connectors are being used in composite beams (Shariati *et al*. 2014a, 2016, Khorramian *et al*. 2017, Majedi *et al*. 2021, Zhou *et al*. 2019, Velu *et al*. 2021), however, economical and structural aspects motivates new innovations like C-shaped and L-shaped angle shear connectors (Shariati *et al*. 2012d, 2020s, Shariati 2013, Hashim *et al*. 2015, Zhu *et al*. 2021a). Present knowledge of the load–displacement behaviors and the shear capacity of shear connectors are mainly limited to the data obtained from the experimental push-out or beam tests (Shariati *et al*. 2011a, Nasrollahi *et al*. 2018, Zhu *et al*. 2018, Xie *et al*. 2021, Xu *et al*. 2021). Experimental tests are expensive and time-consuming option for such investigations and in some cases can even be impractical (Shariati *et al*. 2010, 2011b, 2015, Naghipour *et al*. 2020b, Razavian *et al*. 2020).

According to the experimental studies on channels and angle shear connectors by (Shariati *et al*. 2011c, 2012a, Sharma *et al*. 2018, Thang *et al*. 2018, Rouhanifar *et al*. 2021), and the similarity of channels and angles (except for one leg), it is concluded that push-out test is an appropriate method to find the load-displacement behavior of C-shaped and L-shaped angle shear connectors (Shariati *et al*. 2011d, 2012e, Shahabi *et al*. 2016a, Tahmasbi *et al*. 2016, Paknahad *et al*. 2018, Mehrabi *et al*. 2021). The current research differs from the previous studies in considering different orientation of angle of shear connectors and comparing them in strength (Shariati *et al*. 2012b, c, 2013, 2020e, i, Sedghi *et al*. 2018). Numerical methods to predict the nonlinear load-slip relationship and the ultimate shear capacity of the shear connectors in composite beams are definitely a valuable option when the numerical methods are substantiated by accurate experimental results (Sinaei *et al*. 2011, Mohammadhassani *et al*. 2014c, Arabnejad Khanouki *et al*. 2016, Hosseinpour *et al*. 2018, Shariat *et al*. 2018, 2019b, 2020r). Experimental studies require high-cost and are time-consuming in many cases. However, numerical methods are more accurate and can provide reliable results (Toghroli *et al*. 2017, Nosrati *et al*. 2018, Sajedi *et al*. 2019, Shariati *et al*. 2019c, Suhatril *et al*. 2019, Trung *et al*. 2019b). FE method as one of the numerical approaches has been deployed in addressing various mathematical modelling and engineering problems (Shariati *et al*. 2020a, b, c, d, Toghroli *et al*. 2020b, Nowroozi *et al*. 2021). Finite element (FE) method has become a powerful tool for the numerical analysis of a wide range of engineering problems (Fanaie *et al*. 2017a, Heydari *et al*. 2018, Luo *et al*. 2019, Majedi *et al*. 2020, Rouhanifar *et al*. 2020, Davoodnabi *et*

*Corresponding author, Ph.D.,
E-mail: yousefzandi@aol.com

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al. 2021). An accurate finite element model permits a considerable reduction in the number of experiments needed for the prediction of structural behaviour (Chen *et al*. 2019, Safa *et al*. 2019, Shariati *et al*. 2019a, 2020h, k). Nevertheless, in a study of any structural system beyond the elastic range, the experimental phase is essential (Arabnejad Khanouki *et al*. 2010, Shah *et al*. 2016b, Khorami *et al*. 2017a, Toghroli *et al*. 2018b, Milovancevic *et al*. 2019, Afrazi *et al*. 2021). Taking into account that FE models should be backed by reliable test results, experimental and numerical studies can complement each other in the investigation of a particular structural phenomenon (Fanaie *et al*. 2012, Mohammadhassani *et al*. 2014a, Shariati *et al*. 2018, 2019f, Kumar *et al*. 2019, Xie *et al*. 2019, Afrazi and Yazdani 2021). There are limited studies available on the finite element modeling of the push-out specimens (Moghdam *et al*. 2010, Fanaie *et al*. 2017b, Kazerani *et al*. 2017, Khorami *et al*. 2017b, Najarkolaie *et al*. 2017, Fanaie *et al*. 2019, Majedi *et al*. 2020). The primary studies are concentrated on stud shear connectors conducted by Nakajima *et al*. (2017) and Lam and El-Lobody (1998). A comprehensive finite element study on the behavior of channel shear connectors was conducted by (Hamidian *et al*. 2011, Shah *et al*. 2015, Ho-Huu *et al*. 2018, Nguyen-Thoi *et al*. 2018, Sadeghipour Chahnasir *et al*. 2018, Afrazi *et al.* 2018, Rezamand *et al.* 2021). In another finite element analysis of push-out test, Khalilian and Maleki (2013) suggested a new equation for prediction of shear strength of C-shaped angle connectors in composite beam. There are some other finite element studies that focused on other types of shear connectors and the composite beams and help in better understanding of the way of finite element analysis in this area (Shariati *et al*. 2014b, 2021, Alzo'ubi 2014, 2015, 2016, 2018, Khorramian *et al*. 2015, Shah *et al*. 2016a, Jahanbakhti *et al*. 2017, Davoodnabi *et al*. 2019, Rouhanifar and Afrazi 2019, Toghroli *et al*. 2020a). In this paper, a finite element model for the angle connectors have been conducted that can match the results of the experiments with good accuracy. The push-out test arrangement is modelled in FE environment and all linear and nonlinear properties of components are taken into consideration to establish the ultimate strength and load–displacement behaviour of the connector under monotonic loading (Shariati 2008, Shah *et al*. 2016c, Jahandari *et al*. 2017, 2021a, Naghipour *et al*. 2020a, Shariati *et al*. 2020j, m). The results of the present FE model are compared with push-out tests. Parametric studies using this model are carried out to provide sufficient data for analysis of the using soft computing methods (Khankhaje *et al*. 2016, Zhong *et al*. 2016, Shariati *et al*. 2020f, g, Xiao *et al*. 2021, Jahandar 2021b, Miraki *et al*. 2021). Even though a number of new mathematical functions have been proposed for modeling of the shear capacity of C and L shaped angle shear connectors (Shariati 2014), in this investigation the main aim is to overcome high nonlinearity by applying the soft computing method (Jalali *et al*. 2012, Shahabi *et al*. 2016b, Shariati *et al*. 2017, 2020n, Wei *et al*. 2018, Jafar-Nowdeh *et al*. 2020, Nouri *et al*. 2021). Artificial intelligence (AI) has many applications in different areas of engineering and is able to produce accurate results using experimental data (Aghakhani *et al*. 2015, Ali 2015, Toghroli *et al*. 2018a, Ali Shariati 2019, Xu *et al*. 2019, Hosseini *et al*. 2021). The ANN can be used as an alternative to the analytical approach as ANN (Karimi *et al*. 2016, Maslahati Roudi *et al*. 2018, Sari *et al*. 2018, Nilashi *et al*. 2019, Jahannoosh *et al*. 2021, Naderipour *et al*. 2021) offers advantages such as no required knowledge of internal system parameters, compact solution for multi-variable problems (Mohammadhassani *et al*. 2013, Li *et al*. 2019, Shariati *et al*. 2019d, g, 2020p, Trung *et al*. 2019a, Li *et al*. 2021, Mehdizadeh *et al*. 2021). In this investigation adaptive neuro-fuzzy inference system (ANFIS), which is a specific type of the ANN family, was used to select the most influential parameters for the shear capacity of C and L shaped angle shear connectors for forecasting their behavior (Mohammadhassani *et al*. 2015, Mansouri *et al*. 2016). ANFIS results show very good learning and forecasting capabilities, which makes it an efficient tool to deal with encountered uncertainties in any system (Toghroli *et al*. 2014, Safa *et al*. 2016, Pazhoohan *et al*. 2019, Afshar *et al*. 2020, Shariati *et al*. 2020o, 2021a, b). ANFIS, as a hybrid intelligent system that enhances the ability to automatically learn and adapt, was used by researchers in various engineering systems (Mohammadhassani *et al*. 2014b, Toghroli *et al*. 2016, Ziaei-Nia *et al*. 2018, Shariati *et al*. 2019e, 2020q, Safa *et al*. 2020). So far, there are many studies of the application of ANFIS for estimation and real-time identification of many different systems (Chelgani *et al*. 2010, Panda *et al*. 2014, Ismail *et al*. 2018, Katebi *et al*. 2019, Qi *et al*. 2020, Yazdani *et al*. 2020, Jiang *et al*. 2021). In this study, the main goal was to analyze the influence of variable parameters on the shear strength of C-shaped and L-shaped angle shear connectors. The method of ANFIS was applied to the data in order to select the most influential factors for the mentioned shear strength forecasting. The ANFIS process for variable selection was also implemented in order to detect the predominant factors affecting the forecasting of the shear strength of C-shaped and L-shaped angle shear connectors.

2. Methodology

2.1 General

Push-out tests provide current knowledge of the load-slip behavior of the shear connectors in composite beams. Experimental tests are widely known very expensive and time-consuming option for investigation and in some cases can even be impractical. Analytical methods to predict the nonlinear reaction and the ultimate shear capacity of the shear connectors in composite beams are definitely valuable options. The analytical methods should be substantiated against accurate experimental results. Three-dimensional nonlinear finite element analysis of push-out specimens using ABAQUS (Arabnejad Khanouki *et al*. 2011, Daie *et al*. 2011, Hamidian *et al*. 2012, Sinaei *et al*. 2012, Elham *et al*. 2016, Majedi *et al*. 2021, Sadeghian *et al*. 2021a, b) software is used for further investigation in experimental push-out tests. A comprehensive finite element model

(a)

(b)

Fig. 1 Specimen details of push out test on shear connectors and test set up arrangement (b)

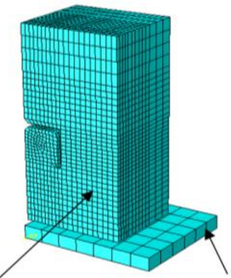

Fig. 2 Finite element type and mesh

permits a considerable reduction in the number of experiments. Both the push-out and finite element analysis methods in C and L-shaped shear angle shear connector have been used for collecting the input data required for the soft computing method analysis.

2.2 Experimental program

Several push out tests with angle shear connectors are fabricated and tested. The specimens consist of two concrete blocks with embedded tie reinforcement, a steel rolled I-section and two angle shear connectors connecting to the flanges of I-section. The angle shear connectors are welded to the steel beam flange in C-shaped and L-shaped configuration as shown in Fig. 1. The materials used in concrete blocks were Portland cement, coarse aggregate, river sand and water. The weight ratios of cement, water, sand and gravel used were 1, 0.42, 2.75 and 1.75, respectively.

Load was applied on each specimen with a universal testing machine of 1000 kN capacity using displacement control with a rate of 0.1mm/s for all specimens. Monotonic loading was continuously applied until the specimen clearly begun to fracture and fail. The load-displacement results of each specimen were automatically plotted by the hardware attached to the universal testing machine. The displacement measured is the relative displacement between the top of the steel beam and the bottom of concrete block in each time step.

2.3 Analytical study

The finite element program ABAQUS (Manual 2010) is used to simulate the push-out tests. This software is able to consider nonlinear material behavior in steel and concrete, nonlinear geometry as large displacement and tensile and compressive damage in concrete. The static implicit analysis method is employed with stepwise displacement loading.

2.3.1 Finite element model and mesh

To achieve accurate results from the finite element program, it is crucial to model all the details of the push-out specimen. The FE model has five parts: concrete slab, steel beam, shear connectors, rebar and rigid base.

The concrete block, steel beam and shear connectors are meshed with solid element C3D8R. This element type is an 8-node brick element with reduced stiffness. Each node has three translational degrees of freedom (DOF). This element can be employed for nonlinear analysis containing contact, large deformation, plasticity and damage. The finite element type and mesh of the specimen is shown in Fig. 2.

2.3.2 Contact interaction and constraint conditions

In the FE model, surface to surface contact between the concrete block and shear connector is employed. In other words, all surfaces of shear connector which is in contact with the surrounding concrete have been modelled with contact surfaces. Normal to the surface contact is defined as hard contact between surfaces, not allowing the penetration of surfaces into each other. The penalty contact method of ABAQUS is used for tangential behavior. The coefficient of friction is set as 0.45. The concrete block is assumed to be the master surface. Embedded regions are used for simulation of rebar inside the concrete block. To impede slipping between the steel beam and the shear connector, the joints at the contact surfaces of the two components is connected via the tie constraint. The contact between concrete slab and rigid base is simulated similarly to shear connector and concrete contact, using a tangential friction coefficient of 0.6 and hard contact in the normal direction. The rigid base is considered as the master surface. Contacts interactions and constraint conditions are shown in Fig. 3.

2.3.3 Loading and boundary conditions

Since push-out test specimens are symmetric, only a quarter of specimen is modelled for the analytical study. The symmetric boundary conditions are applied to the surfaces at the symmetric planes of the specimen as shown in Fig. 4. The rigid base supports the assembly without any

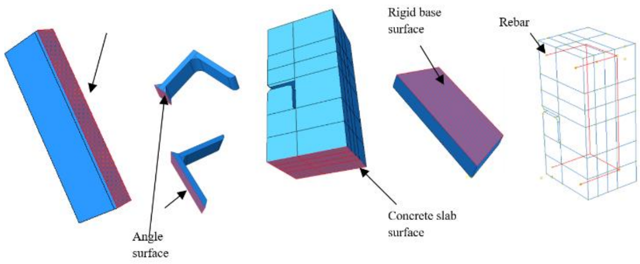

Fig. 3 Contact interaction and constraint conditions surfaces

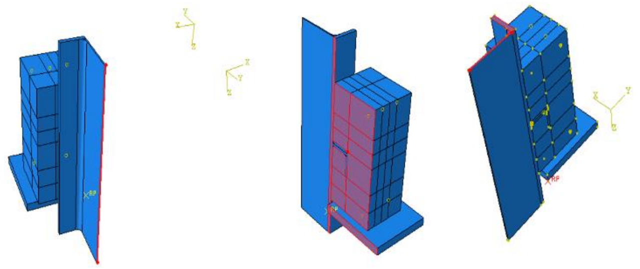

Fig. 4 Boundary conditions and loading surface

Table 1 Input and output parameters

Inputs	Parameters description
input 1	Height (mm)
input 2	Length (mm)
input 3	Thickness (mm)
input 4	Concrete (mm)
output	Load (kN)

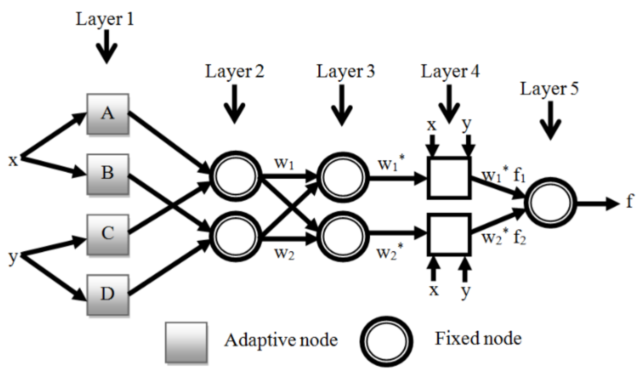

Fig. 5 ANFIS structure

movement. Hence, all DOF of the rigid base are fixed as shown in Fig. 4(c). In this study, displacement control method is used for loading. The load is applied to the top of steel beam (Fig. 4(c)). At the beginning of the analysis, the applied displacement is set to zero and then the displacement is increased linearly according to amplitude function.

2.4 Statistical data

2.5 ANFIS methodology

Fuzzy inference system in MATLAB software is employed in the whole process of the ANFIS training and evaluation. An ANFIS network for 2 input variables is depicted in Fig. 5.

The fuzzy IF-THEN rules of Takagi and Sugeno's class and two inputs for the first-order Sugeno is employed for the purposes of this study:

$$if\ x\ is\ A\ and\ y\ is\ C\ then\ f_1 = p_1x + q_1y + r_1 \quad (1)$$

The 1st layer is made up of input parameters MFs, and it provides the input values to the following layer. 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 membership functions. Bell-shaped membership functions having the maximum value (1.0) and the minimum value (0.0) are selected, such as,

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

where $\{a_i, b_i, c_i, d_i\}$ is the set of parameters set. Tthe parameters of this layer are designated as premise parameters. Here, x and y are the inputs to nodes. The membership layer is the second layer. It looks for the weights of every membership function. This layer gets the receiving signals from the preceding layer and then it acts as membership function to the representation of the fuzzy sets of each input variable, respectively. Second layer nodes are non-adaptive. The layer acts as a multiplier for the receiving signals and sends out the outcome in $w_i = \mu_{AB}(x) * \mu_{CD}(y)$ form. Every output node exhibits the firing strength of a rule. The next layer, the third, is known as the rule layer. All neurons here act as the pre-condition matching the fuzzy rules i.e., each rule's activation level is calculated whereby the number of fuzzy rules is equal to the quantity of layers. Every node computes the normalized weights. The nodes in the 3rd layer are also considered non-adaptive. each of the node computes the value of the rule's firing strength over the sum of all rules' firing strengths in the form of $w_i^* = \frac{w_i}{w_1+w_2}$, $i = 1{,}2$. The outcomes are referred to as the normalized firing strengths. The 4th layer is responsible for providing the output values as a result of the inference of rules. This layer is also known as the defuzzification layer. Every 4th layer node is an adaptive node having the node function $O_i^4 = w_i^* xf = w_i^*(p_i x + q_i y + r_i)$. In this layer, the $\{p_i, q_i, r\}$ is the variable set. The variable set is designated as the consequent parameters. The 5^{t}h and final layer is known as the output layer. It adds up all the receiving inputs from the preceding layer. Thereafter, it converts the fuzzy classification outcomes into a binary (crisp). The single node of the 5th layer is considered non-adaptive. This node calculates the total output as the whole sum of all receiving signals,

$$O_i^5 = \sum_i w_i^* xf = \frac{\sum_i w_i f}{\sum_i w_i} \quad (3)$$

In the process of identification of variables in the ANFIS architectures, the hybrid learning algorithms were applied. The functional signals progress until the 4th layer whereby the hybrid learning algorithm passes. Further, the consequent variables are found by the least squares

Table 2 Input parameters influence on forecasting of the LOAD

One input	Two inputs
ANFIS model 1: in1 --> trn = 75.2195, chk = 75.1775	ANFIS model 1: in1 in2 --> trn = 74.0729, chk = 74.0285
ANFIS model 2: in2 --> trn = 76.2674, chk = 76.2278	ANFIS model 2: in1 in3 --> trn = 75.2195, chk = 75.1775
ANFIS model 3: in3 --> trn = 75.2195, chk = 75.1775	ANFIS model 3: in1 in4 --> trn = 74.0729, chk = 74.0285
ANFIS model 4: in4 --> trn = 74.0729, chk = 74.0285	ANFIS model 4: in2 in3 --> trn = 74.0729, chk = 74.0285
	ANFIS model 5: in2 in4 --> trn = 74.0729, chk = 74.0285
	ANFIS model 6: in3 in4 --> trn = 74.0729, chk = 74.0285

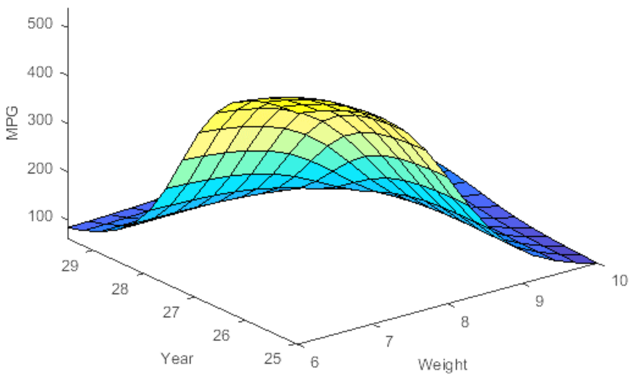

Fig.6 ANFIS forecasted relationship

estimation. In the backward pass, the error rates circulate backwards and the premise variables are synchrornized through the gradient decline order.

3. Result

Table 2 shows the numerical results for the all single parameters influence on the factors on the shear capacity of C and L shaped angle shear connectors and also the two and three inputs combinations influence on the respective strength forecasting. According to the results the combination of factors affecting the shear capacity of C and L shaped angle shear connectors form the optimal combination for the strength forecasting. Furthermore, the combination of factors affecting the shear capacity of C and L shaped angle shear connectors is the optimal combination of the three parameters with the highest influence for the shear strength forecasting (Table 2). For further analysis the selected combinations with two parameters are extracted.

To enable the ANFIS to find the right inputs quickly, the used function for all variables only trains each one for a single epoch. Once the combinations are selected and extracted, the 100 epochs that is the quantity of epoch on the ANFIS training for the selected input combinations in order to track the overfitting between training and checking data. The graph of the model for the ANFIS input-output (decision) surfaces for forecasting of the factors on the shear capacity of C and L shaped angle shear connectors rate is shown in Fig. 6. The figure below also shows the response of ANFIS model for the varying input parameters.

4. Conclusions

The forecasting of the factors on the shear capacity of C and L shaped angle shear connectors is complex due to the many indicators and factors which influence the respective shear strength. Therefore, in this study a new approach was proposed to overcome the forecasting difficulties of the shear capacity of C and L shaped angle shear connectors rate by removing some unnecessary input parameters.

A systematic approach was carried to select the most influential parameters for the shear strength prediction of C and L shaped angle shear connectors forecasting by the ANFIS methodology. The ANFIS is used to eliminate the vagueness in the shear strength prediction and produces the best forecasting conditions. The proposed ANFIS model is used to convert the complicated multiple performance characteristics into the single multi response performance index. As a result, the forecasting methodology developed in this research is useful for enhancing the multiple performances characterizing in the shear strength prediction of C and L shaped angle shear connectors analyzing.

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