**Smart Structures and Systems**, *Vol. 22, No. 3 (2018) 335-340*
DOI: https://doi.org/10.12989/sss.2018.22.3.335


# Application of ANFIS technique on performance of C and L shaped angle shear connectors

Yadollah Sedghi[1], Yousef Zandi[*2], Mahdi Shariati[3,4,5], Ebrahim Ahmadi[1], Vahid Moghimi Azar[6], Ali Toghroli[4], Maryam Safa[**4], Edy Tonnizam Mohamad[7], Majid Khorami[8] and Karzan Wakil[9,10]

[1]*Department of Civil Engineering, Qeshm International Branch, Islamic Azad University, Qeshm, Iran*
[2]*Department of Civil Engineering, Tabriz Branch, Islamic Azad University, Tabriz, Iran*
[3]*Faculty of Civil Engineering, University of Tabriz, Tabriz, Iran*
[4]*Department of Civil Engineering, University of Malaya, Kuala Lumpur, Malaysia*
[5]*Malaysia-Japan International Institute of Technology, Universiti Teknologi Malaysia, Kuala Lumpur*
[6]*Sofian Branch, Islamic Azad University, Sofian, Iran*
[7]*Centre of Tropical Geoengineering (GEOTROPIK), Faculty of Civil Engineering, Universiti Teknologi Malaysia, Johor Bahru, Malaysia*
[8]*Facultad de Arquitectura y Urbanismo, Universidad Tecnológica Equinoccial, Calle Rumipamba s/n y Bourgeois, Quito, Ecuador*
[9]*University of Human Development, Iraq*
[10]*Information Technology Department, Technical College of Informatics, Sulaimani Polytechnic University, Iraq*

*(Received June 4, 2016, Revised May 25, 2018, Accepted August 17, 2018)*

**Abstract.** The behavior of concrete slabs in composite beam with C and L shaped angle shear connectors has been studied in this paper. These two types of angle shear connectors' instalment have been commonly utilized. In this study, the finite element (FE) analysis and soft computing method have been used both to present the shear connectors' push out tests and providing data results used later in soft computing method. The current study has been performed to present the aforementioned shear connectors' behavior based on the variable factors aiming the study of diverse factors' effects on C and L shaped angle in shear connectors. ANFIS (Adaptive Neuro Fuzzy Inference System), has been manipulated in providing the effective parameters in shear strength forecasting by providing input-data comprising: height, length, thickness of shear connectors together with concrete strength and the respective slip of shear connectors. ANFIS has been also used to identify the predominant parameters influencing the shear strength forecast in C and L formed angle shear connectors.

**Keywords:** ANFIS; forecasting; cmposite beams; shear connector ; C-formed angle; L-formed angle; psh-out test; Monotonic loading

## 1. Introduction

Design of buildings for earthquake loads is based on elastic response during minor to moderate earthquakes (Daie *et al.* 2011, Jalali *et al.* 2012, Khorami *et al.* 2017a, Khorami *et al.* 2017b). The buildings are designed with enough lateral stiffness to limit large displacements with enough ductility to survive large inelastic displacements and prevent collapse during extreme earthquakes (Fanaie *et al.* 2012, Fanaie and Dizaj 2014, Fanaie *et al.* 2016). Shear connectors in composite construction play a significant role in the earthquake response of a structure.

They offer necessary shear connection for composite action. Many researches have been conducted on behavior of different types of shear connectors recently (Shariati *et al.* 2010, Shariati *et al.* 2011a, Shariati *et al.* 2011b, Shariati *et al.* 2012a, Shariati *et al.* 2012b, Shariati *et al.* 2012c, Shariati 2013, Fanaie *et al.* 2015, Shariati *et al.* 2015, Khorramian *et al.* 2016, Shariati *et al.* 2016, Tahmasbi *et al.* 2016, Khorramian *et al.* 2017, Hosseinpour *et al.* 2018, Nasrollahi *et al.* 2018, Wei *et al.* 2018).

Various shear connectors have been applied in composite beams. In case of considering cost and structural features, novel C and L formed angle shear connectors have been nominated (Mansouri *et al.* 2017). Despite the fact that laboratory testing method is costly and time-consuming, the information of load-slip behaviors and shear connectors' capacity has been mainly bounded to the data gained by push out or beam tests. The laboratory tests on channels and angle shear connectors have performed by (Shariati *et al.* Shariati *et al.* 2012d, Shariati *et al.* 2013, Shariati *et al.* 2014, Awal *et al.* 2015, Shah *et al.* 2015, Shahabi *et al.* 2016a, Shahabi *et al.* 2016b, Khorramian *et al.* 2017). These tests have approved that push out testing is a proper model in detecting the load slip behavior of C and L. To approve the numerical processing through the accurate laboratory test results, the application of numerical processing to define the nonlinear load-slip connection and the final shear potential of shear connector in composite beams has gained a fundamental value. Finite Element (FE) method as a numerical analysis tool has considerably reduced the number of laboratory tests applied for the structural behavior performance.

Nonetheless, the laboratory test phase has played a crucial role in each system (structure) studying the elastic

*Corresponding author, Ph.D.
E-mail: zand@iaut.ac.ir
**M.Sc.
E-mail: maryamsafa1991@gmail.com


http://www.techno-press.com/journals/sss&subpage=7
ISSN: 1738-1584 (Print), 1738-1991 (Online)

range. When FE is to be supported through the valid test outcomes, there should be a complementation between the laboratory test results and numerical studies to investigate a structural aspect. Regarding the researches performed in FE (finite element) model in push-out specimens, few studies have focused on shear connectors implemented by (Nakajima *et al.* 2003) and (Lam and El-Lobody 2005). A complete FE research in channel shear connectors' behavior has been performed by (Maleki and Bagheri 2008) and (Maleki and Mahoutian 2009). In another FE push-out test, another equation predicting the shear strength of C has been proposed (Khalilian 2013). Furthermore, few more FE methods focusing on other shear connectors and composite beams have been existed (Wang and Chung 2008, Bazzaz *et al.* 2012, Soty and Shima 2013, Majdi *et al.* 2014, Toghroli Ali *et al.* 2014, Bazzaz *et al.* 2015, Chen *et al.* 2015, Fanaie *et al.* 2015, Safa *et al.* 2016, Andalib *et al.* 2018).

This study casts a precise look to FE in the angle connectors based on the accurate laboratory tests. Then soft computing methods have applied. The applications of soft computing methods have been increasingly applied recently (Mohammadhassani *et al.* 2015, Mansouri *et al.* 2016, Heydari and Shariati 2018). Push-out test and relative FE analysis and all linear and nonlinear component features have been performed to obtain the final strength and the connector load-slip behavior across a static load. Comparing the FE results with push-out tests, the models' investigations have provided adequate data required in soft computing methods. Regardless of new mathematical functions proposed to form C and L, the core of this study is to gain more nonlinearity through the soft computing analysis. ANN (Artificial Neural Network) as an alternative to the analyzing approach has not required the knowledge of: 1) internal system factors and 2) compact solution for multi variable defects.

In the current research, ANFIS in ANN domain (Jang 1993, Safa *et al.* 2016, Toghroli *et al.* 2016, Toghroli *et al.* 2018), has been applied to obtain the significant factors affecting the C and L formed angle shear connectors performance. ANFIS has represented high forecasting and learning potentials producing effective tool to encounter uncertainties of the systems. ANFIS as a hybrid intelligent system has provided an automatic learning and adaptive system in various engineering processing (Lo and Lin 2005, Mohammadhassani *et al.* 2013a, Mohammadhassani *et al.* 2013b, Toghroli Ali *et al.* 2014). ANFIS has been utilized to estimate and define the different systems' very moment (Lo and Lin 2005, Tian and Collins 2005, İnal 2008, Al-Ghandoor and Samhouri 2009, Khajeh *et al.* 2009, Kurnaz *et al.* 2010, Ekici and Aksoy 2011, Petković and Ćojbašić 2012, Petković *et al.* 2012a, Petković *et al.* 2012b) so ANFIS method has been widely used in many studies.

## 2. Methodology

### *2.1 General*

Push out tests has enhanced the knowledge of load slip behavior of the shear connectors in composite beams. Considering time and expenses of laboratory tests, analytical methods are more preferable methods to study the nonlinear reaction and the final shear connectors' behavior in composite beams; however, the analyzed results in analytical approach are to be justified toward the accurate experimental findings.

A three dimensional nonlinear finite element analysis of push out specimens using ABAQUS software has been used in push-out tests. A comprehensive FE could provide a notable descending in the number of experiments. Both push-out and FE in C and L formed shear angle shear connector have been enhanced to gain the data applied in soft computing analysis.

### *2.2 Experimental program*

Some push out tests with angle shear connectors is established. The specimens comprise of a double concrete-slab with an embedded steel reinforcement, a steel I-section and two angle shear connectors with I-section flanges. The shear connectors' angle has been welded to C and L (Fig. 1). Concrete slabs have been made of Portland cement, coarse aggregate, river sand and water weighting. The weight of cement, water, sand and gravel is 1, 0.42, 2.75 and 1.75.

In any specimens, the applied load in universal testing machine of 1000 kN capacity through the use of displacement control is 0.1 mm/s. Monotonic loading has been constantly performed, when the specimen has started fracturing and failing. In each specimen, the load-displacement outcomes automatically have been plotted in a global test machine. The related shifting (displacement) measurement has been occurred in top of the steel beam and the bottom of concrete block in all time steps.

### *2.3 Analytical study*

ABAQUS as FE program has been applied to represent push-out tests to check the behavior of nonlinear properties including 1) concrete steel, 2) geometry as large shifting and tensile 3) compressive damage in concrete. Static Implicit analysis has been implemented in stepwise displacement load.

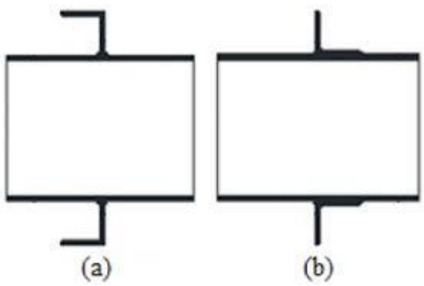


Fig. 1 Push out test on C and L formed angle connectors (Khorramian *et al.* 2015)

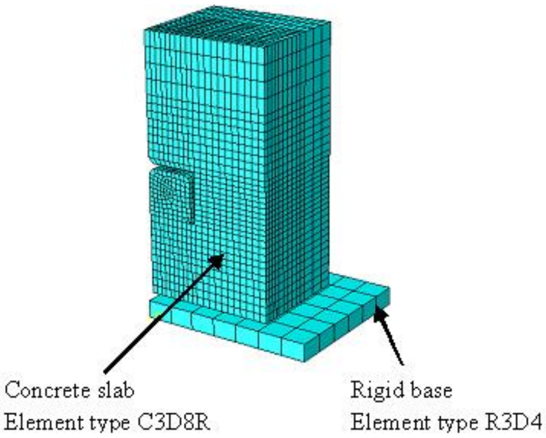


Fig. 2 Finite element meshing

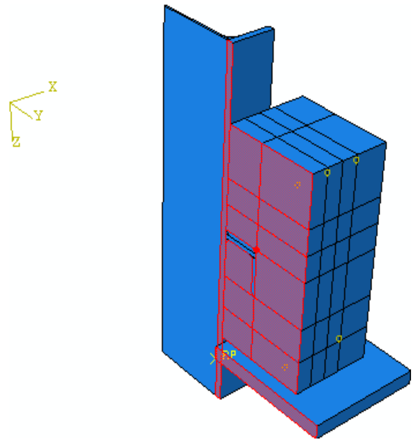

Fig. 4 Boundary conditions

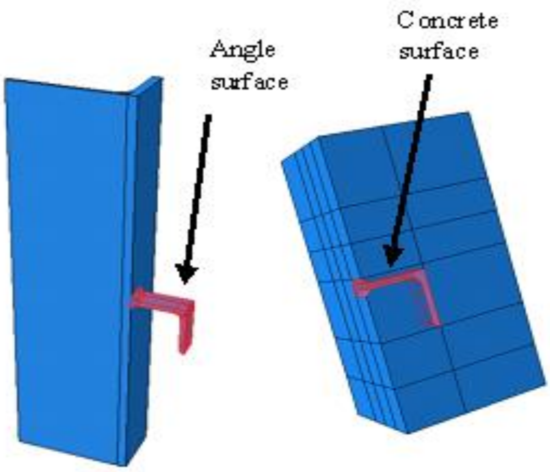


Fig. 3 Interaction of contact and constraint condition surfaces

### 2.3.1 Finite element model and mesh

Considering all details of push-out specimen, obtaining accurate outcomes from FE is possible. FE model has included five categories as: 1) concrete slab, 2) steel beam, 3) shear connectors, 4) rebar and 5) rigid base. C3D8R, an eight node brick element with low stiffness, is used to mesh the concrete slab, steel beam and shear connectors. Each node in C3D8R consists of three translational degree of freedom (DOF) used for non-linear analyzing consist of contact, great deformation, plasticity and damage (Fig. 2).

### 2.3.2 Contact interaction and constraint conditions

A tangential surface contacts produced by finite element (FE) has been seen in concrete slab and shear connector. Indeed, all shear connector surfaces contacted to the surrounding concrete are formed with contact surfaces. Tangential surface contact named hard contact has blocked the surface penetration into each other. ABAQUS penalty contact model has been used as tangential behavior. The co-efficient friction is 0.45. The concrete slab has been regarded as master surface and the embedded regions are to simulate the rebar within the concrete slab. To impede the steel beam and shear connector slipping, tie constraint has connected the joints of two components at contact surfaces. Contacting of concrete slab and rigid base has been similarly shaped to shear connector and concrete contact by utilizing a tangential friction co-efficient 0.6 and hard contact in normal direction. The master surface is the rigid base. Contacts interactions and constraint conditions are shown in Fig. 3.

### 2.3.3 Load and boundary condition

Considering the symmetric features of push out test specimens, a quarter specimens have been analyzed. The symmetric boundary properties have been used to the surfaces of the symmetric planes in specimen (Fig. 4). The rigid base has supported the assembly with no moving. All DOF in rigid base have mighty been fixed. Following this research, displacement control method has been performed to the loading used in top of steel beam. Firstly, the displacement is 0, however, there is a linearly increasing based on the amplitude function.

### 2.4 Data analysis

The input and output used in this study has been presented in Table 1.

### 2.5 ANFIS methodology

In MATLAB (software), fuzzy inference system has been used through all ANFIS training and verification procedures. ANFIS for two variables (input) is presented in Fig. 5.

The purpose of this study is using of Takagi and Sugeno class (IF-THEN rules) and two-input for the first order (Sugeno)

$$if\ x\ is\ A\ and\ y\ is\ C\ then\ f_1 = p_1 x + q_1 y + r_1 \qquad (1)$$

Table 1 Input and output factors

| Input | Parameter description |
|---|---|
| input 1 | Height (mm) |
| input 2 | Length (mm) |
| input 3 | Thickness(mm) |
| input 4 | Concrete(mm) |
| output | Load (kN) |

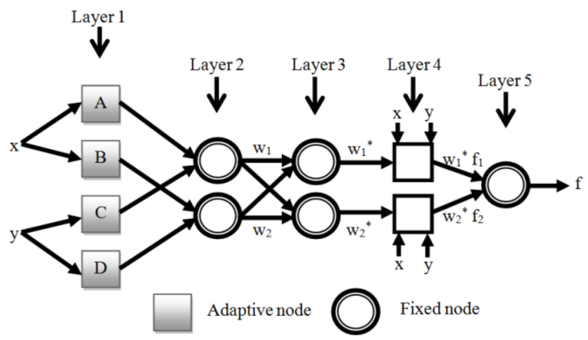


Fig. 5 ANFIS structure

The first layer including MF input parameters have provided values of the same layer (input). The layer's node is adaptive with function of " $O = \mu_{AB}(x)$ and $O = \mu_{CD}(x)$ ". $\mu_{AB}(x)$ and $\mu_{CD}(x)$ are bell formed membership functions with the highest and lowest values as (1.0, 0.0).

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

Regarding the set parameters of $\{a_i, b_i, c_i, d_i\}$, the layer premise parameters are x, $y$ (input to nodes). Membership layer as the second layer has studied all membership function's weight by accepting signals (receiving) of the prior layer and performing as membership function to represent the fuzzy sets for all input variables. Nodes are non-adaptive, and the layer performs as a multiplier in signal receiving and sending the results as $w_i = \mu_{AB}(x) * \mu_{CD}(y)$. All output nodes exhibit the rules' firing strength.
In third layer as rule layer, all neurons are pre-condition and matched the fuzzy rules, say once the rule activation level is analyzed; equality between the fuzzy rule number and the layers has been occurred. Normalizing of weights has been analyzed by the nodes that are non-adaptive and compute the firing strength value of the rule over the sum of all firing strengths of the rules as $w_i^* = \frac{w_i}{w_1+w_2}$, $i = 1,2$.
The results show the normalized firing strengths.
Forth layer as defuzzification has provided output values from the inference rules' results. The layer's adaptive node has function: $O_i^4 = w_i^* xf = w_i^*(p_i x + q_i y + r_i)$ with the variable set of $\{p_i, q_i, r\}$ as consequent parameter.

Fifth layer as output layer has provided all the accepted (receiving) input of the prior layer to change the fuzzy categorized outcome into binary (crisp). The fifth layer's node is non-adaptive to calculate all output as total sum of receiving signal

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

In ANFIS architectures, hybrid learning algorithms has been applied in the process of variables' identification. The function signals have grown up to the forth layer then the hybrid learning algorithm passes. Furthermore, the ultimate variables have been gained by the least squares estimation. In the backward pass, the error rates circulate backwards and the premise variables are synchronized through the gradient decline order.

## 3. Results

Table 2 represents the total numerical outcome of single parameters effective to C and L, also two and three input combinations have influenced the respective strength performance.
Therefore, this is the optimal combination of three factors with the greatest impact on the shear strength performance (Table 2). The optimal combinations with two parameters are proposed as further analysis.
In finding the proper inputs through ANFIS, the function of whole variables only has trained each one for a single epoch. On the combinations' maintenance, 100 epochs is ANFIS amount trained for the aforementioned combinations to line the over fitting between training and checking data.

ANFIS input-output surfaces graph in factors forecasting of C and L is depicted in Fig. 6. The figure also shows ANFIS response to the variable input parameters.

## 4. Conclusions

Considering the factors affecting the respective shear strength, the performance of C and L is complex. In this study, a new method has been suggested to remove the forecasting performance of C and L formed angle shear connector's rate by eliminating redundant input factors.

Table 2 Input parameters affect LOAD forecasting

| 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 |

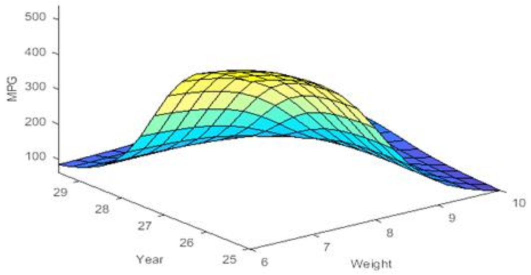


Fig. 6 ANFIS forecasted relationship

A proper method has been performed to find appropriate factors affecting the shear strength prediction of C and L through ANFIS methodology. ANFIS has been applied to remove the vagueness of shear strength prediction producing the highest forecasting conditions. ANFIS has also been implemented to change the complex several functions into the single multi response performance index. Consequently, in this study, the maintained forecasting method would be appropriate to enhance the multiple functions characterized in shear strength prediction of C and L formed angle shear connectors analyzing.

## References


Al-Ghandoor, A. and Samhouri, M. (2009), "Electricity consumption in the industrial sector of Jordan: application of multivariate linear regression and adaptive neuro-fuzzy techniques", JJMIE, **3**(1).

Andalib, Z. *et al.* (2018), "Numerical evaluation of ductility and energy absorption of steel rings constructed from plates", *Eng. Struct*., **169**, 94-106.

Awal, A.A. *et al.* (2015), "Effect of cooling regime on the residual performance of high-volume palm oil fuel ash concrete exposed to high temperatures", *Constr. Build. Mater*., **98**, 875-883.

Bazzaz, M. *et al.* (2015), "Numerical comparison of the seismic performance of steel rings in off-centre bracing system and diagonal bracing system", *Steel Compos. Struct*., **19**(4), 917-937.

Bazzaz, M. *et al.* (2012), "Evaluation of the seismic performance of off-centre bracing system with ductile element in steel frames", *Steel Compos. Struct*., **12**(5), 445-464.

Chen, A. *et al.* (2015), "Experimental investigation and finite element analysis of flexural behavior of insulated concrete sandwich panels with FRP plate shear connectors", *Eng. Struct*., **98**, 95-108.

Daie, M. *et al*. (2011), "A new finite element investigation on pre-bent steel strips as damper for vibration control", *Int. J. Phys. Sci*., **6**(36), 8044 - 8050.

Ekici, B.B. and Aksoy, U.T. (2011), "Prediction of building energy needs in early stage of design by using ANFIS", *Expert Syst. Appl*., **38**(5), 5352-5358.

Fanaie, N. *et al*. (2016), "Theoretical assessment of the behavior of cable bracing system with central steel cylinder", *Adv. Struct. Eng*., **19**(3), 463-472.

Fanaie, N. *et al.* (2012), "Theoretical assessment of wire rope bracing system with soft central cylinder", *Proceedings of the 15th world conference on earthquake engineering*, Month.

Fanaie, N. and Dizaj, E.A. (2014), "Response modification factor of the frames braced with reduced yielding segment BRB", *Struct. Eng. Mech.*, **50**(1), 1-17.

Fanaie, N. *et al.* (2015), "Analytical study of composite beams with different arrangements of channel shear connectors", *Steel Compos. Struct*., **19**(2), 485-501.

Heydari, A. and Shariati, M. (2018), "Buckling analysis of tapered BDFGM nano-beam under variable axial compression resting on elastic medium", *Struct. Eng. Mech*., **66**(6), 737-748.

Hosseinpour, E. *et al.* (2018), "Direct shear behavior of concrete filled hollow steel tube shear connector for slim-floor steel beams", *Steel Compos. Struct*., **26**(4), 485-499.

İnal, M. (2008), "Determination of dielectric properties of insulator materials by means of ANFIS: a comparative study", *J. Mater. Process. Tech*., **195**(1), 34-43.

Jalali, A. *et al.* (2012), "Seismic performance of structures with pre-bent strips as a damper", *Int. J. Phys. Sci*., **7**(26), 4061-4072.

Jang, J.S. (1993), "ANFIS: Adaptive-network-based fuzzy inference system", *IEEE T. Syst. Man Cy.*, **23**(3), 665-685.

Khajeh, A. *et al.* (2009), "Application of adaptive neuro-fuzzy inference system for solubility prediction of carbon dioxide in polymers", *Expert Syst. Appl*., **36**(3), 5728-5732.

Khalilian, M. (2013), The assessment of shear capacity of angle shear connectors Master Sharif University of Technology.

Khorami, M. *et al.* (2017a), "Seismic performance evaluation of buckling restrained braced frames (BRBF) using incremental nonlinear dynamic analysis method (IDA)", *Earthq. Struct*., **13**(6), 531-538.

Khorami, M. *et al.* (2017b), "Evaluation of the seismic performance of special moment frames using incremental nonlinear dynamic analysis", *Struct. Eng. Mech*., **63**(2): 259-268

Khorramian, K. *et al.* (2017), "Numerical analysis of tilted angle shear connectors in steel-concrete composite systems", *Steel Compos. Struct*., **23**(1), 67-85.

Khorramian, K. *et al.* (2015), "Behavior of tilted angle shear connectors", *PLoS ONE*, **10**(12), e0144288.

Khorramian, K. *et al.* (2016), "Behavior of tilted angle shear connectors (vol 10, e0144288, 2015)", *PLOS ONE*, **11**(2).

Kurnaz, S. *et al.* (2010), "Adaptive neuro-fuzzy inference system based autonomous flight control of unmanned air vehicles", *Expert Syst. Appl.*, **37**(2), 1229-1234.

Lam, D. and El-Lobody, E. (2005), "Behavior of headed stud shear connectors in composite beam", *J. Struct. Eng*., **131**, 96.

Lo, S.P. and Lin, Y.Y. (2005), "The prediction of wafer surface non-uniformity using FEM and ANFIS in the chemical mechanical polishing process", *J. Mater. Process. Technol*., **168**(2), 250-257.

Majdi, Y. *et al.* (2014), "Finite element analysis of new composite floors having cold-formed steel and concrete slab", *Eng. Struct*., **77**, 65-83.

Maleki, S. and Bagheri, S. (2008), "Behavior of channel shear connectors, Part II: Analytical study", *J. Constr. Steel Res*., **64** 1341-1348.

Maleki, S. and Mahoutian, M. (2009), "Experimental and analytical study on channel shear connectors in fiber-reinforced concrete", *J. Constr. Steel Res*., **65**(8-9), 1787-1793.

Mansouri, I. *et al.* (2016), "Strength prediction of rotary brace damper using MLR and MARS", *Struct. Eng. Mech*., **60**(3): 471-488.

Mansouri, I. *et al.* (2017), "Analysis of influential factors for predicting the shear strength of a V-shaped angle shear connector in composite beams using an adaptive neuro-fuzzy technique", *J. Intell. Manuf*.,: 1-11.

Mohammadhassani, M. *et al.* (2013a), "Applications of the ANFIS and LR in the prediction of strain in tie section of concrete deep beams", *Comput. Concrete*, **12**(3), 243-259.

Mohammadhassani, M. *et al.* (2013b), "Application of the ANFIS model in deflection prediction of concrete deep beam", *Struct. Eng. Mech*., **45**(3), 319-332.

Mohammadhassani, M. *et al.* (2015), "Fuzzy modelling approach for shear strength prediction of RC deep beams", *Smart Struct.*

*Syst*., **16**(3), 497-519.

Nakajima, A. *et al*. (2003), "Cyclic shear force-slip behavior of studs under alternating and pulsating load condition", *Eng. Struct*., **25**(5), 537-545.

Nasrollahi, S. *et al.* (2018), "Investigation of pipe shear connectors using push out test", *Steel Compos. Struct*., **27**(5), 537-543.

Petković, D. and Ćojbašić, Ž. (2012), "Adaptive neuro-fuzzy estimation of autonomic nervous system parameters effect on heart rate variability", *Neural Comput. Appl*., **21**(8), 2065-2070.

Petković, D. *et al.* (2012a), "Adaptive neuro-fuzzy estimation of conductive silicone rubber mechanical properties", *Expert Syst. Appl*., **39**(10), 9477-9482.

Petković, D. *et al*. (2012b), "Adaptive neuro fuzzy controller for adaptive compliant robotic gripper", *Expert Syst. Appl.*, **39**(18), 13295-13304.

Safa, M. *et al.* (2016), "Potential of adaptive neuro fuzzy inference system for evaluating the factors affecting steel-concrete composite beam's shear strength", *Steel Compos. Struct*., **21**(3), 679-688.

Shah, S. *et al.* (2015), "Steel rack connections: Identification of most influential factors and a comparison of stiffness design methods", *PloS one*, **10**(10), e0139422.

Shahabi, S. *et al.* (2016a), "Numerical analysis of channel connectors under fire and a comparison of performance with different types of shear connectors subjected to fire", *Steel Compos. Struct*., **20**(3), 651-669.

Shahabi, S. *et al*. (2016b), "Performance of shear connectors at elevated temperatures-A review", *Steel Compos. Struct*., **20**(1): 185-203.

Shariati, A. *et al.* (2012a), "Investigation of channel shear connectors for composite concrete and steel T-beam", *Int. J. Phys. Sci.*, **7**(11), 1828-1831.

Shariati, A. *et al.* (2012b), "Various types of shear connectors in composite structures: A review", *Int. J. Phys. Sci*., **7**(22), 2876-2890.

Shariati, A. *et al*. (2014), "Experimental assessment of angle shear connectors under monotonic and fully reversed cyclic loading in high strength concrete", *Constr. Build. Mater*., **52**, 276-283.

Shariati, M. (2013), Behaviour of C-shaped Shear Connectors in Stell Concrete Composite Beams, Jabatan Kejuruteraan Awam, Fakulti Kejuruteraan, Universiti Malaya.

Shariati, M. *et al.* (2010), "Experimental and analytical study on channel shear connectors in light weight aggregate concrete", *Proceedings of the 4th International Conference on Steel & Composite Structures*, 21 - 23 July, 2010, Sydney, Australia, Month.

Shariati, M. *et al*. (2012c), "Experimental assessment of channel shear connectors under monotonic and fully reversed cyclic loading in high strength concrete", *Mater. Des*., **34**, 325-331.

Shariati, M. *et al.* (2011a), "Shear resistance of channel shear connectors in plain, reinforced and lightweight concrete", *Scientific Res. Essays*, **6**(4), 977-983.

Shariati, M. *et al.* (2015), "Behavior of V-shaped angle shear connectors: experimental and parametric study", *Mater. Struct*., 1-18.

Shariati, M. *et al.* (2016), "Comparative performance of channel and angle shear connectors in high strength concrete composites: An experimental study", *Constr. Build. Mater.*, **120**, 382-392.

Shariati, M. *et al.* (2011b), "Behavior of Channel Shear Connectors in Normal and Light Weight Aggregate Concrete (Experimental and Analytical Study)", *Adv. Mater. Res.*, **168**, 2303-2307.

Shariati, M. *et al.* (2013), "Comparison of behaviour between channel and angle shear connectors under monotonic and fully reversed cyclic loading", *Constr. Build. Mater.*, **38**, 582-593.

Shariati, M. *et al.* (2012d), "Behaviour of C-shaped angle shear connectors under monotonic and fully reversed cyclic loading: An experimental study", *Mater. Des*., **41**, 67-73.

Shariati, M. *et al*. (2014),"Fatigue energy dissipation and failure analysis of angle shear connectors embedded in high strength concrete ", *Eng. Fail. Anal*., **41**, 124-134.

Soty, R. and Shima, H. (2013), "Formulation for shear force–relative displacement relationship of L-shape shear connector in steel–concrete composite structures", *Eng. Struct*., **46**, 581-592.

Tahmasbi, F. *et al*. (2016), "Shear capacity of C-shaped and L-shaped angle shear connectors", *PloS one*, **11**(8), e0156989.

Tian, L. and Collins, C. (2005), "Adaptive neuro-fuzzy control of a flexible manipulator", *Mechatronics*, **15**(10), 1305-1320.

Toghroli, A. *et al*. (2018), "Evaluation of the parameters affecting the Schmidt rebound hammer reading using ANFIS method", *Comput. Concrete*, **21**(5), 525-530.

Toghroli, A. *et al.* (2016), "Potential of soft computing approach for evaluating the factors affecting the capacity of steel–concrete composite beam", *J. Intell. Manuf*., 1-9.

Toghroli, A. *et al*. (2014), "Prediction of shear capacity of channel shear connectors using the ANFIS model", *Steel Compos. Struct.*, **17**(5), 623-639.

Wang, A.J. and Chung, K.F. (2008), "Advanced finite element modelling of perforated composite beams with flexible shear connectors", *Eng. Struct*., **30**, 2724-2738.

Wei, X. *et al.* (2018), "Distribution of shear force in perforated shear connectors", *Steel Compos. Struct.*, **27**(3), 389-399.

*CC*