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Application of Extreme Learning Machine (ELM) and Genetic Programming (GP) to design steel-concrete composite floor systems at elevated temperatures

Mahdi Shariati [1a], Mohammad Saeed Mafipour [2b], Peyman Mehrabi [3c], Yousef Zandi [4d], Davoud Dehghani [5e], Alireza Bahadori [2f], Ali Shariati[*6,7], Nguyen Thoi Trung [6,7g], Musab N.A. Salih [8h] and Shek Poi-Ngian [9i]

[1] *Institute of Research and Development, Duy Tan University, Da Nang 550000, Viet Nam*
[2] *School of Civil Engineering, College of Engineering, University of Tehran, Iran*
[3] *Department of Civil Engineering, K.N. Toosi University of Technology, Tehran, Iran*
[4] *Department of Civil Engineering, Tabriz Branch, Islamic Azad University, Tabriz, Iran*
[5] *Department of Civil Engineering, Qeshm International Branch, Islamic Azad University, Qeshm, Iran*
[6] *Division of Computational Mathematics and Engineering, Institute for Computational Science, Ton Duc Thang University, Ho Chi Minh City, Viet Nam*
[7] *Faculty of Civil Engineering, Ton Duc Thang University, Ho Chi Minh City, Viet Nam*
[8] *School of civil engineering, faculty of engineering, Universiti Teknologi Malaysia, 81310 Johor Bahru, Malaysia*
[9] *Construction Research Center (CRC), Institute for Smart Infrastructure & Innovative Construction (ISIIC), School of Civil Engineering, Universiti Teknologi Malaysia, 81310 Johor Bahru, Johor, Malaysia*

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Abstract. This study is aimed to predict the behaviour of channel shear connectors in composite floor systems at different temperatures. For this purpose, a soft computing approach is adopted. Two novel intelligence methods, including an Extreme Learning Machine (ELM) and a Genetic Programming (GP), are developed. In order to generate the required data for the intelligence methods, several push-out tests were conducted on various channel connectors at different temperatures. The dimension of the channel connectors, temperature, and slip are considered as the inputs of the models, and the strength of the connector is predicted as the output. Next, the performance of the ELM and GP is evaluated by developing an Artificial Neural Network (ANN). Finally, the performance of the ELM, GP, and ANN is compared with each other. Results show that ELM is capable of achieving superior performance indices in comparison with GP and ANN in the case of load prediction. Also, it is found that ELM is not only a very fast algorithm but also a more reliable model.

Keywords: elevated temperature; channel shear connector; extreme learning machine; genetic programming; artificial neural network

1. Introduction

Composite floor systems have always been of interest as they benefit from the combined properties of different materials simultaneously. Shear connectors are mainly used in steel-concrete floor systems to connect steel beams and concrete slab to each other (Mafipour *et al*. 2019). Also, shear connectors are a mechanism through which the developed shear forces at the interface of materials can be collected and transferred. Hence, the proper performance of composite floor systems largely depends on the behaviour of connectors (Ghiami Azad *et al*. 2018).

Since the advent of shear connectors, different types of connectors have been suggested. Channel shear connectors are one of these connectors which have been widely used in composite beams. Many advantages of these connectors, such as low-cost manufacturing and easy installation, have made them very popular, especially in developing countries. However, there are few studies that have investigated the performance of channel shear connectors. According to the experimental results, C-shaped shear connectors as the channel, angle, perforated even the pipe shear connectors showed an appropriate shear capacity while they were embedded in well prepared high strength concretes (HSCs). Hence, the high performance concrete could be a reliable alternative for the normal concrete slabs in the floor systems and composite beams.

Channel shear connectors could exhibit ductile

∗Corresponding author, Ph.D. Candidate,
E-mail: alishariati@tdtu.edu.vn
[a] Ph.D., E-mail: mahdishariati@duytan.edu.vn
[b] MS.C., E-mail: m.saeed.mafipour@ut.ac.ir
[c] MS.C., E-mail: peyman804m@gmail.com
[d] Ph.D., E-mail: zandi@iaut.ac.ir
[e] Ph.D. Candidate, E-mail: ddehghani@yahoo.com
[f] MS.C. Student, E-mail: en.ar.bahadori@ut.ac.ir
[g] Ph.D., E-mail: nguyenthoitrung@tdtu.edu.vn
[h] Ph.D., E-mail: nasmusab2@live.utm.my
[i] Ph.D., E-mail: shekpoingian@utm.my

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behaviours when they are subjected to different loading conditions. Also, this behaviour was amplified in more extended channels (Shariati *et al*. 2011a). On the contrary, these connectors showed brittle behaviour in unconfined plain concrete. Embedment of channel connectors in HSCs resulted in more ductile behaviour (Shariati *et al*. 2012e). Moreover, the failure modes were controlled by concrete in HSCs (Pashan 2006). Linear increments in the bearing capacity of channel shear connectors were seen when the length of the connectors was enhanced so that C-shaped channel connectors with 150 mm length exhibited about 60 percent higher bearing capacity in comparison to 100 mm length channels. The thickness and height of channel connectors were also reported as influencing parameters on the load-slip behaviour of channel connectors (Viest 1951).

One of the most important concerns associated with the design of shear connectors in composite floor systems is fire safety. Many studies have been performed with a variety of approaches to mitigate fire-induced damages of steel and concrete. These studies are highly valued not only to increase safety occupancy during and after the fire but also to decrease the refurbishment and retrofitting costs. Shear studs combined with profiled slabs performed better due to steel profile coverage as a shield around the concrete against fire damages. Since lightweight concrete has better strength against fire, shear studs embedded in lightweight concrete showed better ductility in comparison to studs embedded into normal concrete (Mirza and Uy 2009, Mclister *et al*. 2014, Shariati 2014). Angle shear connectors provide a suitable ductility, but they have noticeable stiffness loss. The use of angle as a shear connector at elevated temperatures protects the strength loss by up to 50 percent of the initial strength (Davoodnabi *et al*. 2019). Three main types of failure have been observed during the tests: shear connector fracture, concrete crushing, and concrete shear plain failure. According to experimental studies, shear connectors lose their strength against fire, and this deterioration can vary in different situations (Zhao and Kruppa 1995, Lu *et al*. 2012, Shahabi *et al*. 2016a, b). Studies have shown that C-shaped channel connectors indicate higher energy absorption compared to other connectors at elevated temperatures (Patel *et al*. 2017). Also, the reverse-channel connections enhance the ductility of the connector at high temperatures; however, stiffness of the connectors decreased dramatically (Huang *et al*. 2013). According to analytical studies, when channel shear connectors are in contact with HSCs, they can resist the deterioration induced by fire during the first 10 minutes. However, the failure may be an over-turning mode which does not correspond to failure mode at the ambient temperature. These cases illustrate that channel connectors have appealing features that make them suitable for steel-concrete composite structures. However, the main issue of channel connectors is the prediction of their performance at elevated temperatures.

The shear connector has been employed to enhance the stiffness of the steel-concrete composite systems. However, the behaviour of different connectors could be a complicated issue; thus numerical studies have investigated the shear response and the stiffness of the shear connectors. Moreover, it was found that higher shear capacity leads to greater ductility in shear connectors (Shariati *et al*. 2010, 2011b, 2012a, b, c, d, 2013, 2014a, b, 2015, 2017, Shariati 2013, Khorramian *et al*. 2015, 2016, 2017, Tahmasbi *et al*. 2016, Hosseinpour *et al*. 2018, Nasrollahi *et al*. 2018, Wei *et al*. 2018).

Whereas the behaviour of the beam to column joints are directly related to the interaction between steel and concrete, the friction could be improved by the use of shear connectors. However, the performance of the composite beams and beam to column joints should be controlled at elevated temperatures (Arabnejad Khanouki *et al*. 2011, 2016, Sinaei *et al*. 2011, Mohammadhassani *et al*. 2014b, Shah *et al*. 2016, Heydari and Shariati 2018, Luo *et al*. 2019, Xie *et al*. 2019).

Porous concrete is used in composite structures, where the compressive strength of concrete is the second priority. Therefore, shear connector and the pervious concrete should perform well when the composite system is subjected to the vertical forces. Hence, fire exposure could be investigated on porous concrete used at floor systems (Toghroli *et al*. 2017, Bazzaz 2018, Bazzaz *et al*. 2018, Toghroli *et al*. 2018b, Li *et al*. 2019).

In recent years, experimental and analytical studies have been widely performed on shear performance of the steel-concrete structures, however, using different types of shear connectors and concrete mixtures should be investigated in the floor systems (Arabnejad Khanouki *et al*. 2010, Abedini *et al*. 2017, Nosrati *et al*. 2018, Ziaei-Nia *et al*. 2018, Sajedi and Shariati 2019).

Since the seismic events have always been a concern to the scholars, the dynamic response of the structural composite components was assessed through different experimental studies. Therefore, by conducting a series of cyclic tests on the structural components, the seismic behaviour could be observed not only to evaluate the performance of the specific component but also to find the key design parameter and generate the typical equations and relations of the existed standard provisions (Saleh Asheghabadi *et al*. 2019). Also, the precursor investigations have been performed to evaluate the dynamic performance of the floor systems. The use of steel shear connectors in novel designed composite systems applied to the seismic forces could be an appealing topic to researchers (Daie *et al*. 2011, Jalali *et al*. 2012, Kazerani *et al*. 2014, Ghassemieh and Bahadori 2015, Shah *et al*. 2015, Bahadori

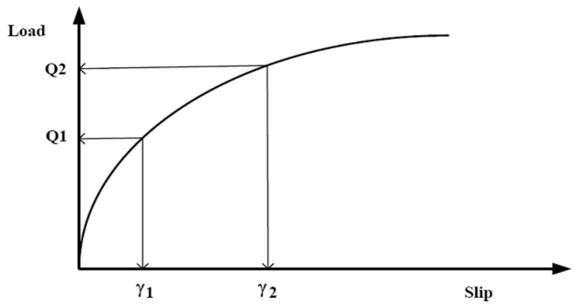


Fig. 1 The typical load-slip curve obtained from the standard test

and Ghassemieh 2016, Khorami *et al*. 2017a, Najarkolaie *et al*. 2017, Ismail *et al*. 2018, Shariati *et al*. 2018, Zandi *et al*. 2018, Abedini *et al*. 2019, Milovancevic *et al*. 2019, Suhatril *et al*. 2019).

The load-slip curve for shear connectors is indicated in Fig. 1, which is generally determined by empirical tests. However, in many cases, these tests are highly expensive and time-consuming. Moreover, although a few mathematical expressions explain the load-slip curve of shear connectors, determining a common regression formula for the stiffness of shear connectors could be slightly challenging due to the scatter manner of load and slip. On the other hand, the finite element modelling of shear connectors is very challenging and requires expertise. Also, the whole finite element modelling process must be repeated even if one of the involving parameters in the problem changes. Therefore, the load-slip behaviour of shear connectors should be evaluated by the use of other alternatives.

The thermal strength of the slabs has a direct effect on the shear capacity and performance of the composite beams in the floor systems at elevated temperatures. Therefore, using SCC mixtures could be able to address the thermal performance of the slabs in the composite structures. Furthermore, porosity is one of the major specifications of the concrete. Whereas the thermal behaviour of concretes depends on the porosity, the porous texture feature could be appealing to scholars who studied the thermal performance of the concretes, especially at the elevated temperatures. Hence, the behaviour of HCSs during and after fire exposure could be examined through various researches (Sajedi and Razak 2011, Beggas and Zeghiche 2013, Chen *et al*. 2019).

The numerical analyses have been applied to the empirical tests, not only to verify the authenticity of the test results, but also to increase the accuracy of different achieved data. Hence, artificial intelligence models have been utilized as one of the numerical approaches to optimize and predict the test results. The artificial neural network (ANN), extreme learning machine (ELM), and genetic programming (GP) can be mentioned as pioneer techniques in the behavior prediction of structural components. Furthermore, new analytical methods have been proposed to improve the optimizations and estimation process results (Sinaei *et al.* 2012, Toghroli *et al.* 2014, 2016, 2018a, Ali 2015, Hamdia *et al.* 2015, Mohammadhassani *et al.* 2015, Le-Duc *et al.* 2016, Mansouri *et al.* 2016, Safa *et al.* 2016, Khorami *et al.* 2017b, Vo-Van *et al.* 2017, Sadeghipour Chahnasir *et al.* 2018, Sari *et al.* 2018, Sedghi *et al.* 2018, Shariat *et al.* 2018, Xu *et al.* 2019, Katebi *et al.* 2019, Mansouri *et al.* 2019, Shariati *et al.* 2019a, b, Trung *et al.* 2019).

A soft computing approach is adopted in the current study to estimate the bearing capacity of channel shear connectors at different temperatures. As two novel intelligence methods, the ELM and GP approaches are developed. The essential feature of the ELM algorithm is its fast learning speed in comparison with other methods. Also, this algorithm minimizes human interventions in target prediction. The required data are generated by performing an empirical method. Channel connectors with different dimensions were embedded into high strength concrete (HSC), and several push-out tests were carried out at different temperatures, including 25°C (ambient), 550°C, 700°C, and 850°C. Also, to evaluate the ELM and GP performance, an artificial neural network (ANN) is developed. Finally, the bearing capacity of the channel connectors is predicted by ELM, GP, and ANN. Moreover, the performance of these methods is compared with each other in terms of performance indices and the required time for the prediction.

Table 1 Particle size analysis

Sieve size (μm)	$W_{ss}+W_s$ (g)	W_s (g)	Silica sand weight (g)	Retained (%)
4570	411.2	409.1	2.1	0.51
2360	448.9	362.95	85.25	18.99
1180	436.7	343.7	93	21.29
600	446.35	316.48	129.87	29.09
300	378.65	290.24	88.41	23.35
150	321.77	275.55	46.22	14.36
72	310.01	276.94	33.07	10.67
Pan	252.33	240.63	11.7	4.63
Total	3005.91	2522.3	489.62	100

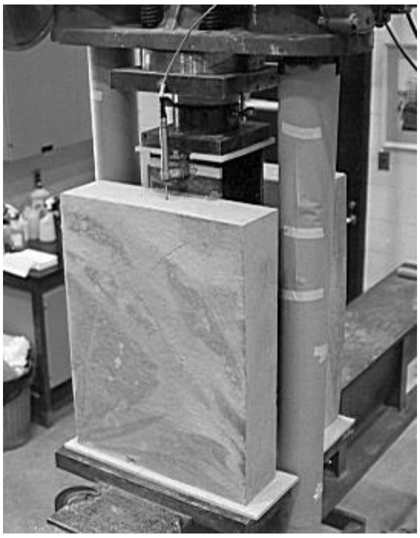
*Blain per cent = 375.011/100 = 3.75;
Moisture absorption for Silica sand is 0.89%

Table 2 Chemical specifications of cement

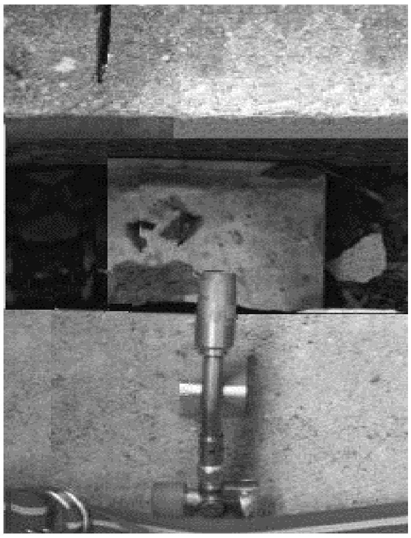
P_2O_5	SiO_2	Al_2O_3	MgO	Fe_2O_3	CaO	MnO	K_2O	TiO_2	SO_3	CO_2	LOI
0.067	17.98	4.45	1.95	1.935	66.16	0.062	0.301	0.101	4.11	4.31	1.62

Table 3 Mixture proportion

Mix design	Cement (kg/m^3)	Coarse aggregate (kg/m^3)	Fine aggregate (kg/m^3)	Water (kg/m^3)	SP (%)	W/C	Compressive strength (MPa)
High strength concrete	360	940	870	180	1	0.5	63



(a)



(b)

Fig. 2 Experimental program: (a) Test sample; (b) Plan view of the blowtorch set-up for a distance d = 100 mm

Table 4 The dimension of the channel shear connectors

Specimen	Height (mm)	Length (mm)	Web thickness (mm)	Flange thickness (mm)
C-100-50-6-8.5	100	50	6	8.5
C-100-30-6-8.5	100	30	6	8.5
C-75-50-5-7.5	75	50	5	7.5
C-75-30-5-7.5	75	30	5	7.5

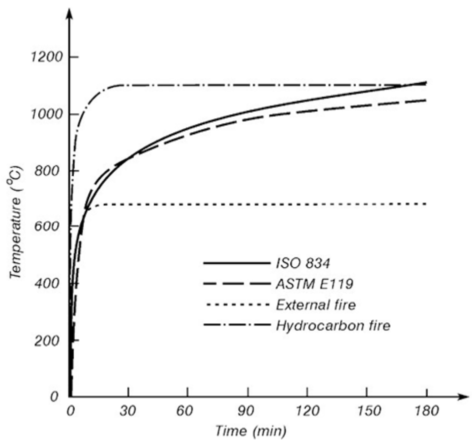


Fig. 3 Standard fire test curve

2. Experimental setup

2.1 Specimen details and test setup

Specimens included a steel I-beam in which two concrete blocks were placed at each side of them. One channel shear connector was welded to each of the beam flanges. In the HSC mixture, air-dry condition aggregates were employed. The fine aggregate was considered as grinded silica sands with a nominal size of about 2 to 4.75 mm, and coarse aggregate included crushed granite with a size of 6 to 10 mm. Table 1 shows the analysis of particle size for the fine aggregates. Based on ASTM C150 Type II cement, Ordinary Portland Cement (OPC) was employed. The results of the chemical analysis of the cement are indicated in Table 2. The superplasticiser (SP) was applied in concrete mixtures in order to obtain acceptable workability. Rheobuild 1100 was the applied SP in this study. The SP has the color of dark brown with a PH ranging from 6.0 to 0.9, and its specific gravity is about 1.195. Prior to the experiment, all the specimens were cured in water for 28 days. In order to achieve the compressive strength, standard cubes with a length of 100 mm and standard cylinders with a diameter of 150 mm and a length of 300 mm were cast along with the push-out specimens at the same time, and all of them were cured in water until the experiment day. The compressive strength is determined through compressive experiments on the standard cylindrical and cube specimens. The ASTM C39 provisions were applied for the compressive strength experiments, and the average value of the compression strength of HSC was employed in the computations. The mix properties and compressive strength of HSC have been presented in Table 3.

The casting process for all the push-out specimens was carried out in a horizontal position analogous to the site situations. Also, the reliable quality of concrete for both sides of slabs was confirmed. Four types of channel shear connectors with different dimensions were considered for this investigation. Details of the channel connectors are demonstrated in Table 4.

2.2 Loading and test procedure

The load-slip behaviour of channel shear connectors was obtained through conducting push out tests on all the specimens of Table 4. The push-out test is more cost-effective than other tests, such as direct shear and large-

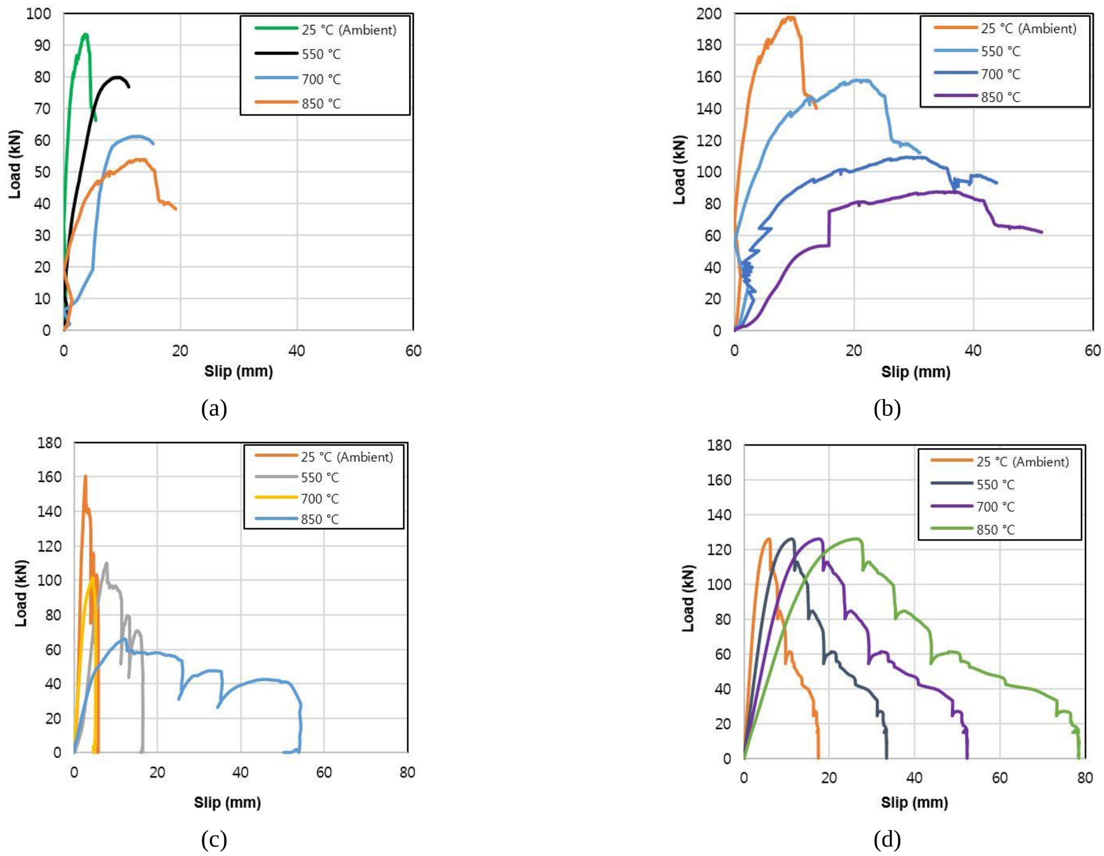


Fig. 4 Load-slip diagram of specimen: (a) C-75-30-5-7.5; (b) C-75-50-5-7.5; (c) C-100-30-6-8.5; (d) C-100-50-6-8.5

scale beam tests. Also, it generally leads to the results as accurate as those of the other test methods. The test sample of the experiment has been demonstrated in Fig. 2(a). At ambient temperature, a universal testing machine with a capacity of 600 kN was used to apply the load. A blowtorch was employed to increase the temperature, as indicated in Fig. 2(b). Using blowtorch is one of the fastest ways to enhance temperature up to the demanded heat. The blowtorch was placed at a distance of 100 mm from the specimen. To ensure that the elevated temperature does not exceed the specified temperatures in the standards, thermocouple and infrared thermometer were also used. To conduct the push-out experiments at elevated temperatures, i.e., 550°C, 700°C, and 850°C, first, the blowtorch gradually pushed the temperature up to the specified temperatures according to the ISO 834 test curve depicted in Fig. 3, then the push-out test was performed same as the ambient state.

The experiment was performed as displacement control, and the loading rate of 0.04 mm/s was considered. Before loading, the specimens were reorganized because of the tension-only mechanism of the set-up frame. Monotonic loading included a slow increase of the loading until failure. The steel I-beams were located on the universal test machine deck, and the load was applied to the upper face of the I-beam. Since some changes in the ultimate strength of the connectors and relative stiffness are created by the orientation of channel connector (Shariati *et al*. 2016, Paknahad *et al*. 2018), this issue was assumed in the push-out test, and the same orientation for the channels against the loading direction was considered. At each time step, the LVDT displacement sensor automatically recorded the actual applying load to the connectors and the relative slip between the I-shaped beam and the concrete.

3. Experimental results

3.1 Modes of failure

In the push-out specimens, two types of failure can be detected. The channel fracture is the first type, and concrete crushing or splitting is the second one. Channel fracture happened in all the push-out specimens embedded in HSC at ambient temperature. On the contrary, at higher temperatures, the concrete crushing was also observed. For the channel fracture type, a sudden end is reached in the load-slip curve. Also, when concrete destruction is a governing parameter in failure modes, the maximum bearing capacity is directly related to the concrete compressive strength (Shariati *et al*. 2012e). Raising load with the square root of compressive strength was indicated by Pashan that also could be observed in the results. Utilizing reinforcement in all specimens is the other reason for the channel fracture (Maleki and Mahoutian 2009). At higher temperatures, concrete loses its mechanical properties, such as the ultimate strength and Elasticity Modulus. Moreover, a considerable amount of water vapour

Table 5 Details of the statistical data

Input & Output	Minimum	Maximum	Average	Standard deviation
Height (mm)	75	100	91.76	11.75
Length (mm)	30	50	39.42	9.98
Web thickness (mm)	5	6	5.67	0.47
Flange thickness (mm)	7.5	8.5	8.17	0.47
Temperature (°C)	25	850	680.12	256.23
Slip (mm)	0	78.53	12.17	13.30
Load (kN)	0	197.63	72.58	41.27

inside the concrete slab reduces its compressive strength and even produces concrete explosions and spallings. Concerning the damages above to concrete at elevated temperatures, the second type of failure occurred at higher temperature.

3.2 The behavior of channel shear connectors

Load-slip diagrams of the channel shear connectors have been depicted in Fig. 4. According to these diagrams, channels performed well in the ambient temperature. However, the effect of length and height was different. Channel connectors with a higher length generally showed higher shear capacity. Nonetheless, the variation in the height of connectors did not exert a far-reaching impact on the shear capacity. However, by creating channel fracture, the concrete cracking was experienced through slabs with greater height channels on the sides of the slabs. On the other hand, the cracking was not formed in slabs with the shorter channel. Therefore, in similar conditions, it can be inferred that concrete cracks are highly possible to happen in specimens with longer channels in height. This matter is also in accordance with the results of Shariati *et al*. (2012e). Although it has been proposed that channels with longer height are able to carry a higher amount of shear forces, concerning the load-slip curves of monotonic loading, the specimen of channel connectors with 75 mm height, represented an enhanced load capacity in comparison with specimens with 100 mm height. This might be due to the presence of the ductility at the higher temperature, which changed the stiffness of the connectors. These curves also show that the more flexibility in the specimens with higher lengths is observed in comparison to that of shorter channels. However, the deteriorative effect of temperature appears at 850°C. Though the HSC performed a determining role in the case of stiffness, it did not affect the loading capacity of the channels considerably.

4. Data and preparation

The required data for this investigation was obtained from the described experimental results in the previous section. Dimensions of channel connectors, including flange thickness, web thickness, height, and length, as well as temperature, and slip were adopted as the inputs of the models and load was predicted as the output. Table 5 shows the details of the used statistical data.

To improve the performance of the models, a pre-processing and post-processing were carried out on the data, and all the input and output data were normalized between -1 and 1 by using the following formulas

$$X_i = \frac{X_{io} - X_{min}}{X_{max} - X_{min}} \times 2 - 1 \tag{1}$$

$$Y_i = \frac{Y_{io} - Y_{min}}{Y_{max} - Y_{min}} \times 2 - 1 \tag{2}$$

where, X_{io} and X_i are the ith component of each input vector before and after normalization, respectively and Y_{io} and Y_i are the ith component of the output vector before and after normalization, respectively. X_{min}, X_{max}, Y_{min}, and Y_{max} are the minimum and maximum value of each input and output vector, respectively.

5. Soft computing prediction algorithms

5.1 Extreme Learning Machine (ELM)

Huang *et al*. (2006) proposed the extreme learning machine in 2006 as an artificial intelligence (AI) tool for single-layer feed-forward neural network (SLFN) architecture. In the ELM algorithm, the weights of SLFN input are selected in a random manner, while the output weights are analytically determined. The most considerable advantage of the ELM algorithm over other intelligence methods is its extremely fast speed in finding the weights of the network. Also, ELM systematically determines all the network factors and therefore prevents unnecessary interference of humans. This method offers a different approach from ANN, ANFIS, and SVM as it uses ELM algorithm for finding the weights of the SLFN. ELM is a newer tool in comparison with the aforementioned intelligence methods. Many benefits of this approach have increased its popularity and usage so that the performance of this method has been evaluated in different fields of study (Petković *et al*. 2012, Shamshirband *et al*. 2014, Moghaddam *et al*. 2015, Mohammadi *et al*. 2015).

A three-step procedure is involved in developing ELM model as follows: (i) a single layer feed-forward neural network (SLFN) is constructed; (ii) weights and biases of the network are randomly selected; (iii) the output weights are estimated by inverting the hidden layer output matrix.

For a dataset containing d-dimensional vectors for $i = 1, 2, 3, \dots, N$ training sample, the SLFN with L hidden nodes is mathematically defined through

$$f_L(x) = \sum_{i=1}^{L} \beta_i G(a_i, b_i, x), \quad x \in R^n, \quad a_i \in R^n \tag{3}$$

Where:

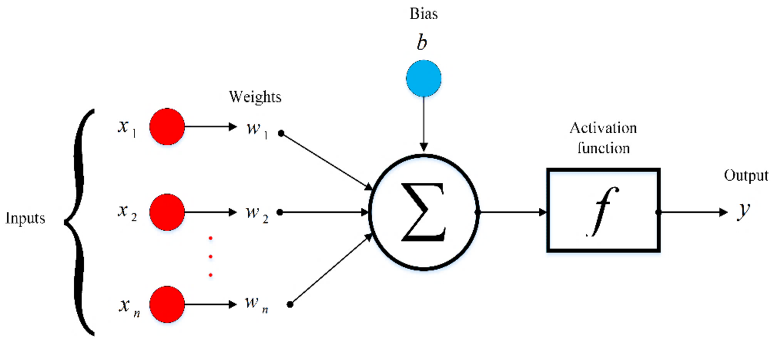


Fig. 5 A typical neuron of ANN

a_i and b_i = learning parameters of hidden nodes.

β_i = the output weight matrix between the hidden neurons and output neurons.

G (a_i, b_i, x) = the output value of the i^{th} hidden node regarding with input x

$G(a_i, b_i, x)$, $g(x): R \rightarrow R$ is a non-linear piecewise continuous function that should meet the ELM approximation theorem. Different activation functions that are generally used in neural network-based modelling can be employed. The sigmoid equation was used herein to develop the ELM model as following

$$G(a_i, b_i, x) = \frac{1}{1 + exp(-a_i x + b_i)} \qquad (4)$$
$$a_i \ \& \ b_i \in R$$

According to Huang *et al.* (2016), the approximation error should be minimized in order to determine the weights, which are connected to the hidden and output layer (β) by the use of least square fitting

$$min\|H\beta - T\|^2 \qquad \beta \in R^{L\times m} \qquad (5)$$

In this equation, the term $\|H\beta - T\|$is the Frobenius norm, and H is the randomized hidden layer output matrix in the form of

$$H = \begin{bmatrix} G(a_1, b_1, x_1) & \cdots & G(a_L, b_L, x_1) \\ \vdots & \cdots & \vdots \\ G(a_1, b_1, x_N) & \cdots & G(a_L, b_L, x_N) \end{bmatrix}_{N\times L} \qquad (6)$$

Moreover, the target matrix in the data training period is determined as

$$T = \begin{bmatrix} t_1^T \\ \vdots \\ t_L^T \end{bmatrix}_{N\times m} = \begin{bmatrix} t_{11} & \cdots & t_{1m} \\ \vdots & & \vdots \\ t_{N1} & \cdots & t_{Nm} \end{bmatrix}_{N\times m} \qquad (7)$$

By solving the following system of linear equations, an optimal solution can be obtained

$$\beta = H^{\dagger}T \qquad (8)$$

where $H^{\dagger}$ is the Moore-Penrose generalized inverse function and$\beta$is the output weights of the network as following

$$\beta = \begin{bmatrix} \beta_1^T \\ \vdots \\ \beta_L^T \end{bmatrix}_{L\times m} = \begin{bmatrix} \beta_{11} & \cdots & \beta_{1m} \\ \vdots & & \vdots \\ \beta_{L1} & \cdots & \beta_{Lm} \end{bmatrix}_{L\times m} \qquad (9)$$

The output weight β can then be used to estimate the targets of the problem for any given input vector, x.

5.2 Genetic Programming (*GP*)

Genetic programming (GP), as an evolutionary algorithm, follows Darwinian theories of natural selection and survival to conduct function-approximation (in a symbolic form). Therefore, this method is also able to predict the relationship between input and output values. This algorithm generates a primitive population of random equations obtained from random combinations of input values, random numbers, mathematical operators (+, –, ×, ÷), and mathematical functions (for ex. sin, cos, exp, log).

The population of potential solutions is adjusted by genetic evolutionary processing, and the 'fitness function' of the program is evaluated. Individual programs with the best fitness value to the data are chosen to exchange different parts of information for developing better programs through 'crossover' and 'mutation', imitating natural re-production processing.

Crossover in GP refers to the co-exchanging of the programs' sections, while mutation corresponds to randomly changing programs to produce new programs. This evolutionary procedure is repeated over subsequent generations until the best symbolic explanation of data can be determined.

5.3 Artificial Neural Network (*ANN*)

ANNs are intelligence tools inspired by biological neural networks of humans and animals, which can conveniently learn patterns and predict results in high dimensional space of the problem (Naderpour *et al.* 2018, Moayedi and Rezaei 2019). They are able to map a set of inputs to a set of outputs in a noisy and complex dataset. Multilayer perceptron (MLP) is a simple and reliable class of feed-forward ANNs. A typical MLP network includes an input layer, one or several hidden layers, and an output layer (Alizamir and Sobhanardakani 2018). The input layer takes the value of inputs and sends them to the available neurons in the hidden layer. Inside each neuron, a weighted sum of inputs is calculated, and this value, plus a value of bias, is transformed by an activation function, as shown in Fig. 5. Then, the calculated value is transferred to the neurons in the next layer.

This mathematical process can be formulated as follows

$$y_j = f\left(\sum_{i=1}^{N} w_{ij}x_i + b_j\right) \tag{10}$$

where x_i and y_j are the nodal values in the previous layer i, and current layer j, respectively. w_{ij} and b_j are also weights and biases of the network.

The used activation (transfer) function in this investigation was tangen hyperbolic function. This function varies between -1 and 1, and is defined as below

$$Out_j = f(net) = \frac{2}{1+e^{-2x}} - 1 \tag{11}$$

where f is the output variable, and x is the input variable. Neural networks should be trained to show efficient performance. Training means that the weights and biases of the network are determined such that the minimal error between targets (actual values) and outputs (network values) occurs. Hence, the training process of neural networks culminates in a minimization problem. Backpropagation (BP) algorithms are commonly used in order to train neural networks. Levenberg-Marquardt algorithm (LMA) is often the fastest BP algorithm in training; thus, LMA was used in this study as the BP algorithm.

6. Performance evaluation

In order to evaluate the models' performance, 70% of the data was devoted randomly to the training phase and the remained 30% was assigned to the testing phase. Performance indices such as root mean squared error (*RMSE*), Pearson correlation coefficient (*r*), and determination coefficient (R^2) were calculated in both of the phases of the models. These statistical indicators can be characterized as follows

$$RMSE = \sqrt{\frac{\sum_{i=1}^{n}(P_i - O_i)^2}{n}} \tag{12}$$

$$r = \frac{n(\sum_{i=1}^{n} O_i \cdot P_i) - (\sum_{i=1}^{n} O_i)\cdot(\sum_{i=1}^{n} P_i)}{\sqrt{\left(n\sum_{i=1}^{n} O_i^2 - (\sum_{i=1}^{n} O_i)^2\right)\cdot\left(n\sum_{i=1}^{n} {P_i}^2 - (\sum_{i=1}^{n} P_i)^2\right)}} \tag{13}$$

$$R^2 = \frac{\left[\sum_{i=1}^{n}(O_i - \overline{O_i})\cdot(P_i - \overline{P_i})\right]^2}{\sum_{i=1}^{n}(O_i - \overline{O_i})\cdot\sum_{i=1}^{n}(P_i - \overline{P_i})} \tag{14}$$

where P_i and O_i are the predicted and observed variables, and n is the total number of considered data.

To compare the performance of the models (i.e., ELM, GP, and ANN), all the codes were developed in the MATLAB environment, and the available MATLAB functions were only used.

7. Results and discussion

The performance of the artificial intelligence (AI) methods largely depend on the architecture and involving parameters in the models. Therefore, the determination of these variables is vital. Hence, in this study, a trial-and-error method was conducted, and the models' structure was considered as demonstrated in Table 6.

The obtained results of the AI methods, including ELM, GP, and ANN, are indicated in Fig. 6. The ELM results in the training phase with performance indices: R^2 = 0.9414, *r* = 0.9702, and *RMSE* = 13.4342 are demonstrated in Fig. 6(a). High values of R^2 and *r* on the one hand, and the low value of *RMSE*, *on the other hand*, show the appropriate performance of the ELM in the training phase. The ELM results in the testing phase are illustrated in Fig. 6(b). High values of R^2 = 0.9447 and *r* = 0.9720, and low value of *RMSE* = 13.2931 demonstrate nice performance of the ELM in this phase. More importantly, the low difference between

Table 6 User-defined parameters for the ELM, GP, and ANN model

ELM		**GP**		**ANN**	
Number of layers	3	Input	6	Number of layers	3
Neurons	Input: 6	Output	1	Neurons	Input: 6
	Hidden: 50-500	Maximum tree dep.th	17		Hidden: 7
	Output: 1	Number of generation	20-50		Output: 1
Activation function	Sigmoid	Population size	25-500	Number of iteration	1000
Learning rule	ELM	Function set	$\times, \div, +, -$ $\sqrt{x}, x^a, ln, e^x, a^x$	Activation function	Tangent hyperbolic function
		Probability of mutation	0.3	Learning rule	Back propagation: LMA
		Probability of crossover	0.7		
		Generation gap	0.8		
		Learning rule	Genetic algorithm (GA)		

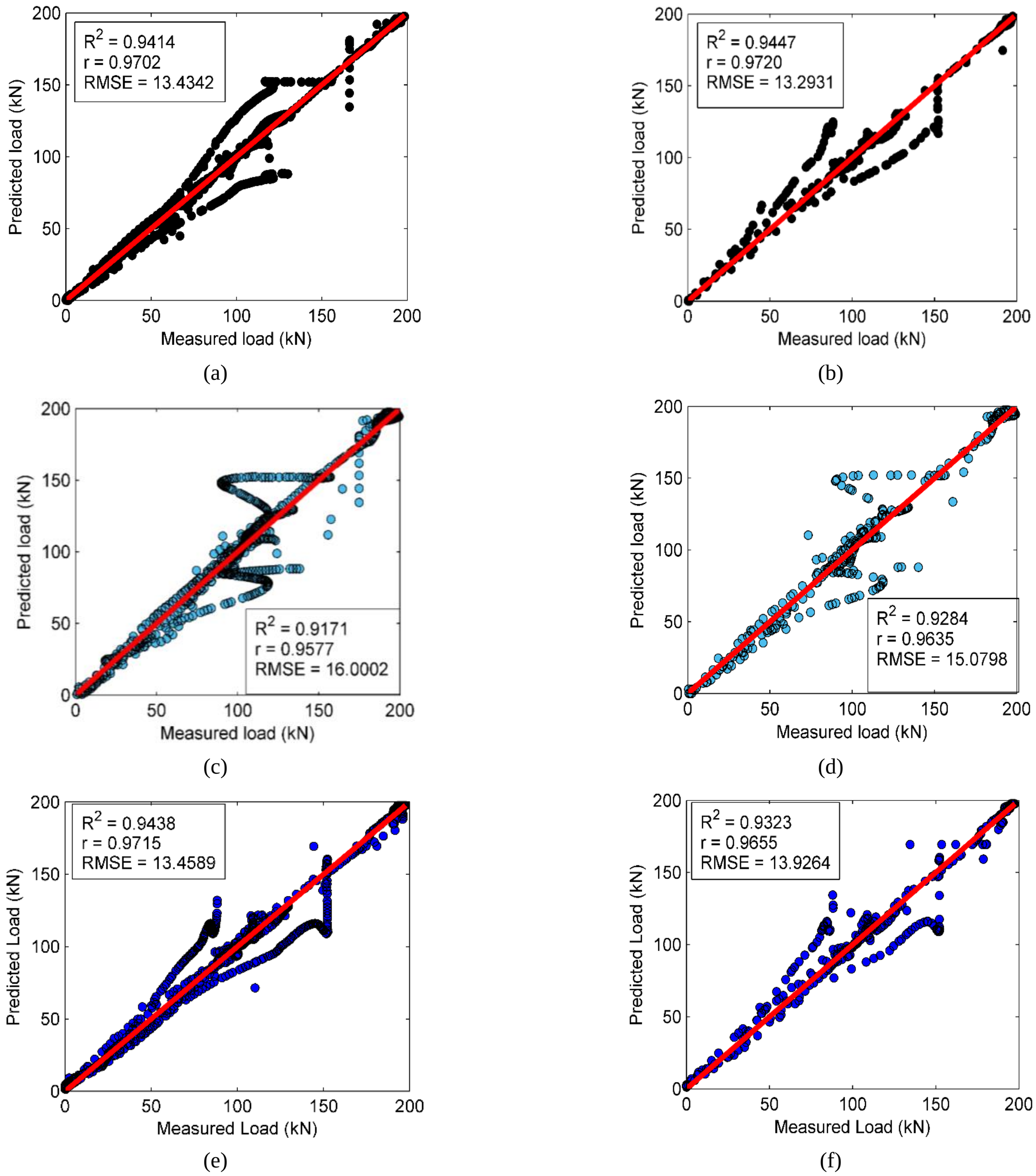


Fig. 6 Results of the artificial intelligence methods: (a) Training phase of the ELM; (b) Testing phase of the ELM; (c) Training phase of GP; (d) Testing phase of GP; (e) Training phase of ANN; (f) Testing phase of ANN

Table 7 Comparison of the performance indices obtained from ELM, GP, and ANN

AI Models	Training phase			Testing phase		
	R^2	*r*	*RMSE*	R^2	*r*	*RMSE*
ELM	0.9414	0.9702	13.4342	0.9447	0.9720	13.2931
GP	0.9171	0.9577	16.0002	0.9284	0.9635	15.0798
ANN	0.9438	0.9715	13.4589	0.9323	0.9655	13.9264

the performance indices in the testing and training phase of the ELM represents the high reliability of the ELM.

Fig. 6(c) shows the result of the GP in the training phase. The performance indices in this phase were obtained equal to R^2 = 0.9171 and r = 0.9577, and *RMSE* = 16.0002. Fig. 6(d) shows the results of the GP in the testing phase with R^2 = 0.9284 and r = 0.9635, and *RMSE* = 15.0798. High values of R^2 and r and the low value of *RMSE* implies the excellent performance of the GP in both of the phases.

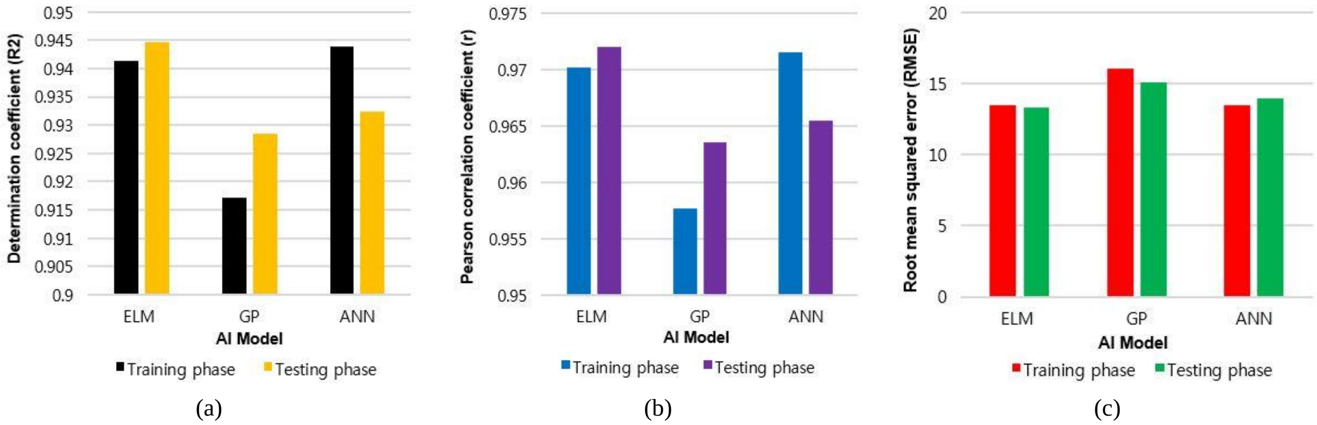


Fig. 7 Comparison of the performance indices in the training and testing phase: (a) Determination coefficient (R^2); (b) Pearson correlation coefficient (r); (c) Root mean squared error ($RMSE$)

Table 8 Comparison of the required time for each of the models

AI Model	ELM	GP	ANN
Required time (sec)	8.5612	187.3257	49.3654

Fig. 6(e) represents the result of the ANN, as a powerful and well-known artificial intelligence method, in the training phase. In this phase, as can be seen, the values of R^2, r, and $RMSE$ were equal to 0.9438, 0.9715, and 13.4589, respectively. Fig. 6(f) depicts the results of the ANN in the testing phase with performance indices: R^2 = 0.9323, r = 0.9655, and $RMSE$ = 13.9264. These values also reveal the acceptable performance of the ANN.

Table 7 represents a comparison of the AI models. As can be seen in this table, the best performance indices in the training phase have resulted from the ANN model. However, in the testing phase, the ELM model has shown the best performance. Among these models, GP has reached the worst results in both of the training and testing phases.

Fig. 7 illustrates the results of Table 7 in a graphical form. As can be observed in this figure, the lowest difference between performance indices in the training and testing phase has been obtained from the ELM model. This means that the ELM model has shown the most reliable performance among all the models.

The requiring time for training of the models has presented in Table 8. According to the recorded time, the fastest performance belonged to the ELM model requiring almost 8.5 sec for training. After ELM, ANN and GP had the lowest time for training, respectively.

8. Conclusions

Bearing capacity of shear connectors is a critical factor in the design of floor systems. However, the prediction of this factor is challenging under different loading conditions, especially where shear connectors are exposed to high temperatures. Hence, in such cases, having a reliable prediction of bearing capacity of shear connectors seems necessary. In the current paper, the strength (load) of the channel shear connectors at different temperatures was predicted employing the ELM, GP, and ANN. To generate the required data for the artificial intelligence (AI) models, four types of channel shear connectors with different dimension were selected, and several push-out tests were conducted at different temperatures, i.e., 25°C (ambient), 550°C, 700°C, and 850°C. Also, the load-slip behavior and failure modes of the channel connectors were evaluated. Finally, the bearing capacity of channel shear connectors at different temperatures was predicted. The results of the paper can be summarized as follows:

- Channel shear connectors showed a reliable performance at the ambient temperature. However, at higher temperatures, the shear capacity of channel connectors reduced, and ductility increased.
- By up to 550°C, the performance of channel shear connectors was acceptable, but at higher temperatures, the reduction in the shear capacity of channel connectors was significant. Also, concrete crushing has occurred in some of the cases.
- Length of the channel shear connectors was realized as the most important parameter in the bearing capacity of channel shear connectors since channel connectors with higher length showed higher bearing capacity.
- All the considered AI methods in the paper showed an excellent performance in the load prediction of channel shear connectors at different temperatures.
- The best performance indices in the training phase resulted from the ANN model. However, the best performance in the testing phase was obtained from the ELM model.
- The lowest difference between the performance indices in the training and testing phase was determined for the ELM model. This means that the ELM has shown more reliable performance in comparison with other models in the case of load prediction.
- Among the three AI models, the lowest requiring time for training was recorded from the ELM method, and after that, ANN, and GP had the lowest time, respectively. This illustrates that ELM

algorithm is a very faster algorithm than both of the evolutionary algorithms and the classic back-propagation algorithms.

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