SynerCrete'18 International Conference on Interdisciplinary Approaches
for Cement-based Materials and Structural Concrete
24-26 October 2018, Funchal, Madeira Island, Portugal

USING INTELLIGENT SYSTEM APPROACH FOR SHEAR STRENGTH FORECASTING OF STEEL FIBER-REINFORCED CONCRETE BEAMS

Ali Kheyroddin [1], Masoud Ahmadi [1], Mahdi Kioumarsi [2]

(1) Semnan University, Semnan, Iran
(2) OsloMet – Oslo Metropolitan University, Oslo, Norway

Abstract
Previous studies have shown that brittle failure in reinforced concrete buildings caused huge losses, both in human and economic terms. The appropriate use of steel fibers to a reinforced concrete beam can change the brittle behavior to a ductile behavior and significantly increase the ductility ratio. The aim of this study is to develop an intelligent system approach for shear strength estimation of steel fiber-reinforced concrete (SFRC) beams without transversal reinforcement using a large number of existing experimental results. The main parameters in this investigation are the steel fiber-volume fraction, the aspect ratio and volume of fiber, compressive strength of concrete, longitudinal reinforcement, effective depth and shear span of beams. The precision of the proposed approach is compared with other existing models for estimating the shear capacity of SFRC beams based on experimental results which showed a reasonable agreement.

1. Introduction

In recent decades different types of fiber, including natural fiber (NF), steel fiber (SF), glass fiber (GF), and synthetic fiber (SNF), were used in various field of the civil engineering concrete construction [1–3]. It is well known that concrete as a material subjected to the tensile stress conditions is brittle. The findings of the previous studies revealed that fibers can significantly boost the post-cracking behavior, flexural toughness, spalling resistance, impact resistance, shear strength, thermal characteristics, and ductility of concrete members under various types of loading conditions [4–6]. SF delays crack propagation in the concrete and noticeably enhances the tensile performance. The brittle failure in reinforced concrete (RC) structures caused huge losses, both in human and economic terms. Thus, it is necessary to prevent brittle failure and change it to ductile mode. The sufficient amount of SF in a RC beam can alter the brittle mode to a ductile behavior and enhance the ductility ratio. Up to now, many researchers have been studying the use of the steel fibers as replacement of the shear reinforcement, which will ultimately help to improve the behavior of RC beam. It is worth mentioning that the orientation, distribution, and resistance to pull out of fibers play a substantial role in the performance improvement of the steel fiber reinforced concrete (SFRC) beams [7]. Among the steel fibers types, hooked and crimped fibers have acceptable efficiency to prevent premature pull out which affects the load carrying ability. A SFRC beam with hooked/crimped fibers, when design appropriately, has superior ductility in comparison with common RC beams [8].

2. Shear capacity of SFRC beam

Several studies have been carried out to identify the effect of steel fibers on shear strength of SFRC beams without stirrups. Researchers based on the theoretical and experimental studies have been proposed several equations for determining shear strength of SFRC beams. These models are mainly categorized in two groups. In the first group, the independent contribution is assumed for steel fibers and its shear strength is added to the contribution of plain concrete and stirrups.

$$V_{SFRC-Beam} = V_c + V_S + V_{SF} \tag{1}$$

where, V_c, V_S and V_{SF} are the shear strength contribution provided by the plain concrete, transverse reinforcement, and steel fibers. The second group assumes that steel fibers influence on the shear strength of concrete. Narayanan and Darwish (1987) [9] studied the effects the steel fibers on the behavior of RC beams under predominant shear. They proposed empirical formulation for design of SFRC beams without stirrups.

$$\upsilon_u = e\left[0.24 f_{spfc} + 80\rho\frac{d}{a}\right] + \upsilon_b \tag{2}$$

where, e is arch action factor, f_{spfc} is split tensile strength of concrete, ρ is reinforcement ratio, $\frac{d}{a}$ is effective depth-to-shear span ratio, and υ_b is calculated based on average bond stress. The arch action factor is 1.0 for $\frac{a}{d} > 2.8$ and $2.8\frac{d}{a}$ for $\frac{a}{d} \leq 2.8$. Khuntia et al. (1999) [10] developed a design equation for calculating the ultimate shear strength of SFRC beams based on the basic shear transfer mechanisms and large number of experimental results. They proposed the following equation for determining shear capacity of SFRC beams without transverse reinforcement:

$$\upsilon_u = (0.167\alpha + 0.25\beta v_f \frac{l_f}{d_f})\sqrt{\acute{f_c}} \tag{3}$$

where, α is arch action factor, v_f is fiber volume fraction, β related to fiber shape and concrete type, $\acute{f_c}$ is compressive strength of concrete, and $\frac{l_f}{d_f}$ is fiber length-to-fiber diameter ratio. Ultimate shear capacity of SFRC beams without stirrups can be determined according to Sharma (1986) [11] from the following equation:

$$v_u = \frac{2}{3}\acute{f}_t\left(\frac{d}{a}\right)^{0.25} \tag{4}$$

where, $\acute{f}_t$ is split-cylinder tensile strength of concrete, and $\frac{d}{a}$ is effective depth-to-shear span ratio.

3. Group method of data handling (GMDH)

GMDH neural network is a self-organizing black-box learning technique proposed by Ivakhnenko in 1971 [12]. Artificial neural networks is a superior tool in forecasting (any non-linear functions or features) and data mining [13–15]. The discrete form of the GMDH model is given in following equation:

$$\bar{y} = a_0 + \sum_{i=1}^{n} a_i f_i \tag{5}$$

where *a* is coefficient, *f* is the basic function based on different sets of inputs, and *n* is the number of the base function components. The Kolmogorov-Gabor (KG) polynomial is the most popular base function used in GMDH approach. The KG-form of equation 5 based on input vector $X(x_1, x_2, x_3, \dots, x_n)$ can be expressed as following equation:

$$\bar{y} = a_0 + \sum_{i}^{n} a_i\, x_i + \sum_{i}^{n}\sum_{i}^{n} a_{ij} x_i x_j + \sum_{i}^{n}\sum_{i}^{n}\sum_{i}^{n} a_{ijk} x_i x_j x_k + \cdots \tag{6}$$

where a_i, a_j, and a_k are the weighting coefficients. The GMDH algorithm is considered as a feedforward multilayer network with low-degree polynomial activation function. The outcomes of the first layer is computed based on only two input variables using partial quadratic polynomial function as given in following:

$$z = z(x_i, x_j) = s_0 + s_1 x_i + s_2 x_j + s_3 x_i x_j + s_4 x_i^2 + s_5 x_j^5 \tag{7}$$

The coefficients of partial function are determined utilizing the least squares method to minimize the difference between real and estimated value for each pair of the input vectors.

4. Experimental database

In order to calculate the average shear stress of steel fiber-reinforced concrete beams without transversal reinforcement, 112 experimental results were gathered from the previous studies. A summary range of mechanical-geometric properties of beams is given in Table 1. The considered parameters include: 1) Shear span-effective depth ratio (a/d), 2) Effective depth of beams (*d-mm*), 3) Longitudinal reinforcement ratios (ρ), 4) Compressive strength of concrete (f_c'-*MPa*), 5) Fiber ratio (F_{SF}). Fiber ratio is determined as follows:

$$F_{SF} = V_{SF}\, {}^{L_{SF}}/_{d_{SF}} \tag{8}$$

where, d_{SF} and L_{SF} are diameter and length of steel fiber, and V_{SF} is volume percentage of fibers.

Table 1. Range of input parameters for network application

Reference	No. of test data	d (mm)		a/d		ρ (%)		f'c (MPa)		F_{SF}		$v_{exp}(MPa)$	
		Min	Max.	Min	Max	Min	Max	Min.	Max.	Min.	Max.	Min.	Max.
[16]	12	197	197	2	3.6	1.3	2	20.6	33.4	30	60	1.5	3.11
[9]	31	126	130	2	3.5	2	5.72	31.9	63.6	25	200	1.94	7.15
[17]	8	215	215	2	4	2.8	4.58	75.0	79.2	37.5	112.	2.27	7.21
[18]	2	204	204	3	3	2.2	2.2	22.7	26	60	100	3.05	3.05
[19]	4	340	340	2	2.5	3.4	3.44	33	36	30	60	3.78	5.34
[20]	7	265	265	2	4.91	1.5	4.31	33.1	40.9	100	100	2.92	5.51
[21]	9	212	212	2	4	1.5	1.5	30.8	68.6	31.2	46.8	2	5.44
[22]	17	260	305	2.5	4	1.0	3.55	26.5	47.6	11.2	48.7	1.57	3.03
[23]	4	219	219	2	2.8	1.9	1.92	40.9	43.2	60	120	2.93	3.52
[24]	10	381	381	3.4	3.5	1.9	2.67	31	49.2	60	90	2.53	3.77
[25]	8	381	381	3.4	3.5	2	2.7	31	44.9	41.2	82.5	2.6	3.4

5. The GMDH-based equation

In order to construct GMDH network and preventing overfitting, the database was divided randomly in two sets. The overfitting occurs when the error on the training set is driven to a very small value, but when new data is presented to the network the error is large. 74 experimental data were considered for training state and remaining data for testing state. Shear span-effective depth ratio, effective depth of beams, longitudinal reinforcement ratios, concrete compressive strength of standard cylinder, and fiber ratio were utilized as the input variables of the model, and average shear stress of SFRC beam was chosen as the target variable. Shear stress can be obtained using the following equations:

$$\begin{aligned} v_{GMDH} = 2.273 + 4 * 10^{-6} d^2 - (1.92 + 0.26\rho + 0.013\acute{f}_c - 0.38\, {}^{a}/_{d})\, {}^{a}/_{d} \\ + (0.84 + 0.00185F_{SF})\rho + 0.07\acute{f}_c + (0.025 - 0.0001F_{SF})F_{SF} \end{aligned} \tag{9}$$

In order to verify and quantify the proposed relationship, the predicted values were compared with the three existing models introduced in Section 2 based on a broad range of experimental results. The simulated shear stress compared to the existing equations are plotted in Figure 1. It is found that, the proposed GMDH-based formulation demonstrated the most optimized result compared to all of the other existing formulations. The average absolute error of the GMDH formulation for determining the experimental results is equal to 10% while the average error for the other three models including Narayanan and Darwish, Khuntia et al., and Sharma are 14.70%, 30.96%,and 22.34% respectively. It should be noted that the best performance of the proposed equation is addressed in the considered ranges of the input parameters.

6. Conclusion

In this paper, a new formulation is developed to determine average shear stress of SFRC beams without web reinforcement. Five input parameters representing shear span-effective depth ratio, effective depth of beams, longitudinal reinforcement ratios, compressive strength of concrete, and fiber ratio were considered as input vectors. In order to overcome overfitting issue, the database was divided randomly in training and testing sets. The results of comparative assessment between existing equations and proposed method reveal that the GMDH model has acceptable ability to determine average shear stress. Finally, it could be concluded that the GMDH-based formulation can be utilized as an alternative method in the pre-design of SFRC beams.

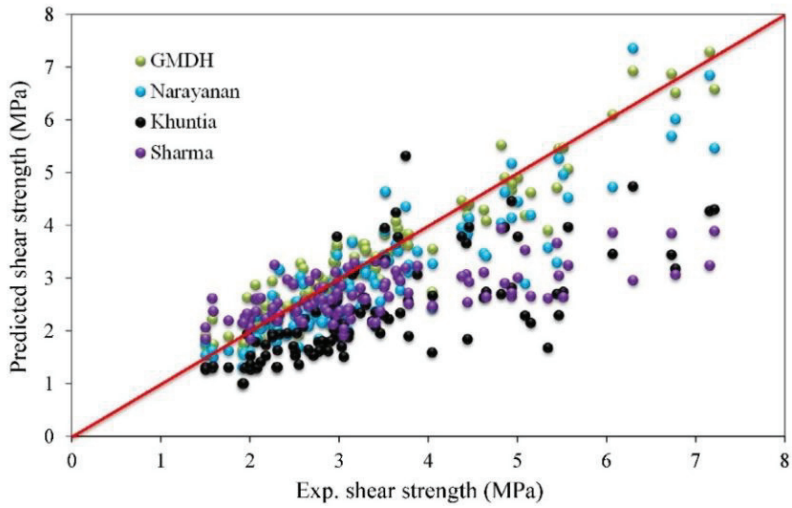

Figure 1. Experimental value against predicted shear strengths

References

[1] M. Shahnewaz, M.S. Alam, Improved shear equations for steel fiber-reinforced concrete deep and slender beams, ACI Struct. J. 111 (2014) 851.

[2] F. Pacheco-Torgal, S. Jalali, Cementitious building materials reinforced with vegetable fibres: A review, Constr. Build. Mater. 25 (2011) 575–581.

[3] C.-C. Chen, C.-Y. Li, Punching shear strength of reinforced concrete slabs strengthened with glass fiber-reinforced polymer laminates, ACI Struct. J. 102 (2005) 535.

[4] E. Cuenca, J. Echegaray, P. Serna, A. Pasetto, Ductility analysis on the post-peak behavior of self-compacting fiber reinforced concrete (SCFRC) beams subjected to shear, in: 8th RILEM Int. Symp. Fibre Reinf. Concr. Challenges Oppor. (BEFIB 2012), 2017.

[5] A. Hemmati, A. Kheyroddin, M. Sharbatdar, Y. Park, A. Abolmaali, Ductile behavior of high performance fiber reinforced cementitious composite (HPFRCC) frames, Constr. Build. Mater. 115 (2016) 681–689.
[6] A. Hemmati, A. Kheyroddin, M.K. Sharbatdar, Plastic hinge rotation capacity of reinforced HPFRCC beams, J. Struct. Eng. 141 (2013) 4014111.
[7] H. Singh, Steel Fiber Reinforced Concrete: Behavior, Modelling and Design, Springer, 2016.
[8] S.-H. Cho, Y.-I. Kim, Effects of steel fibers on short beams loaded in shear, Struct. J. 100 (2003) 765–774.
[9] R. Narayanan, I.Y.S. Darwish, Use of steel fibers as shear reinforcement, Struct. J. 84 (1987) 216–227.
[10] M. Khuntia, B. Stojadinovic, S.C. Goel, Shear strength of normal and high-strength fiber reinforced concrete beams without stirrups, Struct. J. 96 (1999) 282–289.
[11] A.K. Sharma, Shear strength of steel fiber reinforced concrete beams, in: J. Proc., 1986: pp. 624–628.
[12] A.G. Ivakhnenko, Polynomial Theory of Complex Systems, IEEE Trans. Syst. Man. Cybern. SMC-1 (1971) 364–378. doi:10.1109/TSMC.1971.4308320.
[13] M. Ahmadi, H. Naderpour, A. Kheyroddin, Utilization of artificial neural networks to prediction of the capacity of CCFT short columns subject to short term axial load, Arch. Civ. Mech. Eng. 14 (2014) 510–517. doi:10.1016/j.acme.2014.01.006.
[14] M. Ahmadi, H. Naderpour, A. Kheyroddin, ANN Model for Predicting the Compressive Strength of Circular Steel-Confined Concrete, Int. J. Civ. Eng. 15 (2017) 213–221. doi:10.1007/s40999-016-0096-0.
[15] A. Kheyroddin, H. Naderpour, M. Ahmadi, Compressive strength of confined concrete in CCFST columns, J. Rehabil. Civ. Eng. 2 (2014) 106–113.
[16] M.A. Mansur, K.C.G. Ong, P. Paramasivam, Shear strength of fibrous concrete beams without stirrups, J. Struct. Eng. 112 (1986) 2066–2079.
[17] S.A. Ashour, G.S. Hasanain, F.F. Wafa, Shear behavior of high-strength fiber reinforced concrete beams, Struct. J. 89 (1992) 176–184.
[18] V.C. Li, R. Ward, A.M. Hamza, Steel and synthetic fibers as shear reinforcement, ACI Mater. J. 89 (1992) 499–508.
[19] K.H. Tan, K. Murugappan, P. Paramasivam, Shear behavior of steel fiber reinforced concrete beams, Struct. J. 90 (1993) 3–11.
[20] R.N. Swamy, R. Jones, A.T.P. Chiam, Influence of steel fibers on the shear resistance of lightweight concrete I-beams, Struct. J. 90 (1993) 103–114.
[21] Y.-K. Kwak, M.O. Eberhard, W.-S. Kim, J. Kim, Shear strength of steel fiber-reinforced concrete beams without stirrups, ACI Struct. J. 99 (2002) 530–538.
[22] D. Dupont, L. Vandewalle, Shear capacity of concrete beams containing longitudinal reinforcement and steel fibers, Spec. Publ. 216 (2003) 79–94.
[23] C. Cucchiara, L. La Mendola, M. Papia, Effectiveness of stirrups and steel fibres as shear reinforcement, Cem. Concr. Compos. 26 (2004) 777–786.
[24] H.E. Yakoub, Shear stress prediction: Steel fiber-reinforced concrete beams without stirrups, ACI Struct. J. 108 (2011) 304.
[25] H.H. Dinh, G.J. Parra-Montesinos, J.K. Wight, Shear Behavior of Steel Fiber-Reinforced Concrete Beams without Stirrup Reinforcement, ACI Struct. J. 107 (2010).