Shear Capacity of High-Strength Concrete Slender Beams without Transverse Reinforcement

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ABSTRACT

In the present study, a new model is derived to estimate the shear capacity of high-strength concrete slender beams without transverse reinforcement using a hybrid adaptive neuro-fuzzy inference system (ANFIS) and particle swarm optimization (PSO) based on the wide range of experimental results. The proposed model relates the shear capacity of beam to effective depth, the compressive strength of concrete, percent of longitudinal reinforcement, the ratio of shear span to effective depth, and nominal maximum size of coarse aggregate. The experimental data are randomly categorized into two subsets of the training set and test set. After establishing the proposed model, a sensitivity analysis was carried out to assess the validity of the proposed ANFIS-PSO model. For this purpose, the results of the proposed model are calculated by considering the variation of the two selected input parameters, whereas the values of other parameters are fixed at the corresponding median values. To check reliability of the proposed model more accurately, the predicted values are compared with the codes and standards such as: ACI 318-14, Eurocode-2, CEB-FIP Model Code, AS 3600-2009, and JSCE Guidelines against the whole experimental specimens based on the three well-known statistical measures; correlation coefficient (R^2), root mean squared error (RMSE), and mean absolute percentage error (MAPE). It can be found that the proposed ANFIS-PSO model passed desired conditions and could estimate the shear capacity of the high-strength concrete slender beams without transverse reinforcement with a good degree of accuracy.

KEYWORDS

Slender beam, shear capacity, high-strength concrete, adaptive neuro-fuzzy, particle swarm optimization.

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1. Introduction

Precise determination of shear strength is not easy to calculate due to the complexity of the shear transfer mechanism in the reinforced concrete members, and hence numerous models and approaches have been developed in this regard [1-4]. Most of the relationships have been established based on a limited number of experimental results or using numerical and analytical methods. In the other hand, the comparison results of some models with the experimental results shows their inadequate reliability, which can be due to simplifications in the complicated shear transfer mechanism, accuracy within a limited range of shear span (a) to effective depth (d) ratio, and lack of consideration of all effective parameters in shear capacity. The slender beam can be considered as the beams in which the ratio of shear span to the effective depth is greater than 2.5 [5].

In recent years, the structural designers have shown considerable interest in the use of high strength concrete (HSC). Although there is no unique criterion for determining the point of separation between normal and high strength concrete, which is approved by the codes, the HSC may be characterizes as concrete with compressive strength in the range of 50 to 100 MPa. In this paper, HSC has a compressive strength greater than 40 MPa, based on the recommendation in ACI 363R-10 [6].

Computational intelligence is an efficient tool to solve complex problems with an appropriate level of precision. So far, a large number of experimental investigations have been performed to study the effect of mechanical and geometrical properties on the shear strength of slender beams and addressed major parameters that contribute to the purpose of the present study. In this paper, a new approach is derived to estimate the shear capacity of high-strength concrete slender beams without transverse reinforcement using a hybrid adaptive neuro-fuzzy inference system (ANFIS) and particle swarm optimization (PSO).

2. Experimental Database

Various experimental studies have been carried out in recent decades on high strength concrete beams without transverse reinforcement, which have given rise to new relationships and increased reliability. The results of studies revealed that the main affecting parameters on shear strength are compression strength of concrete, the ratio of shear span to effective depth, amount of longitudinal rebars, and cross sectional dimension of beam.

Only experimental results meeting the following criteria are included in the database:

- The beams with a/d greater than 2.5 were considered.
- The slender RC beams were without transverse reinforcement.
- The predominant failure mode is shear.
- The beams should be tested under a monotonically increased concentrated load to avoid dynamic effects on failure.

3. Hybrid ANFIS-PSO

3.1. Details of Membership Functions

The Gaussian type of membership functions is used for the input and output parameters.

$$\mu(x;\sigma,c)=\exp\left(-\frac{(x-c)^2}{2\sigma^2}\right) \qquad (1)$$

where, c and σ are the center and variance of the each parameters. The detail of each membership function is presented in Table 1.

3.2. Linear Functions

The proposed ANFIS-PSO model uses fuzzy c-means clustering to generate a fuzzy inference system with five clusters as a linear function:

$$CL_j = a_1X_1 + a_2X_2 + a_3X_3 + a_4X_4 + a_5X_5 + C \quad j=1,2,3,4,5 \qquad (2)$$

3.3. Fuzzy Rule Base

Five rules are considered in the proposed model, which are presented in Table 2.

4. Results and Discussion

The training and testing phases of the ANFIS-PSO model were done using 139 and 46 samples, respectively. The optimum system has 50 and 30 unknown parameters for the membership and output functions, respectively. The comparison of the predicted results of the test dataset is presented in Figure 1. Results indicate that the proposed hybrid ANFIS–PSO approach has a high accuracy against the test dataset. The MAPE of training and testing data are 6.24, and 10.87, respectively, which show a reasonable agreement between calculated and actual values.

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Table 1. Setting parameters of Gaussian membership function

Membership function	d		a/d		a_g		f'c		ρ	
	σ	c	σ	c	σ	c	σ	c	σ	c
C1	0.0359	0.2651	0.2239	0.232	0.1386	0.2742	0.1676	0.3941	0.0306	0.4401
C2	0.2128	0.3751	0.2346	0.3695	0.253	0.5196	0.2917	0.3306	0.0724	0.3999
C3	0.1773	0.3277	0.0875	0.3104	0.0517	0.2589	0.189	0.4707	0.1501	0.6053
C4	0.1254	0.3753	0.1851	0.6923	0.1086	0.5846	0.0353	0.2783	0.207	0.1946
C5	0.0642	0.0609	0.1575	0.1243	0.2569	0.2971	0.1642	0.4957	0.1763	0.709

Table 2. Rules of ANFIS-PSO model.

Number	Rule
1	$If\ \ d\ is\ C1_d\ and\ a/d\ is\ C1_{a/d}\ and\ a_g\ is\ C1_{a_g}\ and\ f'_c\ is\ C1_{f'_c}\ and\ \rho\ is\ C1_\rho\ then\ \upsilon\ is\ CL_1$
2	$If\ \ d\ is\ C2_d\ and\ a/d\ is\ C2_{a/d}\ and\ a_g\ is\ C2_{a_g}\ and\ f'_c\ is\ C2_{f'_c}\ and\ \rho\ is\ C2_\rho\ then\ \upsilon\ is\ CL_2$
3	$If\ \ d\ is\ C3_d\ and\ a/d\ is\ C3_{a/d}\ and\ a_g\ is\ C3_{a_g}\ and\ f'_c\ is\ C3_{f'_c}\ and\ \rho\ is\ C3_\rho\ then\ \upsilon\ is\ CL_3$
4	$If\ \ d\ is\ C4_d\ and\ a/d\ is\ C4_{a/d}\ and\ a_g\ is\ C4_{a_g}\ and\ f'_c\ is\ C4_{f'_c}\ and\ \rho\ is\ C4_\rho\ then\ \upsilon\ is\ CL_4$
5	$If\ \ d\ is\ C5_d\ and\ a/d\ is\ C5_{a/d}\ and\ a_g\ is\ C5_{a_g}\ and\ f'_c\ is\ C5_{f'_c}\ and\ \rho\ is\ C5_\rho\ then\ \upsilon\ is\ CL_5$

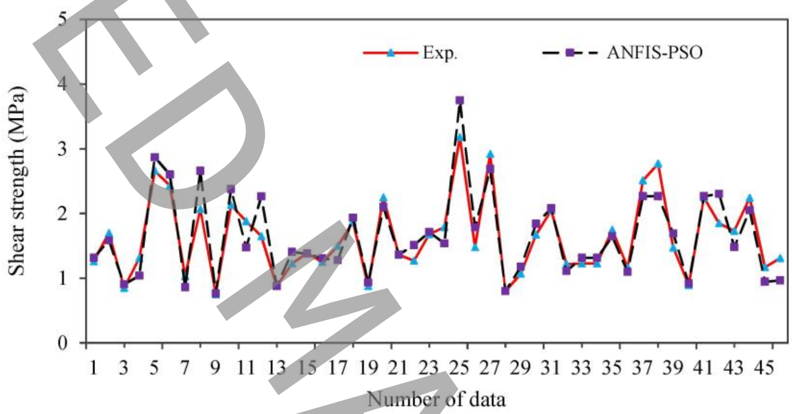

Figure 1. Comparison of ANFIS-PSO versus test data.

5. Conclusions

In this study a new model has been proposed to predict the shear strength of high-strength concrete slender beams without transverse reinforcement using hybrid adaptive neuro-fuzzy inference system and particle swarm optimization algorithm. The input variables in the developed ANFIS-PSO model based on an experimental database are effective depth (mm), span-to-effective depth ratio, maximum size of aggregate (mm), compressive strength of concrete (MPa), and percentage of longitudinal rebars. The average error for the new model for estimating the training and testing dataset are equal to 6.24% and 10.87, respectively. The results show that more than 80% of the simulated results have less than 15% error.

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