Amirkabir Journal of Civil Engineering

Amirkabir J. Civil Eng., 53(9) (2021) 853-856
DOI: 10.22060/ceej.2020.18122.6775

Prediction of shear strength of deep beams of the reinforced concrete using weighted least squares support vector machine method

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ABSTRACT: The shear strength of deep reinforced concrete beams depends on the mechanical and geometrical properties of the beam. Accurate estimation of shear strength in deep reinforced concrete beams is one of the major issues in the design of engineering structures. However, some methods proposed to determine the shear strength in deep reinforced concrete beams do not have high accuracy. One method to accurately estimate shear strength is to use artificial intelligence (AI). Artificial intelligence has many different methods, one of which is the use of artificial intelligence-based on the support vector machine method. In this study, the weighted least squares support vector machine (WLS-SVM), which is a relatively new and efficient method for predicting the shear capacity of reinforced concrete beams, has been used. In this study, a database containing experimental results on deep reinforced concrete beams was first collected. Then, after determining the input and output parameters using a training process in WLS-SVM method and using a part of the collected data, a model was developed to predict the shear strength of deep reinforced concrete beams. In order to determine the accuracy of the WLS-SVM method, the results were compared with those obtained by other AI methods and different regulations. Statistical analysis showed that WLS-SVM has the best performance in terms of statistical evaluation parameters (R2 = 0.9887, RMSE = 0.107, MAE = 0.478 and MAPE = 9.48%) compared to the other method.

Review History:

Received: Mar. 16, 2020
Revised: Jul. 13, 2020
Accepted: Nov. 02, 2020
Available Online: Nov. 03, 2020

Keywords:

Deep beam of reinforced concrete
Shear strength
Artificial intelligence
Weighted least squares support vector machine

1- Introduction

Reinforced concrete deep beams are often used as structural members and load-distributing elements. It is difficult to create a general model to provide and accurately estimate the shear strength due to the complexity of the shear mechanism of deep reinforced concrete beams and the types of parameters affecting it [1]. In recent decades, artificial intelligence (AI) has been the subject of extensive research in the field of civil engineering. AI successfully simulates complex problems, so it has become a powerful predictive method. The support vector machine (SVM) method is one of the most important methods in the field of artificial intelligence and nonlinear modeling, which in recent years has shown good efficiency compared to older methods such as neural networks for classification and estimation of functions [2]. Studies conducted in civil engineering on machine learning as an advanced modeling tool include the studies of Chou et al., Hoang et al., And Khatibinia and Araghi [3-5]. The least squares support vector machine (LS-SVM) is an extension of SVM that includes several advanced features and its capability has been demonstrated by fast calculations [6]. The weighted least squares vector machine (WLS-SVM) method is the LS-SVM weighted mode. In the present study, the performance of WLS-SVM is first examined and then the results of the prediction made by this method are evaluated and compared with the results of existing regulations and different methods of artificial intelligence available in the technical literature.

2- Laboratory data

In this study, the data set includes 214 test results of reinforced concrete deep beams. Input variables in WLS-SVM method corresponding to the parameters affecting the shear capacity of deep reinforced concrete beams were selected based on the regulations.

3- Research Methodology

Support vector machines (SVM) belong to the group of supervised models as one of the most powerful methods in machine learning. SVM has two main drawbacks: 1) the inability in exact regulating of kernel parameter and 2) their reliance on backup vectors alone to determine the decision boundary. Suykens et al. [6] solved various problems by introducing weighted least squares support vector machines (WLS-SVM), in which the LS-SVM method was improved by assigning weight to error variables. Considering the training sample data set equal to N, $\{(x_k, y_k)\}_{k=1}^{N}$ and with input data $x_i \in R^d$ and output data $y_i \in R$, WLS-SVM regression is formulated as an optimization problem in the initial weight space [7]:

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$$Minimize: J(w.e) = \frac{1}{2}w^T w + \frac{1}{2}\gamma\sum_{i=1}^{N}\bar{v}_i e_i^2$$
$$subjectedto: y_i = w^T\phi(x_i) + b + e_i \quad (1)$$
$$i = 1, 2, \cdots, N$$

Where $\phi(0): R^d \to R^{\bar{d}}$ is the operator that maps the input data space to higher dimensional spaces is provider of a weight function for the initial weight space. $b \in R$ And $e_i \in R$ provide error variables and one-way semester, respectively. In the initial weight space, the WLS-SVM method with the problem of optimization (Equation 1) and training is expressed as follows:

$$y(x) = w^T\phi(x) + b \quad (2)$$

4- Analysis of results

In this study, the data set was randomly divided for training and validation using k-fold cross-validation (k=3). The results of WLS-SVM method in training and validation phase are shown in Figures 1-a and 1-b, respectively.

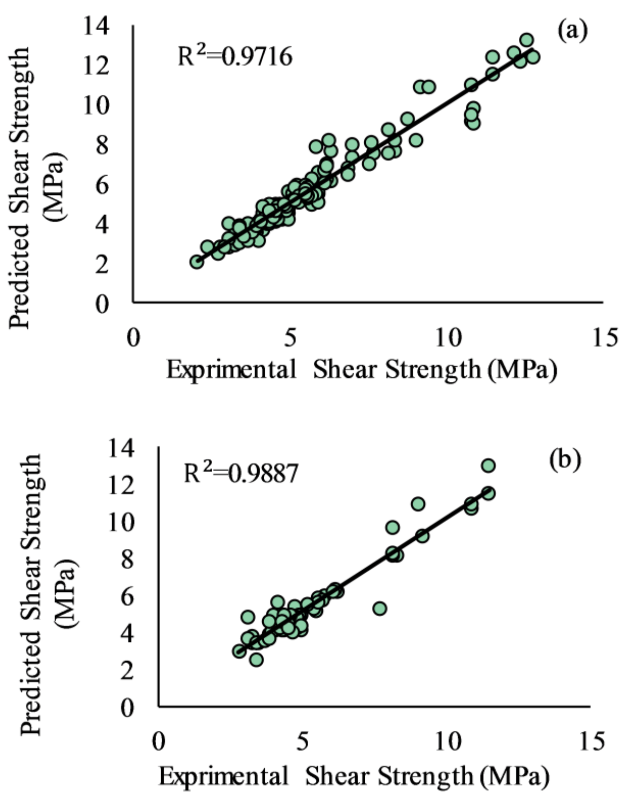

Fig. 1. Comparison of shear capacity predicted in the present study with laboratory shear capacity values (a) Results from the training phase of data (b) Results from the data validation phase

Table 1. Comparison of prediction results obtained from WLS-SVM method with the results in different regulations and artificial intelligence methods

Method	$\frac{Vactual}{Vpredicted}$	MAPE (%)	MAE (MPa)	Ref[1]
ACI318-11	0.571	16.21	1.225	[8]
CSA	0.574	18.91	0.825	[9]
GSA	0.147	10.87	0.506	[1]
Optimized SVM	0.9189	8.26	0.4035	[10]
MLR-Reg Tree	0.9285	10.00	0.5150	[10]
WLS-SVM	0.998	9.48	0.478	C.S.[2]

[1]Refrence, [2]Current Study

The results show that the WLS-SVM method with a value of R^2=0.9716 in the experimental stage and a value of R^2=0.9887 in the validation stage (R^2>0.95) has achieved very good results for the trained model. Comparison of results obtained from WLS-SVM method, CSA and ACI regulations, results from gravitational search algorithm (GSA), SVM method using SOS optimizer and multiple linear regression method (Tree MLR-Reg) is shown in Table 1. According to Table 1, it can be seen that the WLS-SVM method has better results than other comparison methods of artificial intelligence and CSA and ACI regulations.

5- Conclusions

In this study, a new artificial intelligence method called WLS-SVM was used to predict the shear strength of deep concrete beams. Using eight different input parameters in WLS-SVM method, the values of coefficients R2, RMSE, MAEP and MAE for this method were calculated. Comparison of the results obtained from this method with other artificial intelligence methods as well as different regulations show that the accuracy of the WLS-SVM method with the square root of the mean square error is RMSE= 0.107, the coefficient of determination is R2= 0.9887, the percentage of mean absolute error is MAEP =9.48% and mean absolute error MAE =0.478 is much higher than other existing artificial intelligence methods and regulations.

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HOW TO CITE THIS ARTICLE

M. R. Mohammadizadeh, F. Esfandnia, Prediction of shear strength of deep beams of the reinforced concrete using weighted least squares support vector machine method, Amirkabir J. Civil Eng., 53(9) (2021) 853-856

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