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Prediction of Shear Capacity of Reinforced Concrete Beams using Support Vector Regression and Adaptive Neuro-Fuzzy Inference Algorithms Optimized with Meta-Heuristic Algorithms

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ABSTRACT: Considering the complexity of shear mechanisms of reinforced concrete beams and the effects of various parameters, creating a general model for the accurate estimation of the shear capacity is difficult. In addition, most guidelines for the determination of the shear capacity of reinforced concrete beams in empirical design codes have been obtained experimentally. Artificial intelligence algorithms have been widely used in this area in recent years. In this study, SVR, PANFIS, and GANFIS algorithms were used to predict the shear capacity of reinforced concrete beams. In this regard, the data of 175 experimental RC beam samples were collected. In these algorithms, values of nine parameters affecting shear capacity were used as the input parameter and the shear capacity of the reinforced concrete beams as the output parameter. Using the Kfold validation method, training and test data were defined, and the predictions were performed accordingly. The results of predictions showed that the neuro-fuzzy inference system model with the genetic optimization algorithm had a higher accuracy than other algorithms with a second root mean square error of 0.06634 and a correlation coefficient of 0.996. Also, the grey system theory was used to determine the parametric sensitivity of the study variables on the shear capacity of reinforced concrete beams. The results showed that the mean coefficient of sensitivity analysis of the longitudinal rebar percentage parameter is greater than other parameters, indicating that the longitudinal rebar percentage parameter had more effects on shear capacity.

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1. INTRODUCTION

Since shear mechanisms of reinforced concrete beams (RCs) are very complex, it is difficult to develop a general model capable of estimating the shear capacity accurately. Improving prediction performance is significantly important when designing reinforced concrete beams. Recently, artificial intelligence (AI) algorithms were proposed as one of the key strategies that can provide an acceptable model for this purpose [1]. Accordingly, many emphasized the successful application of artificial intelligence in civil engineering including the work of Dao *et al.*, Moshiri and Ala, Sogana *et al.*, and Naderpour and Mirshid [2-5]. In the present paper, first, we studied the parameter sensitivity analysis, and then, the performances of three different artificial intelligence algorithms (SVR, PANFIS, and GANFIS) were investigated. Finally, the obtained results about the prediction performance of these algorithms were analyzed and compared with each other.

2. EXPERIMENTAL DATA

The experiment data are applied as input and output data to conduct the sensitivity analysis on the given parameters using the GST algorithm and predict the shear capacity of reinforced concrete beams using SVR, PANFIS, and GANFIS algorithms. Experimental data obtained from 175 reinforced concrete beams with shear reinforcement have been used for this purpose [6].

3. SENSITIVITY ANALYSIS USING GST (GREY SYSTEM THEORY)

The process of analyzing a particular relationship or a particular model and also examining the impact of changes on each parameter in the model output is called sensitivity analysis. In this section, a numerical model of GST theory [7] is used to determine the parametric sensitivity of variables investigated to determine the shear capacity of reinforced concrete beams. In this theory, λ is used as an indicator of the relationship between independent and dependent variables. The closer the value gets to 1, the stronger the correlation between the two variables. According to the above explanation, the diagram of correlations between each independent parameter and the shear capacity was indicated in Fig. 1. It can be seen that the maximum value is related to the percentage of longitudinal reinforcement (ρ_l).

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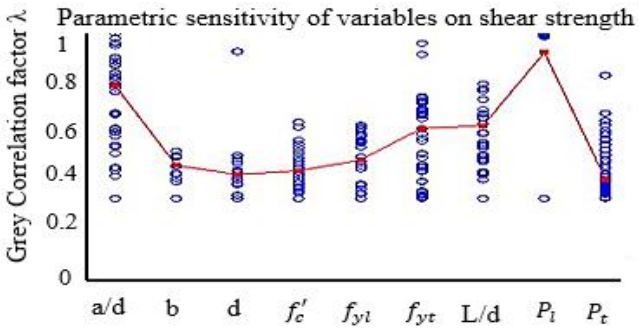

Fig. 1. Parametric sensitivity analysis for key variables of shear capacity

Table 1. Comparison of results obtained by using SVR, PANFIS, GANFIS, ANN algorithms, and ACI-318-02 and CSA regulations

Method	Reference	*RMSE*	R^2
SVR	Present study	0.0994	0.925
PANFIS	Present study	0.07541	0.986
GANFIS	Present study	0.06634	0.996
ACI	[6]	0.14	0.87
CSA	[6]	0.114	0.82
ANN	[6]	0.097	0.96

4. PREDICTING THE SHEAR CAPACITY OF REINFORCED CONCRETE BEAMS WITH SVR, PANFIS, AND GANFIS ALGORITHMS

4.1. Support vector regression (SVR)

Support vector regression is a machine learning algorithm that works based on statistical training theory. This algorithm is one of the supervised training algorithms and connects the input data to the dependent parameter values by minimizing the structural risk. A kernel function is used to solve the operating issue of this algorithm in a high-dimensional space. The purpose of SVR is to estimate the weights and the slopes parameters of the function that have the best compatibility with the data [8].

4.2. An adaptive neuro-fuzzy inference system

The fuzzy inference system (FIS) is introduced as a nonlinear mapping of the input space to the output space. The mapping mechanism is based on converting input parameters from the numerical scale to fuzzy scale using three functional components including (1) a set of rules that consisting of fuzzy rules; (2) a database defining the membership functions (MFs) used in fuzzy rules; and (3) a reasoning mechanism that use the inference method based on the rules to obtain an output. The ANFIS algorithm was applied based on the adaptive network's framework [9]. The ANFIS algorithm uses the advantages of neural networks and fuzzy systems. In this algorithm, data training is considered as a major challenge. Hence, meta-heuristic algorithms with a random search nature may be used as an alternative and useful choice of algorithms. The weights obtained from the previous fuzzy parameters and the linear parameters C_i are adjusted through the heuristic algorithms to solve the optimization problem caused by using PSO and GA algorithms.

4.3. Particle swarm optimization Algorithm (PSO)

The particle swarm optimization Algorithm is considered as one of the most important algorithms in the field of swarm intelligence. This algorithm was introduced by Kennedy *et al.* (1995) and was designed by inspiring the social behavior of animals such as fish and birds that live in small and large groups. This algorithm works based on the fact that in every moment, each particle adjusts its location on the search space by comparing the best location it has positioned into and the best location in all its neighborhoods [10].

4.4. Genetic algorithm (GA)

The genetic algorithm is one of the first evolutionary algorithms, which was defined based on the genetic process of individuals [11]. To solve the problems, the genetic algorithms simulate the "survival of the fittest" principle among members of a population over successive generations. Each generation consists of a string of characters that their functions are similar to DNA chromosomes. Each person represents a point in the search space and a possible solution. Members of each generation also go through a process similar to that of living things.

5. PREDICTION ALGORITHMS ANALYSIS

5.1. Validation method

In the present study, the dataset was divided randomly for training and testing purposes with the use of k-fold cross-validation (k = 10). In each iteration, one subset was used for the validation process, while the other nine subsets were used for the training process. In total, 157 data were randomly selected for the training part and the rest of the data were used for testing.

5.2. Results analysis

In this section, the obtained results of the prediction performance of SVR, PANFIS, and GANFIS algorithms were compared with the shear capacity defined in the ACI [12] and CSA [13] construction regulation. The root mean square error (*RMSE*) and the coefficient of determination (R^2) values are presented in Table 1 for 175 reinforced concrete beam specimens obtained from SVR, PANFIS, GANFIS, ANN algorithms based on ACI-318-02 and CSA regulations. According to the results, the accuracy of predictions of the GANFIS algorithm on the shear strength parameter of reinforced concrete beams is higher than other developed algorithms. According to the results, the GANFIS algorithm with *RMSE* = 0.0634 (the second root mean square error) and R^2 = 0.996 have the highest accuracy when predicting shear capacity in reinforced concrete beams among all the algorithms used in this study.

6. CONCLUSION

The present study suggests that the PANFIS and GANFIS artificial intelligence algorithms can be used to predict the ultimate shear capacity of reinforced concrete beams. The results indicated that the GANFIS algorithm has better and stronger prediction power compared to SVR, PANFIS, ANN algorithms, and ACI-318-02 and CSA regulations. In another part of the study, the sensitivity analysis of parameters was investigated with the use of the GST theory. The results of this analysis exhibited that the average value of the correlation index between shear capacity and effective parameters is higher for the percentage of longitudinal reinforcement (ρ_l) compared to other parameters.

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