인공신경망에 의한 스터럽 없는 FRP 콘크리트 보의 전단강도 예측

Prediction of Shear Strength of FRP Concrete Beams without Stirrups by Artificial Neural Networks

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ABSTRACT

Fiber reinforced plastics (FRP) are light in weight, non-corrosive and exhibits high tensile strength. FRPs having superior material properties to corrosive steels have been widely replacing steel bars or tendons used in concrete structures as flexural reinforcements. Although current design guidelines for estimating shear strength of FRP concrete beam follow the format of conventional reinforced concrete design method, there are noticeable differences among the existing formulas in calculating the contributions of concrete to shear resistance.

In this paper, the artificial neural network (ANN) technique is employed as an analytical alternative to existing methods for predicting shear capacity of FRP concrete beams. Influential factors on shear strength were identified through literature review and input in ANN and the ANN was trained for the target ultimate shear obtained from database. The results from ANN were compared with existing formulas for its accuracy. It was found that the developed ANN were more closely predicting the test data than those of the currently available predictive equations.

요　약

FRP는 중량이 가볍고, 녹이 슬지 않으며 높은 인장 강도를 가진다. 철근에 비해 월등한 재료적 특성을 가지고 있는 FRP는 콘크리트 구조물에 철근이나 긴장재 대용으로 휨 보강재로써 널리 대체되어지고 있다. 현재 FRP 콘크리트 보의 전단강도를 산정함에 있어 설계지침들이 기존의 설계방식을 따르고 있지만 이들 설계 방식에서 제시한 식들은 매우 상이한 형태를 나타낸다.

이 연구에서는 FRP 콘크리트 보의 전단 강도를 예측하는 방법의 대안으로 인공신경망(이하 ANN) 기법을 채택하였다. 전단 강도에 미치는 영향 요소는 문헌조사에 의하여 선정된 후 ANN에 입력되었고, ANN은 데이터베이스를 통해 얻은 극한 전단 강도를 목표 값으로 하여 학습되었다. ANN을 이용하여 얻은 결과 값과 현존하는 이론식의 값을 비교한 결과 이 연구에서 개발한 ANN은 현재 사용하고 있는 예측 이론식에 비하여 더욱 정확하게 예측하였다.

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1. Introduction

Theoretical models and equations predicting the shear strength of FRP concrete beams without stirrups have been presented by different researchers. Because of various parameters involved in complicate mechanisms, however, the accuracy of these models has been shown to be limited to a certain level in predicting experimental results. In order to overcome the limit that conventional theoretical models have, ANN has been developed as an alternative tool for predicting the shear strength of FRP concrete beams without stirrups in this research. Database are constructed using the existing experimental results and used for training the ANN. The accuracy of the existing equations as well as the developed ANN is examined in predicting shear strengths of FRP concrete beams without stirrups by comparing their predictions with test data.

2. Artificial neural networks

A neuron is fundamental unit of biologic neural system. There are hundreds of thousands of neurons in the unit cubic. Each neuron plays an important role in the neural system and takes charge of information reception, operation processing, and output transmission and so forth.

Fig. 1 shows a schematic model with typical single-layered ANN. The input layer receiving n values sends the information to the hidden layer through a process connected to each neuron. Then the received information from the hidden layer is transmitted to the output layer again. The ANN changes the weights of the neural connections so as to minimize the difference between the output and the target values. This process is referred to as a training. The system of artificial intelligence is built through a training process. After a series of modifications of weights imposed on connecting nets, the ANN can represent complex functions with high level of nonlinearity such as shear strength of FRP reinforced concrete beams.

3. Application of ANN to the prediction of shear strength

Since reliable outputs result from an appropriate selection of input variables which physically influence the shear strength of FRP concrete beams without stirrups, input values in this study were carefully chosen from literature review. In this paper, concrete strength(f_{ck}), beam width(b_w), effective depth(d), modulus of elasticity for FRP(E_f), FRP reinforcement ratio(ρ_f), and shear span-to-depth ratio(a/d) are selected as the input values, and the shear strength($V_{c,f}$) is predicted using the existing 63 experimental results. Back-propagation is applied for training the ANN with the tolerance of average relative errors within 0.003 between target values and output values. Different number of nodes in a hidden layer, running rates, and stopping criteria are tested and 6-20-1(number of input nodes-number of nodes in a hidden layer-number of out nodes) system resulted in best result.

Fig. 2 represents convergence trends obtained from the ANN with the formation of 6-20-1 networks that was developed in this study. The rate of convergence was rather rapid in the beginning stage of the training up to 20 iterations, and then gradually decreased until converged at about 2,700 iterations.

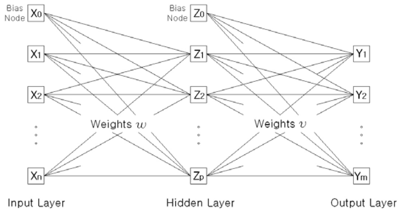

Fig. 1 Schematic diagram of the ANN

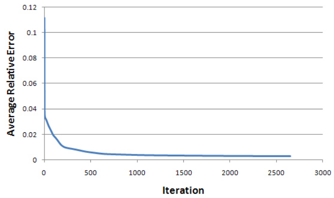

Fig. 2 Convergency Tendency

4. The existing theories of shear strength for FRP reinforced concrete beams

Although FRP has many advantages than the steels, FRP has inherent shortcomings such as brittleness without yielding in tension, and weak in shear. As FRP has different mechanical properties in stress system, different resisting mechanisms other than steels are expected for concrete beams reinforced with logitudinal FRP bars in shear. Accordingly studies about FRP reinforced concrete members in shear have been progressed actively and many equations have been presented. Because of complex mechanism involved with shear behavior, it is difficult to predict the shear strength of FRP concrete beam in a reasonable accuracy.

Predictions by seven equations each presented by ACI 440 4R-04, ACI Committee 440, CSA S806-02, ISIS-M03-01, JSCE, Frosch, and El-Sayed are compared with those from the ANN developed in this study. A total nuber of 63 experimental test results were used for comparison..

5. Comparisons between the results from the ANN and the existing theoretical equations

Table 1 summarizes the results on theoretical predictions obtained by the existing theoretical equations and by the ANN developed in this study. It can be seem that the developed ANN predicted the test results with better accuracy than the others. Although ISIS-M03-01 predicted the test results best among the theoretical equations considered in this study with the average of the theoretical values over the corresponding test values of 0.86, its accuracy seemed to be inferior to the average relative value of 1.01 predicted by the ANN. The code equations especially suggested by ACI440 4R-04 seemed to be unconservative by predicting higher shear strength than experimental results. The reliability of the developed ANN in predicting shear strength of FRP concrete beams without stirrups is further confirmed by the smallest standard deviation the largest R^2. Fig. 3 presents the relationships between predicted values by the ANN and the corresponding test results on shear strength of FRP concrete beam without stirrups.

Table 1 Statistical values

Codes	main variables						Theory/Tests	Standard Deviations	R^2
	f_{ck}	b_w	d	E_f	ρ_f	a/d			
ACI 440 4R-04[1]	○	○	○	·	·	·	1.29	0.57	0.56
ACI Committee 440[2]	○	○	○	○	○	·	0.34	0.15	0.66
CSA S806-02[3]	○	○	○	○	○	○	0.80	0.30	0.67
ISIS-M03-01[4]	○	○	○	○	·	·	0.86	0.35	0.71
JSCE[5]	○	○	○	○	○	·	0.59	0.15	0.79
Frosch[6]	○	○	○	○	○	·	0.59	0.14	0.88
El-Sayed[7]	○	○	○	○	○	·	0.77	0.20	0.84
ANN	○	○	○	○	○	○	1.01	0.09	0.99

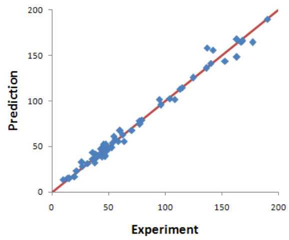

Fig. 3 ANN vs. tests

6. Conclusions

Shear strengths of FRP concrete beams without stirrups are predicted using the ANN developed in this study. Comparisons are made for the accuracy of each model presented in the literature or the code with the model predictions. The following conclusions are made from this study.

1. Most of the existing equations presented in the literature or the codes did not predict the test results in a reasonable accuracy. It is worth mentioning that the equations with lower mean value exhibited higher standard deviation, and vice versa. This may imply the inaccuracy of the existing equations in predicting shear strength of FRP beam without stirrups.
2. Although ISIS-M03-01 predicted the test results best among the existing equations, its mean, standard deviation, and R^2 were 0.86, 0.35, and 0.71, respectively, which leaves a room for a further refinement for its accuracy.
3. The equation presented in ACI 440 4R-04 seemed to be even unconservative predicting the shear strength.
4. The ANN with single hidden layer is developed in this study. Different number of nodes in a hidden layer, running rates, and stopping criteria are tested and 6-20-1 (number of input nodes-number of nodes in a hidden layer-number of out node) system resulted in best result.
5. The developed ANN in this study was found to be superior to the other theoretical equations. The mean, standard deviation, and R^2 were 1.01, 0.09, and 0.99, respectively. The developed ANN seemed to predicts the shear strength of test results more accurately with higher reliability.

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