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Estimation of Shear Strength of RC Beams FRP-Strengthened by Using Soft Computing Method and Codes

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Abstract*—In this study, the efficiency of artificial neural networks (ANN) in predicting the shear strength of reinforced concrete (RC) beams strengthened by means of externally bonded fiber reinforced polymer FRP is explored. Experimental data of rectangular RC beams from an existing database in the literature were used to develop ANN model. Different eight input parameters affecting the shear strength were selected for creating three layered back-propagation method of ANN structure. The initial performance evaluation back propagation was evaluated and discussed. In addition to these, the paper presents a short review of the well-known building codes provisions for the design of RC beams strengthened by means of externally bonded FRP under shear effect. The accuracy of the codes in predicting the shear strength of RC beams FRP strengthened was also examined with comparable way by using same test data. The study concludes that ANN model predicts the shear strength of RC beams FRP strengthened better than existing building code approaches on shear strength. *(Abstract)

***Keywords*—beam, strengthening, FRP, shear strength, artificial neural network**

I. Introduction

Due to the lat of advantages of fiber-reinforced polymers (FRP) have been preferred in strengthened of existing reinforced concrete (RC) structure members to increase the flexure strength, shear strength and confinement effect in recent years. [1-3]. Externally bonded FRP reinforcement can be used to strengthen of many types of RC members especially to increase the shear and flexural strength. Hence, these members provide confinement and ductility to compression members [4]. The commonly available FRP materials for repair and strengthening are glass (GFRP), aramid (AFRP), carbon (CFRP) and basalt (BFRP). These materials are applied to the surface of the concrete to provide additional flexural and shear strength as well as confinement for concrete columns [5].

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The uses of external FRP reinforcement may be generally classified as flexural strengthening, improving the confinement and ductility of compression members, and shear strengthening [6]. Also, the strengthening of infilled walls with FRP overlays, and integrating them to the load carrying system of the frame, is considered as an alternative method for building upgrading [7]. Many of the existing RC beams need to strengthen for shear effect. Some reasons of deficiencies in shear are insufficient shear reinforcement or reduction in steel area due to corrosion, increased service load construction defects [4]. In this case, externally bonded FRP reinforcement can be used to increase the shear capacity [8]. In practice, different code proposals which contained in these existing proposals cover design recommendations for the flexural strengthening of beams and slabs, the shear strengthening of beams and columns and the flexural and compressive strengthening of columns exist about strengthening of RC structural members with externally bonded FRP. The codes are ACI 440.2R-08 [9] CNR-DT 200 [10], fib Bulletin No. 14 [11], fib Bulletin No. 35 [12], ISIS Design Manual No. 4 [13], JSCE-CES41 [14] and TR55 [15].

Artificial Neural Network (ANN) has been successfully applied to a number of areas of structural engineering that is an important branch of civil engineering. ANNs are applied to perform many different tasks as prediction of function approximation, classification, filtering, etc. In the recent literature, structural analysis and design, structural dynamics and control, structural damage assessment and the structural behavior and properties of concrete materials such as strength and constitutive modeling are good examples for the application of ANN [16-19].

In this study, investigation of the usability of artificial neural network (ANN) models in predicting the shear strength of RC beams and to evaluate the accuracy of the building codes in predicting the shear capacity of RC beams FRP-strengthened has been explored. To achieve these objectives, experimental data of 96 beams subjected to shear effect were used from the existing database of Perera et al.'s study [4]. By using their experimental results, the back-propagation algorithm was performed for the training of shear strength of RC beams. In addition to these, some building code approaches and existing literature formulations are also examined by comparing their predictions with the data of the experimental studies results. The results obtained by ANN and code approaches are compared with each other.

II. Shear Strength of Beams with confined FRP

A. *FRP Types*

In beam FRP applications, the shear strength can be evolved by wrapping the FRP around three sides of the member (U-wrap) or bonding to the two sides of the member. In Fig.1, typical FRP wrapping types are given.

The most efficient externally bonded FRP system for shear strengthening is completely FRP wrapping, followed by the three-sided U-wrap. Bonding to two sides of a beam is the least efficient scheme [9]. All FRP wrapping applications can be placed continuously along the span length of a member or positioned as discrete strips.

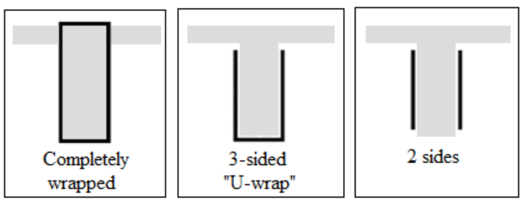

Figure 1. Typical wrapping schemes for shear strengthening using FRP laminates [9]

B. *Code Approaches*

The design shear strength of FRP-strengthened RC beam is determined by adding the contribution of FRP reinforcement to concrete and reinforcing steels like stirrups, bent-up bars, ties or spirals (1). The contributions of concrete and transverse reinforcement to shear strength can be calculated according to the existing RC design codes.

$$V_d = V_c + V_s + V_f \qquad (1)$$

In this formula, V_c is the contribution of concrete, V_s is the contribution of the steel stirrups and V_f is the contribution of the FRP reinforcement. In this study, contributions of V_c and V_s were computed by ACI 318 [20]. The contribution of FRP is found by truss analogy, similar to the determination of the contribution of steel shear reinforcement. To predict the FRP contribution to shear resistance accurately, apart from its tensile strength, the other two key parameters are the strain distribution in the FRP along the shear crack and the shear crack angle [21]. The contribution of FRP reinforcement to shear strength is given by the (2) in the fib-14 code [15].

$$V_f = \rho_f . E_f . \varepsilon_{fe} . b_w . d . (\cot \theta + \cot \alpha) . \sin \alpha \qquad (2)$$

In this guideline, the design strain of FRP ε_{fd} is obtained by following formula (3).

$$\varepsilon_{fd} = k . \varepsilon_{fe} \qquad (3)$$

The contribution of FRP reinforcement to shear strength is given by the (4) in the ACI 440 code [9].

$$V_f = \frac{A_{fv} . f_{fe} . (\sin \alpha + \cos \alpha) . d_{fv}}{s_f} \qquad (4)$$

In here,

$$A_{fv} = 2 . n . t_f . w_f \qquad (5)$$

$$f_{fe} = \varepsilon_{fe} . E_f \qquad (6)$$

In the existing literature (EL) Perera et al. [4], the following modified ACI 318 [20] equation was used to calculate the concrete contribution to the shear strength of the beam. In this formula; c_1=4.28, c_2=0.55 for u-wrapped FRP c_1=2.57, c_2=0.05 for w-wrapped FRP.

$$V_c = \frac{c_1}{(a/d)^{c_2}} \left(\frac{\sqrt{f_c}}{6} \right) b_w d \qquad (7)$$

Equation 7 was used to calculate the contribution of external FRP reinforcement to shear strength in the existing literature Perera et al. [4].

$$V_f = c_3 \rho_f^{c_4} n E_f \varepsilon_{fd,e} (\cos \beta + sen \beta) d_f b_w \qquad (8)$$

In this formula (8), c_3=0.63, c_4=4.13 values for u-wrapped FRP, c_3=0.54, c_4=0.97 values for w-wrapped FRP were determined. All formulas are given in Yavuz et.al [22].

III. Formation of Dataset

In the literature, there is a wide range of available experimental data on the behavior of the FRP-strengthened rectangular RC beams. The tests have been performed under similar loading types. Additionally, the selected parameters in these tests were similar. For instance, the parameters affecting the strength and ductility of FRP-confined RC beams were selected as the dimension of the cross section, shear span to depth ratios, the compressive strength of concrete, the wrapping type of fibers, the volumetric ratio of FRP reinforcement, the FRP thickness, the mechanical properties of FRP and the ratios of internal longitudinal and transverse reinforcements.

In this study, a total of 96 rectangular RC beam tests were collected from the literature and were taken from the paper of Perera et al. [4], who searched and documented the experimental studies of other researchers. The experimental data on real-size type specimens consists of RC beams of rectangular cross-sections subjected to shear load and flexure. In the reference study conducted by Perera et al. [4], the researchers have examined the performances of shear strength of FRP contribution to the RC beam by using the same beams data. The range of parameters covered by the considered specimens and a short definition of dataset can be seen in Table 1. In Fig.2, a typical testing setup is presented with the symbols used for the definition of specimens. In Fig. 3, dimensional variables of the used FRP laminated were also given. In this study, shear strengths of beams strengthened by means of externally bonded FRP have been computed with formulas recommended by EL, FIB and ACI and then an artificial neural network model has been developed using the shear strength values obtained from the literature Perera et al. [4]. Finally, the results of the formulas of guidelines and ANN model have been compared with EL, FIB and ACI expressions.

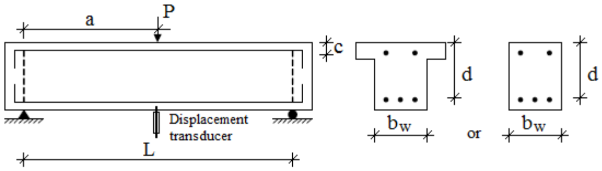

Figure 2. Typical loading system and tested beams [22]

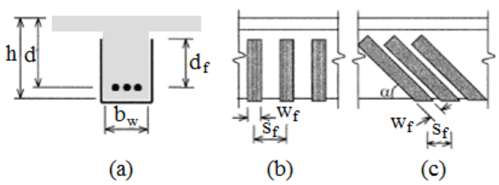

Figure 3. Illustration of the dimensional variables used in shear-strengthening calculations for repair, retrofit, or strengthening using FRP laminates [9]

TABLE I. RANGE OF PARAMETERS

Parameters	Identification	Range
h (mm)	overall height of beam	190-600
b (mm)	width of beam	64-600
c (mm)	concrete cover	26-100
a/d	aspect ratio	1.3-3.5
f_{cm} (MPa)	compressive strength of the concrete	11.205-51.000
$f_{y90,d}$ (MPa)	design yield strength of steel stirrup	20.5-486.1
A_c (mm^2)	area of stirrup	0-157
s_c (mm)	spacing of stirrups	160-400
A_{90} (mm^2/mm)	Stirrup ratio (Ac / s)	0-0.83
A_t (mm^2)	area of long. tension reinforcement	201-11253.8
E_f (MPa)	tensile modulus of elasticity of FRP	5300-390000
f_{fd} (MPa)	design strength of FRP reinforcement	112-4200
w_f (mm)	width of the FRP reinforcing plies	20-900
t_f (mm)	nominal thickness of FRP	0.044-1.3
s_f (mm)	spacing FRP shear reinforcing	40-1800

IV. Main Rules of MLP-NN

A Multi Layer Perceptron Neural Network (MLP-NN) is a feed-forward neural network model. The MLP model consists of one input layer, one or more hidden layers and one output layer [23]. The number of input and output layer neurons is generally determined by the design requirements but the number of neurons in the hidden layer is determined empirically. The neurons of a layer fully connected to the neurons of the neighboring layers with weights. The initial values of these weights are randomly assigned as small real values. Outputs of the hidden layer and output layer neurons are calculated with defined transfer functions. The MLP model is supervised neural networks and is trained by a gradient descent method to minimize an error function [24]. The back-propagation learning algorithm can used to train MLP network so these weights are adjusted for a given set of input–output pairs. [25]. Mean square error (MSE %) can used to evaluate the performance of the ANN model (9).

$$MSE = \frac{1}{n}\sum_{i=1}^{n}\left(Y_i - Y_i^{'}\right)^2 \qquad (9)$$

In this equation, n is the number of sample in training or testing data. Y_i is the desired output, $Y_i^{'}$ is the output of the neural networks. In this study, ANN's are implemented by using MATLAB software package (MATLAB version 7.04 with neural networks toolbox, [26]). The input data was normalized in the range of [-1 1] and output data was normalized [0 1]. A hyperbolic tangent sigmoid transfer function was selected on the hidden layer and a sigmoid transfer function was used on the output layer. Traingdx is used as a training function and updates weight and bias values according to gradient descent momentum and an adaptive learning rate. The performance of the network is very sensitive to the learning rate (l_r) held constant throughout training for standard back propagation. if l_r is selected high the algorithm may oscillate and become unstable so l_r may be select small thus the error of network can be reduced. Momentum coefficient (m_c) is suggested to avoid local minima and low mc cannot reliably avoid local minima [22]. For training process, the maximum training cycles, learning rate, and the momentum coefficient was selected respectively 1000, 0.1, 0.9. MSE is used as a performance function. ANN architecture was consisted of eight input neurons and one output neuron (Fig. 4).

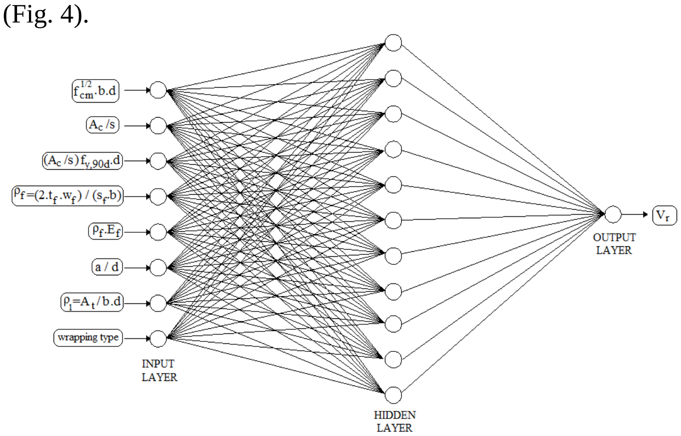

Figure 4. ANN architecture of the selected model

The number of neurons in the hidden layer was varied from 10 to 100. The total data set contain 96x8 data. To make the test results more meaningful and benefit, 2-fold cross-validation was used so the data set was equally divided into training and testing data set contain 48x8 data. Each parameter combination was applied to the training and testing data sets and prediction accuracy of the models were evaluated. The parameter combination that resulted in the best average of training and testing performances was selected as the best one for the corresponding model.

V. Results

A. *MLP-NN Results*

The study shows that the ANN model give reasonable predictions of the ultimate shear strength of RC beams strengthened by external FRP (R^2≈0,937). Performance values of GDX back-propagation method related to the determination of the shear strength of RC beams FRP strengthened. In the study, selecting different number of hidden nodes (HN) between 10 and 100 for the hidden layer, optimum number of nodes was determined by applying separate solutions for each node. Fixing the number of nodes of the hidden layer requires many trials. The most important factor affecting the success of the application except the number of hidden layer neurons (HN), iteration number, learning rate, momentum constant and error tolerance parameters given is the learning algorithm. Each parameter affects the performances during the solution of the problem due to their different properties. It is clear that, the determination of the function type appropriate to the behavior of the problem can change the percentage of success.

It is obvious from the (Figs. 5-8) that the algorithm offered better estimates than the other conventional (EL) and codes approaches (ACI and FIB) in accordance with correlation coefficient (R^2). In addition to these, the back-propagation method was obtained 93.7% averaged accuracy rate (100 % - error %) for test phase of neural network. The training phase of the related algorithm is very high (R^2=98.9).

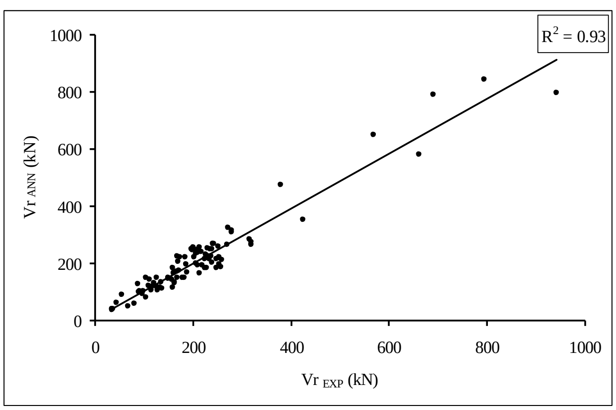

Figure 5. Performance of ANN on estimation of shear strength capacity of beams

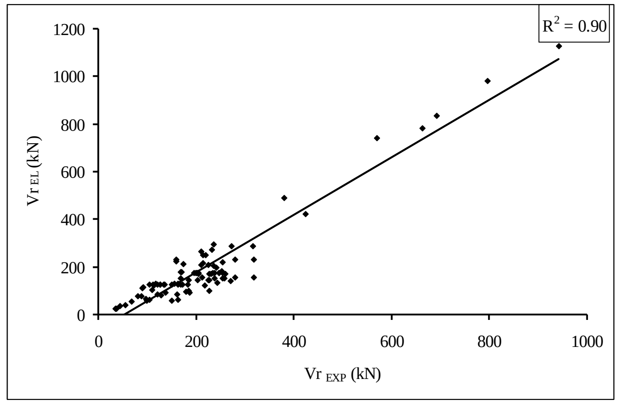

Figure 6. Performance of EL on estimation of shear strength capacity of beams

In order to investigate the accuracy of standards for the shear strength of RC beams FRP strengthened, the test results were compared with the other conventional (EL) and codes approaches (ACI and FIB) of mentioned building codes. The predicting capability of codes related to shear strength of RC beams FRP strengthened for mentioned tested 96 specimens are presented in Fig. 7 and Fig. 8.

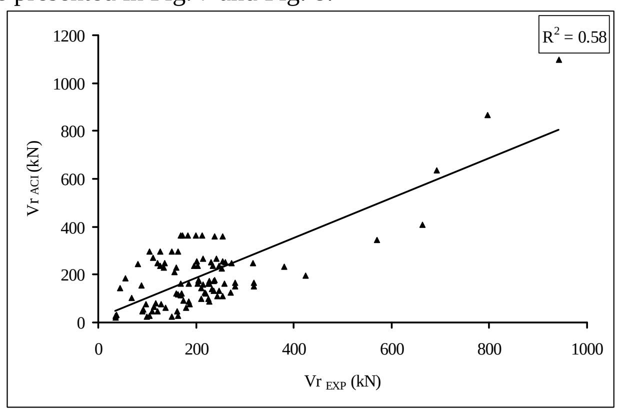

Figure 7. Performance of ACI on estimation of shear strength capacity of beams

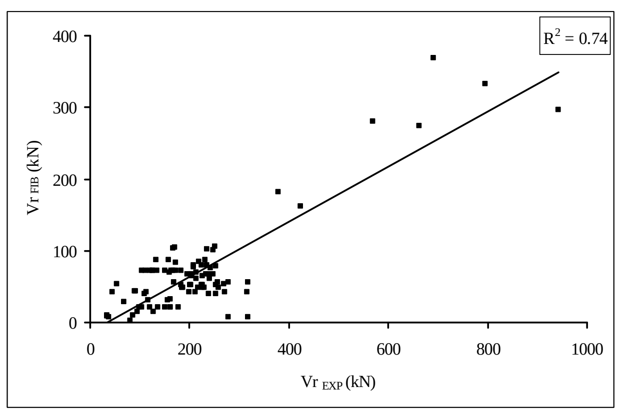

Figure 8. Performance of FIB on estimation of shear strength capacity of beams

The differences between the codes and test results are based on some reasons such as;

1. Shear strength specified in the related codes is proportional to the amounts of transverse reinforcement and the angle of the compression diagonals. The code provisions assume that transverse reinforcement yield prior to the ultimate strength stage. However, in the experiments, yielding of the stirrups is unknown.
2. In the codes the angle of cracks are neglected (or assumed 45^o). This assumption induces the important differences between the code approaches and test results.

VII. Discussion and Conclusion

In this paper, an ANN model was developed for the prediction of the shear capacities of the RC beams FRP strengthened. In the aim of the study, to analyze the performance of the proposed ANN model, 96 different RC beam tests were collected from the literature and performed for the testing and training stages of ANN. Then, the success of the proposed ANN method to conventional approach has been investigated by comparative way. The following conclusions may be drawn based on the results presented. The results obtained from the testing/training dataset of the proposed ANN model were found to be satisfactory level (accuracy rate was calculated as 94%). Furthermore, the ANN model presented a performance slightly better than the EL approach. The appropriateness between the algorithm and the data set used in the training stage directly affects the accuracy and speed of the test results so the selection of the algorithm appropriate to the data set is a significant parameter as optimum hidden nodes, iteration number (training cycles), learning rate, momentum constant and error tolerance for the solution of the problem. Although the performance of the developed ANN model was limited to the range of the input data used in the training and testing processes, the model can easily be further developed with additional new set of data. To improve the accuracy of the model further and more importantly to place it on obvious mechanical bases, additional work is required to verify the applicability of the proposed model over a wider range of geometric and material parameters. Current building codes are limited to predict of shear strength of a RC beam strengthened by FRP. Particularly, ignored parameters in the current codes have also effect on the shear strength.

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