MODLING OF SHEAR BEHAVIOR OF R.C. BEAMS STRENGTHENED WITH CARBON FIBER REINFORCED POLYMER (CFRP) USING ARTIFICIAL NEURAL NETWORKS (ANN)

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ABSTRACT

The behaviors of RC beams strengthened for shear with Carbon Fiber Reinforced Polymer CFRP are inspected in this paper. The shear strength is predicted using artificial neural networks of rectangular beams strengthened with externally bonded (CFRP). A mathematical model is developed to determine shear strength. A model was formed using 90 sets of experimental of rectangular RC beams data existing and published in the literature.

The study revealed that the model (ANN) gave better performance than the building codes approach, the results indicated that the Coefficient of Regression value (R = 0.89) when comparing model outcomes with actual values. Meanwhile the American Guideline ACI 440.2R-17 and the European Recommendations fib TG 9.3 (FIB 2001), offered a Coefficient of Regression of a values (R=0.84) and (R=0.77) respectively.

Keywords: *artificial neural network; shear strength; externally bonded CFRP; reinforced concrete beam.*

1. INTRODUCTION

The strengthening of the structural elements with Externally Bonded FRP Systems dates back to the early 1980s and has been considerably intensified. The codes in many countries provided an arithmetic measure to assess the behavior of these elements. The beams, can be strengthened by Externally Bonded FRP Systems either to improve the shear or the flexural strength. The term “artificial intelligence” is not original. The idea of industrial intelligence started at the mid-1950s, with the first labs of industrial intelligence established by John McCarthy and Marvin Minsky, Allen Noel[1].The beginning of the 1980s, the idea of artificial intelligence came back with great force and flourished at the beginning of the new millennium because of the incredibly development of the compute processer.

The division that emerged from artificial intelligence is Artificial Neural Network (ANN), an interconnected set of virtual synapses created by computer programs to resemble the work of biological neurons to be able to train and learn. Currently in the field of civil engineering, artificial band networks are used in many fields, especially in predicting a specific design or analytical value for a building element, where models are developed using (ANN), as well as being used to evaluate the behavior of a structural element mentioned in the code approaches. Examples of using artificial neural networks in civil engineering are, the prediction of the compressive strength of FRP-confined concrete circular columns[2]. The predicting the thickness of rectangular plates[3]. The linear and nonlinear models updating of reinforced concrete T-beam bridges [4]and predicting concrete compressive strength[5, 6].

The present study will explore the use of (ANN) modeling of the shear strength predicting of CFRP-strengthened RC beams by using artificial neural networks. The models are created through the use of the neural network design (NND) toolbox in MATLAB [7]

The objective of this study is to investigate the behavior of RC beams strengthened for shear with CFRP. This study presents a program with the following's objectives; First, develop the ANN models to predict shear strength of reinforced concrete beams strengthened with the CFRP laminate using MATLAB program package. Second, develop a mathematical model using parameters of the ANN models. Third, perform a parametric study on some influential input parameters in the design of shear strength of reinforced concrete beams and study their relative effect on the shear strength of the reinforced concrete beam strengthened with the CFRP laminate. Finally, compare the results from developed models with existing models such as building code approaches; the American Guideline ACI 440.2R-17][8] and the European Recommendations fib TG 9.3 [9].

2. SHEAR STRENGTH OF BEAMS WITH EXTERALLY BONDED FRP

FRP systems have been used to strengthening concrete structures since the mid-1980s. The FRP systems were first used in Japan in 1980s for strengthening reinforced concrete columns. In the last 20 years, it has been significantly increased in strengthening many structural concrete elements such as beams, slabs and columns. Similarly, its applied on bridges, domes, also in tunnels and other concrete structures. The application of FRP systems in civil engineering is divided into two sections: rehabilitation including repair, strengthening and retrofit of structures and new construction with FRP systems. Externally Bonded FRP Systems, are typically used in columns, beam, slab and bridges. This system was first applied for reinforcing concrete bridges for increasing flexural strengthen [11].

In Externally Bonded FRP Systems are usually using sheet or strip that is bonding to the concrete surface of the beam or slab or column with an epoxy resin. This is used for the system to increase the strength of shear and flexural in beams and columns. In slabs this system applies to increases the flexural strength only. For example, in concrete beam when using the externally bonded FRP Systems at the tension face it will increase the flexural strength from 10 to 160 %. The sheets or strips are used for bonding to the concrete surface of beams with epoxy resin by wrapping or partially wrapping the beams. Three types of FRP wrapping schemes are used in rectangular beams to increase the shear strength. The complete wrap of the four sides of the member (W), three sides of the member (U) and two sides of the member (S) are shown in Figure 1. It is worth mentioning that when using a method four sides wrapping scheme is most efficient than the two other methods.

In practice, the completely wrap-four sides of the member (W) cannot be used in beams because of its slab is present but can be used in the laboratory. Carbon fiber strip can be applied at 90° or 45° angle, as shown in Figure 2. The application of 45° strip is provide more effectiveness in resisting the shear force.

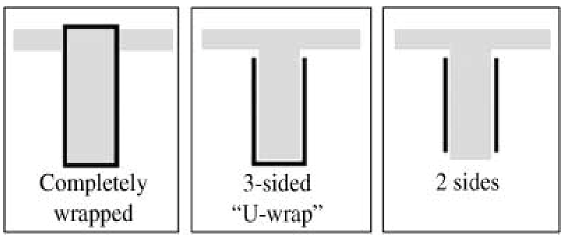

Fig. 1 Typical Wrapping Schemes for Shear Strengthening.

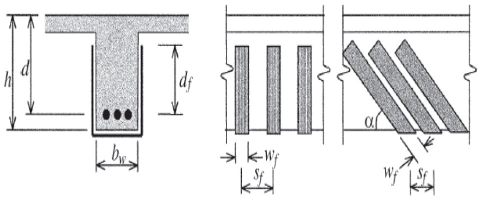

Fig. 2 Externally Bonded FRP Systems with or without Angle.

$$V_f = \frac{A_{fv} f_{fe}\ (\sin\alpha + \mathrm{Cos}\,\alpha) d_f}{S_f} \qquad (1)$$

$$V_f = 0.9\ \ \varepsilon_{fd,e}\, E_f\, \rho_f\, b_w d(1+\cot\alpha)\,\mathrm{Sin}\,\alpha) \qquad (2)$$

Therefore, the shear capacity of beams (V) equals the sum of shear strength provided by concrete (V_C), shear strength provided by shear reinforcement (V_S) , and externally bonded FRP systems (V_f), represented in equation 3.

The contribution of CFRP reinforcements to shear strength is symbolized (V_f), given by equation 1 in the ACI 440.2R -17 [8] and equation 2 for European Recommendations *fib* TG 9.3[9]

$$V = V_c + V_s + V_f \qquad (3)$$

The outcome results from the models(ANN) will be compared with the computed results of the one of the following building code approaches; the American Guideline ACI 440.2R-17 and the European Recommendations *fib* TG 9.3 [9]. Design equations according to these two building code approaches are presented in Table 1.

3. SELECTION OF DATABASE

The data collection process needs a thorough review of the literature to get to experimental data for CFRP strengthened rectangular beams, which we will be used in this study.

At the beginning, the largest number of published papers were published about carbon fiber beam reinforcement to resist shear forces. It was necessary to identify the parameters to be taken from experimental research so that we can establish a database of our own to develop the model ANN, which will be the input layer and the output layer in the network.

After reviewing the literature,90 sets of experimental data were obtained for rectangular beams reinforced with Externally Bonded FRP Systems[10-24].

Table 1 Formulas related to the externally bonded fiber-reinforced polymers (FRP) from American Guideline ACI and European Recommendations.

Designation	ACI318 and ACI 440.2R	Eurocode 2 and *fib* TG 9.3
Nominal shear strength	$V = V_c + V_s + \Psi_f V_f$	$V = V_c + V_s + V_f$
Concrete contribution	$V_c = 0.17\sqrt{f_c'}\ b_w d$	$VRd,c = [0.12k(100\,\rho_l\,fck)1/3]\,bwd$
shear reinforcement contribution	$V_s = \dfrac{A_v f_{yt} d}{S}$	$V\mathrm{Rd,s} = \dfrac{A_{sw}}{s}\ 0.9d\ f_{ywd}$
CFRP contribution	$V_f = \dfrac{A_{fv} f_{fe}\ (\sin\alpha + \cos\alpha) d_f}{S_f}$ $f_{fe} = \varepsilon_{fe} E_f$ $\varepsilon_{fu} = C_E \varepsilon_{fu}{}^*$ *For Completely wrapped members* $\varepsilon_{fe} = 0.004 \le 0.75\varepsilon_{fu}$ *Bonded U-wraps or bonded face plies* $\varepsilon_{fe} = k_v \varepsilon_{fu} \le 0.004$ $k_v = \dfrac{k_1 k_2 L_e}{468\varepsilon_{fu}} \le 0.75$ $L_e = \dfrac{23300}{(nt_f E_f)^{0.58}}$ $k_1 = \left(\dfrac{f_c'}{27}\right)^{2/3}$ $k_2 = \begin{cases} \dfrac{d_f - L_e}{d_f} & \text{for U − wraps} \\ \dfrac{d_f - 2L_e}{d_f} & \text{for two sides bonded} \end{cases}$	$V_f = 0.9\ \varepsilon_{fd,e}\ E_f\,\rho_f\ b_w d(1 + \cot\alpha)\sin\alpha)$ *For fully wrapped carbon FRP:* $\varepsilon_{f,e} = 0.17\ \varepsilon_{f,u}(fc'^{2/3}/E_f\rho_f)^{0.3}$ For side or U-shaped jacket: $\varepsilon_{f,e}\ min\left[0.65\left(\dfrac{fc'^{2/3}}{E_f\rho_f}\right)^{0.65} \times 10^{-3}, 0.17\left(\dfrac{fc'^{2/3}}{E_f\rho_f}\right)^{0.30} \varepsilon_{f,u}\right]$ *FRP reinforcement ratio equal to for continuously bonded shear reinforcement* $\rho_f = \dfrac{2t_f \sin\alpha}{b_w}$ *For FRP reinforcement in the form of strips or sheets.* $\rho_f = \dfrac{2t_f\ b_f}{b_w S_f}$

4.NEURA NETWORK DESIGN AND TRAINING

Neural networks are used in the MATLAB program for this study. During the development of model's stage, many models were examined through controlling the number of parameters, the number of hidden layer and the number of neurons in each layer to reach a network of suitable performance and accuracy. This is accomplished after analyzing the Neural networks using MATLAB[25, 26].

It should be noted that the number of parameters in the input layer has a direct impact in the process of learning the network. The large number of parameters commands the learning process will slow down the process and gives inaccurate results. The solution is to use compound parameters where we replace several parameters with a complex parameter that includes these parameters and is compatible with a cod reinforced concrete.

For the input layer, three composite parameters are operated to obtain results the most accurate and faster training process. These three parameters that enter into form direct in increasing beam resistance to shear forces are shown in Table 3. These three compound parameters are; V_f the shear strength provided by CFRP (kN), V_S the shear strength provided by shear reinforcement (kN) and V_c the shear strength provided by concrete (kN). Corresponding to equations 5, 6 and equations 7 respectively.

$$V_f = \frac{A_{fv} f_{fe}\ (\sin\alpha + \cos\alpha) d_f}{S_f} \qquad (5)$$

$$V_S = \frac{A_v\ f_{yt} d}{S} \qquad (6)$$

$$V_c = 0.17\sqrt{f_c'}\ b_w d \qquad (7)$$

The ANN3-90 is the model contains 90 data set, divided into three parts, 80% for training, 10% for Validation, and 10% for testing. The number of neurons selected are three neurons as shown in Figure 3.

The ANN 3-90 model has three layers, one input layer, one hidden layer, and one output layer. The input layer contains three parameters; nominal shear strength provided by concrete with steel flexural reinforcement (V_c), nominal shear strength provided by steel stirrups (V_s) and nominal shear strength provided by FRP stirrups (V_f) is calculated based on the ACI 440.2R code. The hidden layer is consisting of three neurons, the output layer has a single value (V), shear force, the range of parameters used in the development of this model can be seen in Table 2.

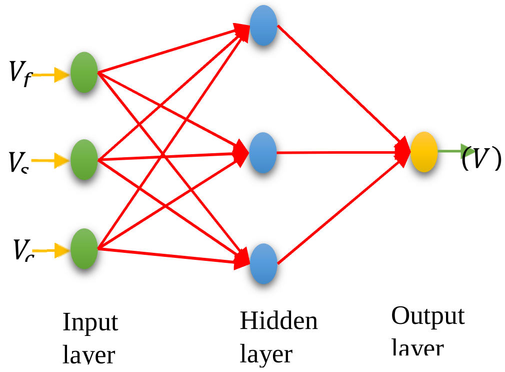

Fig. 3 The Architecture of Multilayer Feedforward Neural Network With One Hidden Layer For Model ANN3-90.

Table 2 The Ranges of Input and Output Data for The Model ANN3-90.

Parameter	Sample	Minimum	Maximum
Shear strength provided by CFRP (kN)	$V_f = \frac{A_{fv}\, f_{fe}\, (\sin\alpha + \text{Cos}\,\alpha) d_f}{S_f}$	12.71	226.41
Shear strength provided by shear reinforcement(kN)	$V_s = \frac{A_v f_{yt} d}{S}$	0	89.96
Shear strength provided by concrete(kN)	$V_c = 0.17\sqrt{f_c'}\ b_w d$	6.52	101.93
Experimental shear force (kN)	V_{EXP}	18.75	343.50

5.RESULTS AND DISCUSSIONS

a) Importance factor

The relative Importance for different input parameters is shown in Figure 4. The highest importance (50.66 %) is given to the parameter (V_f), while the second parameter (V_c) is (33.56%) and (15.79%) for the third parameter (V_s).

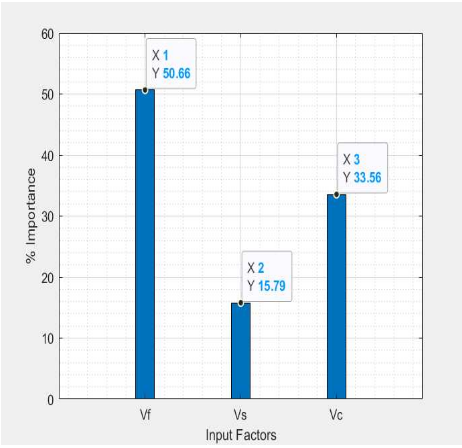

Fig. 4 The Importance of Input Parameters of the Model ANN3-90.

b) Correlation Coefficient

The results of the correlation coefficient indicate that a model works successfully. The correlation coefficient is an important key criterion in determining the performance and accuracy of the model regression for training data between actual shear force and predicted shear force as shown in Figure 5. The correlation coefficient in the training stage value is (R=0.91) and the correlation coefficient value in the validation stage and the testing stage are (R=0.80) and (R=0.83) as in Figure 6 and Figure 7 respectively .

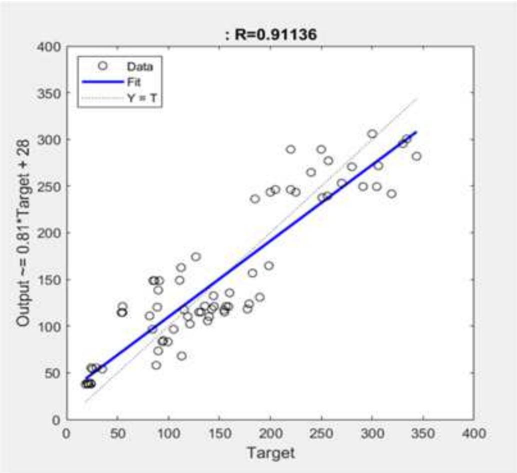

Fig. 5 The Correlation Coefficient in The Training Stage for Model ANN3-90.

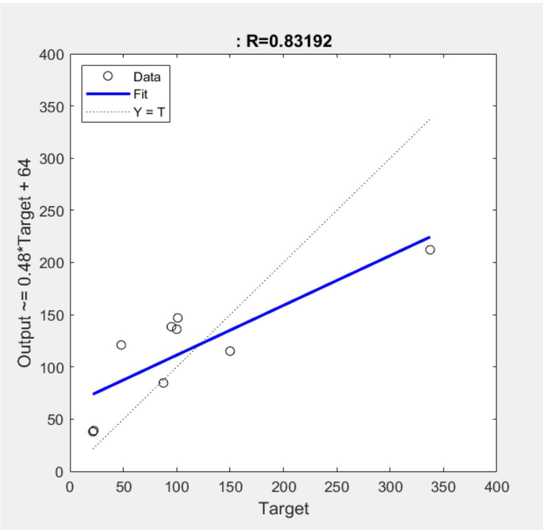

Fig. 6 The Correlation Coefficient in The Testing Stage for Model ANN3-90

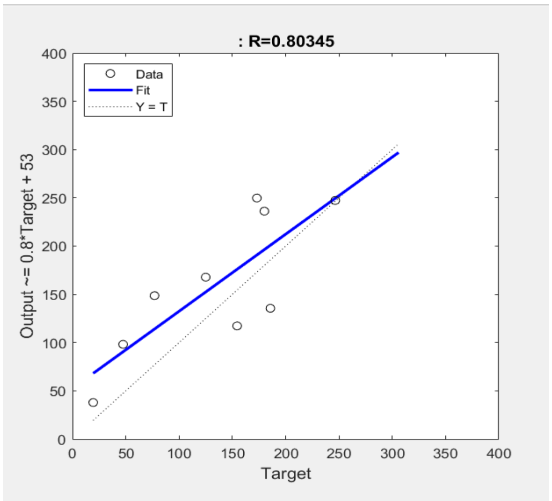

Fig. 7 The Correlation Coefficient in The validation Stage for Model ANN3-90.

c) Parametric Study

The parametric study, is a very powerful criterion in determining the validity and effectiveness of this model, is developed using artificial neural networks.The output values are then calculated which must be compatible with the input value (increase or decrease) based on the model we developed.There are only three Parameters; nominal shear strength provided by concrete with steel flexural reinforcement (V_c) , nominal shear strength provided by steel stirrups (V_S) and nominal shear strength provided by FRP stirrups (V_f) . Accordingly, two relations are obtained by utilizing two parametric studies. The first parametric study is the nominal shear strength provided by FRP (V_f) is maintained fixed while the nominal shear strength provided by steel stirrups (V_S) and the nominal shear strength provided by concrete (V_c) are varied as shown in Figure 8. The relationship reveals that the enlarging the nominal shear strength parameters values provided by concrete (V_c) and increasing the nominal shear strength provided by steel stirrups (V_S) reveals a higher factored shear force. This implying that the developed type with artificial neural networks is functioning accurately. The second parametric study is that the nominal shear strength provided by steel stirrups (V_S) is maintained fixed whereas the nominal shear strength provided by FRP stirrups (V_f) , and the nominal shear strength provided by concrete (V_c) are varied as shown in Figure 9. A similar conclusion can be driven in this case; the model developed is functioning accurately.

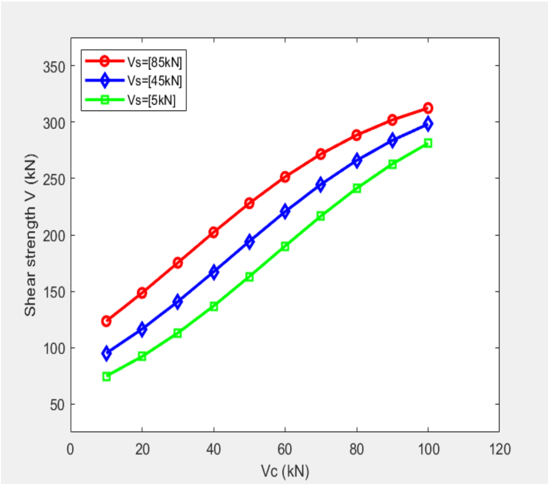

Fig. 8 The Variation of the Shear Strength with Area of Shear Reinforcement and Compressive Strength of Concrete as Predicted by Model ANN3-90.

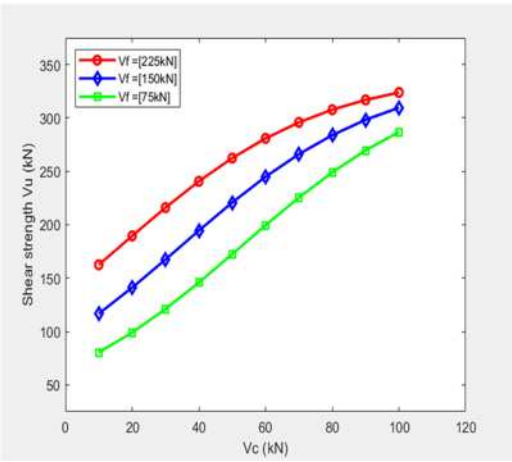

Fig. 9 The Variation of The Shear Strength with Thickness of Ply Of CFRP Reinforcement and Compressive Strength of Concrete as Predicted by Model ANN3-90.

d) Model results and comparisons

The comparisons are very significant to ensure that the efficiency of the developed model is acceptable. Accordingly, the correlation coefficient was calculated between the actual values, the predicted value (ANN) and the values from the building code approaches; the American Guideline ACI 440.2R-17and the European Recommendations fib TG 9.3 [9]. The values of the correlation coefficient presented in Figures 11, 12 &13 are (0.890), (0.835) & (0.771) respectively.

These results of the comparisons which inspecting the three correlation coefficients, revealed that the results of the (ANN) model are better than the results of American Guideline ACI 440.2R-17[8]and European Recommendations fib TG 9.3 [9] .

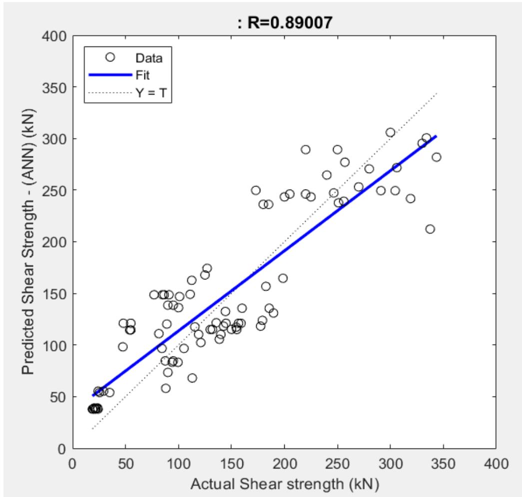

Fig.10 The Correlation Coefficient Between Actual Shear Strength and predicted Value from Model (ANN) .

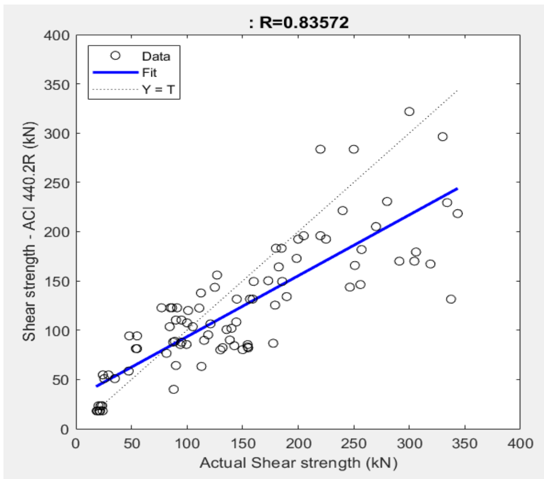

Fig. 11 The Correlation Coefficient Between Actual Shear Strength and resulting values of the ACI 440.2R-17.

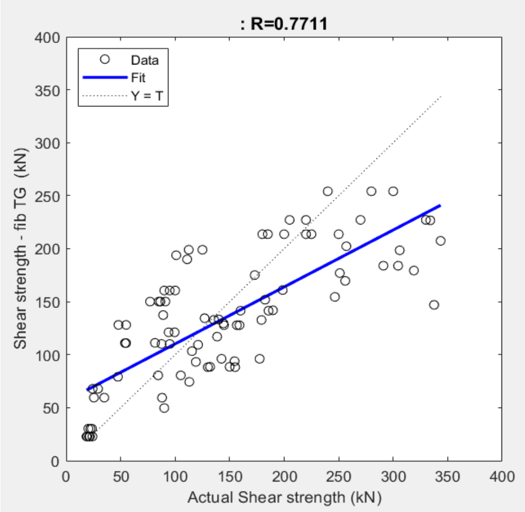

Fig. 12 The Correlation Coefficient Between Actual Shear Strength and resulting values of the fib TG 9.3.

6. MATHMATICL MODEL

An important characteristic of artificial neural networks is the possibility of constructing mathematical models by using weights between layers and also by using the activation methods. In this model there are three parameters; the shear strength provided by CFRP (kN), the shear strength provided by shear reinforcement (kN) and the shear strength provided by concrete (kN). The final result is the shear force, which is the required values presented in Table 3. The properties of carbon fiber reinforced beam should be withen the limits of Table 3 inorder to compute the shear force values accurately.

Table 3 Mathematical model.

$$y_1 = \frac{2(V_f - 226.41)}{(226.41 - 12.71)} + 1$$
$$y_2 = \frac{2(V_s - 89.96)}{(89.96 - 0)} + 1$$
$$y_3 = \frac{2(V_c - 101.93)}{(101.93 - 6.52)} + 1$$
$$x_1 = 15.25 + 2.84y_1 - 1.57y_2 - 3.08y_3$$
$$x_2 = 0.14 + 0.023y_1 + 0.011y_2 + 0.042y_3$$
$$x_3 = 20.49 - 13.14y_1 - 1.765y_2 - 0.759y_3$$
$$xx_1 = \frac{2}{1 + e^{(-2x_1)}} - 1$$
$$xx_2 = \frac{2}{1 + e^{(-2x_2)}} - 1$$
$$xx_3 = \frac{2}{1 + e^{(-2x_3)}} - 1$$
$$XX = -17.15 + 13.03xx_1 + 38.78xx_2 - 35.54xx_3$$
$$X_1 = \frac{1}{1 + e^{(-XX)}}$$
$$V = 18.75 + 324.75X$$

7. CONCLUSIONS

In this study, models (ANN) are developed to obtain the shear capacities of the CFRP-strengthened RC beams. The following conclusions can be drawn based on the findings presented in this study:

1. The developing models (ANN) provide a satisfactory outcomes, the correlation coefficient in the training stage value is 0.91 and the correlation coefficient values in the validation stage and the testing stage are 0.80 and 0.83 respectively .

2. There are indicators other than the correlation coefficient are studied during developing the models (ANN) which shows that the models are working properly as its parametric study gave a very strong impetus.

3. The (ANN) models delivered higher accurate outcomes from that presented by the codes. The correlation coefficient between the models (ANN) and the experimental results is R=0.89. The correlation coefficient between the American Guideline ACI 440.2R-17and European Recommendations fib TG 9.3(FIB 2001) with the experimental results are R=0.83 & R=0.77 respectively.

4. The results offered by the American code are superior to the European code.

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