Prediction of the Shear Strength of Concrete Beams Reinforced with Fiber Reinforced Polymer Bars Using Artificial Neural Networks Model

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Abstract

In this paper an Artificial Neural Networks (ANNs) model is developed to predict the shear strength of concrete beams reinforced with fiber reinforced polymer (FRP) bars. An experimented data set collected from the experimental studies on concrete beams reinforce with FRP bars are used in the artificial neural network. They are arranged in a format of six input parameters including the width and depth of beams, compressive strength of concrete, modulus of elasticity, reinforcement ratio of FRP and the shear span to depth ratio and one output parameter which is shear strength. A parametric study is carried out using ANN to study the influence of each parameter on the shear strength of concrete beams reinforced with fiber reinforced polymers; the results showed that the shear strength increases with increasing all parameters used in ANN model except the shear span to depth ratio. In this case, as the shear span to depth ratio decreases, the shear strength increase. The results of this study indicate that the ANN provides good prediction as compared to the experimental data and the empirical equations.

Keywords: concrete; beams; fiber reinforced polymers; Shear; Artificial Neural Networks.

حساب مقاومة القص للعتبات الخرسانية المسلحة بقضبان البوليمر
باستخدام تقنيات الشبكات العصبية الصناعية

المستخلص

في هذا البحث تم استخدام تقنيات الشبكات العصبية الصناعية للتنبؤ بمقاومة العتبات الخرسانية والمسلحة تسليحا رئيسيا بقضبان البوليمر. تم الاستفادة من التجارب العملية لباحثين سابقين لاستخدامها في إنشاء الشبكة العصبية الصناعية حيث تم اخذ العوامل المؤثرة هندسيا على تصرف العتبات بشكل عام لبناء الشبكة. كانت العوامل المدخلة هي **العرض و السمك الفعال للنموذج، مقاومة الخرسانة،** معامل المرونة ونسبة التسليح لقضبان البوليمر بالإضافة إلى نسبة فضاء القص الى السمك الفعال للنموذج اما المخرجات فهي مقاومة القص للعتبات. كذلك تم في هذا البحث دراسة تأثير كل عنصر من العناصر المدخلة على مقاومة القص للعتبات المسلحة بقضبان البوليمر حيث بينت النتائج بان مقاومة

القص تزداد بزيادة كل من العرض و السمك الفعال للنموذج، **مقاومة الخرسانة**، معامل المرونة ونسبة التسليح لقضبان البوليمر وبنقصان **نسبة فضاء القص الى السمك الفعال للنموذج** .

أثبتت النتائج التي تم الحصول عليها من هذا البحث بان تقنية الشبكات العصبية طريقة موثوقة وجيدة لحساب مقاومة القص وذلك بعد مقارنتها مع بعض النتائج العملية والطرق المقترحة الأخرى.

1. Introduction

FRP bar is made from filaments or fibers held in a polymeric resin matrix binder. The FRP Bar can be made from various types of fibers such as Glass (GFRP) or Carbon (CFRP). FRP bars have a surface treatment that facilitates a bond between the finished bar and the structural element into which they are placed [1].

During the last two decades, fiber reinforced polymer (FRP) materials have been used in a variety of configurations as an alternative reinforcement for new and strengthening civil engineering structures. The attractiveness of the material lies mainly in their high corrosion resistance, high strength and fatigue resistance. In some cases, the non-magnetic characteristics became more important for some special structures. An important application of FRP, which is becoming more popular [2], is the use of FRP as reinforcement in concrete structures. The use of the FRP in concrete structures includes: (a) the internal reinforcing (rod or bar) which will be used instead of the steel wire (rod) equivalent; and (b) the external bonded reinforcement, which is typically used to repair/strengthen the structure by plating or wrapping FRP tape, sheet or fabric around the member.

There are fundamental differences between the steel and FRP reinforcements: the latter has a lower modulus of elasticity, The modulus of elasticity for commercially available glass and aramid FRP bars is 20 to 25 % that of steel compared to 60 to 75 % for carbon FRP bars [1] and linear stress–strain diagram up to rupture with no discernible yield point and different bond strength according to the type of FRP product. These characteristics affect the shear capacity of FRP reinforced concrete members. Due to the relatively low modulus of elasticity of FRP bars, concrete members reinforced longitudinally with FRP bars experience reduced shear strength compared to the shear strength of those reinforced with the same amounts of steel reinforcement. This fact is supported by the findings from the experimental investigations on concrete beams without stirrups and reinforced longitudinally with carbon and glass FRP bars [3, 4].

El-Sayed et al. [4], carried out an experimental study to investigate the shear strength of concrete beams without shear reinforcement (stirrups) and reinforced in the longitudinal direction with different types and ratios of FRP bars. They found that the ratio of shear strength of concrete beams reinforced with FRP bars to that of beams reinforced with steel is proportional to the cube root of the axial stiffness ratio between FRP and steel reinforcing bars. El-Sayed et al. [5], They proposed equation to calculate the shear strength of concrete beams reinforced with FRP bars. They verified the proposed equation with many test results.

F.M. Wegian, H.A. Abdalla [6], presented an experimental investigation on the behavior of concrete beams reinforced with different FRP bars. Three beams were reinforced by GFRP, Isorod, two beams were reinforced by GFRP, C-bar, and two beams were reinforced by CFRP, Leadline. The ultimate behavior of the seven simply supported FRP reinforced concrete beams was used to evaluate their flexural and shear capacities. They concluded that the concrete beams reinforced with fiber reinforced polymers, behave linearly up to cracking, and linearly after cracking with reduced stiffness. Strains and deflections are generally higher in concrete beams reinforced with FRP bars than in concrete beams reinforced with steel. Omeman et al. [7], investigated the shear strength, deflection, and mode of failure of concrete short beams reinforced with CFRP bars and compared with that of similar beams reinforced with steel bars. The experimental study showed that using CFRP bars as tensile reinforcement in RC short beams had a significant effect on the shear strength and deflection of tested beams.

Soft computing is a new field appears in recent past to solve some problems such as decision-making, modeling and control problems. Soft computing is an emerging approach to computing with parallels the remarkable ability of the human mind to reason and learn in an environment of uncertainty and imprecision [8]. Soft computing consists of many complementary tools such as artificial neural networks.

Artificial neural networks have been used extensively in the area of civil engineering to solve many problems. Rafiq et al. [9] presented practical guidelines for designing Artificial Neural Networks for engineering applications. Hsu and Chung [10] developed a model of damage diagnosing for reinforced concrete structures with artificial neural network technique. Learning procedure for the network showed that the capability of the convergence is acceptable, and the test results showed the proposed technique to be efficient for the structural damage diagnosing purpose. Cladera A. [11] developed an artificial neural network to predict the shear strength of reinforced concrete members without stirrups reinforcement based on database available from experimental tests. Based on the artificial neural network results, a parametric analysis was carried out to study the influence of each parameter affecting the failure shear strength. Inel [12] developed an ANN model to estimate the strength of RC columns whose behavior is dominated by flexural failure. Experimental data of 237 rectangular columns from an existing database were used. Abdallaa et al. [13] presented application of ANN for predicting the shear resistance of rectangular R/C beams. Six parameters that influence the shear resistance of beams are used as input for the ANN. It is concluded that ANN can predict the shear resistance of rectangular R/C beams, to a great degree of accuracy.

Most of the problems solved in civil and structural engineering using ANN predicts the behavior of structural elements such as beams and columns based on given experimental results that are used as a training, testing and verification data. Artificial neural networks (ANN) are the most commonly used in structural engineering applications where a set of input parameters are mapped through single or several hidden layers, using weights, into output parameters.

In this study an Artificial Neural Network (ANN) model is developed to predict the shear strength of concrete beams reinforced with FRP bars. The results obtained by ANN model are compared with experimental values and with those determined by other models to assess the efficiency of these models. The developed ANN model is also utilized to evaluate the influence of various variables which govern the behavior of such members. The study based on the available databases with 76 tested members. The data set is randomly split into two groups: the first group of 64 is used for training the neural network model, and the remaining 12 data (about 16% of the data) are used for testing the model.

2. Review of the design equations

Most of the shear design provisions incorporated in codes and guides are based on the design formulas of members reinforced with conventional steel considering some modifications to account for the substantial differences between FRP and steel reinforcement. These provisions use the well-known $V_c + V_s$ method of shear design, which is based on the truss analogy. This section reviews the concrete shear strength of members longitudinally reinforced with FRP bars (V_{cf}) [5, 14, 15].

a-American concrete institute (ACI 440.1R-03)

The equation for shear strength proposed by the American Concrete Institute (ACI 440.1R-03) [14], can be expressed as follows:

$$V_{cf} = \frac{\rho_f E_f}{90\beta_1 f_c'}\left(\frac{\sqrt{f_c'}}{6}\, b_w\, d\right) \le \frac{\sqrt{f_c'}}{6}\, b_w\, d \qquad 1$$

b-Tureyen and Frosch equation [15]

This equation developed by Tureyen and Frosch [15]. It was developed from a model that calculates the concrete contribution to shear strength of reinforced concrete beams. The equation was simplified to provide a design formula applicable FRP reinforced beams as follows:

$$V_{cf} = \frac{2}{5}\left(\frac{\sqrt{f_c'}}{6}\, b_w\, c\right) \qquad 2$$

where $c = kd$= cracked transformed section neutral axis depth (mm).

$$k = \sqrt{2\rho_f n_f + (\rho_f n_f)^2} - \rho_f n_f$$

c- El-Sayed et al. equation [5]

They were applying the same procedure in ACI 440.1R-03 to derive Eq. 1 above, with some modification for proposing the Eq. below :

$$V_{cf} = 0.037\left(\frac{\rho_f E_f \sqrt{f_c'}}{\beta_1}\right)^{1/3} b_w\, d \le \frac{\sqrt{f_c'}}{6}\, b_w\, d \qquad 3$$

According to ACI 440.1R-03, the factor β_1 in the denominator of Eq. 3 is a function of the concrete compressive strength. It can be simply expressed by the following equation:

$$0.85 \ge \beta_1 = 0.85 - 0.007(f_c' - 28) \ge 0.65$$

3. Shear database

From the review of literatures [4, 6, 7, 15-26], a number (76) of shear strength test are used for developing the ANN. The all specimens were simply supported and were tested in three-point loading. The main reinforcement of all specimens is FRP (carbon FRP bars, and glass FRP bars) and there is no transverse reinforcement. All specimens were failed in shear, in other words, the failure of specimens is due to the propagated the cracks from the support toward the point of load application in an inclined direction. The collection data are divided into two sets: a training set containing 64 members, and testing set comprised of 12 members.

Six input variables are selected to build the ANN model. These variables are width (b_w), and depth (d) of the beams, modulus of elasticity of FRP (E_f), compressive strength of concrete (f_c'), reinforcement ratio of FRP (ρ_f) and the shear span to depth ratio (a/d). The output value is the shear strength of FRP beams. Table 1 summarizes the ranges of the different variables.

Table (1). Range of parameters in the database.

Parameters	Range
Width of beams (b_w) mm	89-1000
Effective depth of beams (d) mm	143-360
Shear span to depth ratio ($^a/_d$)	1.3-6.5
Compressive strength of concrete (f_c') MPa	24-81
modulus of elasticity of FRP (E_f) (GPa)	37-145
Reinforcement ratio of FRP (ρ_f)	0.25-2.63

4. Artificial Neural Network Model

Neural networks can be thought of as "computational system" that accept inputs and produces outputs [27]. Figure(1) shows a typical neural network structure consisting of three layers [27]:

●Input Layer: A layer of neurons that receives information from external sources, and passes this information to the network for processing. These may be either sensory inputs or signals from other systems outside the one being modeled.

●Hidden Layer: A layer of neurons that receives information from the input layer and processes them in a hidden way. It has no direct connections to the outside world (inputs or outputs information). All connections from the hidden layer are to other layers within the system.

●Output Layer: A layer of neurons that receives processed information and sends output signals out of the system.

Additionally bias, acts on a neuron like an offset. The function of the bias is to provide a threshold for the activation of neurons. The bias input is connected to each of the hidden and output neurons in a network.

The number of input neurons corresponds to the number of input variables into the neural network, and the number of output neurons is the same as the number of desired output variables. The number of neurons in the hidden layer(s) depends on the application of the network.

As inputs enter the input layer from an external source, the input layer becomes "activated" and emits signals to its neighbors (hidden layer) without any modification. Neurons in the input layer act as distribution nodes and transfer input signals to neurons in the hidden layer. The neighbors receive excitation from the input layer, and in turn emit an output to their neighbors (second hidden layer or output layer). Each input connection is associated with a quantity, called "a weight factor" or "a connection strength" [27].

The strength of a connection between two neurons determines the relative effect that one neuron can have on another. The weight is positive if the associated connection is excitatory and negative if the connection is inhibitory [27].

5. Shear strength of concrete beams with (FRP) bars using ANN

ANN is used to investigate the shear strength of concrete beams reinforced with FRP bars. The configuration and training of neural networks is a trail-and-error process due to such undetermined parameters as the number of nodes in the hidden layer, and the number of training patterns.

In the developed ANN, there is an input layer, where input data are presented to network and an output layer, with one neuron representing shear strength of concrete beams reinforced with FRP bars. One hidden layer as an intermediate layer is also included. The network with one hidden layer and four nodes in the hidden layer gave the optimal configuration with minimum mean square error (MSE).

Six input variables are: width (b_w), and depth (d) of the beams, modulus of elasticity of FRP (E_f), compressive strength of concrete (f_c'), reinforcement ratio of FRP (ρ_f) and the shear span to depth ratio ($^a/_d$).

The back-propagation neural network model used for this study is trained by feeding a set of mapping data with input and target variables. The main objective of training the neural network is to assign the connection weights by reducing the errors between the predicted and actual target values to a satisfactory level. This process is carried out through the minimization of the defined error function by updating the connection weights. Also, the number of hidden layers, number of hidden nodes, transfer functions, and normalization of data are chosen to get the best performance of the model. After the errors are minimized, the model with all the parameters including the connection weights is tested with a separate set of "testing" data that is not used in the training phase. At the end of the training, the neural network represents a model that should be able to predict the target value.

The network has trained continually through updating of the weights until error goal of $15.1*10^{-4}$ is achieved. Figure (2) shows the performance for training and generalization (testing). A resilient back propagation training algorithm is used to train the network, for 800 epochs to check if the performance (MSE) for either training or testing sets might diverge.

The network performance with resilient back propagation training algorithm have been tested for training and testing patterns, as shown in Figures (3 and 4). A good agreement has been noted in the predicting values compared with the actual (targets) values.

6. Parametric analyses based on ANN

Once the artificial neural network has been trained, a parametric analysis is used to study the influence of the various parameters on the shear strength of beams. The basic idea is to predict the effect of varying the value of only one variable while the remaining variables are kept constant with the same updated weights and bias matrices after being trained.

Figure(5) shows the effect of width of specimen on shear strength of concrete beams reinforced with FRP. It can be seen from this figure that the shear strength variation is non-linearly with width of specimen and as the width increases, the shear strength increase and this in agreement with the results obtained by Eqs. (1), (2) and (3).

In Figure6 the shear strength of concrete beams reinforced with FRP is plotted versus the depth of member (d mm). It can be clearly seen from the figure that the increase in depth of beams leads the shear strength to increase. which is in agreement with the experimental results of Omeman et al. [7] and the ACI 440.1R-03, Tureyen and Frosch and proposed by El-Sayed et al equations [4,14,15] respectively. The result in this study supports and proves that the beam's effective depth has a significant effect on the shear strength, so the shear strength is a function of the beam effective depth in addition to other parameters.

The results of five concrete beams reinforced with FRP with a compressive strength of concrete varying from 25 to 80 MPa showed that the shear strength increased as compressive strength of concrete (f_c') increased as shown in Figure (7). The conclusion of increasing shear strength with increasing f_c' is in agreement with the Canadian standard (CSA 2002) [28] and the American Concrete Institute (ACI) [14]. According to ACI the shear strength of beams reinforced with FRP can be estimated by using Eq. (1). Eqs. (2) and (3) also strongly supported this observation. Also El-Sayed et. al. [17] in experimental study, showed that the shear strength of concrete beams reinforced with FRP increased with increasing f_c'.

Figure (8) shows the influence of modulus of elasticity (E_f) of FRP on shear strength. As smaller to previous parameter when the E_f increases, the shear strength increase. El-Sayed

[18] concluded that the shear strength of concrete beams reinforced with FRP increased with increasing the modulus of elasticity of FRP with same amount of FRP. Also Esq. (1), (2) and (3) supported this conclusion.

The shear span to depth ratio has a very important influence on the shear strength of concrete beams reinforced with FRP. Figure (9) shows that the relationship between shear span to depth ratio ($^{a}/_{d}$) and shear strength is non-linear and also can be seen that the shear strength significantly increased with decreasing $^{a}/_{d}$. Figure (9) shows that the decreasing $^{a}/_{d}$ by 35% in other words, from 2 to 1.3 increased the shear strength by 184%. El sayed [18] found that the shear strength of concrete beams reinforced with carbon fire reinforced polymer increase with decreasing shear span to depth ratio. He found that when the decreasing $^{a}/_{d}$ by 23.1% (from 1.69 to 1.3), increased the shear strength by 90.8%. Also Figure(9) shows that the increasing in shear strength is insignificantly after $^{a}/_{d} > 2.5$ this may be attributed to the fact that the beam behaved as a deep beams when $^{a}/_{d} < 2.5$, in this case the arch action will be occurred. For such beams, a significant of redistribution of internal forces expected after cracking and a large part of shear force is transferred to support, however, the arch action enhance the shear strength of member [4, 18, 29].

In the present study, also a sensitivity notation has been conducted using ANN model to investigate the effect of longitudinal reinforcement ratio (ρ_f) on the shear strength of FRP reinforced concrete beams without stirrups. Figure (10) presents the effect of ρ_f on the shear strength of reinforced concrete beams. It is shown that the shear strength increases with increase the ratio of FRP (ρ_f). However, a linear relationship is seems in Figure(10). In general this prediction is agree with the experimental study conducted by different authors [7, 18, 26].

It is observed from these figures that the shear span to depth ratio ($^{a}/_{d}$) is the most important factor among the input variables.

7. Comparison between experimental and theoretical results

The predictions of shear strength of beams reinforced with FRP as that obtained from ANN, ACI 440.1R-03, Tureyen and Frosch equation**,** and proposed equation by El-Sayed et al., are compared with the experimental results and shown for both training and testing sets in Figures(11 and 12) and Table (2).

In Table (2) the ratios of experimental (V_e) to theoretical (V_i) predictions of the shear strength of beams reinforced with FRP along with their average and standard deviation are presented. The theoretical predications include those obtained by ANN (V_1), proposed equation by El-Sayed et al. (V_2), ACI 440.1R-03 (V_3), and Tureyen and Frosch equation (V_4). It can be seen that ANN model gives average values for testing set of V_e/V_1 of 0.97 and standard deviations of 0.1 which is much better than the values obtained from other methods. Figures (11 and 12) confirm the same conclusion that the predictions of ANN model are better than those of the other methods.

Also in Table (3) the correlation coefficient R of predicted shear strength that evaluated by ANN and the other methods are summarized. As shown in Table (3), the ANN produces a higher correlation coefficient R as compared with the other methods. Therefore the ANN can serve as reliable and simple tool for the prediction of shear strength of beams reinforced with FRP.

8. Conclusion

This research can be considered as contribution to an ongoing effort to develop artificial neural network system for solving the civil engineering problems. In this study the model based on Artificial Neural Network (ANN) are developed to predict the shear strength of beams reinforced with FRP. A database of a seventy six (76) tests data developed from the review of literature for the training and testing of model. Six variables are selected as input to ANN model with one target variable, shear strength of beams reinforced with FRP.

With the developed ANN, predictions of shear strength are made using back-propagation neural network as well as available methods, and they are also compared with experimental results. We found that the ANN prediction agree much better with the experimental values as compared to those from the other methods. The results of this study indicate that ANN provides a reliable and simple tool for the prediction of shear strength of beams reinforced with FRP. Also through the parametric study based on ANN, the network is able to learn about the effect of each input variables on the final outputs.

Table (2). Comparison Between Experimental and Analytical Results Obtained by Different Methods for Training and Testing Sets for Shear Strength reinforced with FRP.

No.	Shear Strength V_u (kN)					Ratio			
	Exp. V_e	ANN V_1	El-Sayed Eq. V_2	ACI 440 V_3	Tureyen and et al. Eq. V_4	$\frac{V_e}{V_1}$	$\frac{V_e}{V_2}$	$\frac{V_e}{V_3}$	$\frac{V_e}{V_4}$
	Training Set								
1	140	149.49	99.66	28.09	66.34	0.94	1.40	4.98	2.11
2	167	160.68	125.56	56.18	90.54	1.04	1.33	2.97	1.84
3	190	178.38	139.95	82.53	105.15	1.07	1.36	2.30	1.81
4	113	114.69	89.72	21.32	57.82	0.99	1.26	5.30	1.95
5	163	142.79	112.82	42.38	79.04	1.14	1.44	3.85	2.06
6	163	170.25	124.58	59.32	90.71	0.96	1.31	2.75	1.80
7	168	182.25	123.8	61.97	90.83	0.92	1.36	2.71	1.85
8	77.5	80.61	69.26	34.15	52.45	0.96	1.12	2.27	1.48
9	70.5	60.5	46.6	10.41	30.67	1.17	1.51	6.77	2.30
10	104	93.38	77.65	51.17	60.25	1.11	1.34	2.03	1.73
11	124.5	116.95	86.27	71.11	68.5	1.06	1.44	1.75	1.82
12	77.5	74.87	58.49	22.16	41.6	1.04	1.33	3.50	1.86
13	130	136.36	91.77	67.53	76.42	0.95	1.42	1.93	1.70
14	87	91.15	62.19	21.01	46.04	0.95	1.40	4.14	1.89
15	115.5	107.41	67.63	27.03	51.54	1.08	1.71	4.27	2.24
16	36.1	42.77	25.4	6.23	16.5	0.84	1.42	5.79	2.19
17	47	50.23	33.03	12.28	23.82	0.94	1.42	3.83	1.97
18	42.7	50.12	38.63	21.91	28.93	0.85	1.11	1.95	1.48
19	49.7	33.57	32	12.45	22.6	1.48	1.55	3.99	2.20
20	38.5	29.71	32	12.45	22.6	1.30	1.20	3.09	1.70
21	14	28.54	11.85	3.06	8.26	0.49	1.18	4.58	1.69
22	20	20.06	17.72	6.55	13.27	1.00	1.13	3.05	1.51
23	15.4	10.37	15.45	5.69	12.3	1.49	1.00	2.71	1.25
24	59.1	60.86	29.01	6.47	18.26	0.97	2.04	9.13	3.24
25	44.1	56.72	34.24	9.69	23.09	0.78	1.29	4.55	1.91
26	46.8	47.67	34.59	13.21	23.66	0.98	1.35	3.54	1.98
27	47.5	48	29.97	13.45	21.37	0.99	1.58	3.53	2.22
28	57.1	57.26	38.04	29.26	28.78	1.00	1.50	1.95	1.98
29	38	37.49	32.2	7.35	23.38	1.01	1.18	5.17	1.63
30	35.77	41.46	30.97	9.99	23.97	0.86	1.15	3.58	1.49
31	46.4	49.54	40.7	14.98	32.23	0.94	1.14	3.10	1.44
32	108.1	102.63	94.73	24.48	61.97	1.05	1.14	4.42	1.74
33	94.7	101.43	92.49	22.71	59.96	0.93	1.02	4.17	1.58
34	137	154.78	120.62	48.57	86.26	0.89	1.14	2.82	1.59
35	152.6	152.53	117.76	45.07	83.57	1.00	1.30	3.39	1.83
36	177	160.31	127	56.45	92.4	1.10	1.39	3.14	1.92
37	38.13	28.53	30.63	8.95	20.2	1.34	1.24	4.26	1.89

Table(2). Continued.

38	44.43	33.4	35.02	13.38	24.22	1.33	1.27	3.32	1.83
39	45.27	37.56	43.92	17.77	30.66	1.21	1.03	2.55	1.48
40	45.1	38.02	41.49	18.24	29.36	1.19	1.09	2.47	1.54
41	42.2	39.56	38.7	18.21	27.68	1.07	1.09	2.32	1.52
42	53.4	65	35.06	20.28	23.92	0.82	1.52	2.63	2.23
43	36.1	42.58	25.04	6.98	15.11	0.85	1.44	5.17	2.39
44	40.1	50.04	30.12	12.15	19.42	0.80	1.33	3.30	2.06
45	26.8	30.64	23.8	5.74	14.52	0.87	1.13	4.67	1.85
46	28.3	28.29	24.01	5.67	14.72	1.00	1.18	4.99	1.92
47	28.5	33.45	23.75	5.76	14.46	0.85	1.20	4.95	1.97
48	27.6	26.74	24.1	5.64	14.81	1.03	1.15	4.89	1.86
49	185.2	191.16	19.93	13.34	14.87	0.97	9.29	13.88	12.45
50	154.9	138.61	20.31	13.07	15.37	1.12	7.63	11.85	10.08
51	91.5	101.61	20.46	13	15.57	0.90	4.47	7.04	5.88
52	185.5	184.17	25.67	26.08	20.48	1.01	7.23	7.11	9.06
53	298.1	300.76	36.34	25.8	28.16	0.99	8.20	11.55	10.59
54	468.2	466.03	48.22	32.84	36.55	1.00	9.71	14.26	12.81
55	226.9	226.76	22.02	12.22	17.67	1.00	10.30	18.57	12.84
56	179.5	194.63	65.33	32.56	47.91	0.92	2.75	5.51	3.75
57	164.5	153.92	43.66	9.72	27.79	1.07	3.77	16.92	5.92
58	175	167.49	50.96	15.45	34.38	1.04	3.43	11.33	5.09
59	233.5	251.09	84.87	71.38	66.61	0.93	2.75	3.27	3.51
60	196	184.3	56.72	21.31	39.74	1.06	3.46	9.20	4.93
61	372	351.68	76.25	51.76	58.37	1.06	4.88	7.19	6.37
62	269	285.74	50.96	15.45	34.38	0.94	5.28	17.41	7.82
63	42.6	48.51	69.42	16.25	47.46	0.88	0.61	2.62	0.90
64	86.1	83.92	93.61	19.05	62.25	1.03	0.92	4.52	1.38
AVERAGE						1.01	2.30	5.32	3.17
STDEV						0.158	2.31	3.94	2.98
	Testing Set								
65	142	149.23	110.44	41.3	77.3	0.95	1.29	3.44	1.84
66	60	64.1	52.46	15.78	35.95	0.94	1.14	3.80	1.67
67	174	169.09	99.82	86.88	84.69	1.03	1.74	2.00	2.05
68	47.2	47.07	34.56	15.69	25.03	1.00	1.37	3.01	1.89
69	9.8	9.42	9.82	2.63	7.39	1.04	1.00	3.73	1.33
70	50.15	44.46	35.37	20.16	26.78	1.13	1.42	2.49	1.87
71	32.53	36.93	26.5	7.31	19.94	0.88	1.23	4.45	1.63
72	114.8	105.88	99.87	28.41	66.67	1.08	1.15	4.04	1.72
73	31.73	31.67	25.84	8.9	17.55	1.00	1.23	3.57	1.81
74	29.2	37.52	23.58	5.88	14.29	0.78	1.24	4.97	2.04
75	162.3	170.3	23.12	19.79	17.98	0.95	7.02	8.20	9.03
76	195	219.37	76.25	51.76	58.37	0.89	2.56	3.77	3.34
AVERAGE						0.97	2.01	3.93	2.73
STDEV						0.10	1.72	1.62	2.27

Table (3). Comparison summary of correlation R.

Type	Correlation R	
	Training	Testing
ANN	0.995	0.993
El-Sayed Eq.	0.62	0.63
ACI 440	0.51	0.78
Tureyen and et al. Eq.	0.4	0.69

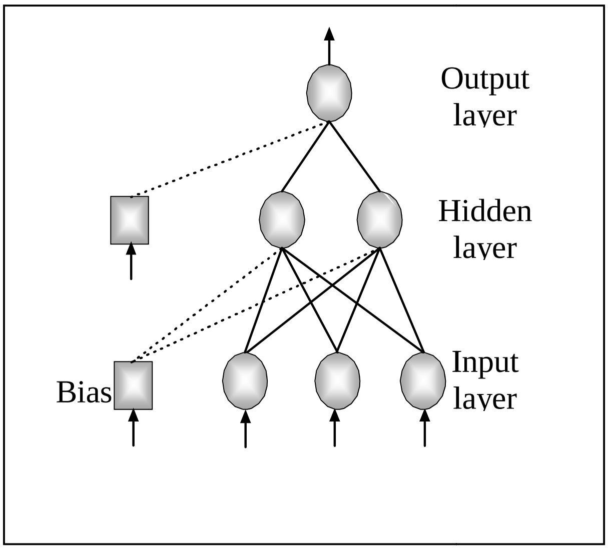


Figure (1). Structure of a typical multilayer neural.

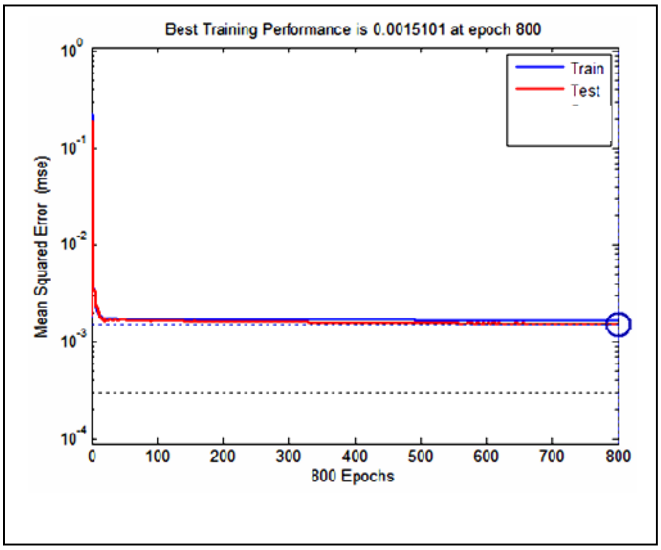
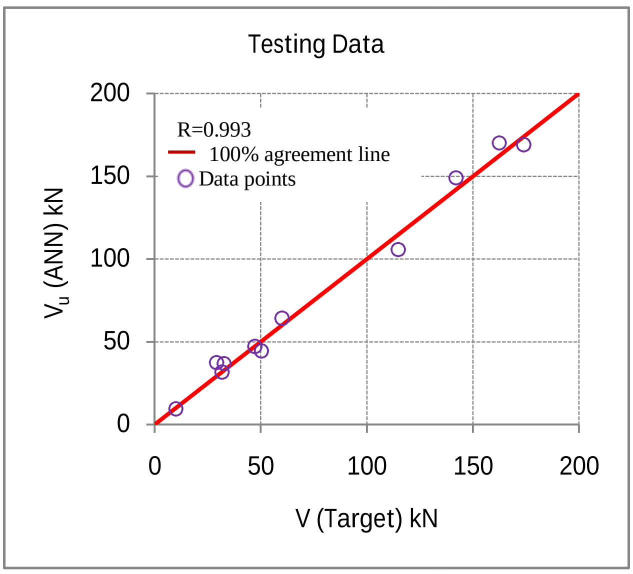
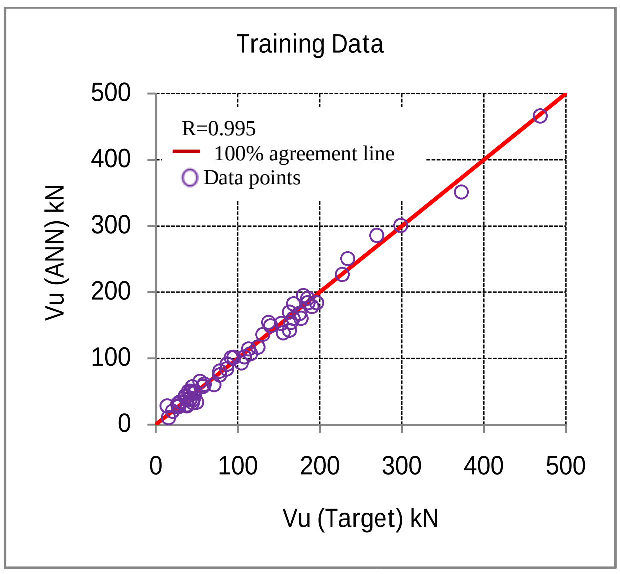


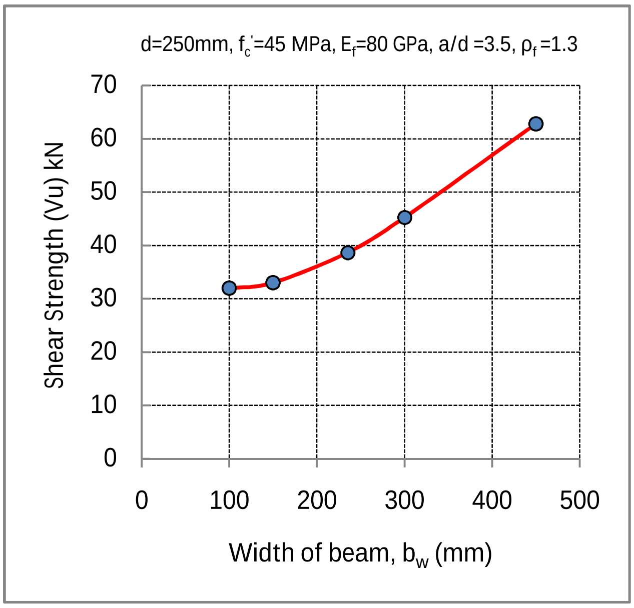
Figure (2). Convergence of the ANN for training and testing sets.



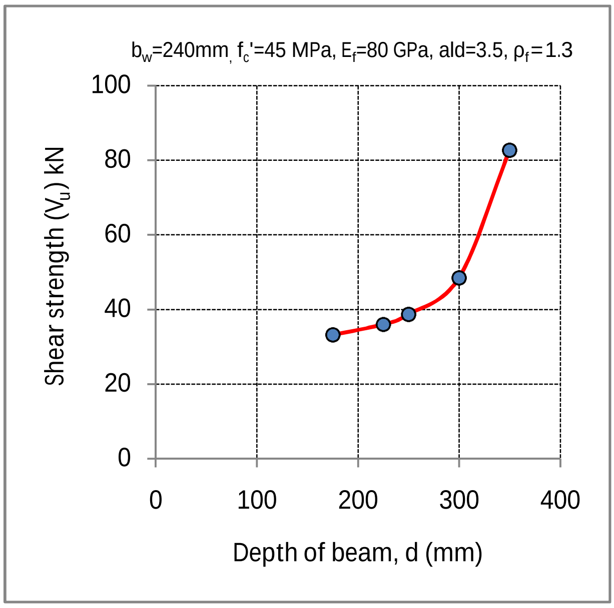
Figure(3). Comparison between ANN results and target results for training patterns sets.



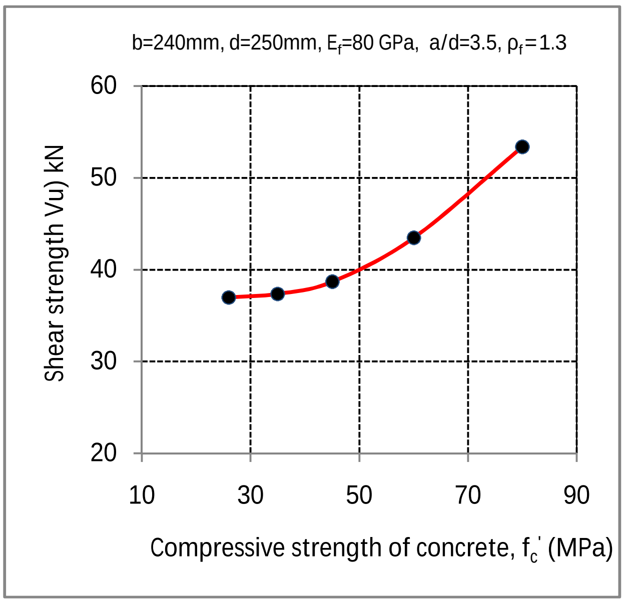
Figure(4). Comparison between ANN results and target results for testing patterns sets.



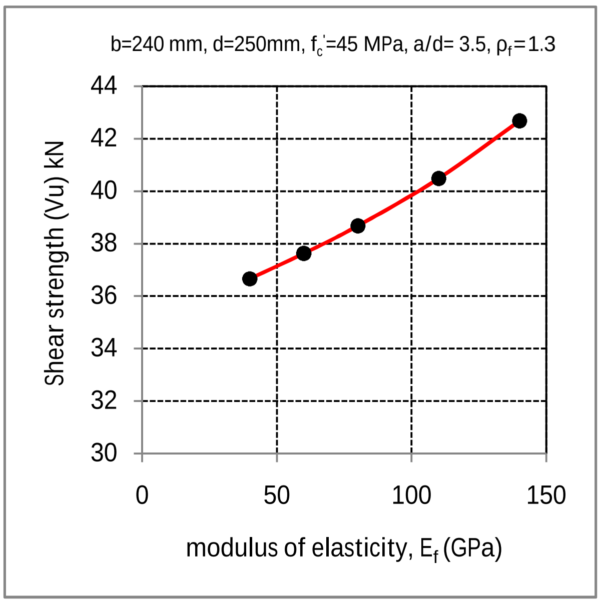
Figure(5). Effect the width of beams on shear strength of FRP beams.



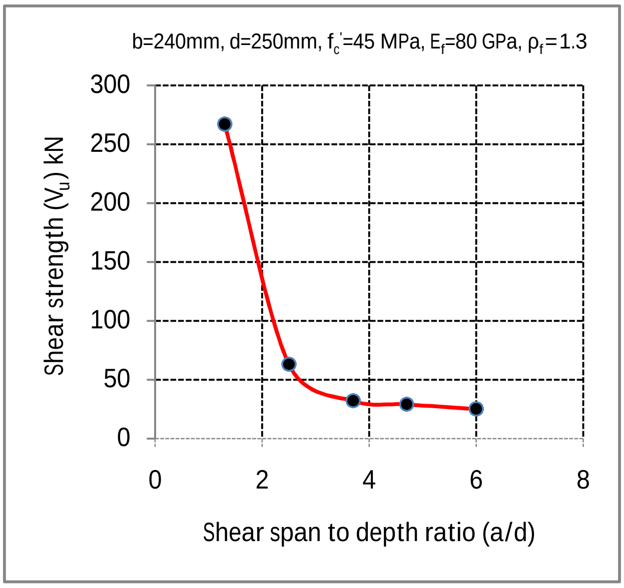
Figure(6). Effect the depth of beams on shear strength of FRP beams.



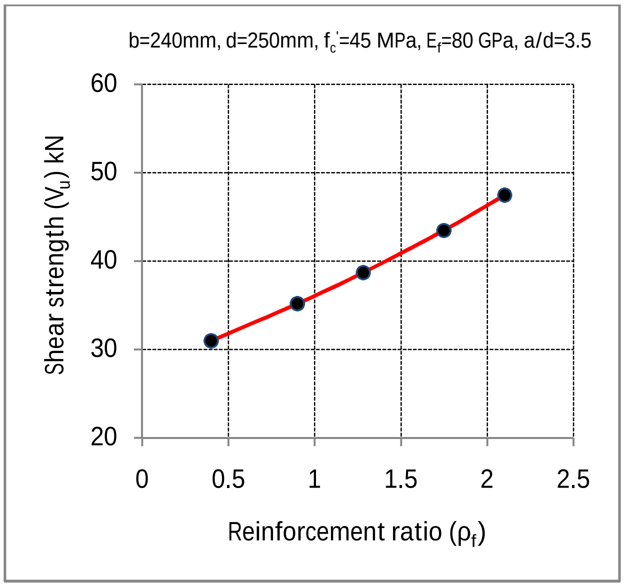
Figure(7). Effect of the compressive strength of concrete on shear strength of FRP beams .



Figure(8). Effect of the modulus of elasticity (E_f) on shear strength of FRP beams .



Figure(9). Effect the shear span to depth ratio on shear strength of FRP beams.



Figure(10). Effect of the reinforcement ratio on shear strength of FRP beams.

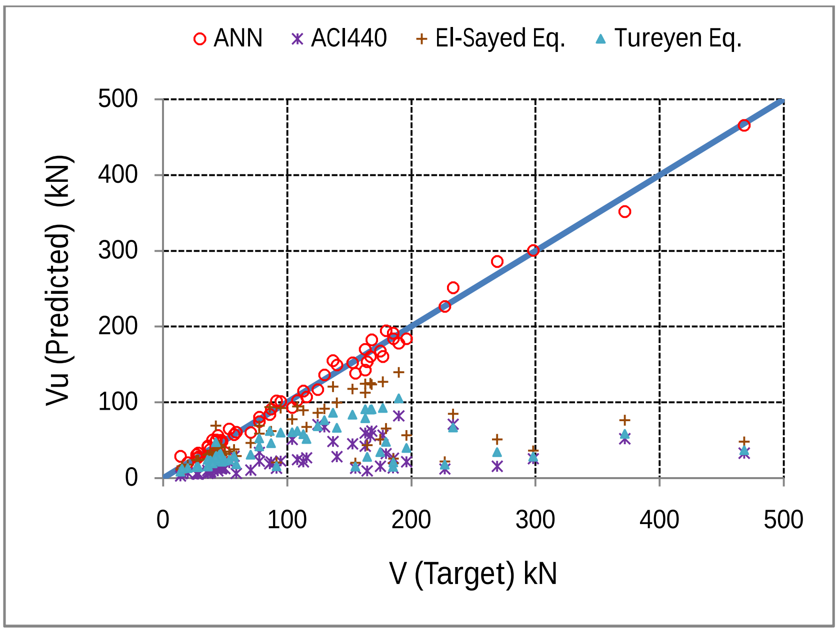


Figure (11). Comparison experimental and predicted values for training data Set.

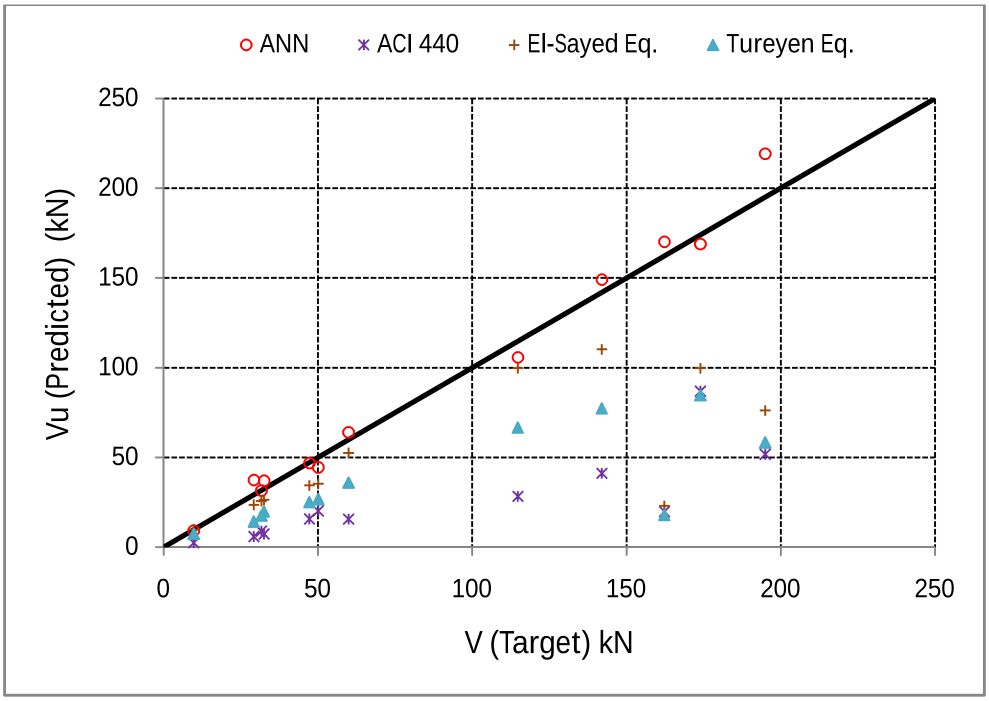


Figure (12). Comparison experimental and predicted values for testing data Set.

9. References

[1] Bank .L.C., 2006, "Composites for Construction: Structural Design with FRP Materials", Book, John Wiley .

[2] Tan, K.H., 2003, "Fibre-Reinforced Polymer Reinforcement for Concrete Structures", Book, World Scientific Pub Co., 1528 pp.

[3] El-Sayed, A. K., El-Salakawy, E. F., and Benmokrane, B., 2004, "Evaluation of Concrete Shear Strength for Beams Reinforced with FRP Bars", 5th Structural Specialty Conference of the Canadian Society for Civil Engineering, CSCE, Saskatoon, Saskatchewan, Canada, June, 10p.

[4] El-Sayed, A. K., El-Salakawy, E. F., and Benmokrane, B., 2006, "Shear Strength of FRP Reinforced Concrete Beams without Transverse Reinforcement", ACI Structural Journal, 103 (2), pp.235-243.

[5] El-Sayed A.K., El-Salakawy E.F., and Benmokrane B., 2005," Shear Strength of Concrete Beams Reinforced with FRP Bars: Design Method, ACI-SP-230, USA, Nov, pp.955-974.

[6] Wegian F.M., Abdalla H.A., 2005, " Shear capacity of concrete beams reinforced with fiber reinforced polymers; Composite Structures, 71, pp. 130–138.

[7] Omeman Z., Nehdi M., El-Chabib H., 2008," Experimental study on shear behavior of carbon-fiber-reinforced polymer reinforced concrete short beams without web reinforcement", Canadian Journal of Civil Engineering, 35, pp.1-10.

[8] Jang R.S., Sun T. C., Mizutani E., 1997, " Neuro-Fuzzy and Soft Computing A Computational Approach to Learning and Machine intelligence", Book.

[9] Rafiq, M.Y., Bugmann, G. and Easterbrook, D.J., 2001,"Neural Network Design for Engineering Applications" Journal of Computers and Structures,79 (17), pp. 1451-1552.

[10] Hsu D.S., and Chung H.T., 2002, "Diagnosis of Reinforced Concrete Structural Damage Base on Displacement Time History using the Back-Propagation Neural Network Technique", Journal of Computing in civil engineering, 16(1), pp.49-58.

[11] Cladera A., Mar A.R., 2004, "Shear design procedure for reinforced normal and high-strength concrete beams using artificial neural networks", Part II: beams with stirrups, Journal Engineering Structure, 26, pp. 927-936.

[12] Mehmet Inel, 2007, "Modeling Ultimate Deformation Capacity of RC Columns Using Artificial Neural Networks", Engineering Structures.; 29, pp. 329–335.

[13] Abdallaa J.A., Elsanosib A., Abdelwahab A., 2007, "Modeling and Simulation of Shear Resistance of R/C Beams Using Artificial Neural Network", Journal of the Franklin Institute 344, pp. 741-756.

[14] Guide for the Design and Construction of Concrete Reinforced with FRP Bars (ACI 440.1R-03), Reported by ACI Committee 440, 2003.

[15] Tureyen, A. K. and Frosch, R. J., 2003, “Concrete Shear Strength: Another Perspective” ACI Structural Journal, 100 (5), pp. 609-615.

[16] El-Sayed, A. K., El-Salakawy, E. F., and Benmokrane, B., 2005, “Shear Strength of One-way Concrete Slabs Reinforced with FRP Composite Bars”, Journal of Composites for Construction, ASCE, 9(2), pp.147-157.

[17] El-Sayed, A. K., El-Salakawy, E. F., and Benmokrane, B., 2006, “Shear Capacity of High-Strength Concrete Beams Reinforced with FRP Bars”, Submitted to ACI Structural Journal,,103(3), pp.383-389.

[18] El-Sayed, A. K., 2006, "Concrete Contribution to the Shear Resistance of FPR-Reinforced Concrete beams" PhD Thesis, Sherbrook University,.

[19] Gross, S. P., Dinehart, D. W., Yost, J. R., and Theisz, P. M., 2004, “Experimental Tests of High-Strength Concrete Beams Reinforced with CFRP Bars”, Proceedings of the

4th International Conference on Advanced Composite Materials in Bridges and Structures (ACMBS-4), Calgary, Alberta, Canada, July 20-23, 8p.

[20] Gross, S. P., Yost, J. R., Dinehart, D. W., Svensen, E., and Liu, N.,2003, “Shear Strength of Normal and High Strength Concrete Beams Reinforced with GFRP Reinforcing Bars”, Proc. of the Int. Conference on High Performance Materials in Bridges, ASCE, 426-437.

[21] Razaqpur, A. G., Isgor, B. O., Greenaway, S., and Selley, A.,2004, “Concrete Contribution to the Shear Resistance of Fiber Reinforced Polymer Reinforced Concrete Members”, Journal of Composites for Construction, ASCE, 8(5), pp. 452-460.

[22] Tariq, M., and Newhook, J. P.,2003, “Shear Testing of FRP reinforced Concrete without Transverse Reinforcement,” Proceedings of CSCE 2003-Anuual Conference, Moncton, NB, Canada, 10p.

[23] Tureyen, A. K., and Frosch, R. J.,2002, “Shear Tests of FRP-Reinforced Concrete Beams without Stirrups”, ACI Structural Journal, 99(4), pp.427-434.

[24] Yost, J. R., Gross, S. P., and Dinehart, D. W. 2001, “Shear Strength of Normal Strength Concrete Beams Reinforced with Deformed GFRP Bars”, Journal of Composites for Construction, ASCE, 5(4), pp. 263-275.

[25] Deitz, D. H., Harik, I. E., and Gesund, H.,1999, “One-Way Slabs Reinforced with Glass Fiber Reinforced Polymer Reinforcing Bars”, Proceedings of the 4th International Symposium, Fiber Reinforced Polymer Reinforcement for Reinforced Concrete Structures, MI., pp. 279-286.

[26] Alkhrdaji, T., Wideman, M., Belarbi, A., and Nanni, A.,2001, “Shear Strength of GFRP RC Beams and Slabs”, Proceedings of the International Conference, Composites in Construction-CCC 2001, Porto/Portugal, pp. 409-414.

[27] Baughman, D.R. and Liu, Y.A., 1995, "Neural Network in Bioprocessing and Chemical Engineering", Book, Academic Press, San Diego, CA.

[28] CSA. 2002. Design and construction of building components with fiber-reinforced polymers. Standard S806-02. Canadian Standards Association.

[29] Yang, K.H., Chung, H.S., Lee, E.T., and Eun, H.C., 2003, "Shear Characteristics of High-Strength Concrete Deep Beams without Shear Reinforcements. Engineering Structures, 25(10), pp 1343–1352.

10.Nomenclature

V_u: Shear strength.

V_{cf}: The shear resistance of members reinforced with FRP bars as flexural reinforcement.

V_c: The shear strength provided by the concrete.

V_s: The shear strength provided by steel.

b_w: Width of the specimen.

d: Effective depth of the specimen.

E_f: Modulus of elasticity of fiber reinforced polymers

ρ_f: Reinforcement ratio of flexural FRP.

n_f: ratio of the modulus of elasticity of FRP bars to the modulus of elasticity of concrete.

f_c': Compressive strength of concrete.

f_y: Yield strength of the mesh wire.

$^a/_d$: Shear span to depth ratio.

β_1: function of the concrete compressive strength (f_c').