Evaluation of Shear Strength of Deep Beams using Artificial Neural Networks

Mohammad Tasleema, M. Anil Kumar, J. Leon Raj

Abstract: In reinforced concrete deep beams, the customary standards of stress analysis are neither appropriate to define failure mechanism nor sufficient to forecast the shear capacity of deep beams. This paper reports the prediction of shear strength of deep beams using Artificial Neural Networks (ANNs), and the results are compared with experimentally measured shear strength as well as expressions suggested by codes of practice. Test data is collected from the past research works and the artificial neural network is trained using this test data. MATLAB is used for training and analyzing the collected experimental data. The comparison of results show that ANN has predicted the shear strength of concrete deep beams more precisely when compared with the other existing models with coefficient of variation 5 %, whereas other models COV varied in between 37 and 47 %.

Index Terms: Artificial Neural Networks (ANN), Reinforced Concrete Deep Beams, Shear strength, Shear span-to-depth ratio.

I. INTRODUCTION

Reinforced concrete deep beams are structural members that allow heavy gravity loads predominantly through shearing action to their supports. Deep beams are distinguished with normal beam in terms of small effective span-to-effective depth ratio. Concrete members become flexurally rigid if the depth of the beam is increased without changing the length of the beam, and vulnerable for shear failure. In those members, the applied load is efficiently transferred shear force through arch action from loading points to supports, as shown in Figure 1, rather than by truss action.

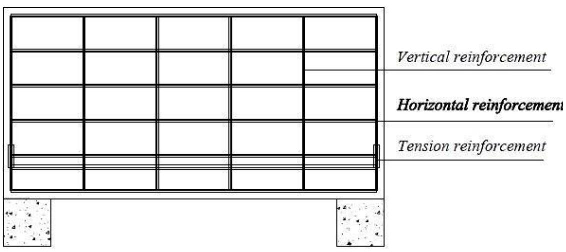

Figure1: Deep beam

The effective span-to-effective depth ratio is restricted to 4 [1] and this ratio is restricted to 2.0 for a simply supported beam and 2.5 for a continuous beam [9]. These often appeared in the form of girders in tall buildings and in pile caps, tanks, bins, folded plate roof structures, foundation walls, floor diaphragms, shear walls and bracket or corbels. The failure of deep beams is mainly dominated by the shear preferably than flexure. So shear action is critical in these concrete members and, if underestimated, or ignored it could lead to a catastrophic failure without any warning. Hence, shear is a major application in the design of deep beams. Many analysis attempts have been carried out in order to find out the most effective method to forecast the shear capacity of deep beams and to determine their structural performance. Accounting for all these, Artificial Neural Network (ANN) is one among the methods used for forecasting the shear strength of deep beams.

ANNs are networks developed to resolve issues by trying to copy the form and the role of our nerve system. Artificial Neural networks are dependent on assumed neurons (nodes). These neurons are joined together in a variety of ways to form networks. This Network reflects the human brain in two ways: Access knowledge through learning and accessed knowledge is stored within the interconnection weight. A typical diagram of the Artificial Neural Network is as shown in the Figure 2.

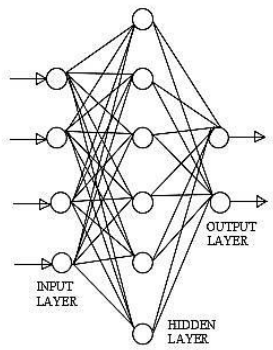

Figure 2: Artificial neural network

A basic model of ANN contains node interconnections, learning, training rules, and activation function. This paper describes how neural network is developed for the forecasting of the shear capacity of deep beams. Obtained results are correlated with both the test values and with those determined from the ACI code method, EURO code method, Zsutty method (Zsutty, T.C 1968) and Russo method (Russo, G., and Puleri, G., 1997).

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II. RESEARCH SIGNIFICANCE

The expressions for predicting the shear capacity of deep beams proposed by different authors were found exaggerated with shear span to depth (a/d) ratio less than 2.0. An Artificial Neural Network model was developed using experimental data. The ANN is trained, validated and tested using this experimental database. Also shear strength values are predicted for the available input data using the developed net.

III. EXPERIMENTAL DATA

The test data is gathered from the past research work. It is important to have to more data for training the network so data is collected from the previous research works.

Based on previous research works, the basic parameters which are controlling the shear capacity of deep beams are taken.

Table I: Range of parameters in the collected data

Parameters	Range
b	0.02-0.15
d	0.216-0.94
a	0.234-2.7
a/d	0.125-76
f'_c	12.5-76
f_{yh}	0-600
f_{yv}	0-460
ρ_h %	0.05-1.94
ρ_{ht} %	0-2.95
ρ_v %	0-2.45

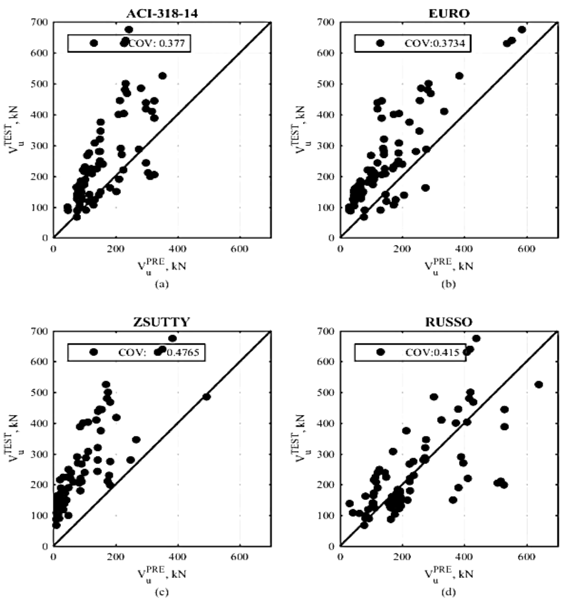

Figure 3: Plots of predicted shear strength vs. tested shear strength for different methods

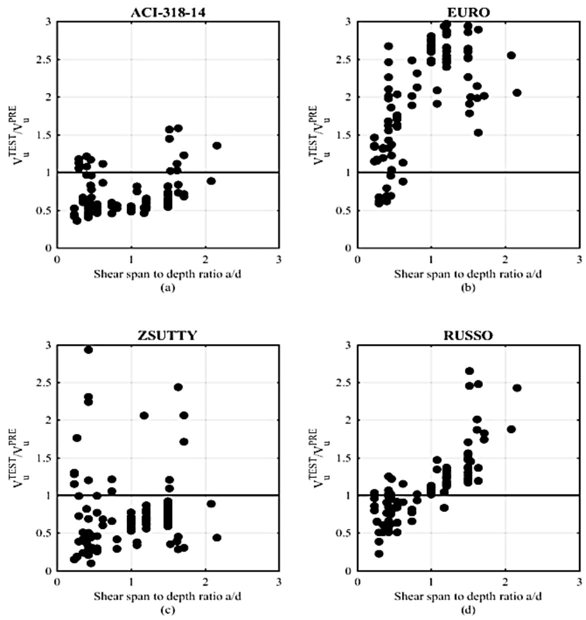

Figure 4: Variation of Actual Shear Strength to Predicted Shear Strength with a/d Ratio for different methods

These basic parameters include span (*L*), Breadth (*bw*), depth (*d*), and Shear span (*a*) of the beam.

Reinforcement ratio of horizontal tensile steel (ρ_h), total horizontal steel (ρ_{ht}), transverse steel (ρ_v), compressive strength of concrete ($f'c$), Yield strength of horizontal steel (fyh) and vertical steel (fyv). Collected test data includes results of deep beam, taken from the experimental works carried out by researchers [12], [15], [20], [21], and [22]. The parameters are taken in such a way that these cover both material and geometrical properties of the concrete deep beams as shown in the Table I.

IV. EXISTING EXPRESSIONS

To forecast the ultimate shear strength of the concrete deep beams following expressions exist in the literature.

A. *ACI Code 318 (2008)*

Based on the large amount of experimental data in which the beams failed due to crushing of support regions, code encloses a set of empirical based rule for shear capacity of deep beams. The formula is developed using the shear friction theory. The formula for the ultimate shear strength of concrete deep beams (Vn) is given in the section 11.8 of the ACI code is

$$Vn = \emptyset \times (Vc + Vs) \quad (1)$$

To prevent the diagonal compression failure and to prevent the cracking within live and dead loads in deep beams the limit imposed is

$$V_n = \emptyset\, 0.83\sqrt{f'c}bd, \emptyset = 0.85$$

Where, *Vn* = nominal shear strength of the deep beam; ϕ=shear capacity reduction factor, *Vc* and *Vs* =shear strengths provided by concrete and shear reinforcements, reciprocally;

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B. EURO Code CEN (1992)

Based on the truss model, the EURO code had proposed a very simple formulation. Euro code is useful for beams or for prestressed beams and it is slightly conventional for heavily reinforced concrete members. Nominal shear capacity of the members is given by:

$$Vn = Vc + Vs \quad (2)$$

Where, $Vc = \tau_{rd} k\beta(1.2 + 40\beta)bd$, $Vs = 0.9\rho_v f_{vy} bd$, k=1.6−d >1, β=1 for a/d ≥2.5 or β=2.5d/a ≤5 for a/d<2.5, ρ= min [As / (b*d); 0.02], $\tau_{rd} = 0.25 f_{ck0.05}/\gamma_c$, γ_c=1.5,

Vn = nominal shear strength of the deep beam, Vc and Vs are shear strengths provided by concrete and shear reinforcements.

C. Zsutty Model

Zsutty and T. C. had proposed an empirical equation for the calculation of the nominal shear strength, which is a combination of analysis of physical quantities and regression. According to Zsutty the nominal shear strength is given by

$$Vn = Vc + Vs \quad (3)$$

Where,

$Vc = 2.2(f_c\rho\frac{d}{a})^{1/3}bd$; f'c in MPa; $\frac{a}{d} > 2.5$

$$Vc = \left(2.5\frac{d}{a}\right)2.2(fc\rho\frac{d}{a})^{1/3}bd$$

$$Vs = \rho_v fvybd$$

D. Russo model

The ultimate shear strength (v_n) is given by

$$v_n = c_1(\text{k}\chi\text{f'c}\cos\theta + c_2 p_h f_{yh}\cot\theta + c_3\frac{a}{d}\,p_v f_{yv}) \quad (4)$$

Where c_1, c_2, c_3 are determined from the experimental results c_1=0.76, c_2=0.35, c_3=0.25,

$$v_n = 0.76\left(\text{k}\chi\text{f'c}\cos\theta + 0.35 p_h f_{yh}\cot\theta + 0.25\frac{a}{d}\,p_v f_{yv}\right),$$

"K" is obtained from the classical theory of flexure

$$k = \sqrt{(n\rho)^2 + 2n\rho} - n\rho$$

With ($n = E_s/E_c$) and the ρ (= A_s / (bd), with b=width),

E_s = 200,000 N/mm^2.

χ Is the non-dimensional interpolating function

$$\chi = \left[0.74\left(\frac{f'c}{105}\right)^3 - 1.28\left(\frac{f'c}{105}\right)^2 + 0.22\left(\frac{f'c}{105}\right) + 0.87\right]$$

$$\theta = 2arc\tan\left(\frac{\sqrt{\left(\frac{a}{d} - \frac{wl}{2d}\right)^2 + \left(1 - \frac{k^2}{4}\right)} - 1}{\frac{a}{d} - \frac{wl}{2d} - \frac{k}{2}}\right)$$

V. NEURAL NETWORK MODELING

ANN consists of network of nodes that are connected to each other for processing the feeded data. Alike to the original performance of a biological neuron, every operating component can send only one output, if the total inputs to a given operating component exceeds a set of threshold, it sends an input to other neighboring operating component.

ANN consists of three layers (input, middle, and output). Weights are applied to nodes present in input layer, which are the capacity of the links between the organizing components.

Weight values are resolved utilizing a large number of training input and output data. The network gets its problem solving ability through this training process. ANN is a repetitive process, replicates till the fallacy is reduced. MATLAB is utilized to expand an artificial neural network through which the ultimate shear strength of a concrete deep beam was forecasted.

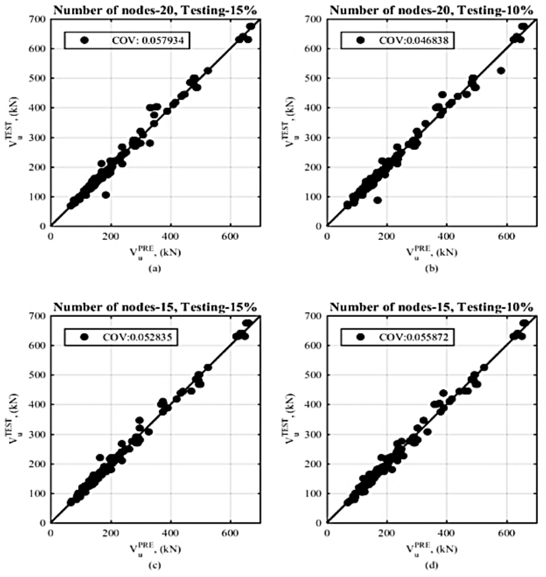

Figure 5: Plots of predicted shear strength vs. tested shear strength for different methods

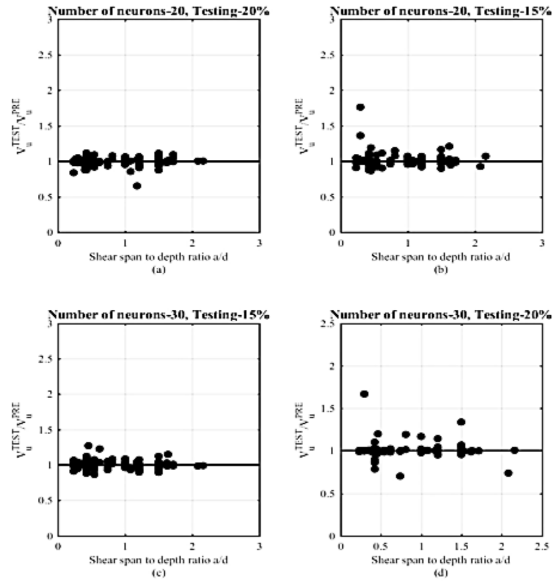

Figure 6: Variation of Actual Shear Strength to Predicted Shear Strength with a/d Ratio of ANN method

Before providing the data to the network, some of the input specifications selected earlier are changed into the non-dimensional shape: L/d d/bw, (a/d), (ρh), (ρht), (ρv), (f'_c), (fyh), and (fyv). Different algorithms were used in developing the artificial neural network. Numbers of nodes in the hidden layer are varied based on the number of input parameters. Percentage of testing parameters is also

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changed, and the results are shown in Figure 3. The mean, standard deviation and coefficient of variation of different values of neuron is merely same.

VI. ANALYSIS OF RESULTS

The shear capacity of deep beams found through artificial neural network was compared with four methods, namely, ACI, EURO, Zsutty and Russo, which are shown in Figure 3 – 5 and Table II. From the results it is clear that the ACI method and EURO code are overestimated the predicted actual strength whereas the Zsutty and Russo models underestimated the actual strength.

The mean of actual shear strength to predicted shear strength of all test samples is 1.65 in the ACI code method, 2.13 in EURO code method, 0.60 in the Zsutty method, and 0.995 in the artificial neural network. Even though the mean value of the actual shear strength to predicted shear strength was 0.67 for all deep beams in the ACI code method, 1.184 in the EURO code method, 0.605 in the Zsutty method, 1.13 in the Russo method, it was only 1 in the artificial neural network.

From all these values it is very clear that the ANN performs very much better than the other models chosen in this study. An exclusive variation of actual strength to predicted strength with the ratio of shear span to depth is shown in Figure 4 for different chosen methods and in Figure 6 for the ANN method.

Table II: Statistical description of results

	ACI	EURO	ZSUTTY	RUSSO	ANN
MEAN	0.67	1.185	5.275	1.14	1
STD.	0.25	0.4423	2.514	0.47	0.08
COV	0.38	0.3733	0.477	0.41	0.08

VII. CONCLUSION

Form the prediction analysis, it is concluded that the strength values obtained from the neural network are more precise than those found from the ACI code, EURO, Zsutty and Russo methods.

Also, ANN results are more accurate than the other methods. The similarities have revealed that even though the ACI, EURO, Zsutty and Russo methods were affected with the variations of *a*/*d* ratios and the compressive strength of concrete but the artificial neural network performance was not affected by these differences.

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