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.

Figure 1: 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).
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 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

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>b</td>
<td>0.02-0.15</td>
</tr>
<tr>
<td>d</td>
<td>0.216-0.94</td>
</tr>
<tr>
<td>a</td>
<td>0.234-2.7</td>
</tr>
<tr>
<td>a/d</td>
<td>0.125-7.6</td>
</tr>
<tr>
<td>f'_c</td>
<td>12.5-76</td>
</tr>
<tr>
<td>f_yh</td>
<td>0-600</td>
</tr>
<tr>
<td>f_yv</td>
<td>0-460</td>
</tr>
<tr>
<td>ρ_h %</td>
<td>0.05-1.94</td>
</tr>
<tr>
<td>ρ_h %</td>
<td>0-2.95</td>
</tr>
<tr>
<td>ρ_v %</td>
<td>0-2.45</td>
</tr>
</tbody>
</table>

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_h), transverse steel (ρ_v), compressive strength of concrete (f'_c), Yield strength of horizontal steel (f_yh) and vertical steel (f_yv). 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 (V_n) is given in the section 11.8 of the ACI code is

\[
V_n = \phi \times (V_c + V_s)
\]

Where, \(V_n = \text{nominal shear strength of the deep beam; } \phi = \text{shear capacity reduction factor, } V_c \text{ and } V_s = \text{shear strengths provided by concrete and shear reinforcements, reciprocally;}

B. EURO

C. ZSUTTY

D. RUSSO
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:

\[ V_n = V_c + V_s \]  
\[ V_c = \tau_r d b f_y d; \quad V_s = 0.9 \rho f_y d b, \]
\[ k=1.6 - d > 1; \quad \beta = 1 \text{ for } a/d \geq 2.5 \text{ or } \beta = 2.5 d / a \leq 5 \text{ for } a/d < 2.5, \]
\[ \rho = \min (\{1/8d \}; 0.02) \text{, } \tau_r a = 0.25 f_{c,ko} \gamma_c / \gamma_c, \quad \gamma_c = 1.5. \]

\[ V_n = \text{nominial shear strength of the deep beam, } V_c \text{ and } V_s \text{ are shear strengths provided by concrete and shear reinforcements.} \]

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

\[ V_n = V_c + V_s \]

\[ V_c = 2.2 (f_c d a^3 / d^3) ; f_c \text{ in MPa; } a / d > 2.5 \]

\[ V_c = (2.5 a d) 2.2 (f_c d a^3 / d^3) \]

\[ V_s = \rho f_y d b \]

D. Russo Model

The ultimate shear strength \((v_n)\) is given by

\[ v_n = c_1 (k f c \cos \theta + c_2 p f y \cot \theta + c_3 a d p f y) \]

Where \(c_1, c_2, c_3\) are determined from the experimental results

\(c_1 = 0.76,\quad c_2 = 0.35,\quad c_3 = 0.25\). The non-dimensional interpolating function

\[ k = \sqrt{(n p)^2 \leq 2 n p - np} \]

With \((n = E_s / E_c)\) and the \(\rho = (A_e / (b d))\), with \(b = \text{width}\), \(E_s = 200,000 \text{ N/mm}^2\).

The non-dimensional interpolating function

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

\[ \theta = 2 \arctan \left( \frac{a}{w} - \frac{w}{2a} \right) \quad \left( 1 - \frac{k}{2} \right) - 1 \]

V. NEURAL NETWORK MODELING

MATLAB is utilized to expand an artificial neural network through which the ultimate shear strength of a concrete deep beam was forecasted.

The processing ability through this training process. ANN is a repetitive process, replicates till the fallacy is reduced.
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

<table>
<thead>
<tr>
<th></th>
<th>ACI</th>
<th>EURO</th>
<th>ZSUTTY</th>
<th>RUSSO</th>
<th>ANN</th>
</tr>
</thead>
<tbody>
<tr>
<td>MEAN</td>
<td>0.67</td>
<td>1.185</td>
<td>5.275</td>
<td>1.14</td>
<td>1</td>
</tr>
<tr>
<td>STD.</td>
<td>0.25</td>
<td>0.4423</td>
<td>2.514</td>
<td>0.47</td>
<td>0.08</td>
</tr>
<tr>
<td>COV</td>
<td>0.38</td>
<td>0.3733</td>
<td>0.477</td>
<td>0.41</td>
<td>0.08</td>
</tr>
</tbody>
</table>

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 $ald$ ratios and the compressive strength of concrete but the artificial neural network performance was not affected by these differences.

REFERENCES

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