Prediction of Deflection of Reinforced Concrete Beams using Machine Learning Tools

Preetham S[1], Ravi Kumar H [2], Prema Kumar W P[3] and Shivaraj M[4]
[1]M.Tech. Scholar, Department of Civil Engineering, Reva Institute of Technology and Management, Bengaluru
[2]Associate Professor, Sir M.Visvesvaraya Institute of Technology, Bengaluru
[3]Senior Professor, Department of Civil Engineering, Reva Institute of Technology and Management, Bengaluru
[4]M.Tech. Scholar, Department of Civil Engineering, Reva Institute of Technology and Management, Bengaluru

***Abstract*—This paper deals with the application of Support Vector Machine Technique (SVM) and Artificial Neural Network (ANN) for predicting the midspan deflection of simply supported reinforced concrete beams under two point loading. Using the SVM technique and the experimental test data available in the literature, an equation has been developed for midspan deflection. Further, 18 singly reinforced beams were cast and tested under symmetrical two point loading in the present work. The experimental results so obtained are compared with those given by the developed equation. The main parameters considered in the equation are: length of beam, breadth of beam, depth of beam, compressive strength of concrete, magnitude of load, area of tension steel, characteristic strength of steel, shear span and midspan deflection. It is seen that there is reasonable agreement between the experimental results and those obtained by using SVM (discrepancy ranging from 1 to 21%). The experimental results are also compared with those given by ANN and it is observed that the discrepancy is greater (ranging from 16 to 53%). The results given by SVM are closer to the experimental values than those given by ANN.**

Keywords*— Singly Reinforced Concrete Beam, Support Vector Machine Technique (SVM), Artificial Neural Network (ANN), Deflection

I. INTRODUCTION

Beams have wide application in civil, mechanical, automobile, aerospace and other areas of engineering. Concrete is known to possess very low tensile strength compared to its compressive strength. The tensile strength of a concrete beam is enhanced by including steel reinforcement which has high tensile strength in the tension zone. Often, in civil engineering, reinforced concrete beams are used to support slabs, walls etc. From serviceability point of view, the deflections of beams are restricted by Codes of Practice. Accurate assessment of deflection of reinforced concrete beams is very essential in the design. The deflections can be predicted using machine learning tools. Machine learning is a scientific discipline that explores the construction and study of algorithms that can learn from data. Such algorithms operate by building a model based on inputs and using them to make predictions or decisions, rather than following only explicitly programmed instructions. The present study is carried out to develop an equation for predicting the deflection of reinforced concrete beams using SVM and the experimental data available in literature. Then the values given by the equation are compared with the results of experiments carried out on reinforced concrete beams in the present work. A comparison is made between the results given by SVM and ANN relative to the experimental values. References [1] through [11] deal with machine learning tools. The other references deal with the experimental studies on reinforced concrete beams. Reference [33] mentions some of the applications of SVM to concrete in the context of civil engineering.

II. SUPPORT VECTOR MACHINE TECHNIQUE

A. Introduction

SVM is one of the machine learning techniques (MLT) derived from statistical learning theory by Vapnik and Chervonenkis in 1964. The foundations of SVM have been developed by Vapnik (1995) at AT&T Bell Laboratories. SVM is recognized as an attractive and promising tool to solve classification and regression related problems (Gunn 1998). Initially, SVM as a classifier focused on optical character recognition and object recognition tasks. SVM has also excelled in regression and time series prediction applications. Compared to regression methods by conventional ANN, SVM in regression approximation has three distinct characteristics as follows:

• SVM uses a set of linear functions defined in a high dimensional space.
• SVM carries out risk minimization using loss functions.
• SVM uses a risk function consisting of empirical error and a regularization term which is derived from the support regression method.

The main idea of SVM is to transform the input space into a high-dimensional space. SVM calculation takes the form of a problem in convex quadratic optimization ensuring that the solution is optimal. It is better than the traditional artificial neural network which is based on the traditional minimization principle of experience risk. The SVM has a good ability to generalize and resolve some practical problems such as small samples, nonlinearity and high-dimensional input space.

In this section, a brief description of the process of constructing a SVM for a regression problem is presented. There are three distinct characteristics to consider when an SVM is used to solve a regression problem. First, the SVM estimates the regression by a set of linear functions that are defined in a high-dimensional space. Second, the SVM carries out the regression estimation by risk minimization where the risk is measured using Vapnik's ε-insensitive loss function. Third, the SVM uses a risk function consisting of empirical error and a regularization term which is derived from the structural risk minimization (SRM) principle.

B. WEKA Software

Weka software is based on SVM technique. It processes a collection of machine learning algorithms for data mining and machine learning tasks, feature selection, classification, regression, clustering, association rules and visualization. Using this software an equation for the midspan deflection of a simply supported reinforced concrete beam under two-point loading is developed considering the the following parameters: length of beam, breadth of beam, depth of beam, compressive strength of concrete, load, area of steel, characteristic strength of reinforcing steel, shear span and midspan deflection. The equation developed in the present work is

$$\Delta_{theoretical} = - (0.009*L) - (0.0065*B) - (0.0324*D) + (0.073*F_c) + (0.0222*F_y) - (0.0042*A_{st}) + (0.022*W) + (0.0493*a) - 5.508 \quad \ldots\ldots (1)$$

where,
L is the span of the beam
B is the width of the beam
D is the depth of the beam
F_c is the compressive strength of concrete
F_y is the characteristic strength of reinforcing steel
A_{st} is the area of tension steel
W is the total load on the beam
a is the shear span
Δ is the central deflection of beam

The midspan deflections predicted by using SVM Technique in respect of reinforced concrete beams tested in the present work are tabulated in Table 1 along with other relevant results.

III.ARTIFICIAL NEURAL NETWORK

ANN has emerged as a useful concept from the field of artificial intelligence and has been successful over the past decade in modeling engineering problems.

ANN generally consists of a number of layers. The layer where the patterns are applied is called input layer. This layer could include the properties of beam such as L(mm), B(mm), D(mm), F_c(N/mm^2), F_y(N/mm^2), A_{st}(mm^2), W(kN), and a(mm). The layer where the output is obtained is the output layer. In addition, there may be one or more layers between input and output, called hidden layers which are so named because their outputs are not directly observed. The addition of hidden layers enables the network to extract higher order statistics which are particularly valuable when the size of input is very large. Neurons in each layer are interconnected to neurons of subsequent layer.

Neuron Model

The experimental data available in literature were taken for neural network training. The software employed is Alyuda Neuro Intelligence. The percentage of data used for training is 68.91%. The percentage of data used for validation is 15.54%. The percentage of data used for testing is 15.54%. To train the model 9 different network architectures were considered. The number of hidden layers was varied from 1 - 25. The 9 networks were auto-verified by the software. The architecture selected for training is [10-14-1] which is shown in Fig.1.

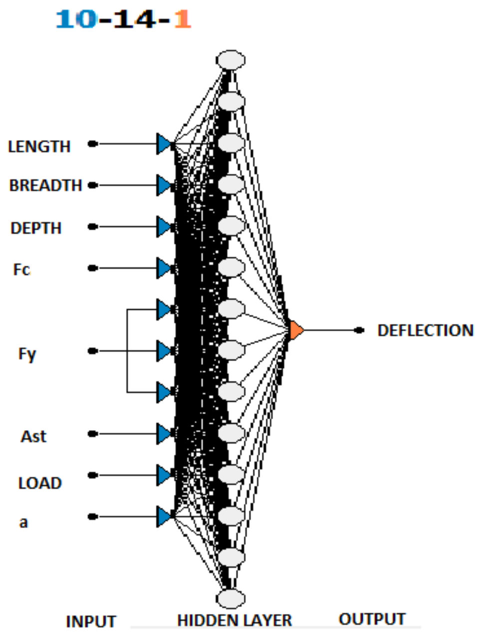

Fig.1: ANN Model

The midspan deflections predicted by using Artificial Neural Network in respect of reinforced concrete beams tested in the present work are tabulated in Table 1 along with other relevant results. The work flow chart is shown in Fig.2.

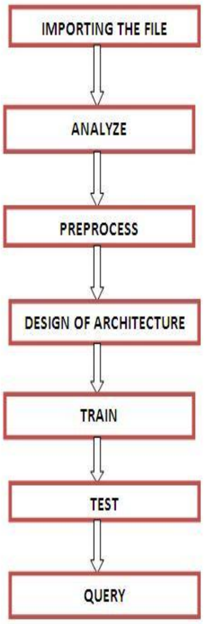

Fig.2: Work Flow Chart

Table 1: Experimental, SVM and ANN Values of Midspan Deflection

Beam Desig	W (kN)	Δ,Exp (mm)	Δ,SVM (mm)	Δ,ANN (mm)
B1	37.27	7.1	6.897514 (2.85%)	8.567051 (20.66%)
B2	37.76	7.3	6.908294 (5.36%)	8.566965 (17.3%)
B3	36.78	7.4	6.886734 (6.93%)	8.567137 (15.77%)
B4	38.74	6.1	6.69268 (9.71%)	8.575214 (40.57%)
B5	38.25	5.9	6.6819 (13.25%)	8.575303 (45.34%)
B6	39.24	6.2	6.70368 (8.12%)	8.575124 (38.30%)
B7	39.73	7.1	7.287434 (2.63%)	8.888498 (25.19%)
B8	38.74	7.3	7.265654 (0.47%)	8.888799 (21.76%)
B9	37.27	7.4	7.233314 (2.25%)	8.889246 (20.12%)
B10	39.24	5.8	7.03948 (21.37%)	8.892183 (53.33%)
B11	40.22	5.8	7.06104 (21.74%)	8.89188 (53.30%)
B12	39.24	5.9	7.03948 (19.31%)	8.892183 (50.71%)
B13	40.22	7.9	7.823814 (0.96%)	9.269019 (17.32%)
B14	41.2	8.0	7.845374 (1.93%)	9.268501 (15.85%)
B15	39.73	7.6	7.813034 (2.80%)	9.269278 (21.96%)
B16	42.67	7.1	7.64054 (7.61%)	9.261023 (30.43%)
B17	41.69	7.5	7.61898 (1.58%)	9.261547 (23.48%)
B18	42.18	7.4	7.62976 (3.10%)	9.261285 (25.15%)

Note: Figures within parentheses indicate the magnitude of discrepancy between SVM/ANN value and the experimental value expressed in percentage

IV. EXPERIMENTAL WORK

A. Concrete Properties

18 no. of singly reinforced concrete beams were cast and tested after 28 days of curing. All the beams (B1 to B18) were of same size of 100mm (width) X 80mm (depth) X 700mm (length) and tested under two point loading on a simply supported span. Beams B1 to B6 were cast using a proportion of 0.6 (Cement): 0.4 (GGBS): 2.54 (Sand): 3.82 (Coarse Aggregate) with a water-cement ratio of 0.52 (herein referred to as Type 1 Concrete). Beams B7 to B12 were cast using a proportion of 0.7 (Cement): 0.3 (GGBS): 2.08 (Sand): 3.12 (Coarse Aggregate) with a water-cement ratio of 0.45 (herein referred to as Type 2 Concrete). Beams B13 to B18 were cast using a proportion of 0.8 (Cement): 0.2 (GGBS): 2.10 (Sand): 3.16 (Coarse Aggregate) with a water-cement ratio of 0.43(herein referred to as Type 3 Concrete). Ordinary Portland cement of grade 53 was used for all the beams. Natural river sand conforming to Zone II was used for all the beams. Beams B1, B2, B3, B7, B8, B9, B13, B14 and B15 were reinforced with two numbers of 8 mm diameter tension steel. Beams B4, B5, B6, B10, B11, B12, B16, B17 and B18 were reinforced with two numbers of 10 mm diameter tension steel. All the beams were reinforced with two legged 6 mm diameter stirrups at 150 mm c/c. All the reinforcing steels were of grade Fe415. The results of the compression test conducted on 150 mm cubes at 7, 14 and 28 days are given in Table 2. The midspan deflections were measured at different load levels using a dial gauge.

Table 2: Compressive Strength of Concrete at Different Ages

AGE (days)	AVERAGE COMPRESSIVE STRENGTH OF CONCRETE (N/mm^2)		
	TYPE 1	TYPE 2	TYPE 3
7	15.3	15.7	22.3
14	17.4	20.96	27.8
28	21.6	26.2	33.3

V. DISCUSSION OF RESULTS

Table 1 shows that the machine learning tool SVM gives results whose discrepancy relative to experimental value varies from 1 to 22%. Table 1 also shows that the machine learning tool ANN gives results whose discrepancy relative to the experimental value varies from 16 to 53%. Thus the SVM is seen to predict the experimental values better than ANN.

VI. CONCLUSIONS

Based on the above study the following conclusions are made:

- Using SVM technique an equation has been developed for predicting the midspan deflection of simply supported singly reinforced concrete beam under two-point loading.
- The machine learning tool SVM gives results whose discrepancy relative to experimental value varies from 1 to 22%.
- The machine learning tool ANN gives results whose discrepancy relative to the experimental value varies from 16 to 53%.
- SVM is seen to predict the experimental values better than ANN and holds great promise as a better predicting tool.

ACKNOWLEDGEMENT

The first, the third and the last authors gratefully acknowledge the encouragement and support provided by the Management, Principal and Head of the Department of Civil Engineering Dr. Y.Ramalinga Reddy, Reva Institute of Technology and Management, Bengaluru 560 064. The second author gratefully acknowledges the encouragement and support provided by the Management, Principal and HOD(Civil) of Sir M Visvesvaraya Institute of Technology, Bengaluru 560 064.

VII. REFERENCES

1. K.U.Muthu, N.S.Kumar and H. Ravi Kumar - "Concrete Filled Steel Tubular Columns-A critical review", Cement and Concrete Composites, Elixir international journal 45 (2012) 8034-8038.
2. Kasthurirangan Gopalakrishnan - "Support Vector Machines for Nonlinear Pavement Backanalysis", Journal of Civil Engineering (IEB), 38 (2) (2010) 173-190.
3. J. Salajegheh and S.Khosravib -"Optimal Shape Design of Gravity Dams Based on a Hybrid Meta-Heuristic Method and Weighted Least Squares Support Vector Machine", Int. J. Optim. Civil Eng., 2011; 4:609-632.
4. Weihang Zhang - "Prediction of Concrete Corrosion in Sulfuric Acid by SVM-Based Method"-2nd International Conference on Electronic & Mechanical Engineering and Information Technology (EMEIT-2012).
5. Satish B Satpal -"Structural Health Monitoring of a Cantilever Beam Using Support Vector Machine", International Journal of Advanced Structural Engineering 2013, 5:2.
6. Kezhen Yan, Hongbing Xu - "Prediction of Splitting Tensile Strength from Cylinder Compressive Strength of Concrete by Support Vector Machine",- Advances in Materials Science and Engineering ,Volume 2013, Article ID 597257, 13 pages.
7. Yogesh Aggarwal - "Modelling of Reinforcement in Concrete Beams Using Machine Learning Tools", International Journal of Civil, Architectural, Structural and Construction Engineering Vol:1, No:8, 2007.
8. Uday Naik - "Span-to-Depth Ratio Effect on Shear Strength of Steel Fiber-Reinforced High-Strength Concrete Deep Beams using ANN model", International Journal of Advanced Structural Engineering,2013, 5:29
9. Parthasarathi Behera – "Vibration Analysis of a beam using neural network technique", National Institute of Technology, Rourkela.
10. Onwuka. O. David - "Artificial Neural Network for the Modulus of Rupture of Concrete", Advances in Applied Science Research, 2013, 4(4):214-223.
11. Abdul Raheman - "Prediction of Properties of Self Compacting Concrete Using Artificial Neural Network", International Journal of Engineering Research and Applications (IJERA) ISSN: 2248-9622, Vol. 3, Issue 4, Jul-Aug 2013, pp. 333-339.
12. Arivalagan. S - "Engineering Performance of Concrete Beams Reinforced with GFRP Bars and Stainless steel", Global Journal of Researches in Engineering Civil And Structural Engineering Volume 12, Issue 1, Version 1.0, January 2012.
13. J.M. Khatib - "Effect of Incorporating Foamed Glass on the Flexural Behaviour of Reinforced Concrete Beams", World Applied Sciences Journal 19 (1): 47-51, 2012, ISSN 1818-4952.
14. Mini Soman - "Strength and Behaviour of High Volume FlyAsh Concrete", International Journal of Innovative Research in Science, Engineering and Technology, Vol. 3, Issue 5, May 2014.
15. S.Kumaravel - "Flexural Behaviour of Geopolymer Concrete Beams", International Journal of Advanced Engineering Research and Studies, E-ISSN2249–8974.
16. Arivalagan. S – "Flexural Behaviour of Reinforced Fly Ash Concrete Beams", International Journal of Structural and Civil Engineering, ISSN : 2277-7032 Volume 1, Issue 1.
17. Khair Al-Deen Bsisu - "Flexural Ductility Behavior of Strengthened Reinforced Concrete Beams Using Steel and CFRP Plates", Jordan Journal of Civil Engineering, Volume 6, No. 3, 2012.
18. R Singaravadivelan - "Flexural Behaviour of Basalt Chopped Strands Fiber Reinforced Concrete Beams", International Conference on Chemical, Ecology and Environmental Sciences (ICEES'2013) June 17-18, 2013, London (UK).
19. Iman Chitsazan - "An Experimental Study on The Flexural Behavior of FRP RC Beams and A Comparison of the Ultimate Moment Capacity with ACI", Journal of Civil Engineering and Construction Technology, Vol. 1(2), pp. 27-42, December 2010.
20. Vinubhai Ratilal Patel - "A Comprehensive Study on Shear Strain, Crack Patterns and Crack Width Profile for Moderate Deep Beam with Fibres", The Maharaja Sayajirao, university of Baroda, Vadodara.
21. S.C. Chin - "Effects of Used Engine Oil in Reinforced Concrete Beams", The Structural Behaviour, World Academy of Science, Engineering and Technology Vol:6, 2012-03-21.
22. Dattatreya J K - "Flexural Behaviour of Reinforced Geopolymer Concrete Beams", International Journal of Civil and Structural Engineering, Volume 2, no 1, 2011.
23. Saravana Raja Mohan - "Strength and Behaviour of Fly ash based Steel Fibre Reinforced Concrete Composite", International Journal of civil and Structural Engineering volume 2, no 1, 2011.
24. Sagar Patel - "Flexural Behaviour of Reinforced Concrete Beams Replacing GGBS as Cement and Slag Sand as Fine Aggregate", International Journal of Civil and Structural Engineering Research ISSN 2348-7607 (Online), Vol. 2, Issue 1, pp: (66-75), Month: April 2014 - September 2014.
25. M Mithra - "Flexural Behaviour of Reinforced Self Compacting Concrete Containing GGBFS", International Journal of Engineering and Innovative Technology (IJEIT) Volume 1, Issue 4, April 2012.
26. K.R.Venkatesan - Flexural Behavior of High Strength Steel Fibre Reinforced Concrete Beams, International Journal of Engineering Science and Innovative Technology (IJESIT), Volume 4, Issue 1, January 2015.
27. Sreedhari S –"Size Effect on Flexural Behaviour of Reinforced High Strength Concrete Beams", International Journal of Engineering and Technical Research (IJETR) ISSN: 2321-0869, Volume-2, Issue-9, September 2014.
28. D.N. Shinde - "Flexural Behaviour of Reinforced Cement Concrete Beam Wrapped with GFRP sheet", International Journal of Research in Engineering and Technology eissn: 2319-1163 | pissn: 2321-7308.
29. Felix F - "Strength Performance and Behavior of Concrete Containing Industrial Wastes as Supplementary Cementitious Material (scm)", vol.12, issue1, IJRRAS_12_1_03.
30. Abins Aziz – "Effect of Superplasticizers on the Behavior of fly ash Concrete Beams in Flexure", International Journal for Scientific Research & Development| Vol. 2, Issue 01, 2014 | ISSN (online): 2321-0613.
31. Efe Ikponmwosa - "Flexural Behavior of Reinforced Concrete Beams Containing Polyvinyl Waste Powder (PWP) as Replacement of Cement", The Pacific Journal of Science and Technology, Volume 15, Number 2, November 2014.
32. S.P.Sangeetha - "Flexural Behaviour of Reinforced Concrete Beams with Partial Replacement of GGBS", American Journal of Engineering Research (AJER) e-ISSN: 2320-0847 p-ISSN : 2320-0936 Volume-03, Issue-01, pp-119-127.
33. Preetham S, Shivaraj M, Prema Kumar W P, Ravi Kumar - "Support Vector Machines Technique in Analysis of Concrete – Critical Review", IJETE, Vol.1, Issue 9, October 2014, pp. 199-203, ISSN:2348-8050.