International Journal of Architectural, Civil and Construction Sciences
ISSN: 2415-1734
Vol:1, No:8, 2007

Modeling of Reinforcement in Concrete Beams Using Machine Learning Tools

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***Abstract*—The paper discusses the results obtained to predict reinforcement in singly reinforced beam using Neural Net (NN), Support Vector Machines (SVM's) and Tree Based Models. Major advantage of SVM's over NN is of minimizing a bound on the generalization error of model rather than minimizing a bound on mean square error over the data set as done in NN. Tree Based approach divides the problem into a small number of sub problems to reach at a conclusion. Number of data was created for different parameters of beam to calculate the reinforcement using limit state method for creation of models and validation. The results from this study suggest a remarkably good performance of tree based and SVM's models. Further, this study found that these two techniques work well and even better than Neural Network methods. A comparison of predicted values with actual values suggests a very good correlation coefficient with all four techniques.

***Keywords*—Linear Regression, M5 Model Tree, Neural Network, Support Vector Machines.

I. Introduction

REINFORCEMENT provided in singly reinforced beam is influenced by number of parameters/attributes. The work establishes ready to use relationship between area of steel and attributes used for determining it in the design of beams. The present work is aimed at establishing a predictive relationship between area of steel and other parameters like width, depth, length, minimum steel etc. Several data driven techniques like regression analysis, MLP (multi layer perceptron), M5 modal trees, and support vector machines (SVM) are used in this study. Comparative study of application of these techniques to design of singly reinforced beam has also been carried out. As it is quite complex to simulate all the parameters/ attributes that affect the area of steel, the following selected parameters have been considered in the present analysis and the functional form is expressed as: Area of steel = f (width, depth, length, load, moment, minimum depth, percentage of steel, concrete grade, grade of steel, minimum steel). Determination of area of steel or reinforcement in singly reinforced beam is normally based on equations describing the behavior of different parameters.

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Model can be built on the basis of large amounts of data collected. This modeling approach can be called data-driven modeling. It borrows methods from various areas related to computational intelligence, machine learning, data mining, soft computing etc. The paper gives an overview of successful applications of several data-driven techniques to the design of singly reinforced beam.

The models for the prediction of area of steel reinforcement are developed using different parameters affecting quantity of steel and different techniques mentioned earlier. These models are validated on a different set, independent of the set used to develop the models. A model can be defined as representation of reality with an objective of its explanation or prediction. “The model can be either behavioral or physically based (knowledge-driven, process, simulation). If based on the analysis of all the data characterizing the system under study, the model can be defined on the basis of connections between the system state variables (input, internal and output variables)”. Such models are called data-driven models. Linear regression model, artificial neural network (ANN), decision trees classification and support vector machines (SVM) follow this approach.

The above mentioned techniques have been applied to civil engineering problems in general and structural engineering, in particular. Also, comparative study between the different techniques has been carried out in different environments like remote sensing, hydrology, strength of concrete mix etc.

Formulation of data structures and algorithms for the solid modeling of reinforced concrete beam structures composed of three dimensional concrete solids and steel reinforcing bar trajectories was done. Also, ultimate flexural strength was obtained by slicing the beam solid at selected locations and extracting the cross-section. It further leads to the development of interactive software tool that allowed the user to freely move between a two dimensional design and analysis environment. The prototype's future versions will be capable of analyzing cross-sections subjected to axial loads and biaxial bending. [1]

Use of Feed Forward Neural Network using back propagation algorithm was employed for active control of structures under dynamic loading. Study was carried on the structure of roof during three earthquakes and it was found that by application of controllers, the maximum displacements reduced to less than 15% of the measured responses. [2]

A comparative study of performance of two data driven modeling techniques i.e. ANN and Modal Trees (MTs), in rainfall-runoff modeling was also carried out. Prediction of runoff from various rainfall data over the years was also done. [3]

A ready to use relationship between the strength of concrete and the properties of ingredients using linear regression analysis and artificial neural network was established. The approaches, capable of predicting reliably the compressive strength of hardened concrete based on the properties of the ingredients and wet concrete, were complementary to the existing workability tests routinely carried out during concreting. [5]

Guidelines like selection of training pairs and determination of number of nodes in a hidden layer were developed for designing and training a neural network for simulation of a structural analysis program. The main advantage of simulating structural analysis with neural network was to obtain an optimum design in less time. Also, once the neural network has been trained it can be used to perform different design studies with the model. [7]

Basic ideas underlying SVMs were reviewed. Also, comparative study of potential of SVMs and Neural Network for feature classification and multiple regression modeling problems was carried out, using digital remote sensing data on the horizontal force exerted by dynamic waves on a vertical structure [9]

A. Variables used in the Analysis

The variables used in the present study are as follows:
Breadth = Breadth of beam in mm
Depth = Depth of beam in mm.
Length = Length of beam in m
Load = uniformly distributed load in KN/m
Moment = Moment due to loading on the beam in KN-m
Persteel = Percentage of steel required calculated from the tables given in SP-16.
Minsteel = Minimum steel required in mm²
Steelprovided = Area of steel provided in mm².
Among these, the variable for grade of concrete and steel has been kept constant for M-20 and Fe-415.

II. Modeling Approaches

All modeling approaches used for this study are briefly described below.

A. Neural Network Approach

In this approach, the independent variables (input parameters) and the dependent variables (output parameters) are related through a set of weights. This set of weights, randomly generated initially, is updated so as to minimize the error between the predicted output and the actual known value. This process is known as training which is brought about by least mean square (LMS) error rule or ‘delta rule’. The error between the known and the predicted output is actually distributed considering the magnitudes of the weights at that stage of training and hence the model is termed as error back-propagation model. When the error falls within the specified level the network is said to have been well-trained. The set of weights at this stage is the final one which can be used to predict for new problems, using a kind of weighted summation of the input values. ANNs, are solely specified by the characteristics of their process of units and the selected training on learning rule. The network topology i.e. a number of hidden layers, number of nodes in hidden layer and their interconnections, also has an influence on the performance of Neural Network.

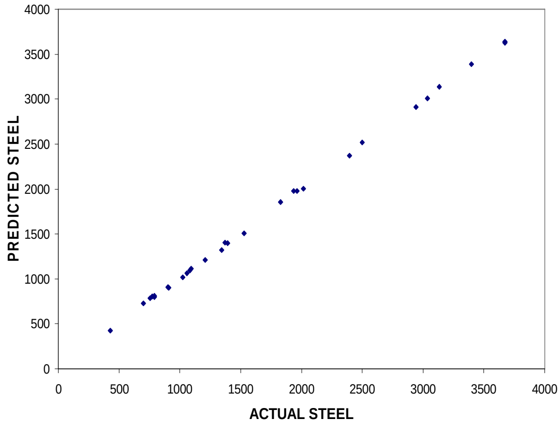

Fig. 1 Plot between Actual Steel vs Steel Predicted by ANN

Briefly, the description of the computational process is given as:
Test mode: User supplied validation set: 30 instances
Weights and threshold value calculated

Momentum = 0.2
Learning rate coefficient = 0.3
Number of iterations = 500.

B. M5 Modal Trees (Regression Splines)

Decision trees, widely used in classification problems, can be generalized to regression trees and modal trees that can deal with continuous attributes. Trees-structured regression is built on the assumption that the functional dependency is not constant in the whole domain but can be approximate as such on smaller sub domains. Depending on the nature of such model, there are several types of trees used for numerical prediction, like regression tree, model tree etc.

The M5 model tree splitting criterion is SDR (standard deviation reduction). It is used to determine which attribute is the best to split the portion of the training data that reaches a particular node.

The linear regression method is based on an assumption of linear dependencies between input and output. In M5 model tree a step towards non-linearity is made since it builds a model that is locally linear, but overall non-linear. In fact M5 tree is a modular model. It consists of modules that are responsible for modeling particular subspace of the input space. Model trees may serve as an alternative to ANNs (which are global model). These are often as accurate as ANNs and have important advantages:

- ►Training of MT (Modal Trees) is much faster than ANN, and it always converges;
- ►the results can be easily understood by decision makers;

►by applying pruning (that is making trees smaller by combining sub trees in one node) it is possible to generate a range of MTs from an inaccurate but simple linear regression (one leave only) to a much more accurate but complex combination of local models (many branches and leaves).

The algorithm known as the M5 algorithm is used for inducing a model tree [8], the aim is to construct a model that relates a target value of the training cases to the values of their input attributes. The quality of the model will generally be measured by the accuracy with which it predicts the target values of the unseen cases.
Equation developed using M5 Modal Trees is:
Steel provided = 1.8633 * Breadth + 2.4103 * Moment + 1619.2404 * Persteel + (-983.6049)

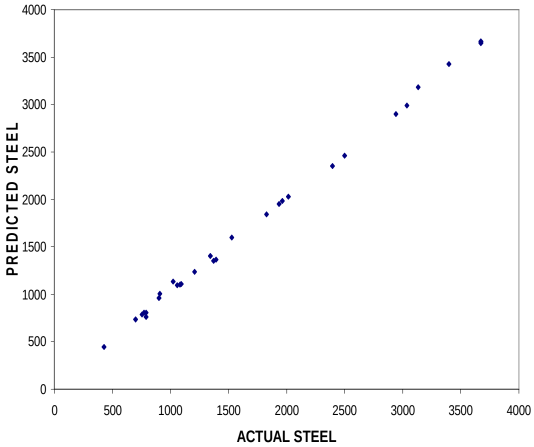

Fig. 2 Plot between Actual Steel Vs Steel Predicted by M5 Modal Tree

C. Linear Regression Model

Linear Regression is an excellent, simple scheme for numeric prediction. It is used for classification in domains with numeric attributes. The linear models serve very well as building blocks for more complex learning schemes. Linear regression analysis is carried out to establish a relationship between the parameters listed

Equation developed using Linear Regression is:
Steel provided = 6.688 * Breadth + (-2.9439 * Depth) + 40.801 * Length + 3.7152 * Load + 3.2729 * Moment +0.2723 * Minimum depth + 511.6551 * Persteel + (-0.4283 * Minsteel) + (-744.15)

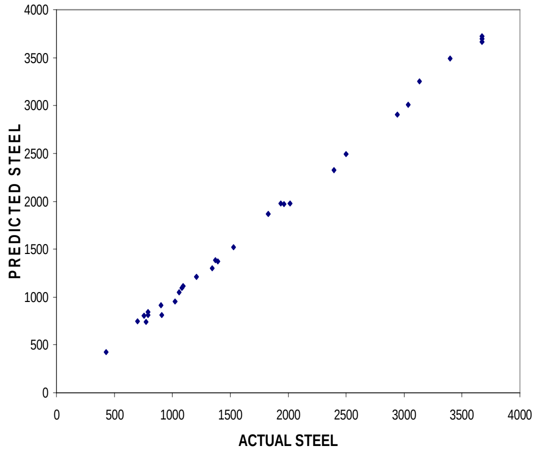

Fig. 3 Plot between Actual Steel Vs Steel Predicted by Linear Regression

D. Support Vector Machines

Support vector machines (SVM) are classification & regression methods based on statistical learning theory. These classification regression techniques are based on the principal of optimal separation, in which if the classes are separable, this method selects, from among the data, the one that minimize the generalization error, or at least an upper bound on this error, derived from structural risk minimization.

If the two classes are non-separable, the SVM tries to find the hyper plane that maximizes the margin and that, at the same time, minimizes a quantity proportional to the number of misclassification errors. The tradeoff between margin and misclassification error is controlled by a positive constant C that has to be chosen beforehand.

The technique of designing SVMs can be extended for non-linear decision surfaces also, suggested projecting input data into a high dimensional feature space through some nonlinear mapping and formulating a linear classification problem in that feature space. Further, kernel function $(x.y)^n$, which computes the dot product of two vector x and y and raises the result to the power n, called a polynomial kernel, was used to reduce the computational cost in feature space.
C = 1.0
$\gamma = 0.01$

Equation developed using SVMs is:
(Normalized) steel provided = 0.3443 * (normalized) Breadth + -0.1883 * (normalized) Depth + 0.1707 * (normalized) Length + 0.0445 * (normalized) Load + 0.745 * (normalized) Moment + 0.2306 * (normalized) Minimum depth + 0.069 * (normalized) persteel + -0.3066 * (normalized) Minsteel - 0.0886

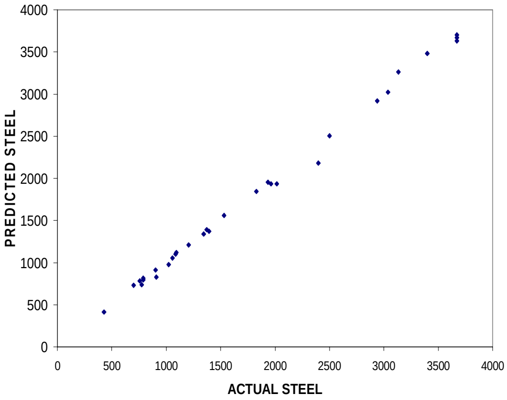

Fig. 4 Plot between Actual Steel Vs Steel Predicted by SVMs

III. Methodology & Data Used

Following steps were carried out for present problem development

I. Identification of input and output parameters
II. Calculation of training examples/data
III. Training and validation

A number of trials were carried out to select user defined parameters in Neural Network, as several parameters affect their performance as discussed earlier. After several trials, one hidden layer with 20 nodes was found to be performing well for this data. Learning rate and momentum was chosen to be 0.3 and 0.2 respectively. A total of 500 iterations were carried out to reach up to the optimal solution, as these numbers were found to be enough for this data set.

Similarly, the performance of SVMs is also affected by few user defined parameters such as regularization parameter C, type of kernel used and kernel specific parameters. After a number of trials, a value of C = 1.0, with RBF kernel $\gamma = 0.01$ was found to perform quite well.

This study involves a total of 130 data generated based on limit state method of design for a singly reinforced beam. The parameters considered for the design are: Breadth, depth, length, load, moment, minimum depth, percentage of steel, minimum steel & steel provided. Out of total number of 130 data, 100 data were used to create a model using different techniques and 30 were used to validate the models, so as to remove any bias in using same data set for creating and testing the model.

IV. Result & Conclusion

Successful analysis and prediction should be always based on the use of various types of models (Tables I and II). Different models, although in close accuracy, offer various advantages over each other.

- ►ANN approach gives results with good prediction and has an inbuilt flexibility for choosing any number of independent variables without assuming an explicit equation. But it requires non linear optimization with the possibility of converging only in local minima.
- ►Prediction of strength by linear regression is found to be adequate and the approach can be easily adopted for ready use because of the explicit nature of the strength equation.
- ►SVMs has shown a satisfactory performance for the prediction of strength. The time taken to build model by SVMs is comparatively less than that required by NN.

TABLE I
Validation of the Proposed Models: A Comparison

Breadth	Depth	Length	Load	Moment	Actual Steel (mm^2)	Predicted Steel (mm^2) by			
						ANN	M5 Modal Tree	Linear Regression	SVM
225	350	4	24	48	428.4	426.593	447.578	425.809	414.418
225	350	6	16	72	699.615	726.229	735.297	749.146	731.126
225	350	6	17	76.5	756	786.88	787.671	807.261	783.342
250	400	6.5	18	95.06	789	798.373	807.31	811.892	813.432
250	400	6.5	20	105.625	901	908.129	956.814	916.637	910.444
275	450	8	18	144	1084.05	1097.438	1101.218	1094.86	1100.965
275	450	8.5	16	144.5	1092.713	1117.17	1110.707	1113.252	1122.087
300	500	9	20	202.5	1392	1396.5	1367.622	1374.626	1373.659
300	500	10	16	200	1372.5	1402.618	1351.618	1384.905	1392.048
350	600	6	35	157.5	789.6	814.531	757.14	842.311	796.465
350	600	11	23	347.875	2016	2000.961	2030.746	1976.706	1934.701
350	600	12	18	324	1827.84	1856.499	1842.977	1869.28	1844.078
350	600	12	19	342	1962.03	1976.578	1981.308	1968.894	1937.15
350	600	13	16	338	1934.1	1976.208	1954.061	1977.709	1954.764
375	700	7	30	183.75	774.375	802.239	802.547	741.595	737.902
375	700	7	40	245	1058.72	1064.083	1094.261	1052.251	1055.58
375	700	7	45	275.625	1207.5	1209.419	1239.065	1208.052	1212.037

375	700	14	20	490	2396.66	2372.888	2352.452	2326.237	2180.833
375	700	15	18	506.24	2500.969	2515.963	2463.73	2490.601	2505.732
400	800	7	40	245	907.2	900.227	1007.179	810.333	831.144
400	800	7	45	275.625	1022.54	1016.336	1134.193	955.289	979.56
400	800	14	28	686	2940.339	2909.963	2897.38	2905.544	2916.54
400	800	15	25	703.125	3036.67	3009.07	2986.453	3009.293	3022.203
425	900	9	40	405	1344.289	1322.658	1402.516	1301.174	1342.535
425	900	9	45	455.625	1529.962	1506.163	1595.481	1519.844	1558.814
425	900	13	45	950.625	3672	3624.34	3644.686	3664.627	3628.601
425	900	14	39	955.5	3672	3634.544	3661.37	3699.716	3669.818
425	900	15	34	956.25	3672	3637.762	3667.11	3724.492	3701.38
425	900	15	32	900	3399.46	3387.2	3424.747	3489.189	3482.65
425	900	15	30	843.75	3132.312	3134.014	3184.553	3254.421	3263.527

TABLE II
COMPARISON BETWEEN DIFFERENT TECHNIQUES

Techniques	Correlation Factor	Root mean square value	Mean absolute error	Time taken to build model
Neural Network NN	0.762	54.2897	23.2087	5.05 sec.
Linear Regression	0.742	70.1985	42.8274	0.04 sec.
Support Vector Machine SVMs	0.7679	63.633	42.2695	0.96 sec
Model Tree M5 Model Tree	0.7642	102.2663	42.7188	0.91 sec.

► Modal Trees have advantages in both compactness and prediction accuracy, attributable to the ability of modal trees to use the local linearity in the data. It is more understandable and allows one to build a family of models of varying complexity and accuracy.

The proposed approaches affirm the existence of a pattern in the relationship between the strength and other salient parameters pertaining to the design of singly reinforced beam. Thus, machine learning tools can be used for building hybrid models combining models of different types and optimal and adaptive model structures of such hybrid models. Graphs of actual and predicted values obtained from different techniques are plotted (figures 1, 2, 3, 4). Figures suggest a very good correlation between actual and predicted values with all four techniques, thus suggesting their utility for different type of problems in design.

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