Prediction of Compressive Strength Using Artificial Neural Network

Vijay Pal Singh, Yogesh Chandra Kotiyal

***Abstract*—**Structures are a combination of various load carrying members which transfer the loads to the foundation from the superstructure safely. At the design stage, the loading of the structure is defined and appropriate material choices are made based upon their properties, mainly related to strength. The strength of materials kept on reducing with time because of many factors like environmental exposure and deformation caused by unpredictable external loads. Hence, to predict the strength of materials used in structures, various techniques are used. Among these techniques, Non-destructive techniques (NDT) are the one that can be used to predict the strength without damaging the structure. In the present study, the compressive strength of concrete has been predicted using Artificial Neural Network (ANN). The predicted strength was compared with the experimentally obtained actual compressive strength of concrete and equations were developed for different models. A good co-relation has been obtained between the predicted strength by these models and experimental values. Further, the co-relation has been developed using two NDT techniques for prediction of strength by regression analysis. It was found that the percentage error has been reduced between the predicted strength by using combined techniques in place of single techniques.

***Keywords*—**Rebound, ultra-sonic pulse, penetration, ANN, NDT, regression.

I. Introduction

A structure should meet the requirement of safety, durability, serviceability and sustainability for a long-term operation. The performance of a structure deteriorated with the passage of time for its whole life. This deterioration is mainly because of damages due to material aging, environmental conditions and change in nature of service load. This causes catastrophic structural failures which include loss of life and economic disruption. The structural health monitoring technology provides a way to evaluate the safety and durability of a structure during its service life, to ensure its serviceability and sustainability. With increasing number of collapses in major infrastructures, structural health monitoring (SHM) becomes significantly important. The various important structures, like bridges, nuclear plants need regular inspection and testing with reliable technologies. Non-destructive testing (NDT) methods have a large potential to be part of such a technology. A variety of advanced NDT methods have been developed and are available for investigating and evaluating the different parameters related to strength, durability and overall quality of concrete.

The concept of Non-Destructive Testing (NDT) is to obtain material properties of in place material without damaging the structure. The principal objective of a NDT is to achieve by detecting, locating flaws within structure due to cracks, voids, corrosion, impact damage etc. The NDT equipment like rebound hammer, penetration resistance method, ultrasonic pulse velocity method etc. are used for finding the existing strength and quality of material used in the structure. It was observed that the result given by one method did not confirm the result given by other method. Hence, it is difficult to decide the correct value of strength of material. Therefore, more than one method is generally used in combination to adjust the difference in values given by different methods.

In the present study, an attempt has been made to correlate the strength obtained by rebound hammer, penetration resistance method with experimental obtained actual compressive strength using regression analysis as well as by ANN modeling.

II. Related Works

Schmidt E. a Swiss engineer developed a device for testing concrete based on rebound principle [1]. Schmidt standardized the hammer blow by developing a spring loaded hammer and introduced a method to measure the rebound of the hammer that was eventually adopted for field use. Further rebound hammer was constructed and tested extensively at the Swiss federal material testing and experimental institute in Zurich. A correlation was developed between the compressive strength of standard cube and the rebound number, and this co-relation is provided with the instrument. However, as other investigator began to develop co-relation between strength and rebound number, it becomes evident that there was not a unique relationship between strength and rebound number [2]. Further, Jones R. [3] in England was involved in independent research to develop an ultrasonic testing apparatus. Jones reviewed the test program carried out with the newly developed ultrasonic concrete tester to determine quality of concrete pavements by considering the effect of parameters like aggregate type, water-cement ratio etc. These studies found that the pulse velocity was much influenced by type and content of aggregate used. Further, Whitehurst [4] established a classification for using pulse velocity as an indicator of quality of concrete as shown in Table I.

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TABLE I
PULSE VELOCITY VS. CONDITION OF CONCRETE

Sr. No	Pulse Velocity (in m/s)	Condition
1	Above 4570	Excellent
2	3660 to 4570	Generally good
3	3050 to 3660	Questionable
4	2130 to 3050	Generally poor
5	Below 2130	Very poor

Parker [5] developed relationship between pulse velocity and compressive strength. Forty-six mixtures involving the same aggregate, different cement type, and different admixtures were investigated. The result indicates no significant differences in the velocity-strength relationship for the different mixtures and the best fit relationship was determined. Bungey J. H. et al. [6] evaluated the reliability of partial- destructive testing for assessing the strength of concrete on site and focused primarily upon pull-out and pull-off techniques to assess early age strength of lightweight and high strength concretes, and testing of repairs and observed that partially-destructive tests are capable to estimation of in-situ concrete strength for a range of concrete types. Breysse D. [7] used ultrasonic pulse velocity, rebound hammer and many empirical strength-NDT models and concluded that the model error were much smaller than that due to the measurement uncertainties and emphasized on the reduction of NDT measurement error. Synthetic simulations have shown that the quality of NDT measurements directly impacts the quality of assessment both for NDT used alone and in combination. Machado M. D. et al. [8] performed nondestructive tests on various specimens caste with concrete used in several constructions and supplied by different ready-mixed concrete producers using ultrasonic pulse velocity, rebound hammer and penetration resistance. The correlation curves have been developed between various test constants. On the basis of the analysis of the obtained results, it was found that the correlation between the rebound number and the compressive strength present the best results, followed in decreasing order by the (penetration resistance) x (compressive strength) and (pulse velocity) x (compressive strength) correlations. The worst result showed by the pulse velocity and compressive strength relationship. Mürsel Erdal [9] developed an artificial neural network (ANN) for the estimation of compressive strength of vacuum processed concrete. On these concrete samples, Windsor probe penetration tests, Schmidt hammer tests and pulse velocity determination tests, were performed. A multi linear regression using Windsor probe exposed length, pulse velocity, density and water absorption ratio as predictor variables was developed. A neural network was also developed for the estimation of compressive strength. Finally prediction performances of previously published empirical equations, single and multiple variable regression equations developed during this study and ANN were compared. It was reported that the best prediction performance belongs to ANN. Windsor probe penetration test results were very well correlated with the compressive strength. Among the multivariable equations, equation using exposed probe length, pulse velocity and Schmidt hammer rebound value has the best prediction performance. Atici U. [10] applies multiple regression analysis and an artificial neural network in estimating the compressive strength of concrete that contains varying amounts of blast furnace slag and fly ash. The results reveal that the artificial neural network models performed better than multiple regression analysis models. Samia H. et al. [11] applied regression analysis models between compressive strength of *in situ* concrete on existing structure and the nondestructive tests values. Equations were derived using statistical analysis (simple and multiple regressions) to estimate compressive strength of concrete on site and the reliability of the technique for prediction of the strength is discussed. It was observed that using more than one non-destructive technique provides a better correlation and in this sense contributes to more reliable strength evaluation of concrete.

III. EXPERIMENTAL METHODOLOGY

The experimental study has been carried out on concrete cubes of dimensions 150mmx150mmx150mm. About 350 numbers of cubes of said dimensions were caste in the laboratory with different composition of Cement, Sand and Coarse aggregate, to maintain variation in compressive strength of each cube. The various cubes were cured under controlled temperature at room temperature (i.e. 25±2) and tested after 28 days. Each cube was tested first by NDT techniques like Rebound hammer, Windsor' probe method, ultra sonic pulse velocity method, and finally the cube was crushed under compression testing machine to have its actual compressive strength. The experimental results were obtained in the form of rebound number, penetration depth in mm, pulse velocity in kilometer/seconds and finally the compressive strength in N/mm^2.

IV. ANALYTIC STUDY USING ANN

An artificial neural network (ANN) is a family of massively parallel architectures that can be used to solve difficult problems via the cooperation of highly interconnected but simple computing elements (or artificial neurons). Neural networks are simplified models of the biological structure of the human brain. ANNs are based on the principle that a highly interconnected system of simple processing elements can learn the nature of complex interrelationships between independent and dependent variables as shown in Fig. 1. ANN is a parallel distributed processing system consisting of an input layer, an output layer, and one or more hidden layers connected by neurons. Each neuron receives weighted inputs from other neurons and communicates its output to other neurons through an activation function. The goal of any training algorithm is to minimize the mean square error (MSE) between predicted and observed outputs and to maintain the good generality of the network.

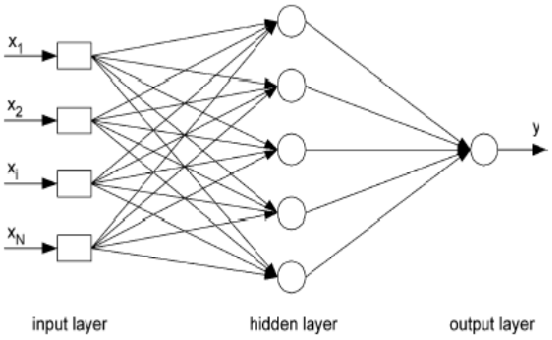

Fig. 1 Model of Artificial Neural network

The function of hidden layer neurons is to detect the relationship between network inputs and outputs. The various units or parameters (like rebound number, penetration depth and ultrasonic pulse velocity) in the input layer represent the factors which may affect the network output and having no computational activities. The output layer contains one or more processing units that compute the network output. Further, there may be large number of layers between input and output layer containing hidden processing units are called hidden layers. The computational propagation takes place in a feed forward manner from input layer to output layer and the obtained output is compared with known targets, and propagates back to the network to adjust the weight and biases until the errors are sufficiently small.

In present study, the ANN toolbox of the program MATLAB was used to perform the necessary computations. A back-propagation training algorithm was utilized in a two-layer feed-forward network trained using the Levenberg–Marquardt algorithm. The learning, validation, and testing phases employed 70%, 15%, and 15% of the data sets (selected randomly), respectively. Initially, compressive strength is predicted using ANN using different network models for each type of NDT technique as well as in combination. The several networks with different numbers of hidden neurons are trained and predicted results were compared with the with the desired output i.e. actual compressive strength obtained after crushing the cube on the basis of root mean square (RMSE) and the coefficient of determination R^2. A good correlation has been obtained between the predicted and measured values of compressive strength of cubes.

V. Result and Discussion

The analysis of data obtained from experimental study has been analyzed using ANN. The various models has been developed by considering output data of each NDT technique as input for the ANN model and the target was given as the actual value of compressive strength obtained from crushing of concrete cubes. The prediction of compressive strength has been made for individual NDT technique using ANN model. Similarly, the strength has also been predicted by combining the output of two NDT techniques as well as the target values were kept same as for individual techniques. The various curves and related equations have been developed to predict the strength by individual techniques and by combined techniques as shown in Figs. 2-4. The comparison has also been made between the predicted strength given by developed equations and the actual compressive strength and is shown in Figs. 5-7. Finally, a single model comprising combined technique i.e. rebound number and penetration depth has been proposed to predict the strength more accurately as shown in Fig. 8.

The final equations from Figs. 2-4, have been developed to predict the strength for individual NDT techniques. The various equations used for predicting the strength for different NDT techniques as well as for combined models i.e. (Rebound number + Penetration depth) are given in Table I.

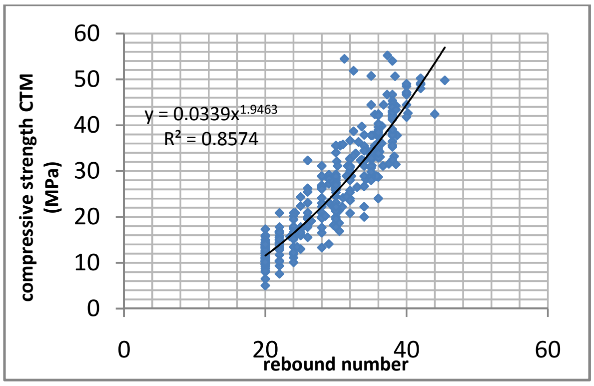

Fig. 2 Relationship between rebound no. and actual Compressive strength using CTM

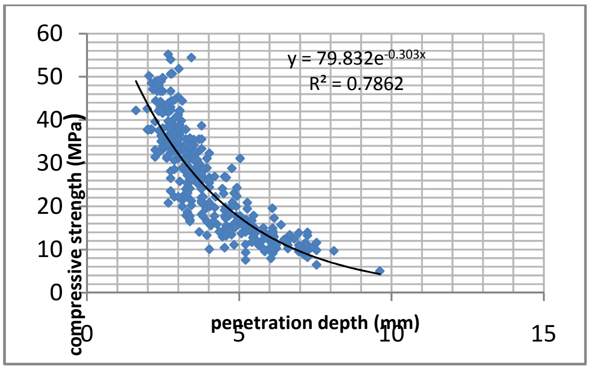

Fig. 3 Relationship between penetration depth and actual compressive strength using CTM

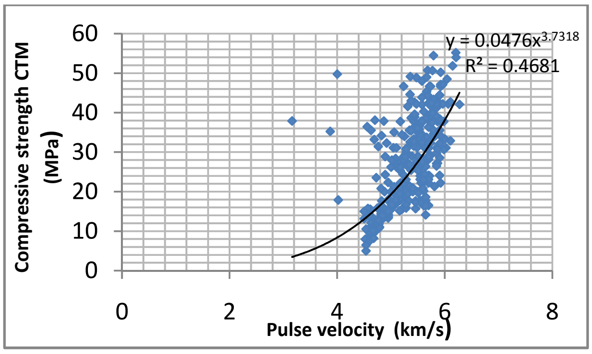

Fig. 4 Relationship between pulse velocity and actual compressive strength using CTM

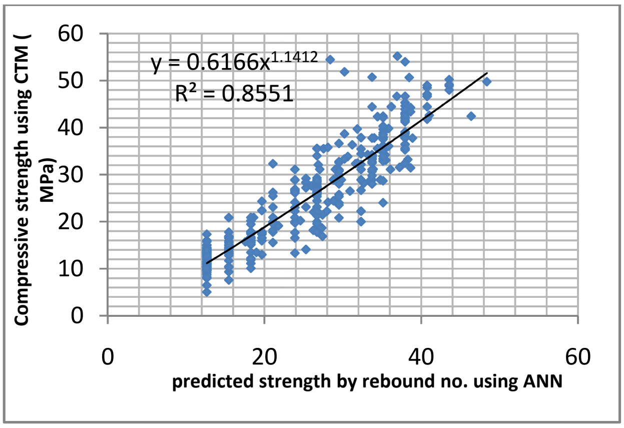

Fig. 5 Comparison between predicted strength by ANN vs actual compressive strength using CTM based on rebound number

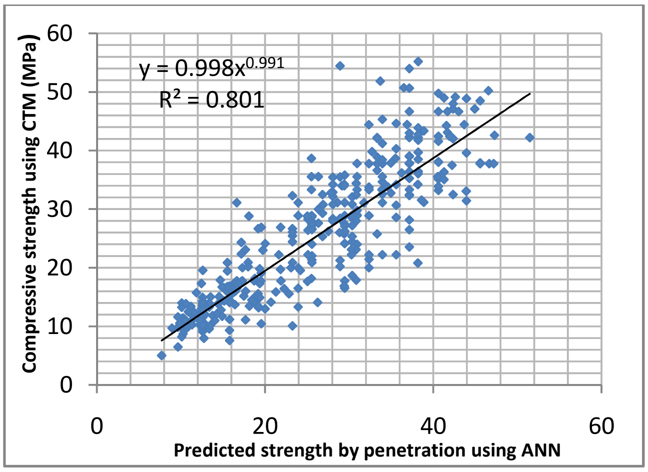

Fig. 6 Comparison between predicted strength by ANN vs. actual compressive strength using CTM based on penetration depth

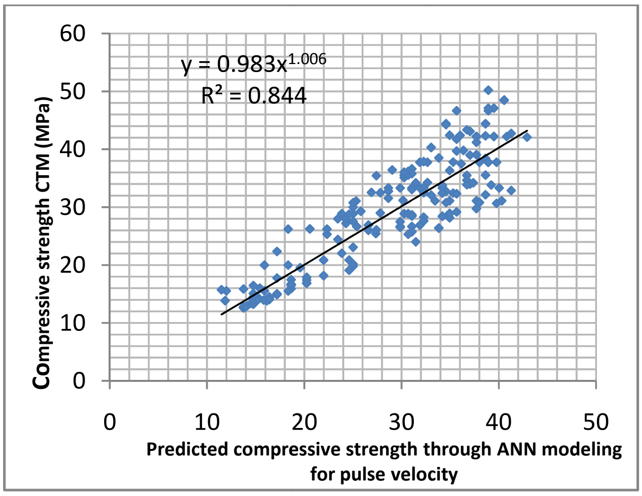

Fig. 7 Comparison between predicted strength by ANN vs. actual compressive strength using CTM based on pulse velocity

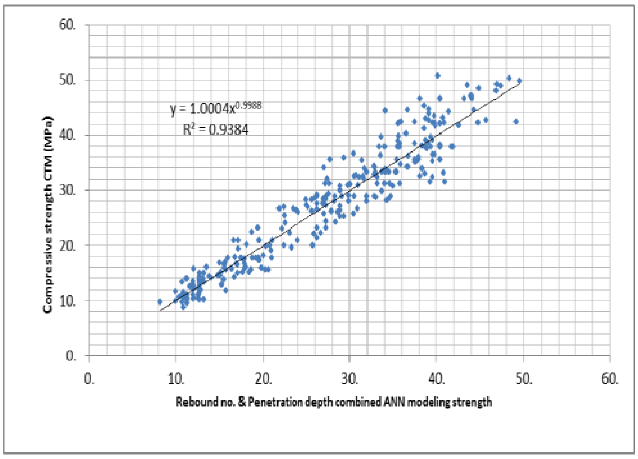

Fig. 8 ANN predicted compressive strength by combined model of rebound number and penetration depth versus compressive strength by CTM

TABLE II
COEFFICIENT OF DETERMINATION FOR DIFFERENT TECHNIQUES

Sr. No.	Name of Technique/Method	Equation	Coefficient of determination
1	Rebound Hammer	$fc=0.0339Rn^{1.9463}$	0.857
2	Windsor' Penetration	$fc=79.832e^{-.303}P_d$	0.786
3	Ultra Sonic pulse velocity	$fc=0.047V_p^{3.7318}$	0.468
4	Combined method	$f_c = 0.020R_n^2 + 0.261P_d^2 - 0.093R_n - 4.689P_d + 25.100$	0.922

From Table II, it has been observed that value of coefficient of determination, which decide the best fit curve, for Ultra sonic pulse velocity has been decreased sharply in comparison to other two single NDT methods, which shows that the correlation between predicted strength and actual strength obtained from crushing of cubes is very poor and can't be used for predicting the strength alone without the support of other methods. However, the prediction of strength based on combined methods gives best coefficient of determination than single NDT methods.

Figs. 5-7 show the comparison between the compressive strength observed by crushing of cubes and the predicted strength by ANN model for the various techniques used in the present study. It has been observed from the Figs. 5-8 that the values of coefficient of determination for curve are 0.8551, 0.8012 and 0.8441 also the %age root mean square error are 16.72, 18.521 and 12.758 which shows a good correlation between the predicted strength as well as between actual strength of concrete cubes. Hence the use of machine learning by ANN is found very useful in predicting the strength for single methods also. Also the ANN model has been developed and the strength has been predicted by using combined inputs from rebound hammer and penetration depth. Fig. 8 shows that values of coefficient of determination as 0.9384, which shows that the strength prediction is more close to the actual values and this combination is best to consider for the strength prediction. The percentage root mean square error by this method was found 3.144.

VI. Conclusion

The present study shows that ANN can predict the strength very close to the actual strength of material. The accuracy of the prediction also increased in manifolds and depends upon the learning of networks as well as the numbers of NDT techniques used. It has been concluded that

- In case of single NDT technique, it was found that the prediction of strength using rebound hammer is suitable to predict the compressive strength of concrete which makes engineering judgment quite easy. The use of the rebound hammer methods yields more reliable and closer results to the actual strength with high coefficient of determination and percentage root mean square error of 16.720.
- An acceptable level of accuracy was achieved for strength estimation of concrete using Windsor' probe penetration method but it is not recommended to be used alone to predict strength of concrete.
- A combined model developed in ANN by using inputs from rebound hammer as well as penetration predicts more accurately in comparison to prediction made by ANN model having input from single NDT techniques. The average percentage root mean square error between the actual compressive strength and predicted compressive strength was found to the order of 3.144.
- It has been observed that Ultra sonic pulse velocity method cannot be used as alone for prediction of strength, which shows worst relationship between predicted strength and actual strength. This could be explained of the fact that the pulse velocity is most affected by concrete composition in comparison to other NDT method. However, ANN analysis of pulse velocity strength relationship represents a good correlation between pulse velocity and compressive strength and could be used to predict the strength. The percentage root mean square error was found 12.758.

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