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Modeling for Prediction of Characteristic Deflection of Flexible Pavements- Comparison of Models based on Artificial Neural Network and Multivariate Regression Analysis

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ABSTRACT

Pavement surface deflection of a highway is a primary factor for evaluating the pavement strength of a flexible pavement. Benkelman Beam Deflection (BBD) technique is widely used in the country for evaluating the structural capacity of an existing flexible pavement as also for estimation and design of overlays for strengthening of a weak pavement. The field test for measuring the surface deflection is expensive and time consuming, and alternate modeling methods to estimate surface deflection of a pavement, therefore, would result in substantial savings in time and money in the preparation of detailed project reports for the large highway rehabilitation and strengthening projects being undertaken in the country. An attempt has been made in this paper to compare the results obtained from the models based on Multivariate Regression analysis and Artificial Neural Network to predict reasonably accurate characteristic deflection of flexible pavements. Data used for building the model was collected from field tests conducted by various entities in the state of Madhya Pradesh engaged in the rehabilitation and strengthening of highways in the State passing through extensive black cotton soil areas.

Keywords: Flexible pavements, Artificial Neural Network, Multivariate Regression analysis.

INTRODUCTION

Large-scale work of strengthening of Highways has, in the recent years, been taken up throughout the country, including National Highways passing through the state of Madhya Pradesh. The state government has also undertaken extensive work of strengthening on its crumbling State Highway network. Large stretches of the roads in M .P. pass through black cotton soil areas. Expansive soils, such as black cotton soil, are subject to heaving on wetting and extreme hardness and cracking when dry. This results in volumetric changes in sub-grade and the resultant severe damage to highways with weak pavements, especially under the increasing volume of traffic.

Flexible pavement surface deflection data plays an important role in the evaluation of pavement structural capacity for strengthening, maintenance and design of pavement rehabilitation programs. Evaluation of structural adequacy is accomplished by well known Non Destructive Testing procedures, such as Benkelman Beam Deflection method. A.C. Benkelman devised a simple deflection beam in 1953 for measurement of pavement surface deflection. Deflection beams are now used in India by different organisations to measure the surface deflection, as surface deflection is considered to be the best indicator of the structural condition of a pavement. Benkelman Beam measures the rebound and residual deflections of the pavement structure. Rebound deflection is related to pavement performance and is used for the overlay design. Overlay design for a given section depends not on the individual deflection values but on the characteristic deflection which is based on the statistical analysis of all the measurement in the section corrected for the temperature and seasonal variations.

The field test is not only expensive and time consuming but also slow and labour intensive, and involves substantial cost and time in the preparation of detailed project reports for the design of overlays. Overall economy in time and money, for any project can be achieved, if field tests could be substituted by building a model which can predict the characteristic deflection from the simpler basic observations and tests. Many researchers[6] have predicted and correlated deflection with the soil properties and pavement characteristics. An attempt have been made in this paper to compare the results obtained by a Non Linear Multivariate Regression model with those obtained from an Artificial Neural Network model, modelled and based on the extensive test data collected by various agencies engaged in the strengthening of highways in the State of Madhya Pradesh, located largely in the black cotton soil areas that cover large parts of the state.

Non linear multivariate regression model

In statistics, multivariate data [11,12] analysis refers to statistical technique used to analyze data that arises from more than one variable. Nonlinear regression is a form of regression analysis in which observational data is modeled by nonlinear functions[8] like exponential functions, logarithmic functions, trigonometric functions and power functions. The data is fitted by a method of successive approximations. Some nonlinear functions such as the exponential or logarithmic functions can be transformed so that they are linear. When so transformed, the standard linear regression can be performed but it is applied with caution. In transformed state these models are fit using linear regression in order to evaluate the constant coefficients. They could then be transformed back to their original state and used for prediction of the parameter defined by the model. The form of the function used to develop the model is:

$$Y=\beta_0 X_1^{\beta 1} X_2^{\beta 2} X_3^{\beta 3} X_4^{\beta 4}$$

where,

Y = Characteristic deflection (Target variable).

X_1 = Thickness of bituminous macadam (Predictor variable).

X_2 = Thickness of water bound macadam / water mixed macadam (Predictor variable)

X_3 = Thickness of granular subbase (Predictor variable).

X_4 = California bearing ratio of subgrade soil (Predictor variable).

β_0, β_1, β_2, β_3 *and* β_4 are the coefficients of each predictor variable.

Artificial neural network model

Artificial Neural Networks have the ability to relate between the input data and the corresponding output data which can be defined depending on single or multiple parameters for solving a linear or nonlinear problem. Consequently, ANNs do not require any prior knowledge or a physical model to solve the problem. The nature of the relationship between the input and output parameters is captured by means of learning through samples in the data set. This study for characteristic deflection estimation employs only one hidden layer. The number of nodes in the input layer is four for this ANN model, an individual node accounting for each input parameter. Only three neurons in the hidden layer were found to be satisfactory. The ANN model has one output node representing the value of characteristic deflection.

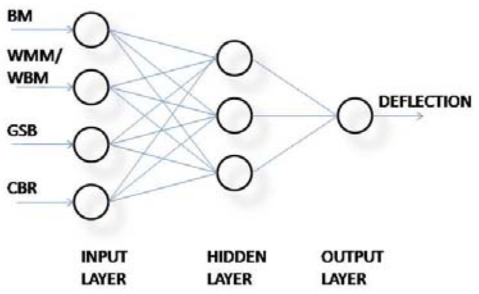

Fig. 1: Network Model Architecture

Back propagation neural network learning algorithm, suitable for most civil engineering applications, has been used in this study. A process called Bayesian regularization was adopted to produce a network that generalizes well so as to make the model relevant for a wide data range. It updates the weight and bias values according to Levenberg-Marquardt optimization. Logarithmic sigmoid transfer function was used for the input and

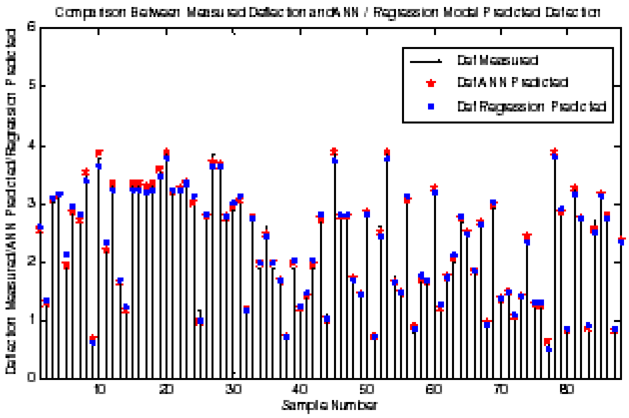

Fig. 1: Measured and ANN/ Nonlinear Regression Model Predicted Deflection

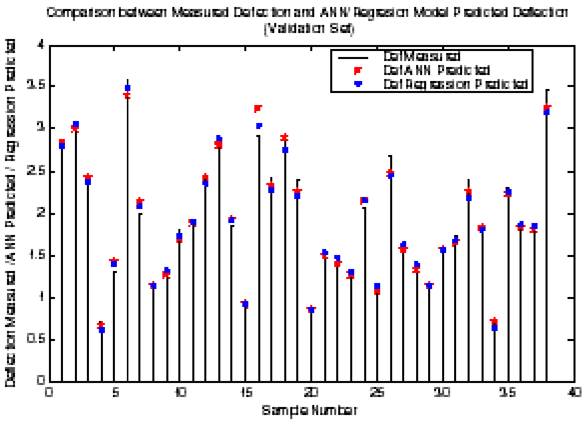

Fig. 2: Measured and ANN/ Non linear Regression Model Predicted Deflection (Validation Set)

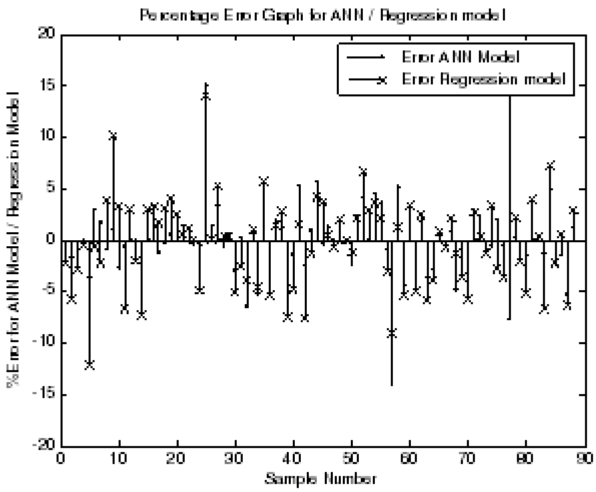

Fig. 3: Percentage Error Graph for ANN and Non linear Regression Model Predicted Deflection

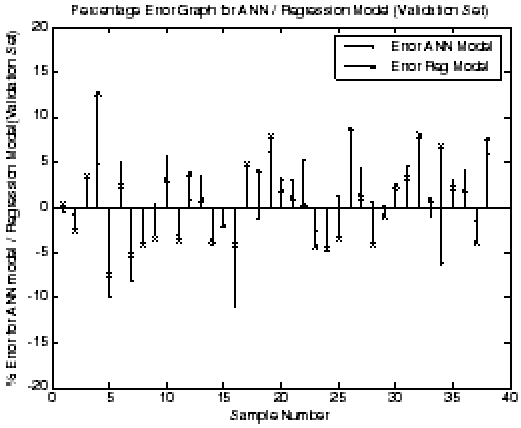

Fig. 4: Percentage Error Graph for ANN and Nonlinear Regression Model Predicted Deflection (Validation Set)

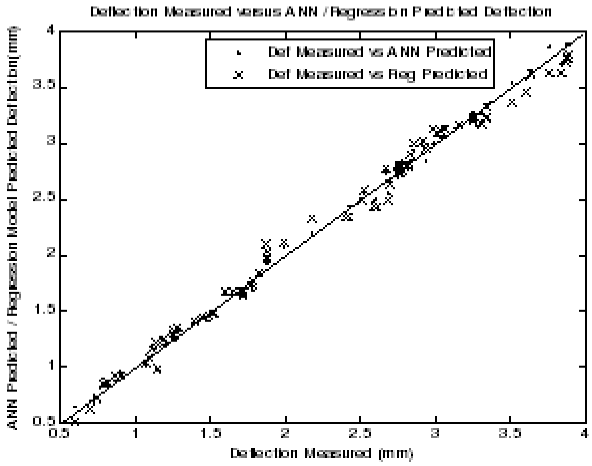

Fig. 5: Measured versus ANN/ Nonlinear Regression Model Predicted Deflection

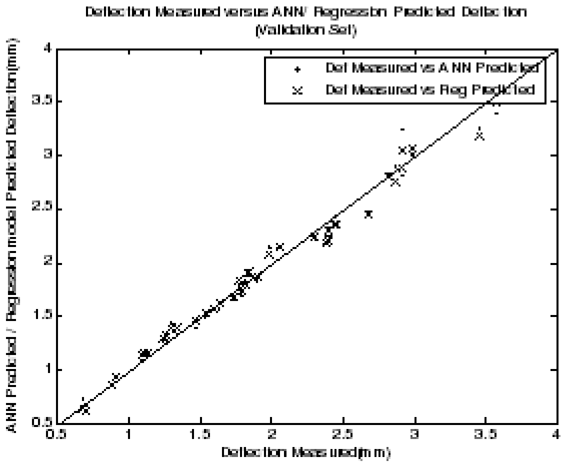

Fig. 6: Measured versus ANN/ Nonlinear Regression Model Predicted Deflection (Validation Set)

the output layers. Hyperbolic tangent sigmoid transfer function was used in the hidden layer. Generalization capability of the trained network was tested with a separate set of validation data set. The diagram in figure -1 represents the network model architecture. The program used in the running of network models was written in MATLAB language code.

Model database

A thorough understanding of the factors affecting deflection is needed in order to obtain an accurate deflection prediction. Database used for generating both the models in the present study is based on the data collected from M.P. State authorities pertaining to Morena - Porsa Road, Shivpuri- Sheopur Road, Khalghat-Kasrawat Road, Barwah-Dhamnod Road, Gaitarganj - Silwani Road, Bareli - Piparia Road, Deshgaon - Khargon Road and Khasravad - Khargone Road in Madhya Pradesh, and includes both black cotton soil areas and some areas with other soils, in an effort to make the model suitable for different sub-soil areas. The available data is divided into two groups, one employed to develop the nonlinear multivariate regression model and to train the ANN model, and the other group to independently validate and test the performance of the developed models. In this study, 88 samples are used to build the model and 38 samples were used in the validation/testing set.

Comparison of measured and ann model/ regression model predicted deflection

Figure-1 exhibits the comparison between the measured deflection and the predicted deflection by the Regression model and ANN model. Similarly, Figure-2, exhibits the comparison between the measured and the predicted deflection by the Regression model and ANN model for the validation data Set. Figure-3 exhibits the comparison of the Error graph for each sample between the measured and the predicted deflection for the Regression model and ANN model. Figure-4 exhibit the comparison of the Error graph for each sample between measured and predicted deflection for the Regression model and ANN model for validation data set. Figure-5 exhibits the comparison between the relative measured deflection versus the predicted deflection for both regression model and ANN model. Figure-6 exhibit the comparison between the relative measured deflection versus the predicted deflection for both Regression model and ANN model for the validation set.

Statistical analysis

Performance of the model is indicated by the coefficient of determination (R^2), Root mean square error (RMSE) and mean absolute relative error (MARE). R-Square, also known as the Coefficient of determination is commonly used in statistic to evaluate model fit. R-square is 1 minus the ratio of residual variability. When the variability of the residual values around the regression line relative to the overall variability is small, the predictions from the regression equation are good. The R-square value is an indicator of how good a predictor might be constructed from the modeled values. R^2 value is calculated as the square of the correlation coefficient between the original and modeled data values. The $R^{2,}$ RMSE, MARE values for the regression model and the ANN model are compiled in the Table 1.

Table 1: Result Analysis

Performance Parameter	Ann Model		Regression Model	
	Training Data Set	Testing Data Set	Model Creation Data Set	Validation Data Set
R^2	0.992	0.981	0.991	0.982
RMSE	0.086	0.117	0.089	0.111
MARE	2.269	4.904	3.600	5.223

Sensitivity analysis proposed by Garson[10] for the ANN model, gives 90% importance to the thickness of Bituminous Macadam. It is thus the most significant parameter having maximum impact on the characteristic deflection. Similarly in regression, the size of the coefficient for each independent variable give us the size of the effect that variable has on the dependent variable, and the sign on the coefficient (positive or negative) gives the direction of the effect. The coefficients generated by the model also show that the thickness of Bituminous Macadam is predominant factor for predicting characteristic deflection.

CONCLUSIONS

The R-square value calculated for the measured deflection and the predicted deflection for the ANN model and Regression model both have a good correlation between the original and modeled values. The coefficients generated by the regression model and the result of sensitivity analysis for the ANN model clearly indicate that the thickness of Bituminous Macadam has the greatest influence on the characteristic deflection. Compared to the statistical method, ANNs do provide a general framework for determining relationships between data and do not require the specification of any functional form. A large number of test data is available from the field and laboratory testing carried out for many highway projects in the country, and can be used to further improve and further generalize the models.

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