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Application of Artificial Neural Network to Predict CBR of Fine Grained Soil Mixed with Fly Ash

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Abstract. Laboratory testing has been the base for investigating the applicability of soil mixed with any material or additive. Several studies have been reported on fly ash stabilized fine grained soil. In order to reduce the tedious laboratory method of finding the CBR value of soil-fly ash mixes prior to their field application, attempt has been made to use Artificial Neural Network (ANN) technique for obtaining the CBR by using different influencing parameters of soil and fly ash. The properties of the fly ash and the fine grained soils have been studied individually and when mixed together in different proportions from the past literatures. Factors affecting the CBR of fine grained soil mixed with fly ash have been identified and data have been collected. Using those data, CBR of fine grained soils mixed with the fly ash has been calculated using ANN technique considering the percentage of soil and fly ash, MDD and OMC as inputs under both soaked and unsoaked condition. The CBR value predicted is found to be nearly close to that of laboratory data, and thus ANN can be used satisfactory for predicting the CBR of fine grained soil mixed with fly ash before its field application.

Keywords: CBR, ANN, Fly ash, Fine grained soil, MDD, OMC.

1 Introduction

Industries are an essential part of a country which is the main source of economic, financial, technological and all over growth of a country. Industrial wastes have been a major cause of environmental pollutions and the disposal of the industrial wastes has always been a tedious and a difficult process which have also been the cause of land pollution and release of toxic substances to the environment leading to air and water pollution as well. One such industry is that of the thermal power industries utilising coal or lignite for electricity production. The coal available in India are of low grade and hence with a higher ash content of approximately 30-45 percent. These coals when used in the industries generate large quantities of fly ash which are expelled into the atmosphere as leading to the land, air and water pollution. Therefore, so as to regulate the disposal of fly ash, MoEF and CC, India has issued various notifications. One such notification is that of 2009 which aimed at utilization of 100 percentage of fly ash to be achieved by applying it in a phased manner. Utilization has hence increased in various sectors of construction and manufacturing.

Fly ash finds its use in various construction sectors such as production of cement, mine fillings, bricks and tiles, ash dyke raising, roads and flyovers, agriculture, concrete, hydropower sector and many more. Roads and highways sector is one where of the total generated fly ash, only around 9.27 percent had been utilized for the financial year 2019-20 even though India is considered to have the second largest network of road. The application of fly ash in roads though it has been successfully implemented but has been gaining popularity only in the recent times.

Experts from various fields have been doing ample amount of research on the application of fly ash in various fields. As they are cheap and easily available they can be economical and even using these materials can relieve the environment from it being toxic to a great extent. Sen and Mishra [1] in their study to find the usage of industrial wastes in village road construction found that wastes like fly ash, blast furnace slag, cement kiln dust, phosphogypsum showed characteristics which were beneficial and if treated and used might be able to replace most of the construction material that are used in road construction purposes. Among many applications that experts and researchers have worked upon, one is the improvement of soil. Soil in different areas has different soil properties some of which might not be workable enough for construction purposes. Therefore, it is necessary to stabilize the soil before a construction activity is carried out.

Eskioglou and Oikonomou [2] and Cokca [3] have worked on fly ash with soil to make it usable in road construction. Fly ash contains a certain cementitious proper-ties making it an efficient additive that finds its use in improvement of the soil and is also used in concrete to increase strength. Fly Ash has been combined with other ad-ditives like cement [4] and used in different proportions to find the most effective proportion that would be most economical. Other than that with the technological advancements, there have been success in prediction of various soil related experi-mental parameters like settlement [5], maximum Dry Density and Optimum Moisture Content [6], CBR [7] etc. using different computing systems.

One such advancement is the use of Artificial Neural Network (ANN) in the process of Machine Learning. Artificial Neural network algorithms are designed such that it imitates the human neural system structure. In this project an attempt has been made to train an Artificial Neural Networks with the help of the Neural Fit Toolbox in the MATLAB Software and thus predict the CBR values, both soaked and unsoaked conditions considering the percentage of additives, soil, MDD and OMC as the inputs or the independent variables.

The main objective of the present study is to predict the CBR values of fine grained soil-fly ash mixes using ANN. An attempt has been made to utilize the Artificial Neural Network which is a computer based Machine Learning method for the prediction of the California Bearing Ratio of both soaked and unsoaked conditions of soil and fly ash as additives. CBR is a soil strength parameter and is usually obtained from conventional laboratory tests. In this study the ease and accuracy of the predictions made through ANN is explored with the help of data obtained from previous laboratory based researches done by experts. The data of soil with fly ash as additives, their respective MDD and OMC values of previous studies [4, 8-14] has been considered for the ANN training and thus the prediction has been done for the CBR values.

2 Analysis and Discussions

2.1 Artificial Neural Network Analysis

ANN training using Neural Net Fitting Toolbox. The branch of machine learning which is based on the human neural network is termed as the Artificial Neural Network (ANN). The ANN network is trained using the neural fitting toolbox in the MATLAB [13]. In this study the data set used to train the network contains the soaked CBR values and percentage content of the wastes used as additives and the soil as the inputs for the analysis. The data set contains a set of predetermined results from previous studies done by researchers on some of the fine grained soil that can be classified under the USCS as CH, CL, MI and MH. In the computation of neural network, the processes involved are as follows:

Step 1: The data extraction has been done from the compilation of previous studies [8-10, 16-18]. The data includes the soaked and unsoaked CBR, percentage of soil and the waste materials, maximum dry density and optimum moisture content. One of the defining characteristics which affect the CBR values are the dry density and the optimum moisture content, there-fore they are considered as one of the outputs for ANN training.

Step 2: Assigning the inputs and outputs. The inputs for the neural network training that has been taken are the percentage of soils and waste materials, maximum dry density and optimum moisture content has been named as “x” and the desired output is the CBR values which contains the soaked CBR values and un-soaked CBR values which has been denoted in a variable “y”.

Step 3: Assigning the percentage of train, validation and test data. From the data set 70 percent has been assigned for training, 15% of the total dataset has been used for validation and the rest of the 15% for testing the neural network.

Step4: Assigning the number of hidden layer neurons. Here in this training, the 10 hidden layer neurons were trained which has been chosen.

Step 5: Selecting the training algorithm. After selecting the hidden neuron layers, the algorithm that is to be used is selected for the training. The Levenberg Marquardt algorithm has been selected for the training purpose.

Step 6: Training the dataset. After the above steps from Step 2 to Step 4 are done, the network is trained accordingly and it gives us a set of results.

Step 7: Validation and retrain. The training data set is validated inside the neural network system to check the workings of the network and the performance is given by the system. If after computation, the performance of the network is not satisfactory, retraining needs to be done. The network can be retrained either by changing the hidden layer neuron size or changing the algorithm or training with a larger data set. The obtained neural network can also be further tested if one wants to do so.

Step 8: End of training. The performance if found satisfactory, the function used and the NN network can be generated and the results of the computed values of the trained network can be saved. Applications of obtained results are possible for further fitting purposes or prediction purposes as per the usage.

Program for ANN network training and prediction. Along with the use of the nftool, one can also compute it using some simple codes which is as follows:

```
% Define variables
data = readmatrix(“Untitled.xlsx);
x = data(:,4:8);
y = data(:,2:3);
x = transpose(x);
t = transpose(y);
% Choose a Training Function
trainFcn = 'trainlm';  %Levenberg-Marquardt backpropagation.
% Create a Fitting Network
hiddenLayerSize = 10;
net = fitnet(hiddenLayerSize,trainFcn);
% Setup Division of Data for Training, Validation, Testing
net.divideParam.trainRatio = 70/100;
net.divideParam.valRatio = 15/100;
net.divideParam.testRatio = 15/100;
% Train the Network
[net,tr] = train(net,x,t);
% Test the Network
y = net(x);
e = gsubtract(t,y);
performance = perform(net,t,y)
% View the Network
view(net)
% Plots
plot  perform(tr)
plottrainstate(tr)
plot errhist(e)
plot regression(t,y)
```

2.2 Working of the Neural Network

After the program has been run, the 5 element input of the neural network gets trained in 2 layers where the hidden layer had a total of 10 hidden nodes and the activation function used was a tangent sigmoid function, after which it proceeded to the next layer which is the output layer to ultimately return the two output as shown in Fig. 1.

The training of the network was done using the Levenberg Marquardt Algorithm, the function for which is trainlm that is supported in MATLAB [15] and the performance of the network is determined using the Mean Squared Error method. The network had gone through the maximum of 6 validation checks after which it stopped. During this period, it had undergone a total of 13iterations.

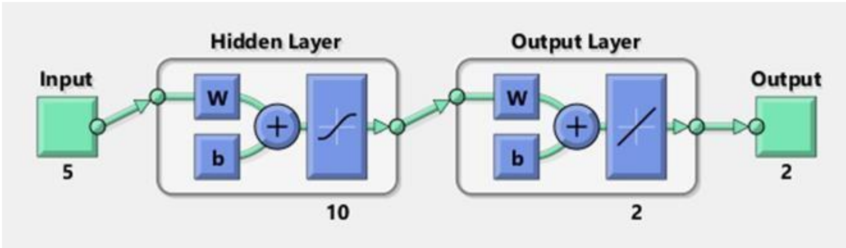

Fig. 1. Trained ANN Network diagram

2.3 Performance, Prediction and Error of ANN Training

The network achieved the best validation performance Mean Squared Error of 5.9007eat 7 epochs as shown in Fig. 2. The regression values which are measured to determine the relation between Outputs and targets for training dataset returned a value of 9.8031e-1, for validation set 9.8015e-1 and for test set 9.2646e-1 and an overall value of 9.6649e-1 as shown in Fig. 3 which is quite close to 1 and hence can be said to have garnered a satisfactory result.

The experimentation results of Soaked CBR and Unsoaked CBR are compared with the Predicted Values as obtained from the ANN training and the errors obtained from finding the difference between the actual and predicted CBR values are in the Fig 4 and Fig 5.

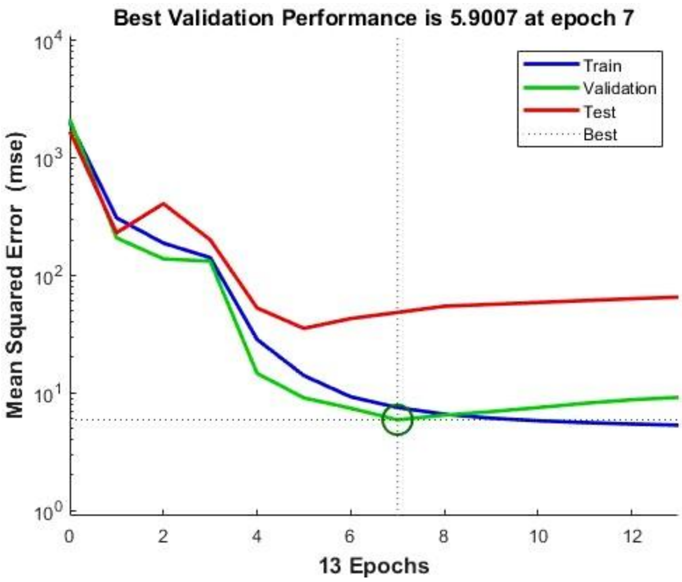

Fig. 2. Performance graph depicting MSE for each epoch.

The predicted data which has been plotted in the Fig. 4.and Fig. 5 for Soaked CBR and Unsoaked CBR respectively where Series 1 is the predicted value and Series 2 is the actual value in both the figures. The predicted data shows less variation from its actual value for almost the entire set except in two of the samples which shows considerable variation.

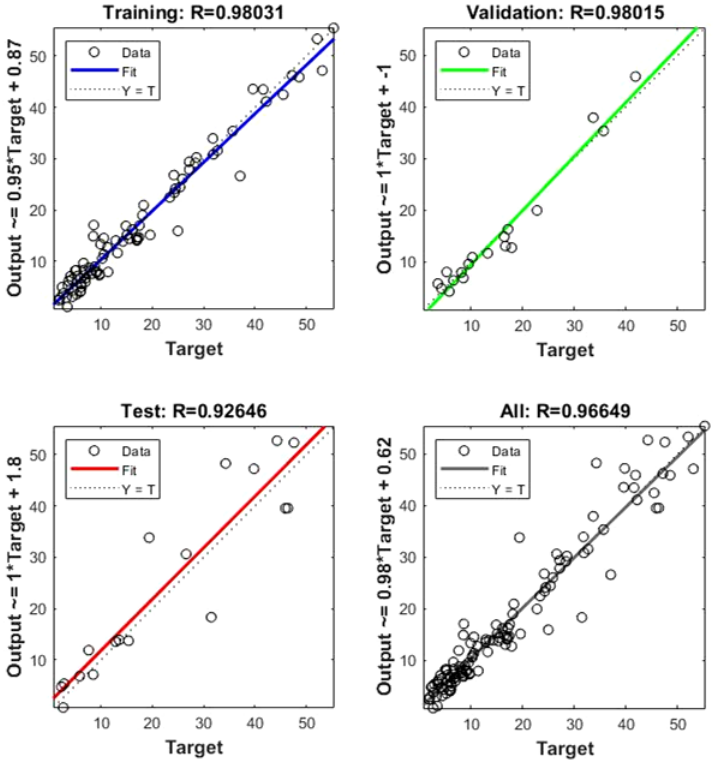

Fig. 3. Regression analysis representation in graph of the trained NN.

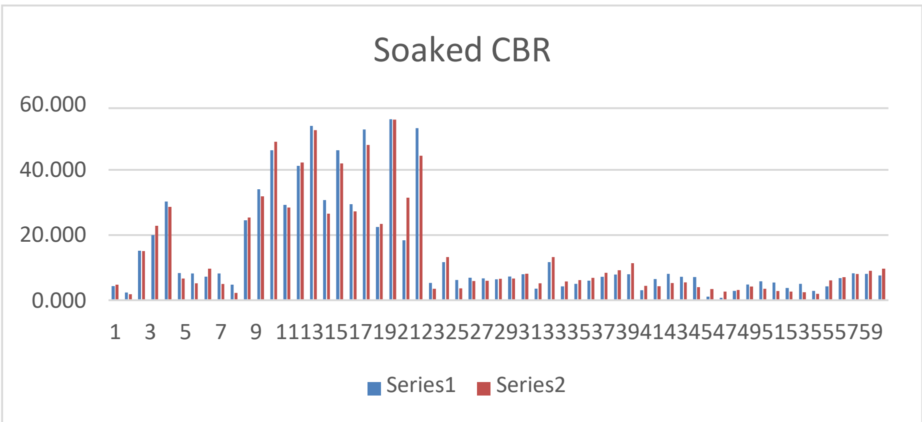

Fig. 4. Actual v/s Predicted of Soaked CBR

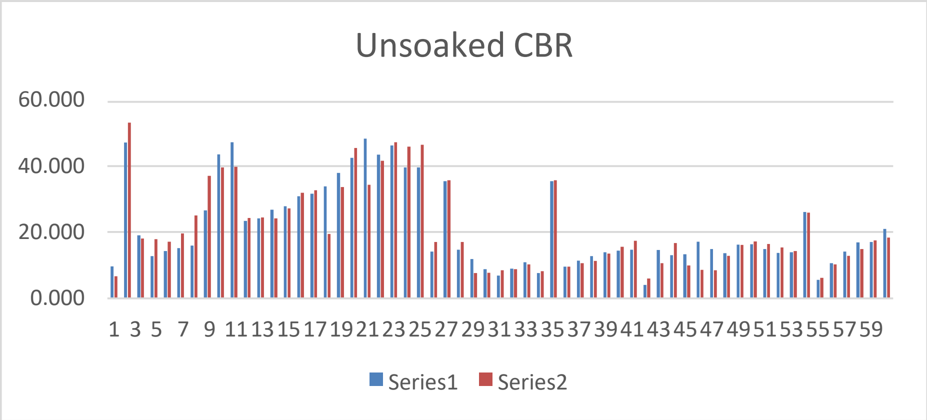

Fig. 5. Actual v/s Predicted of Unsoaked CBR

Fig. 6 below shows the distribution of the errors which are the variations that is seen between the Actual and the Predicted. From the Fig. 6, it can be seen that the error distribution is around zero for most of the values but though it contains a few outliers.

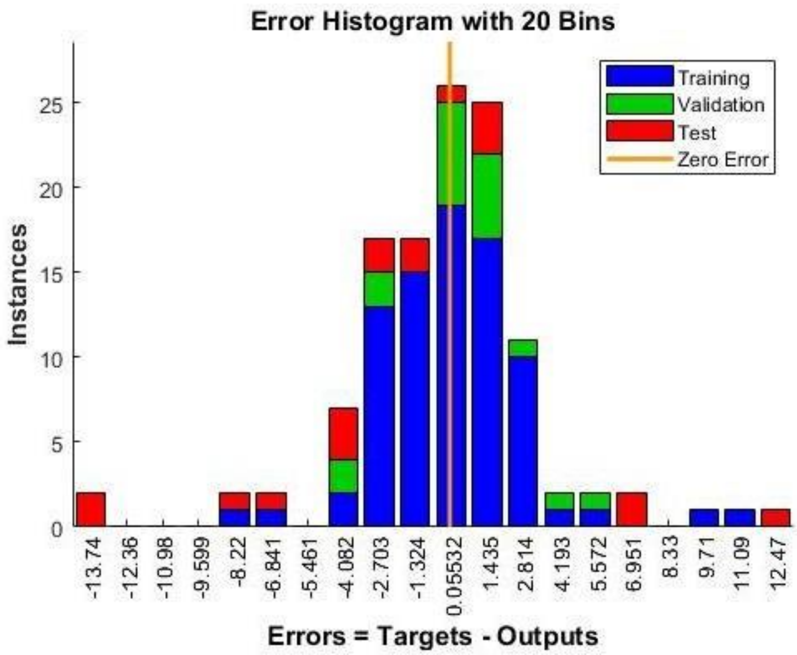

Fig. 6. Error histogram showing the error distribution

3 Conclusions

The following are the conclusions that can be surmised from the study:

1. Class C fly ash with a higher proportion of Calcium has self-cementing properties hence does not require any additive or cementing agents. While in case of Class F fly ash due to absence of self-cementing property which is a result of less CaO, there is a necessity to use additional cementing agents to gain the desired strength.
2. Addition of fly ash results in lowering of MDD and increase of OMC of soil causing formation of relatively light weight fill material for civil engineering application.
3. The training of Artificial Neural Network can be done either in the MATLAB (2021) using the Neural Fit Toolbox or by using understandable codes for programming of the ANN and its subsequent prediction.
4. The ANN analysis predicted the CBR value very close to that of laboratory results at varying fly ash content using the MDD and OMC value of respective fine grained soil and fly ash mixes having maximum errors lying near about zero. This indicates that ANN can effectively predict the CBR of soil-fly ash mixes which can reduce the laboratory test to find CBR of soil-fly ash mixes prior to field application.

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