PREDICTION OF CALIFORNIA BEARING RATIO OF A BLACK COTTON SOIL STABILIZED WITH WASTE GLASS AND EGGSHELL POWDER USING ARTIFICIAL NEURAL NETWORK

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Abstract- **The laboratory test process to determine the California bearing ratio (CBR) of black cotton soils is not only overpriced but also time-consuming as well. Hence advanced prediction of CBR plays a significant role as it is applicable in pavement design. The prediction of CBR of treated soil was executed by Artificial Neural Networks (ANNs) which is a computational tool based on the properties of the biological neural system. To observe CBR values, combined eggshell and waste glass was added to soil as 4, 8, 12, and 16 % of the weights of the soil samples. Accordingly, the laboratory related tests were conducted to get the required best model. The maximum CBR value found at 5.8 at 8 % of eggshell-waste glass powder addition. The model was developed using CBR as an output layer variable. CBR was considered as a function of joint effect of liquid limit, plastic limit, and plastic index, optimum moisture content and maximum dry density. The best model that has been found was ANN with 5, 6 and 1 neurons in the input, hidden and output layer correspondingly. The performance of selected ANN has been 0.99996, 4.44E-05, 0.00353 and 0.0067 which are correlation coefficient (R), mean square error (MSE), mean absolute error (MAE) and root mean square error (RMSE) respectively. The research presented or summarized above throws light on future scope on stabilization with waste glass combined with different percentages of eggshell that leads to the economical design of CBR acceptable to pavement sub-base or base, as desired.**

Keywords – ***CBR, Artificial Neural Network, Liquid Limit, Plastic Limit, Maximum Dry Density, OMC***

I. INTRODUCTION

The soil consists of air, water, and solid particles which are generated by the disintegration of rocks and found on the top of the earth layers. Black cotton soil contains a high amount of clay. It has a property of low bearing capacity, low permeability, and high volume change. Due to these properties, black cotton soil (BCS) is not used for the constructing and building of civil engineering structures without stabilization. It is indicated that the use of glass, plastics, and rubber stabilizes the black cotton soil (BCS) to be used in construction (Babatunde *et al.*, 2019). California Bearing Ratio value improvement is the main advantage of the stabilization. Improvement on-site material (soil) for construction, such as solid and strong sub-base and base course stabilization is necessary. Glass is among the waste materials that might be used to stabilize black cotton soil. Glass is a hard material and its composed of sand (silicate) and alkali. It is free of hurting the environment and non-degradable. Once it is broken, it is considered useless and discarded. It has a physical property of high permeability, high crushing resistance, and small strain stiffness. This property makes glass as an alternative material for stabilizing soil (I. Ikara *et al.*, 2015). The eggshell is another unwanted material which might be used as an additive to improve the characteristics of black cotton soil. (Birundha *et al.*, 2017) indicate that the similarity of chemical composition present in egg shell could be a good replacement for industrial lime. Chicken eggshell is one of waste materials which can be obtained from restaurants and homes. In this document, the combined effect of waste glass and egg shell powder will be investigated experimentally. California Bearing Ratio may be determined by many features like maximum dry density, optimum moisture content, liquid limit, plastic limit, plasticity index, permeability of the soil, etc. Its determination is a time-consuming process. In this study, an effort has been made to relate soaked California bearing ratio values with LL, PL, PI, OMC, and MDD by artificial neural network techniques. Finally, CBR of BCS that is stabilized with waste glass and eggshell powder was modelled using artificial neural networks.

II. LITERATURE REVIEW

(Babatunde *et al.*, 2019) studied the effect in treatment of BCS via waste glass powder. The maximum plastic limit and liquid limit of 22% and 79% correspondingly, were recorded in the addition of 0% percent waste glass powder. The influence on treatment of black cotton by increasing waste glass powder dosage shows a drop in the plastic limit. However, the liquid limit shows the same trend first with a small increment in the amount of liquid limit at 8% waste glass powder content was observed. In the 2% addition of waste glass powder on BCS treatment, the optimum moisture content was recorded. This indicates an 8% increase when we compared to that of BCS, which has a glass content of 0%. At 4% glass powder treatment with BCS, the maximum dry density and unconfined compressive strength of 1.57 mg/m3 and 140 kN/m^2 were recorded correspondingly. The lowest liquid limit of 75.9% was documented in 6% glass powder by weight of BCS treatment. At the same time, the maximum dry density content noted was 1.48 mg / m for the glass content of 6%. On the other hand, the highest CBR value of 3.9% was recorded for the same glass powder content. This is a 95% increase compared to the untreated BCS. At 8 percent glass powder, minimum plastic limit, optimum moisture content, and CBR value were recorded. Conversely, in the introduction of 8% of the WGP dosage in the BCS plasticity index, notes down the highest value. (Ibrahim *et al.*, 2019) uses a stained glass powder to stabilize high-plasticity clay in Arbill, Iraq.6%, 12%, 18%, 27%, and 36% of stained glass powder were used to study the highest content to stabilize the soil. When stained glass increased from 3% to 36%, the PI percentage decreased by 9%, MDD value also increased with additional percentage of glass powder added to the soil sample. However, the OMC did not. USC was increased Up to 27% by waste glass powder increment in the soil sample (from 282 kPa to 560 kPa) and reduced to 517 kPa at 36%. d CBR value presents a 100% increment and has little outcome on the strength of soaked soil samples. (Diana *et al.*, 2017) do experimental investigation to improve the sub grade clayey soil using ESP. Optimum dosage of ESP that stabilizes clay soil well was determined. According to this study investigation, 12 % of ESP can replace the 4 % dosage of lime which can help to stabilize clay soil to be used as a sub grade material. (Kurnaz *et al.*, 2016) Study on topic regarding to Prediction of soil compressibility parameters using neural artificial networks. In this document, an ANN technique was conducted using the index parameters of fine-grained soils as a predictor to figure out the compressibility parameters Both the compression and recompression index were attempted to estimate during this analysis by using a two-output hybrid ANN model. The model is based on natural water content (wn), initial ratio of void (e0), LL, and PI. The proposed model of a convolutional neural network is divided into three subsets: training, validation, and testing. The compressibility parameters were also predicted by 70 percent of the samples used for preparation, 15 percent of the overall dataset for validation, and 15 percent of the database for testing. To track the efficiency of the proposed ANN model, the correlation (R) coefficient and the mean squared error (MSE) coefficient were used as statistical tools to compare the observed and predicted values. For modeling, ANN with 1 hidden layer has already been used. The feed-forward with the back-propagation algorithm, which is that the most favored algorithm was used during the training stage in neural networks. Standard Levenberg–Marquardt training function used as a learning algorithm within the established ANN model. The best performance was obtained from the ANN model with 20 neurons within the hidden layer. Therefore, the 20 neurons within the hidden layer are often considered as an optimum value for the ANN model.

III. METHODOLOGY

3.1 Material Description

a. Black Cotton Soil

Black cotton soil used for experimental investigation was collected near the main road of Koye Roundabout-Meshualekiya main road and Koye Roundabout of – Tulu Dimtu interchange in Addis Ababa city inside Addis Ababa Science and Technology University. Disturbed BCS sample was taken at three pits at a depth of 3m below normal ground level. This helps to avoid organic matter impact. The sample is prudently conveyed to the laboratory without losing the natural moisture content to know its moisture content value accurately.

Table -1 Index Properties of Soil

Property	Value
Natural Moisture Content (%)	15.7
Particle Size Distribution	
Sand (%)	4.4
Silt (%)	36.5
Clay (%)	59.1
Specific Gravity	2.48
Liquid Limit (%)	97.43
Plastic Limit (%)	53.07
Plastic Index (%)	44.37
OMC (%)	27.9
MDD (g/cm3)	1.45
CBR (%)	1.67
Free Swell Index	96

b. Eggshell Powder

The chicken egg shell that was used for this study is collected from Addis Ababa Science and Technology University Cafeterias. The collected egg shell were washed and dried in the sun to remove impurities and bad odor. After that, these egg shells are powdered using juice machine and sieved through 0.075mm (#200) sieve.

c. Waste Glass Powder

The waste glass to be used in the study was collected from Addis Ababa city waste disposal site. The glass powder was crushed and sieved through 0.075mm (#200) sieve. The chemical compositions that were found in waste glass are described in Table 2.

Table -2 Chemical Composition of Eggshell and Waste Glass Powder

Chemical Name	Eggshell Powder %by mass	Waste Glass Powder % by mass
SiO_2	1.94	80.84
Al_2O_3	<0.01	<0.01
Fe_2O_3	<0.01	<0.01
CaO	48.56	9.78
MgO	0.52	3.48
Na_2O	0.08	5.50
K_2O	1.76	<0.01
MnO	<0.01	<0.01
P_2O_5	0.35	0.09
TiO_2	<0.01	<0.01
H_2O	1.54	0.09
LOI	44.4	0.18

3.2 Experimental Analysis

The first phase in this study is investigating the index and strength properties of black cotton soil. Index properties include sieve analysis, Atterberg limits, and moisture density relation testing. Strength tests include CBR test. The second phase is studying the index and strength properties of combined equal dosage of waste glass and eggshell powder mix, starting from 4% to 16 % with 4 % increment with black cotton soil. Atterberg limits, moisture density relation, and CBR tests were done to characterize the property of treated soil.

3.2 Artificial Neural Network (ANN) Model Development

(Pradeep *et al.*, 2016), (Ali *et al.*, 2016),(I. A. Ikara *et al.*, 2019) and C. Rajakumr et.al, 2016 used 15, 16, 20 and 18 datasets respectively to predict CBR value of soil from addition of different admixtures using artificial neural network. In this study, for the neural network modeling, totally 15 datasets were taken for analysis. These data sets were taken from experimental results of native and eggshell waste glass treated black cotton soil. For this study, from the available data, 70%, 15% and 15% of them were used for testing, validation, and training of the neural network, respectively. Testing data sets were not used during the development of the neural network. As a result, they can be a good indicator for testing the accuracy of the developed neural network. The data used for training, validation, and testing are divided randomly. Before offering the input and output parameter values for ANN model training, they were mounted between -1 and 1 and 0 to 1. This helps to eradicate their dimension and to confirm that all variables obtain the same devotion during training. For each variable X with lowest and largest value of Xmin and Xmax, respectively and the range that we want to scale with minimum and maximum value of Ymin and Ymax, respectively, the scaled value Xn is calculated as follows:

$$\text{Xn} = \frac{(\text{Ymax}-\text{Ymin}) * (\text{X}-\text{Xmin})}{(\text{Xmax}-\text{Xmin})} + \text{Ymin} \qquad (1)$$

The minimum hidden node layer taken was 1 and the best ANN model structure was checked until no significant improvement was recorded. After that, the best model that performs well was selected. In this study, the Bp algorithm with momentum and learning rate applied. To measure the neural network performance and show the error rate of the proposed, the most regularly used performance measuring parameters were MSE, RMSE, MAE, and R. These measuring parameters are calculated by the following equations.

$$\text{MSE} = \frac{1}{n}\sum_{i=1}^{n}(Xt - X't)^2 \qquad (2)$$

$$\text{RMSE} = \sqrt{\frac{1}{n}\sum_{i=1}^{n}(Xt - X't)^2} \qquad (3)$$

$$\text{MAE} = \frac{1}{n}\sum_{i=1}^{n} \left|Xt - X't\right| \qquad (4)$$

$$\text{R} = \frac{\sum_{i=1}^{n}(Xt-\overline{Xt})(X't-\overline{X't})}{\sqrt{\sum_{i=1}^{n}(Xt-\overline{Xt})^2 \sum_{i=1}^{n}(X't-\overline{X't})^2}} \qquad (5)$$

Where Xt is Actual CBR value, X't is Predicted CBR value, $\overline{Xt}$ is the average value of actual CBR, $\overline{X't}$ is the average value of predicted CBR and n is the total number of observations. For each ANN modeling structure, the training results of MSE, RMSE, R and R^2 values were analyzed and the better ANN model structure that is better in prediction is selected. After the better ANN model structure is selected, mathematical formula development was conducted based on the model training weight and bias results.

IV. RESULT AND DISCUSSION

4.1 Experimental Results

The average liquid limit, plastic limit and liquid limit of the native BCS is determined as 97.43%, 53.07% and 44.37% correspondingly. However, after the addition of combined eggshell and waste glass powder, the result shows a decrement in liquid limit, plastic limit and plastic index value up to 8% and again shows an increment up to 12% as shown in figure 1 below.

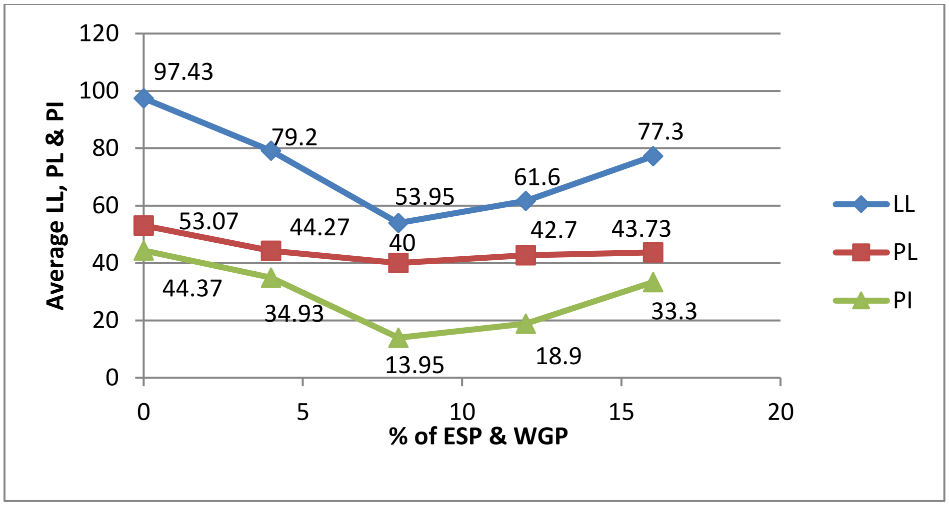

Figure 1. Variation of Average Atterberg Limits vs. percentage of ESP & WGP

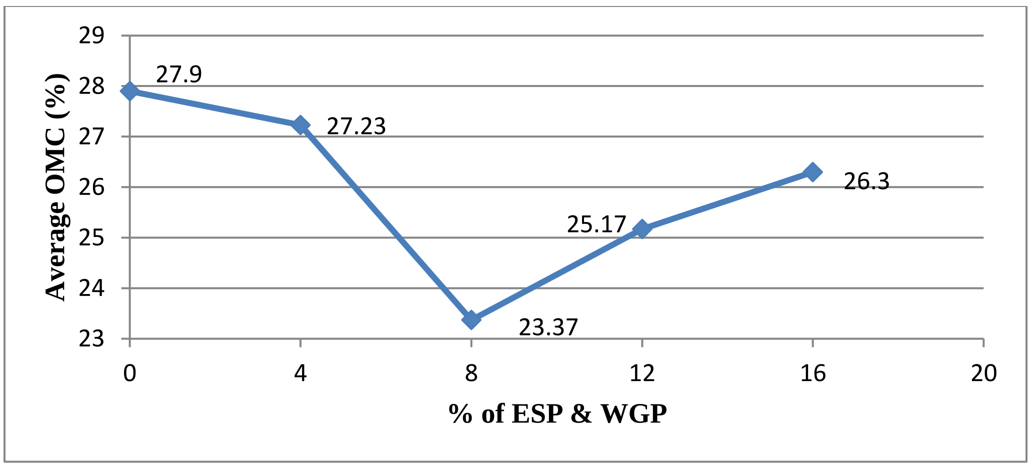

Figure 2. Average Optimum Moisture Content vs. percentage of ESP & WGP

The addition of combined eggshell waste glass powder shows an enhancement in the optimum moisture content of native black cotton soil. The lowest content is obtained at 8% addition of combined eggshell- waste glass powder with an average value of 23.37%.

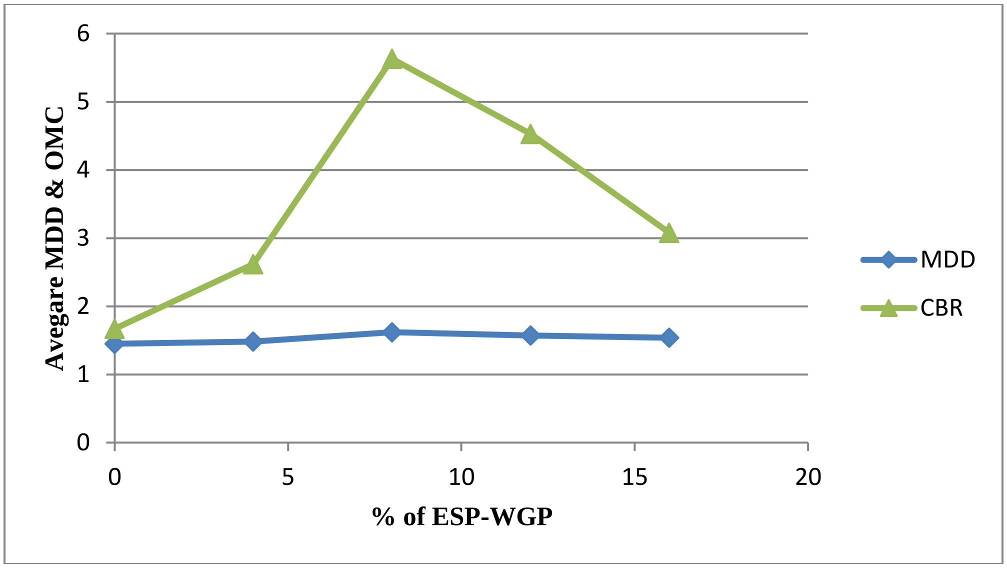

Figure 3. Average MDD & CBR vs. percentage of ESP & WGP

In all percentage addition of eggshell waste glass additives, the dry density and CBR value is higher than the native soil. However, the optimum dry density and CBR value is obtained at 8% addition of combined eggshell waste glass powder which is 1.62g/cm3 and 5.63 respectively. From the graph it is showed that the dry density and CBR value increases to 8% by addition of eggshell and waste glass powder additives. After 8 % addition, it shows a decrement in dry density values.

4.2 Artificial Neural Network Model Results

Table -3 Model Performance Results Based on TANSIG-PURELIN Activation Function Link

Architecture	TANSIG(from input to hidden layer) -PURELIN(from hidden to output layer)			
	MSE	RMSE	R	MAE
5-1-1	0.00184	0.04286	0.99854	0.03044
5-2-1	0.00167	0.04092	0.99881	0.02917
5-3-1	0.0009	0.03003	0.99927	0.01139
5-4-1	0.00074	0.02719	0.99924	0.02354
5-5-1	0.00043	0.02075	0.99955	0.0137
5-6-1	4.4E-05	0.00666	0.99996	0.00353
5-7-1	6.3E-05	0.00796	0.99994	0.0036
5-8-1	0.00041	0.02023	0.99965	0.01442
5-9-1	0.00077	0.02773	0.99941	0.02077
5-10-1	0.00049	0.02216	0.99948	0.00988
5-11-1	0.00062	0.02487	0.99942	0.00946
5-12-1	0.00074	0.02728	0.9994	0.01193
5-13-1	0.00072	0.02681	0.99932	0.01122
5-14-1	0.00105	0.03246	0.99899	0.01604
5-15-1	0.0025	0.04999	0.99872	0.03798

Table -4 Model Performance Results Based on LOGSIG-PURELIN Activation Function Link

Architecture	**LOGSIG(from input to hidden layer) -PURELIN(from hidden to output layer)**			
	MSE	**RMSE**	**R**	**MAE**
5-1-1	**0.002026**	**0.045011**	**0.993509**	**0.028413**
5-2-1	**0.000818**	**0.028593**	**0.998872**	**0.023122**
5-3-1	**0.000348**	**0.018651**	**0.998839**	**0.011971**
5-4-1	**0.000233**	**0.015278**	**0.999319**	**0.00734**
5-5-1	**0.000168**	**0.012948**	**0.999353**	**0.005164**
5-6-1	**8.37E-05**	**0.009148**	**0.999732**	**0.007263**
5-7-1	**5.28E-05**	**0.007266**	**0.999806**	**0.00533**
5-8-1	**0.000199**	**0.014107**	**0.999183**	**0.006318**
5-9-1	**0.000858**	**0.029297**	**0.996591**	**0.024105**
5-10-1	**3.82E-05**	**0.006177**	**0.999839**	**0.002747**
5-11-1	**0.000183**	**0.013511**	**0.999231**	**0.008157**
5-12-1	**0.000502**	**0.022409**	**0.998353**	**0.01701**
5-13-1	**0.001872**	**0.043271**	**0.997052**	**0.032124**
5-14-1	**0.001029**	**0.032071**	**0.996602**	**0.014854**
5-15-1	**0.000145**	**0.012022**	**0.999418**	**0.006102**

Based on the comparison of parameters MSE, R, RMSE, and R^2 values, the better architecture found to be is 5-6-1 with TANSIG activation function from input to hidden layer and PURELIN activation function from hidden to output layer. The efficiency of the selected artificial neural network model is 4.4E-05, 0.00666, 0.99996, and 0.00353, which are MSE, RMSE, R and MAE values respectively. This indicates that the model can predict the measured and predicted value with minimum error and high coefficient of correlation. Therefore, the final formula that helps to predict CBR value from index properties(liquid limit, plastic limit, plastic index, optimum moisture content, and maximum dry density) of eggshell waste glass powder treated black cotton soil is:

Where

$$\text{CBR Actual} = 2.075\left(-0.81018128376010734026\left(\frac{2}{1+e^{-2H1}}-1\right) - 0.34836251100291981686\left(\frac{2}{1+e^{-2H2}}-1\right) + 0.49299278097791721098\left(\frac{2}{1+e^{-2H3}}-1\right) + 0.52821035182518105 7\left(\frac{2}{1+e^{-2H4}}-1\right) + 0.53662154145509965986\left(\frac{2}{1+e^{-2H5}}-1\right) - 0.37022169680925431923\left(\frac{2}{1+e^{-2H6}}-1\right) + 0.57288871676244890185\right) + 2.15 \quad (6)$$

$$H1 = 1.0812613605887058 11LL + 0.77523549989976681118PL + 0.64091276014206344236PI - 0.10957110520309557011OMC - 1.5616233421424570 16MDD - 2.4539144313858276547 \quad (7)$$

$$H2 = -0.77493003865533649499LL - 0.42297330710208036475PL + 0.39364927270333238685PI - 1.1831579265480942631OMC + 1.0096818685772526 17MDD - 0.34836251100291981686 \quad (8)$$

$$H3 = -0.061619029323177088031LL + 0.62226073654848417460 2PL + 0.22152037602482652079PI - 0.41237918182868987804OMC + 1.7578124661485721 17MDD + 0.49299278097791721098 \quad (9)$$

$$H4 = -1.2465185501725983 83LL - 0.70665376031073035001PL - 0.93620777101158025868PI + 0.85586604105533126141OMC + 0.59031375245371908722MDD + 0.52821035182518105 7 \quad (10)$$

$$H5 = -0.80876595934589068371LL + 0.56120775948131529365PL + 1.4614442174491815152PI - 0.70534054556426983851OMC - 1.1136337164995246951MDD - 1.1149483307266840892 \quad (11)$$

$$H6 = 1.0624417948791100574LL + 0.60982588694571937538PL - 0.36865526593826092316PI + 0.52884556743969246551OMC + 1.3271966173293823221MDD + 2.2635542408868425 39 \quad (12)$$

V. CONCLUSION

Based on the study and outcomes of the examination, the following conclusions are drawn. The soil classified under A-7-5 soil. Black cotton soil treated with 4%, 8%, 12%, and 16% eggshell and waste glass powder shows a significant improvement in plasticity index, dry density, and CBR value. The optimum percentage was obtained at 8% addition of eggshell waste glass powder admixtures. 30 numbers of artificial neural network architectures were examined. 15 of them were having TANSIG activation function from input to hidden layer and PURELIN activation function from hidden layer to output layer and the rest of them were having LOGSIG activation function from input layer to the hidden layer and PURELIN activation function from hidden layer to output layer. Although, most of them satisfy the requirements the best model satisfies well from all of them was ANN of 5-6-1. The selected artificial neural model has a performance of 4.4E-05, 0.00666, 0.99996, and 0.00353, which are MSE, RMSE, R and MAE values respectively. This entails us the developed model satisfies the requirement of a correlation coefficient greater than 0.8 and MSE, RMSE, and MAE value close to 1. Accordingly, the model can be applied to predict the CBR value of eggshell waste glass treated black cotton soil.

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