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Artificial Neural Network Modeling of Sub grade Soil stabilized with Bagasse Ash and Geogrid

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ABSTRACT: For highway construction projects, sub grade soil stabilization is one of the prime and major processes. The strength of the sub grade soil is indicated by its California bearing ratio (CBR) value which is quite expensive and time consuming. In order to overcome this situation, the present study aims in predicting the soaked CBR value for the stabilized soil by Multiple Regression Analysis (MRA) and Artificial Neural Network (ANN) modeling. Experiments were done to stabilize the soil with the addition of varying percentages of bagasse ash ranging from 0% to 10%, in an increment of 2% and also with geogrid layers. Maximum dry density, optimum moisture content, plasticity index, bagasse ash fraction and number of geogrid layers were taken as input variables and soaked CBR value as output variable for the regression based models. It is observed that ANN model is accurate than the MRA model in predicting the soaked CBR value of soil stabilized with bagasse ash and geogrid, both the measured experimental values and predicted values are in good agreement.

KEYWORDS: Clayey Subgrade, Bagasse ash, Geogrid, OMC, UCC, CBR, ANN, MRA.

1 INTRODUCTION

For highway pavement construction, it requires good earth material in very huge quantity. In urban areas, use earth is not easily available which has to be hauled from an extended distance. Fairly often, large areas are covered with highly plastic and expansive soil, which is not suitable to be used as earth material. Extensive laboratory and field trials have been carried out by various researchers and have shown promising results for application of such expansive soil after stabilization ([3], [7]).

Expansive clay soils are those that change significantly in volume with changes in water content. It is therefore, necessary to mitigate the problems posed by expansive soils and prevent cracking of structures. This creates engineering problems and affects the service of structures and riding qualities in pavements. Owning to this fact, continuous researches have been carried and these lead to the concept called soil stabilization which is any treatment applied to a soil to improve its strength and reduce its susceptibility to water, if the treated soil is able to withstand the stresses imposed on it by traffic under all weather conditions without extreme deformation, then it is generally regard as stable. The need to bring down the cost of waste disposal and the growing cost of soil stabilizers has lead to intense global research towards economic utilization of wastes for engineering purposes. The safe disposal of industrial and agricultural waste products demands urgent and cost effective solutions because of the debilitating effect of these materials on the environment and to the health hazards that these wastes constitute. Hence bagasse ash is utilized for stabilizing the soil and the application of geogrid was also introduced. The strength of the sub grade soil is indicated by its California Bearing Ratio (CBR) value which is quite expensive and time consuming [2]. To conduct CBR test on sub grade soil, a representative sample shall be collected, from which a remolded sample is prepared, compacted at predetermined OMC with standard proctor’s (light) compaction. The specimen prepared is soaked for 4 days under water and penetration test is conducted. To obtain soaked CBR value of a soil sample, it takes about a week. CBR test is expensive, time consuming and laborious. Obtaining a proper idea about the soaked CBR of sub grade materials over total length of the road is very difficult. So, it is not really possible to take a large number of samples.

In addition, CBR test in laboratory requires a large soil sample and is laborious as well as time consuming. This would result in serious delay in the progress of the project, since in most situations the materials for earth work construction come from highly variable sources. Any delay in construction inevitably leads to rise of project cost. To overcome this situation, it is better to predict CBR value of sub grade soil with easily determinable parameters. To exercise the right judgment during various phases of professional activities, the engineer is constantly required to predict. Hence the prediction of CBR is achieved by performing genetic algorithm and artificial intelligence, which is, developing multiple regression analysis and artificial neural networking as a function of different soil parameters which is directly proportional to the strength of the soil ([1], [4], [5], [6], [8], [9]).

2 MATERIALS AND METHODOLOGY

2.1 MATERIALS

2.1.1 SOIL SAMPLE

The representative soil sample was collected from Cheranmaanagar, Coimbatore, Tamilnadu state, India at the location 11.057°, 77.019°. The soil sample used for analysis is clay. The laboratory investigations confirm that the soil falls under the category Clay with Intermediate Compressibility.

2.1.2 BAGASSE ASH

The Bagasse ash utilized for this project is obtained from Sakthi sugars, Erode, tamilnadustate, India. The mineralogical composition of bagasse ash is given in table 1.

Table 1. Mineral composition of Bagasse ash

S.No	Minerals	Composition %
1	Silica	75.34
2	Alumina	11.55
3	Iron oxide	3.61
4	Potassium oxide	3.46
5	Calcium oxide	2.15
6	Phosphorous	1.07
7	Magnesium oxide	0.13
8	Sodium oxide	0.12
9	Titanium oxide	0.50
10	Barium oxide	0.16

2.1.3 GEOGRID

In this project, the role of geogrid in the road application is studied based on economic, technical and ecological aspect. The properties of geogrid are given in table 2.

Table 2. Properties of geogrid

S.No	Properties	Geogrid
1	Material	TechGrid B Series
2	Ultimate tensile strength	60 kN/m
3	Elongation at maximum load	15%
4	Aperture size	25 x 25 mm
5	Roll length	50 m
6	Roll width	2.5 m

2.2 Flow Chart (Methodology)

The following flow chat (Fig.1) represents the methodology of the study

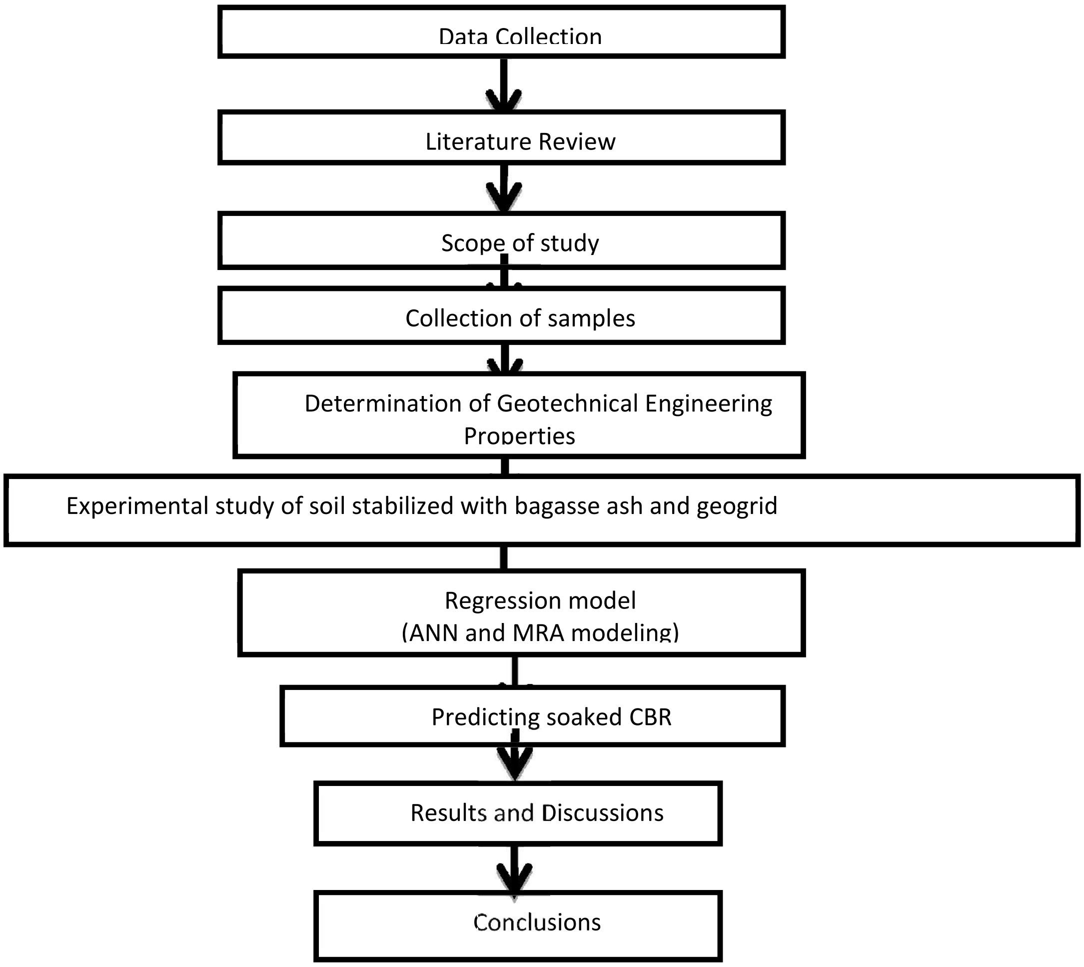

Fig.1. Methodology

3 Laboratory Investigation

This elaborates the determination of various physical and engineering properties of the soil sample. The soil sample was analyzed in laboratory with various percentages of bagasse ash and also by changing number of geogrid layers for its compaction and strength characteristics. The laboratory investigations were carried out as per IS codes.

The properties of the soil sample are summarized in Table 3.

Table 3.Properties of soil sample

Sl.no	Properties		Result
1	Initial Moisture Content		8.3%
2	Specific Gravity		2.71
3	Sieve Analysis	% of Gravel	2.1%
		% of sand	30.5%
		% of Silt	22.1%
		% of Clay	45.3%
4	Free Swell Index		50%
5	Liquid Limit (W_L)		47%
	Plastic Limit (W_P)		17%
	Shrinkage Limit (W_S)		12%
	Plasticity Index (I_P)		30%
6	Soil Classification		CI
7	Optimum Moisture Content		15%
	Maximum Dry Density		1.658 g/cc
8	Unconfined Compressive Strength (q_u)		84.12 kN/m^2
	Cohesion (C_u)		42.06 kN/m^2
9	CBR unsoaked		12.88%
	CBR soaked		2.68 %

3.1 ATTERBERG'S LIMIT TEST

Consistency test was performed on the soil added with different percentage of bagasse ash such as 2%, 4%, 6%, 8% and 10%. From this test the plasticity characteristics of the treated samples were studied. The consistency test was conducted as per IS 2720 (Part 5)-1985 in the previous phase and the readings are tabulated in Table 4.

Table 4. Liquid Limit, Plastic Limit and Plasticity Index

Sl No	% BA	LIQUID LIMIT (w_l) (%)	PLASTIC LIMIT (w_p) (%)	PLASTICITY INDEX (I_p) (%)
1	0	47	17	30
2	2	45	18	27
3	4	43	19	24
4	6	39	20	19
5	8	42	19.5	22.5
6	10	44	19	25

3.2 FREE SWELL INDEX TEST

The free swell test was performed on the soil added with different percentage of bagasse ash such as 2%, 4%, 6%, 8% and 10%. The test was conducted as per IS 2720 (Part 40)-1977 in the previous phase and the readings are tabulated in Table 5.

Table 5. Free Swell Index test values

Sl No	% BA	Free Swell (%)
1	0	50
2	2	40
3	4	35
4	6	30
5	8	43
6	10	45

3.3 COMPACTION TEST

The OMC and MDD were determined in the laboratory by conducting standard proctor compaction test. The test was carried out in soil with bagasse ash and geogrid and the optimum moisture content and maximum dry density of the soil sample are listed in the following tables(table 6,7 and 8).

Table 6. OMC and MDD for soil with bagasse ash

Sl No	% BA	Optimum Moisture Content (%)	Maximum Dry Density (g/cc)
1	0	15	1.66
2	2	16	1.64
3	4	17	1.61
4	6	17.5	1.58
5	8	18	1.53
6	10	16	1.46

Table 7. OMC and MDD for soil with bagasse ash and single geogrid layer

Sl No	% BA	Optimum Moisture Content (%)	Maximum Dry Density (g/cc)
1	0	15	1.65
2	2	16	1.62
3	4	17	1.59
4	6	17.5	1.56
5	8	18	1.51
6	10	16	1.44

Table 8. OMC and MDD for soil with bagasse ash and double geogrid layer

Sl No	% BA	Optimum Moisture Content (%)	Maximum Dry Density (g/cc)
1	0	15	1.62
2	2	16	1.58
3	4	17	1.55
4	6	17.5	1.53
5	8	18	1.48
6	10	16	1.41

3.4 UNCONFINED COMPRESSION TEST

Unconfined compression test was performed on the soil sample mixed with varying amount of bagasse ash such as 2%, 4%, 6%, 8%, 10%. From this test the shear strength characteristics of the soil samples were studied by determining unconfined compression strength and undrained cohesion. Table 9. Gives the unconfined compression strength and cohesion.

Table 9. Unconfined compression strength and undrained cohesion of soil with bagasse ash

Sl No	% BA	Unconfined compression strength (kN/m^2)	Undrained cohesion (kN/m^2)
1	0	84.12	42.06
2	2	128.66	64.33
3	4	189.84	94.92
4	6	242.19	121.09
5	8	195.73	97.86
6	10	149.23	74.61

3.5 CALIFORNIA BEARING RATIO TEST

The California Bearing Ratio value was determined in the laboratory by conducting California Bearing Ratio test. The test was carried as per IS2720 (Part 16) – 1987 in soil with bagasse ash and geogrid and the California Bearing Ratio value are listed in the table 10, 11 and 12. The test results were plotted in a graph and it is showed in figure 2, 3 and 4.

Table 10. California Bearing Ratio value of soil with bagasse ash

Sl No	% BA	Unsoaked CBR value (%)	Soaked CBR value (%)
1	0	12.66	2.68
2	2	14.31	3.042
3	4	15.38	3.101
4	6	17.53	4.12
5	8	16.82	3.93
6	10	15.74	3.22

Table 11. California Bearing Ratio value of soil with bagasse ash and single layer geogrid

Sl No	% BA	Soaked CBR value (%)
1	0	2.86
2	2	3.22
3	4	3.4
4	6	4.29
5	8	4.12
6	10	3.47

Table 12. California Bearing Ratio value of soil with bagasse ash and double layer geogrid

Sl No	% BA	Soaked CBR value (%)
1	0	3.12
2	2	3.57
3	4	3.75
4	6	4.65
5	8	4.36
6	10	3.7

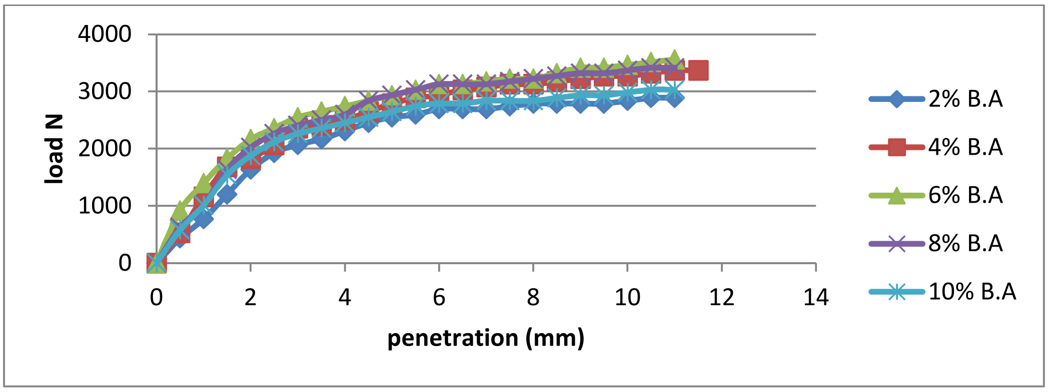

Fig. 2. CBR plot for soil with bagasse ash

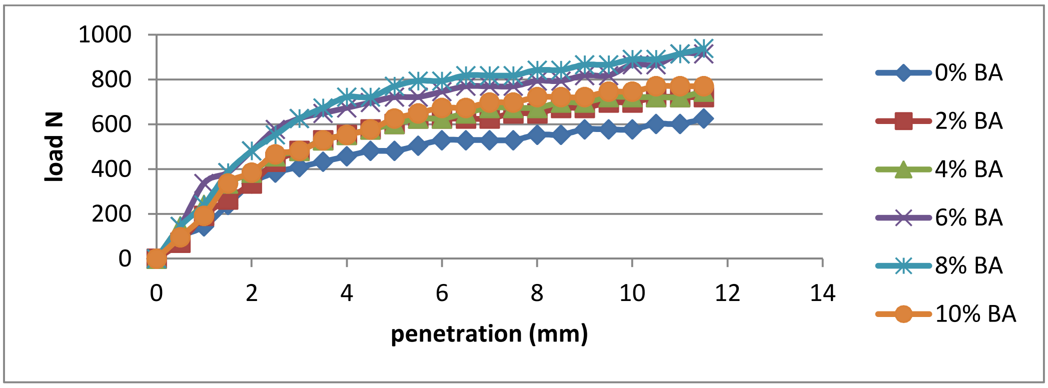

Fig. 3. CBR plot for soil with bagasse ash and single layer geogrid

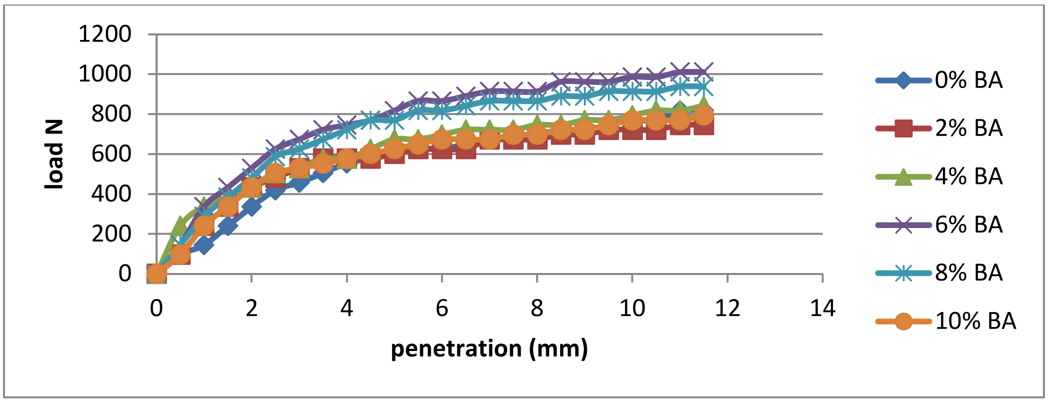

Fig. 4. CBR plot for soil with bagasse ash and double layer geogrid

4 Data Analysis

The strength of the subgrade soil is indicated by its California Bearing Ratio (CBR) value which is quite expensive and time consuming. Inorder to overcome this situation, the soaked CBR value is predicted for the stabilized soil by Genetic Algorithm (GA) and Artificial Intelligence (AI). Genetic Algorithm was performed in Excel using Evolver tool for multiple regression analysis and Artificial Intelligence was performed using Neural Networking in MATLAB computer aided software. Experiments were done to stabilize the soil with bagasse ash and geogrid in the laboratory and these values were taken as variables for the prediction of CBR.

4.1 MULTIPLE REGRESSION ANALYSIS

MRA has been carried out by considering soaked CBR value as the dependent variable and the rest of soil properties as independent variables. With Genetic Algorithm each possible solution becomes an independent "organism" that can "breed" with other organisms. The spreadsheet model acts as an environment for the organisms, determining which are “fit” enough to survive based on their results.

MRA can be carried out using standard statistical software like Data Analysis Tool Bar of Microsoft Excel in order to derive the relationship statistically.The Objective Function for applying Genetic Algorithm in this research study will be formulated as follows. Y is directly proportional to the variables X1, X2, X3, X4,X5. So, the equation created will be

$Y = b0 + b1X1 + b2X2 + b3X3 + b4X4 + b5X5$

Where b0, b1, b2, b3, b4 and b5 are the constants.

The values of above constants will be solved using the Multiple Regression Analysis in the Data Analysis Toolpak a built-in Add-In for Microsoft Excel. So by inputting the values of California Bearing Ratio, Plasticity Index, Optimum Moisture Content, no of geogrid layers and bagasse Ash Fractions we can obtain the values for the constants.Correlation quantifies the degree to which dependent and independent variables are related. When R is 0.0, there is no relationship. When R is 1, there is a good relation. Any correlation with R2 value equal to 0.80 or above will be viewed as a best fit.

To test the significance of regressions, analysis of variance (ANOVA) was employed. In this test, a 95% level of confidence was chosen. If the calculated F value is greater than the tabulated F value, the null hypothesis is rejected and there is a real relation between dependent and independent variables ([1], [4], [10], [11], [12]).

4.2 ARTIFICIAL NEURAL NETWORK

Due to difficulties in solutions of the complex engineering systems, there is an increased demand to study on artificial neural network (ANN) inspired by the behavior of human brain and nervous system. Each ANN model can be differently organized according to the same basic structure. There are three main layers in ANN structure; a set of input nodes, one or more layers of hidden nodes, and a set of output nodes. Each layer basically contains a number of neurons working as an independent processing element and densely interconnected with each other. The neurons using the parallel computation algorithms are simply compiled with an adjustable connection weights, summation function and transfer function. The methodology of ANNs is based on the learning procedure from the data set presented it from the input layer and testing with other data set for the validation. A net workis trained by using a special learning function and learning rule. In ANNs analyses, some function called learning functions is used for initialization; training, adaptation and performance function. During the training process, a network is continuously updated by a training function which repeatedly applies the input variables to a network till a desired error criterion is obtained. Adapt functions is employed for the simulation of a network, while the network is updated fore ach time step of the input vector before continuing the simulation to the next input. Performance functions are used to grade the network results. In the learning stage, network initially starts by randomly assigning the adjustable weights and threshold values for each connection between the neurons in accordance with selected ANNs model. After the weighted inputs are summed and added the threshold values, they are passed through a differentiable non-linear function defined as a transfer function. This process is continued, until a particular input captures to their output (i.e., target)or as far as the lowest possible error can be obtained by using an error criterion. In other words the network training is the determination of the weights and the biases. An ANN model can be differently composed in terms of architecture, learning rule and self-organization. The neural network training is given in figure.5 ([1], [4], [10], [11], [12]).

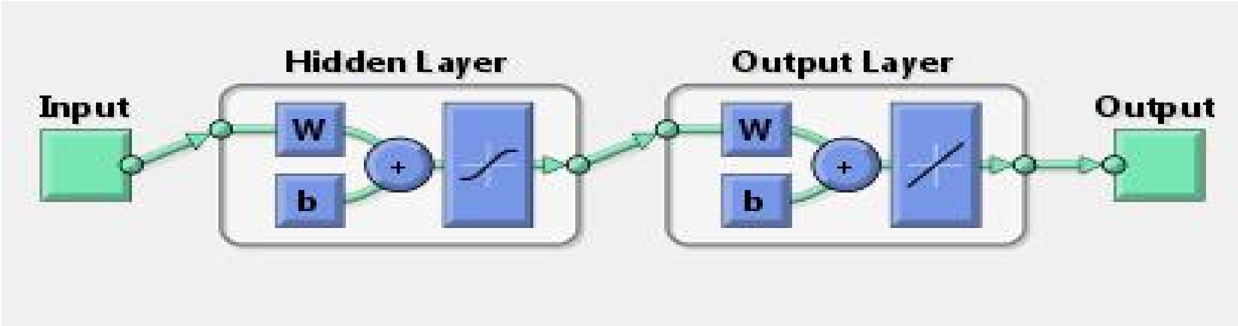

Fig. 5. Neural network

5 Results And Discussions

This elaborates the results obtained from various tests on the soil with bagasse ash and geogrid. The tests were conducted on the soil sample at optimum moisture content. Also soaked CBR tests on soil are expensive and time consuming to conduct, it would be useful for practical purpose relations based on easily measurable parameters. For a certain type of soil the purpose is to establish relations between the geotechnical parameters both mechanical and physical in order to facilitate the input process for computer analysis.

5.1 Effect of Bagasse Ash and Geogrid on Compaction

The variation of change in maximum dry density with respect to the % of bagasse ash added and the number of geogrid layers is shown in figure 6.

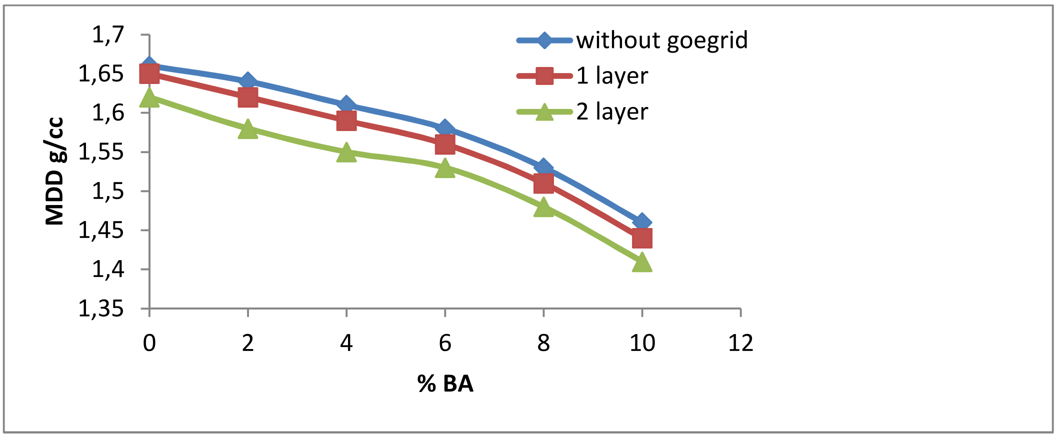

Fig.6. Variation of MDD

5.2 Effect of Bagasse Ash and Geogrid on Shear Strength

A graph showing the variation of unconfined compression strength of soil sample mixed with varying percentage of bagasse ash is shown in figure 7.

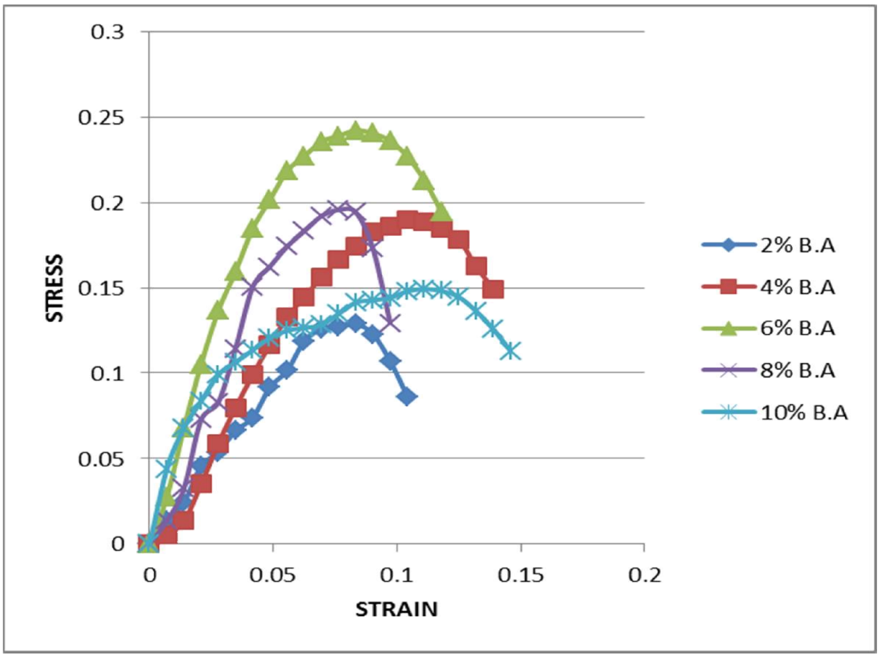

Fig.7. Comparison UCC graph for soil with bagasse ash

5.3 EFFECT OF BAGASSE ASH AND GEOGRID ON STRENGTH

A graph showing the variation of California bearing ratio value of soil sample is shown in figure 8.

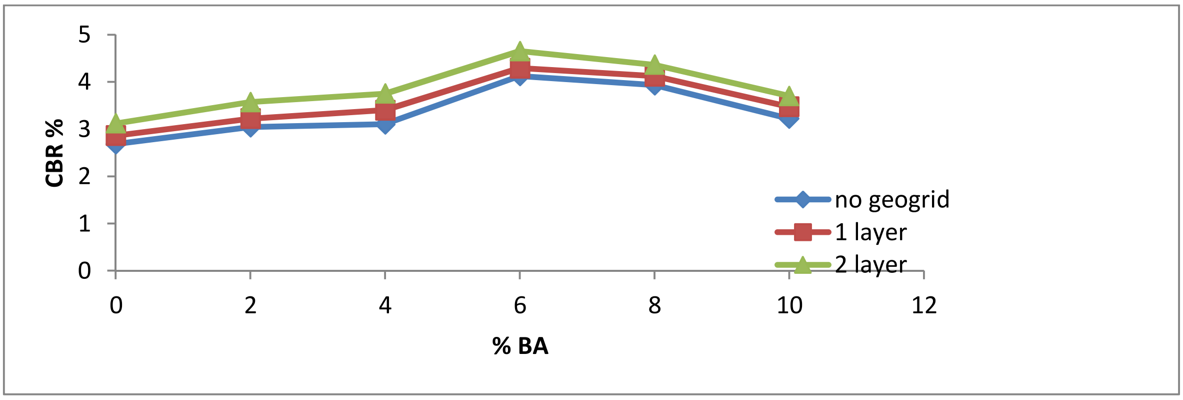

Fig.8. Variation of CBR value

5.4 PREDICTION OF SOAKED CBR

The Strength of the subgrade soil is indicated by its California Bearing Ratio (CBR) value which is quite expensive and time consuming. In order to overcome this situation, the CBR value is predicted by regression models using the soil parameters which are proportional to the strength of the soil. The methods used for predicting the CBR value are as follows.

1. Multiple Regression Analysis
2. Artificial Neural Network

5.5 CORRELATION PARAMETERS

The correlation parameters are:

Table 13. Correlation parameters

Y	X1	X2	X3	X4	X5
2.68	15	1.66	30	0	0
3.042	16	1.64	27	2	0
3.101	17	1.61	24	4	0
4.12	17.5	1.58	19	6	0
3.93	18	1.53	22.5	8	0
3.22	16	1.46	25	10	0
2.86	15	1.65	30	0	1
3.22	16	1.62	27	2	1
3.4	17	1.59	24	4	1
4.29	17.5	1.56	19	6	1
4.12	18	1.51	22.5	8	1
3.47	16	1.44	25	10	1
3.12	15	1.62	30	0	2
3.57	16	1.58	27	2	2
3.75	17	1.55	24	4	2
4.65	17.5	1.53	19	6	2
4.36	18	1.48	22.5	8	2
3.7	16	1.41	25	10	2

5.6 REGRESSION MODEL

In statistics, regression analysis is a statistical process for estimating the relationships among variables. It includes many techniques for modeling and analyzing several variables, when the focus is on the relationship between a dependent variable and one or more independent variable.

For the X and Y values, the regression equation is developed.

The output is given in the coefficients column in the last set of output

So our regression equation is

$Y=9.89+0.144562X_1-3.52975X_2-0.12072X_3-0.07613X_4+0.149065X_5$

The correlation is

CBR=0.144562OMC-3.52975MDD-0.12072PI-0.07613BA+0.149065 geogrid+9.89

Also in the regression statistics output gives the goodness of fit measure. Correlation quantifies the degree to which dependent and independent variables are related. When R is 0.0, there is no relationship. When R is 1, there is a good relation. Any correlation with R2 value equal to 0.80 or above will be viewed as a best fit.

Adjusted R square = 0.89 which measures the fit

This means 89% of Y is determined by X

A graph is plotted between observed and predicted values and this graph is shown in figure.9.

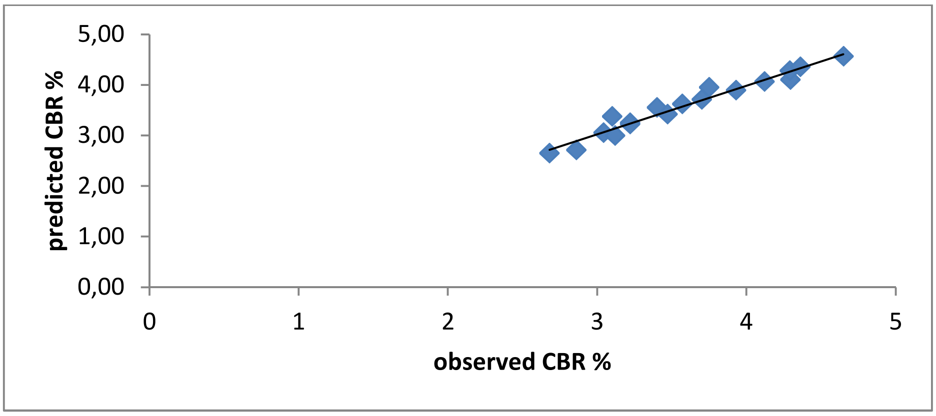

Fig.9. Correlation between predicted & observed CBR

5.7 Reliability Checking Using ANOVA Single factor

Analysis of variance (ANOVA) is a collection of statistical models used to analyze the differences between group means and their associated procedures (such as "variation" among and between groups). In ANOVA setting, the observed variance in a particular variable is partitioned into components attributable to different sources of variation. In its simplest form, ANOVA provides a statistical test, whether or not the means of several groups are equal, and therefore generalizes *t*-test to more than two groups. Doing multiple two-sample t-tests would result in an increased chance of committing a type I error for this reason, ANOVAs are useful in comparing (testing three or more means (groups or variables) for statistical significance.

When p-vaue is less than 0.05, the correlation is very reliable and F-value is greater than that of F_{crit} value, then the correlation is very reliable.

In this test, a 95% level of confidence was chosen. If the calculated F value is greater than the tabulated F value, the null hypothesis is rejected and there is a real relation between dependent and independent variables.

Since the calculated F value (=30.47) is greater than the tabulated F value (F=2.30), the null hypothesis is rejected. Therefore, it is concluded that the model is reliable.

5.8 Artificial Neural Network

For the neural network modelling, totally 18 datasets were taken for analysis. The variables that have been identified in the literature review and others which appear to have high significance over CBR value were used for ANN prediction modeling. The parameters such as plasticity index (PI), maximum dry density (cd), optimum water content, bagasse ash fraction and no. of geogrid layers were taken into consideration as input parameters for the ANN modeling. The soil parameters used herein were obtained by routine laboratory tests. For this study, 70% data were used for testing, 15% data were used for validation and the remaining 15% for training the neural network. Testing data set were not used during development of the neural network, so that they can be a good indicator for testing the accuracy of the developed network.

The ANN tool of MATLAB computer aided Software was used to execute the necessary computations. In order to compute the most appropriate ANN architecture for the modeling, the number of neurons in the hidden layer and number of multi-layer networks were tried to predict best CBR values. The architecture of the modeling was formed by using feed-forward artificial neural networks with inputs is shown in figure 10. The results of the developed ANN model are evaluated by the coefficient of determination (R2).

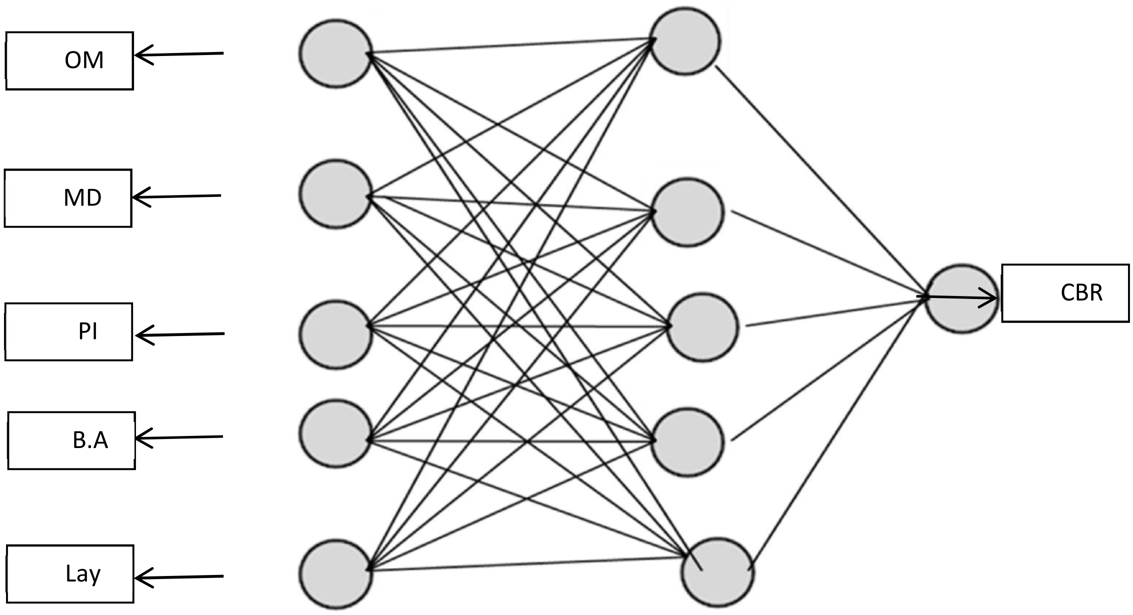

Fig.10. Architecture of Neural Network model

5.9 COMPARISON OF MRA AND ANN MODEL

A comparison of the predicted accuracies of the ANN and MRA model has been taken into account. The coefficient of determination R2 and error were taken for comparison of both the models in checking their accuracy.

In MRA the coefficient of determination R2 is 0.89 and in ANN the value is observed to be 0.94. The values in MRA are found with error percentage higher. In ANN the values are found to be more promising with minimum error percentage. The soil parameters like optimum moisture content, maximum dry density, plasticity index, bagasse ash fraction are found to be reasonable in the prediction of CBR in both the MRA and ANN modeling.

6 CONCLUSIONS

The following conclusions were obtained from the study carried out.

- The CBR value is observed to be maximum when 6% of bagasse ash is added to the soil with double layer geogrid.
- The statistical parameters such as optimum moisture content, maximum dry density, plasticity index and bagasse ash fraction appears to be reasonable in the prediction of CBR value.
- Both the ANN and MRA models are very accurate in predicting the CBR of bagasse ash with geogrid stabilized soil.
- It is found that the ANN is found to be a valuable tool for predicting the values when the inputs are given with minimal error percentage than that for the MRA.

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