Experimental and numerical prediction of California bearing ratio of expansive soil stabilized by bagasse ash and geotextile reinforcement

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Abstract

The target of this paper is to predict the CBR value by correlating the optimum moisture content, maximum dry density, Plasticity Index, proportion of sugarcane bagasse ash and also the variety of Geotextile layers. The linear relationships between the higher than mentioned properties and CBR worth exploitation Multiple rectilinear regression Analysis resulted during a sturdy correlation between the parameters. ANN model is developed exploitation ANN tool of MATLAB R2014a software. A multilayer perceptron network with feed forward back propagation is used to model variable the number of hidden layers. The graph aforesaid between the predicted and experimental values shows that everyone the values are getting ready to equality line, indicating foreseen values are regarding the discovered values.

Keywords: Expansive soil, Bagasse ash, Geotextile, CBR, MLRA, ANN Modelling;

1. Introduction

The strength of the subgrade soil is well outlined in terms of California Bearing ratio relation (CBR) worth and it's essential in crucial the pavement thickness. The check is performed within the laboratory on compacted specimens in soaked conditions. In this study, the soil with the addition of bagasse ash and Geotextile reinforcement in layers is subjected to strength tests to see the CBR esteem of the soil specimen. Pavement style in accordance with IRC 37-2001 and 2012 tips were accustomed assess the thickness of pavement of virgin soil and treated soil. the share reduction in pavement thickness is decided to attain the effectiveness of stabilization and soil reinforcement technique\cite{1-42}.

The check needs for determination of soaked CBR esteem worth of soil specimens are typically elaborate and time-consuming. generally, the geotechnical engineer is curious about inward at the CBR value with no time to conduct laboratory tests. this can be doable if the index properties of the soil are known. To cope up with this, engineering modelling approaches are justifiable. during this study an endeavor to develop the prophetic equation for CBR with multivariate analysis and design model victimisation Artificial Neural Network (ANN) in MATLAB2014a is done. The responsibleness of the numerical work to predict the California bearing quantitative relation of Virgin and treated soil samples is analyzed \cite{1-42}.

2. Materials and Methodology

2.1. Soil sample

The representative soil sample was collected from Government College of Technology campus, Coimbatore, Tamilnadu, India at the placement 11.0124’N and 76.942’E. The soil sample collected is clay and therefore the laboratory investigations ensure that the soil is Clay of High squeezeability (CH).
2.2 Bagasse ash and Geo textile

The bagasse ash used for the soil stabilization is collected from Sakthi sugars, Erode, Tamilnadu. The textile material utilized in soil (geo) atmosphere within the style of plain-woven and non-woven chemical compound material materials and natural materials, resembling jute is employed at the interface of the soft subgrade and granular pavement layer. The geotextile used in this study is plastic non-woven geotextile cloth (Table 1).

Table 1. Oxide composition of Bagasse ash

| Abbreviation | Percentage |
|--------------|------------|
| SiO$_2$      | 75.34      |
| Al$_2$O$_3$  | 11.55      |
| Fe$_2$O$_3$  | 3.61       |
| K$_2$O       | 3.46       |
| CaO          | 2.15       |
| P$_2$O$_5$   | 1.07       |
| MgO          | 0.13       |
| Na$_2$O      | 0.12       |
| TiO$_2$      | 0.50       |
| BaO          | 0.16       |

Figure 1. Flow Chart for Methodology

3. Methodology

3.1 Experimental work

Experimental half elaborates the varied properties of natural soil and treated soil particularly natural wet content, specific gravity, Atterberg’s limit, grain size distribution, optimum moisture content, most dry density, unconfined compressive strength and California bearing magnitude relation (shown in figure 1).

3.1.1 California bearing ratio test

California bearing quantitative relation check is conducted so as to work out the California bearing ratio for soil with optimum percentage of bagasse ash that is found to be 10%. The samples are compacted at optimum wet content for each unsoaked and soaked check (table 2).

Table 2. CBR test results of stabilized soil

| S. No | Bagasse ash replaced (%) | Water added (%) | Soaked CBR value (%) |
|-------|--------------------------|-----------------|----------------------|
| 1     | 0                        | 21.6            | 2.24                 |
| 2     | 5                        | 24              | 3.04                 |
| 3     | 10                       | 26              | 5.12                 |
3.1.2 CBR test on soil with bagasse ash & geotextile reinforcement

In addition to the stabilization with Bagasse ash, soil reinforcement is provided in the form of Geotextile layers. California Bearing Ratio test is conducted on the treated soil sample to determine its strength property in accordance with BIS 2720 (Part 16) – 1987. The methodology of placing geotextile cut into sheets of circular shape of in different layers.

4. Pavement design

The style of versatile pavement with the CBR values obtained for unmodified soil sample, stabilized soil sample and stabilized soil with geotextile reinforcement is completed in accordance with IRC 37-2001. This chapter discusses on the variation within the pavement thickness to conclude on the effectiveness of modified soil pavement to be used as subgrade. The thickness of pavement is calculated using the standard data provided as per IRC 37-2001 (Table.3).

Table 3. Total Pavement Thickness for natural and modified soil sample

| Soil sample                                  | Soaked CBR value (%) | Total pavement thickness (mm) | Reduction in pavement thickness (%) |
|----------------------------------------------|----------------------|-------------------------------|------------------------------------|
| Natural soil                                 | 2.26                 | 880                           | -                                  |
| Soil + 10% BA                                | 5.12                 | 700                           | 20.45                              |
| Soil + 10% BA + single geotextile layer       | 5.23                 | 680                           | 22.73                              |
| Soil + 10% BA + double geotextile layer       | 5.47                 | 670                           | 23.86                              |

5. Numerical analysis

The checks performed within the laboratory to see the California Bearing magnitude relation of a subgrade soil is usually arduous and time consuming. The results obtained from the experimental investigation don’t seem to be correct because of the poor laboratory conditions and human errors. In some cases, the test results are expected to be ready wherever there's no time to arrange the specimen to check the samples in soaked condition. In concern to the on top of mentioned issues there are extended range of analysis works to predict the cosmic background radiation price by generating numerical equations and models. In this study, tools of Artificial Intelligence reminiscent of statistical procedure analysis and artificial neural networking is performed to develop a relationship between numerous independent variables and a variable quantity. The prediction of a dependent variable (CBR) using the on top of tools is finished so as to eliminate the arduous processes concerned within the prediction of identical price by typical experimental work [1-42].

5.1. Multiple linear regression analysis (MLRA)

Multiple regression is a technique that allows additional factors to enter the analysis separately so that the effect of each can be estimated. It is valuable for quantifying the impact of various simultaneous influences upon a single dependent variable.

Elements of a multiple regression equation

\[ y = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \cdots + \beta_n X_n \]

Where,

- \( Y \) is the value of the dependent variable.
- \( \beta_0 \) is the constant or intercept
- \( \beta_1 \) is the slope for \( X_1 \)
- \( X_1 \) is the first independent variable that is explaining the variance in \( Y \)

The correlation coefficient \( R^2 \) is reported to illustrate a quantitative measure of statistical relationships between two or more random variables or observed data values. Goodness of fit is described by the discrepancy between observed values and the predicted values with the correlation coefficient of 0.1 – 1.0.

The Data Analysis add-ins of excel spreadsheet is used to perform the regression analysis. The independent variables chosen for the regression includes the following:

- Optimum moisture content (OMC),
- Maximum dry density \( (\gamma_{d,max}) \),
- Plasticity index \( (I_p) \),
- Percentage of bagasse Ash (BA),
- Number of geotextile layer \( (GL) \)
The dependent variable to be predicted is the California Bearing Ratio (CBR) value. The one way Analysis of Variance is used to determine whether there are any significant differences between the means of independent groups and tests the null hypothesis. F-tests mainly arise when the models have been fitted to the data using least squares. The $F_{\text{crit}}$ is compared with $F$-value from regression. The test results are reported as the statically significant difference between the groups as determined by one-way ANOVA $F(\text{df}_{\text{between}}/\text{df}_{\text{within}}) = F_{\text{ratio}}, p = p\text{-value}$ Where $\text{df} = \text{degree of freedom}$.

5.2 Artificial Neural Network (ANN)

In ANN model, the method of fitting a model to the info is named coaching, the primary stage of modelling of to partition the dataset into a training set, a validation set and a test set. The training set is to coach (fit) the model, the validation set is to validate the training process. Finally, the test set is to check the performance of the model once the training was carried out. Determinist the amount of hidden layers and hidden neurons is that the decisive introduce ANN modelling. once training the network output is paralleled with the anticipated leads to terms of the mean sq. error. A multilayer perceptron vegetative cell network is known and a info is employed for coaching and testing the network. Feed- forward back propagation network is presently utilized in applications regarding science and engineering. Figure 4. shows the final design of the neural network. the target of the current study is to develop a neural network model with output as California bearing ratio. The input parameters, for the networking is basic soil properties that have vital influence on the CBR worth[1-42].

6. Results and Discussions

This half includes the check results of the natural soil sample beside bagasse ash addition and geotextile reinforcement. The experimental and numerical analysis of the Calif. bearing magnitude relation of the subgrade soil sample is discussed. The comparative study to grasp the dependability of the sorted applied math analysis along with discovered CBR values is explained.

6.1. Soil properties

The natural soil sample is subjected to classification tests, compaction test and strength test. The soil is classified as highly compressible clay and the test results are summarized in table 4.

Table 4. Properties of Natural Soil Sample

| S.No | Properties                        | Result  | Remarks                        |
|------|-----------------------------------|---------|--------------------------------|
| 1    | Natural Moisture Content          | 31.3%   |                                |
| 2    | Specific Gravity                  | 2.765   |                                |
|      | Sieve analysis                    |         |                                |
| 3    | % of Gravel                       | 3.0 %   | Degree of expansion is high    |
|      | % of sand                         | 26.9%   | Compressibility is High        |
|      | % of Silt + % of Clay             | 70.1%   |                                |
| 4    | Differential Free Swell           | 50%     |                                |
|      | Liquid Limit ($W_L$)              | 52%     | Compressibility is High        |
|      | Plastic Limit ($W_P$)             | 25%     |                                |
| 5    | Shrinkage Limit ($W_S$)           | 12%     | Swell potential is high        |
|      | Plasticity Index (I_p)            | 35%     | High Plasticity                |
|      | Soil Classification               | CH      | Clay Of High Compressibility   |
|      | Optimum Moisture Content          | 21.60%  |                                |
| 6    | Maximum Dry Density               | 1.72 g/cc|                                |
| 7    | Unconfined Compressive Strength   | 133.05 kN/m² |                                |
|      | Cohesion ($C_u$)                  | 66.57 kN/m² |                                |
| 8    | California Bearing Ratio          | Unsoaked 5.55% | soaked 2.26% |
6.1.1. Effect of Bagasse ash and Geotextile on strength characteristics

The study regarding the impact of the addition of bagasse ash and therefore the reinforcement of soil sample with geotextile on the strength property of the soil sample in terms of Calif. bearing quantitative relation is performed. The California bearing ratio check on soil sample treated with varied percentages of bagasse ash within the vary of 5%, 10%, 15% and 20% in conjunction with single geotextile layer positioned at \( \frac{1}{3} \) rd depth from all-time low of the mould is conducted. The test results shown in table 4. It's clear from the test results that with the addition of bagasse the cosmic background radiation worth increases. The check results of soil sample with pulp ash and double geotextile layer is discussed.

6.2 Prediction of California Bearing Ratio

The predicted California bearing ratio value from the statistical analysis and the ANN modeling technique is presented to conclude at the reliable method.

6.2.1 Correlation of the Variables

The MLR analysis is administrated by taking all the freelance variables to urge the most effective correlation or determination coefficients. The independent variables were optimum wet content (OMC), most dry density (\( \gamma_{\text{dmax}} \)), physical property index (\( I_p \)), share of pulp ash additional (BA) and also the range of geotextile layer (GL). The cosmic microwave background worth is taken because the dependent variable. Table 5 gives the dataset used for the analysis. The steps concerned within the development of regression model victimisation computer programme is discussed.

Table 5. Dataset used for the Correlation

| S.NO. | OMC  | \( \gamma_{\text{dmax}} \) | \( I_p \) | BA | GL  | CBR  |
|-------|------|--------------------------|---------|----|-----|------|
| 1     | 21.6 | 1.72                     | 34      | 0  | 0   | 2.26 |
| 2     | 24   | 1.69                     | 33      | 5  | 0   | 3.04 |
| 3     | 26   | 1.67                     | 27      | 10 | 0   | 5.12 |
| 4     | 28   | 1.64                     | 31      | 15 | 0   | 4.23 |
| 5     | 31   | 1.61                     | 35      | 20 | 0   | 3.67 |
| 6     | 21.6 | 1.71                     | 34      | 0  | 1   | 2.62 |
| 7     | 24   | 1.67                     | 33      | 5  | 1   | 3.56 |
| 8     | 26   | 1.65                     | 27      | 10 | 1   | 5.23 |
| 9     | 28   | 1.62                     | 31      | 15 | 1   | 4.67 |
| 10    | 31   | 1.59                     | 35      | 20 | 1   | 3.83 |
| 11    | 21.6 | 1.68                     | 34      | 0  | 2   | 2.93 |
| 12    | 24   | 1.64                     | 33      | 5  | 2   | 4.68 |
| 13    | 26   | 1.62                     | 27      | 10 | 2   | 5.47 |
| 14    | 28   | 1.59                     | 31      | 15 | 2   | 4.92 |
| 15    | 31   | 1.56                     | 35      | 20 | 2   | 4.18 |

The predictive model for CBR value containing the dependent variables ang giving the significant coefficient of determination is given below.

\[
\text{CBR} = 62.546 + 0.1039\text{OMC} - 30.717\ \gamma_{\text{dmax}} - 0.2767\ \text{I}_p - 0.1529\ \text{BA} - 0.3512\ \text{GL}
\]

The correlation coefficient is represented as adjusted R² = 0.914 which measures the fit. From the adjusted R² value it is understood that 91% of CBR value is predicted from the dependent variables.

The comparative figure showing the plot of the observed CBR values and the predicted CBR values obtained from regression analysis is shown.

The one way analysis of variance is performed with the independent variables to test the statistical significance. The ANOVA is carried out in the spreadsheet to find the F value.

The F value is represented in the form of the following equation:

\[
F (\text{df}_{\text{between},\text{df}_{\text{within}}}) = F_{\text{crit}}
\]

\[
F (4, 70) = 2.5027
\]
The calculated F value is 30.773 is greater than \( F_{\text{crit}} \) value of 2.5027 which indicates that the null hypothesis is rejected and there is real relationship between the independent and dependent variables.

### 6.3 Artificial Neural Network modelling

The dataset used for coaching the network is shown in Table 6. The feed forward back propagation training network models are coded in MATLAB mistreatment neural network toolbox. The neural network models studied during this investigation uses transfer perform ‘TANSIG’ as activation function. when this the network model is prepared for prediction of desired output. The parametric statistic is employed for the performance analysis of ANN models. the amount of hidden layers and number of neurons are varied to search out the optimum structure with the goal to realize convergence.

| Input | Hidden Layer | Output |
|-------|--------------|--------|
|       |              |        |

![Figure 2. Architecture of proposed Neural Network Model](image)

![Figure 3. Regression Plot](image)

#### 6.3.1 Training the Neural Network Model

In this study, the feed forward neural network with Levenberg – Marquardt back propagation rule consisting of multilayer perceptions is used to estimate the CBR of soil. The coaching of the model was performed as five - 5 -1 (input-hidden layers-output). The neural network training is shown in figure 2. The regression plot is obtained from the training of the neural model that shows a coefficient of correlation of \( R^2 = 0.932 \). The regression plot shows that there's smart relationship existing between the input and also the output variable and the technique is reliable. The regression plot is shown as figure 3[1-42].

#### 6.3.2 Validation and Comparison of Network Performance

After training the NN models were used to predict the California Bearing Ratio value of 4 soil samples. The model performance gave satisfactory results to that obtained from laboratory investigation. The correlation coefficient is higher than that obtained MLRA technique, The ANN model exhibits a higher performance in comparison to the regression technique to predict the soaked CBR value (Table.6 and Figure 4).

**Table 6. Comparison of observed and predicted CBR values**

| sample | Actual CBR | MLR Predicted | ANN Predicted |
|--------|------------|---------------|---------------|
| 1      | 2.26       | 2.55          | 2.36          |
| 2      | 3.04       | 3.23          | 3.04          |
| 3      | 5.12       | 4.95          | 4.88          |
| 4      | 4.23       | 4.21          | 4.09          |
| 5      | 3.67       | 3.57          | 3.60          |
| 6      | 2.62       | 2.51          | 2.68          |
| 7      | 3.56       | 3.50          | 3.50          |
| 8      | 5.23       | 5.21          | 4.97          |
| 9      | 4.67       | 4.47          | 4.48          |
| 10     | 3.83       | 3.83          | 3.74          |
| 11     | 2.93       | 3.08          | 2.95          |
Figure 4. Comparison of Actual and Predicted CBR

7. Conclusion
Based on the results of the experimental tests on the soil sample and the numerical analysis, the following conclusions are drawn:

1. The highly compressible clay soil can be stabilized with an optimum of 10% BA and Double Geotextile reinforcement placed each at 1/3rd the height of the mould from the base and top respectively.
2. The pavement thickness for the soil with Bagasse ash and double layers of geotextile showed a reduction of 23.86% when compared with the natural soil subgrade.
3. The increase in the strength of the treated soil sample is observed to be 6.84% of that the unmodified soil sample.
4. The prediction of CBR value can be done from the parameters such as optimum moisture content, maximum dry density, plasticity index, bagasse ash fraction.
5. The statistical analysis with multilinear regression analysis tool is found to be 91% reliable to predict the CBR value.
6. ANN model of 5-5-1 is with 93% accuracy in predicting the CBR values and they are found to exhibit real relationship with the input and output values.
7. ANN modelling and MLRA is recommended for the prediction of CBR values where the ANN model is better than MLRA with minimal error.

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