

PREDICTION OF CALIFORNIA BEARING RATIO OF FINE-GRAINED SOIL STABILIZED WITH ADMIXTURES USING SOFT COMPUTING SYSTEMS

Islam M. Rafizul* and Animesh Chandra Roy

Department of Civil Engineering, Khulna University of Engineering & Technology, Khulna-9203, Bangladesh

Date received: 14/01/2020 Date accepted: 05/03/2020

*Corresponding author's email: imrafizul@yahoo.com

DOI: 10.33736/jcest.2035.2020

Abstract—The main focus of this study was to predict California bearing ratio (CBR) of stabilized soils with quarry dust (QD) and lime as well as rice husk ash (RHA) and lime. In the laboratory, stabilized soils were prepared at varying mixing proportions of QD as 0, 10, 20, 30, 40 and 50%; lime of 2, 4 and 6% with varying curing periods of 0, 7 and 28 days. Moreover, admixtures of RHA with 0, 4, 8, 12 and 16%; lime of 0, 3, 4 and 5% was used to stabilize soil with RHA and lime. In this study, soft computing systems like SLR, MLR, ANN and SVM were implemented for the prediction of CBR of stabilized soils. The result of ANN reveals QD, lime and OMC were the best independent variables for the stabilization of soil with QD, while, RHA, lime, CP, OMC and MDD for the stabilization of soil with RHA. In addition, SVM proved QD and lime as well as RHA, lime, CP, OMC and MDD were the best independent variables for the stabilization of soil with QD and RHA, respectively. The optimum content of QD was found 40% and lime 4% at varying curing periods to get better CBR of stabilized soil with QD and lime. Moreover, the optimum content of RHA was also found 12% and lime 4% at varying curing periods to get better CBR of stabilized soil with RHA and lime. The observed CBR and selected independent variables can be expressed by a series of developed equations with reasonable degree of accuracy and judgment from SLR and MLR analysis. The model ANN showed comparatively better values of CBR with satisfactory limits of prediction parameters (RMSE, OR, R² and MAE) as compared to SLR, MLR and SVM. Therefore, model ANN can be considered as best fitted for the prediction of CBR of stabilized soils. Finally, it might be concluded that the selected optimum content of admixtures and newly developed techniques of soft computing systems will further be used of other researchers to stabilize soil easily and then predict CBR of stabilized soils.

Copyright © 2020 UNIMAS Publisher. This is an open access article distributed under the Creative Commons Attribution-NonCommercial-ShareAlike 4.0 International License which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited.

Keywords: Soil, Admixtures, CBR, Regression Analysis, ANN, SVM

1.0 INTRODUCTION

The strength of an underlying soil to be used as a subgrade of highway and foundation is assessed from its California Bearing Ratio (CBR) value [1]. Moreover, geotechnical engineer needs to ensure bearing capacity of underlying soil for the subgrade of highway and the design of foundation for civil infrastructures. If the value of CBR in soil is low, the thickness of pavement is high, which will result in high cost of construction and vice-versa. To increase the CBR value of soil, soil improvement or stabilized techniques may be applied to existing soft soil. Soil stabilization may be defined as any process by which a soil material is improved and made more stable resulting in improved bearing capacity, increase in soil strength and durability under adverse moisture and stress conditions [2]. The CBR of stabilized soil depends on different factors like percentage of admixtures, curing period, curing temperature, compaction properties of soil, Atterberg's limit of soil, particle sizes of soil, etc. The test of CBR is not only expensive but also time consuming. There are different techniques for improving CBR of soil, one being stabilization using different admixtures like cement, lime, fly ash, rich husk ash (RHA), gypsum, baggage ash, quarry dust (QD), geotextile, etc. The successful stabilization of soils has to depend on the proper selection of admixtures and amount of admixtures added [3]. In this study, to stabilize soil, the admixtures such QD, lime and RHA at varying percentages were used. The QD is a byproduct of the crushing process which is a concentrated material to use as aggregates for concreting purpose, especially as fine aggregates [4,5]. The lime is a calcium-containing inorganic mineral in which oxides, and hydroxides predominate. The lime usually used for the stabilization of soil is commercially available quick lime. RHA is a by-product from the burning of rice husk. In the literature various researchers in civil engineering field are used soft

computing systems such as artificial neural network (ANN), support vector machine (SVM), simple linear regression (SLR) and multiple linear regressions (MLR) for the prediction of CBR of stabilized soils [6]. CBR of soil has been predicted using ANN by a number of researchers [6]. ANN is an effective tool for analyzing and predicting of CBR stabilized soil. ANNs are a form of artificial intelligence and mimics the nervous system of the human brain [7]. The coefficient of regression (R^2), mean square error (MSE) and over fitting ratio (OR) is mostly used for evaluating the performance of ANN models. The root means square error (RMSE) indicates the accuracy of approximation as overall, without indicating the individual data points [7,8]. The OR is defined as the ratio of Root mean square error (RMSE) for testing and training data and its value close to 1.0 shows good generalization of the ANN model [9, 10,11]. In addition, SVM has also been applied for the prediction and analysis of geotechnical parameters of stabilized soils. SVM has been also applied for prediction of settlement of foundations on cohesionless soil, swelling pressure of expansive soil and compaction behavior of stabilized soil [12,13,14].

In this study, the soft computing systems such as simple linear regression (SLR) and multiple linear regressions (MLR) were performed to establish relationship between CBR and other independent variables of SLR and MLR techniques. In addition, the algorithms of Levenberg-Marquardt neural network (LMNN), Bayesian regularization neural network (BRNN) and scaled conjugate gradient neural network (SCGNN) of ANN's back propagation was performed for the prediction of CBR of stabilized soils. The SVM with different kernel functions like support vector machine-linear (SVM-L), support vector machine-quadratic (SVM-Q) and support vector machine-cubic (SVM-C) was performed to select a best fitted model of SVM. The coefficient of regression (R^2), root mean square error (RMSE) and mean absolute error (MAE) is mostly used for evaluating the performance of SVM models. The aim of this study is to analyze CBR of fine-grained soil stabilized with different admixtures, to predict CBR of stabilized soil using soft computing systems and to check the accuracy of the observed and predicted CBR of stabilized soil from soft computing systems. In this study, the selected optimum content of admixtures and newly developed techniques of soft computing systems will further be used of other researchers to stabilize soil easily and then predict CBR of stabilized soils.

2.0 METHODOLOGY

In this study, for the prediction of CBR of stabilized soils, the soft computing systems like SLR, MLR, ANN and SVM with different kernel functions were performed. The overall methodology of this study is described in the following articles.

2.1 COLLECTION OF SOIL SAMPLE

In the laboratory, for the preparation stabilized soils, disturbed soil samples were collected at a depth of 5 feet from the existing ground surface from KUET campus, Bangladesh. Proper care was taken to remove any loose soil during sampling of soil sample.

2.2 LABORATORY INVESTIGATIONS

In the laboratory, the physical and index properties of soil sample were measured through ASTM standard test methods. The laboratory results of soil samples with ASTM testing standards are provided in Table 1. Besides, in the laboratory, specific gravity, OMC, MDD, gravel, sand, silt and was found 2.65, 10.02%, 19.8kN/m³, 0.38%, 86.02%, 9.03% and 4.57%, respectively, of QS.

Table 1: Physical properties of soil used in this study

Soil parameters	Unit	Value	Analytical method
Specific Gravity	--	2.70%	ASTM D 854
Initial Moisture Content	--	26%	ASTM D 2216
OMC	--	13.9%	ASTM D 1557 (Modified)
MDD	kN/m ³	17.6	
LL	--	32%	ASTM D 4318
PL	--	22%	
PI	--	10%	
Soaked CBR	--	6.74%	AASHTO T 193
Gravel: Sand: Silt: Clay in %	--	0: 2.70: 73.2: 24.1	ASTM D 421 and D 422

2.3 MIXING OF THE SOIL SAMPLE

The collected soil sample was first air and oven dried and then powdered manually. This powdered sample was then sieved through #4 sieve which were mixed with QD and lime as well as with RHA and lime at varying mixing proportions. Then, the mixing samples were mixed with various percentage of water to get OMC and MDD of stabilized soil.

2.4 PREPARATION OF STABILIZED SOILS

In the laboratory, the stabilized soils were prepared at varying mixing proportions of QD as 0, 10, 20, 30, 40 and 50%; lime of 2, 4 and 6% with varying curing periods of 0, 7 and 28 days. Moreover, the admixtures of RHA with 0, 4, 8, 12 and 16%; lime of 0, 3, 4 and 5% was used to stabilize soil with RHA and lime. The stabilized samples were curing for 0, 7 and 28 days to get CBR of stabilized soils. In addition, for CBR test, samples were prepared by using 6 inch diameter and 7 inch height compaction mold. In addition, a spacer disk height and collar height was considered as 60 and 40mm, respectively. The soil samples were prepared for mixing with QD and lime as well as RHA and lime. Thereafter, same quantity of OMC was added in soil prepared with QD and lime as well as in soil prepared with RHA and lime to make ready for blows.

2.5 COMPACTION OF SAMPLES FOR CBR TEST

The prepared soil samples were compacted using modified proctor test. At first all the measurement and weight were taken before the compaction. The spacer disk was placed on the base plate and a filter paper kept on the spacer disk. Then the mold was placed over the spacer disk as well as a collar was fixed up on the mold. Later sample was poured in the mold of five layers and the compaction conducted per layer was 10, 30 and 65 blows, respectively. But the mold was clamped with base plate tightly during compaction. After compaction of five layers in each mold, it was level its top surface. Then the mold was removed from the base plate and spacer disk to take the weight of sample and mold. Further this sample was ready for curing periods of 0, 7 and 28 days.

2.6 CURING OF SAMPLES FOR CBR TEST

Total 54 samples for QD and lime as well as 60 samples for RHA and lime were curing for 0, 7 and 28 days. The samples were kept in water for curing. The water used in the curing was as the room temperature. The water temperature varies from 32 to 35°C.

2.7 CBR TEST OF SAMPLES

The curing samples were kept in open dry condition after removing the surcharge. When the molds become saturated dry, then the molds were untying its clamp for weighting of cured sample and mold. Later it was placed under the loading machine for CBR test. CBR machine is a gradual loading machine

which measures load with respect to deformation. Three molds were placed in the CBR testing machine to fix by wooden pieces for the tight hardly of sample. Then a collar and 4.70 kg of surcharge were placed on the mold. A deformation dial gauge was attached with the machine. By making the loading in dial gauge as zero, the load was gradually applied. The deformation was recorded for 0, 0.25, 0.50, 1.00, 1.25, 1.50, 2.00, 2.50, 3.00, 3.50, 3.75, 4.00, 4.50, 5.00, 6.00, 7.50, 10.00 and 12.50 mm, respectively and at the same time, the corresponding load was recorded. After the loading completed on sample, the mold was removed from the machine and the same procedure were repeated for the other samples.

2.8 SOFT COMPUTING SYSTEMS

In this study, to predict CBR of stabilized soil, the soft computing systems such as SLR and MLR through MS excel was performed. In addition, ANN with the different algorithm through MATLAB was implemented. Moreover, SVM with the different kernel functions was also performed and hence discussed in the following articles.

2.8.1 SIMPLE AND MULTIPLE LINEAR REGRESSIONS

The relationship between dependent variable CBR and other independent variables such as lime (%), QD (%) or RHA (%), curing period, CP (days), OMC (%) or MDD (kN/m^3) was established using SLR and MLR as well as R^2 was carried out. The dependent variable of SLR technique can be predicted by using the following Equation 1.

$$y = a + bx \quad (1)$$

Where y is dependent variable and x is the independent variable as well as b is the slope of the line and a is the intercept, where the line cuts the y axis. Moreover, values of a and b can obtain as constant after the analysis of SLR technique. In addition, the dependent variable of MLR technique can be predicted by using the following Equation 2.

$$Y = a + b_1X_1 + b_2X_2 + b_3X_3 + b_4X_4 + b_5X_5 + \dots + b_nX_n \quad (2)$$

Where Y is a dependent variable and $X_1, X_2, X_3, X_4, X_5, \dots, X_n$ are the independent variable as well as a is the coefficient of intercept and $b_1, b_2, b_3, b_4, b_5, \dots, b_n$ are coefficient of independent variables, respectively. Independent variables become two or more input values at the curing period of 0, 7 and 28 days.

2.8.2 ARTIFICIAL NEURAL NETWORK

In this analysis, the back-propagation ANN with different algorithms like Levenberg-Marquardt neural network (LMNN), bayesian regularization neural network (BRNN) and scaled conjugate gradient neural network (SCGNN) was implemented for the prediction of CBR of stabilized soils. In ANN analysis, to select the best model, the MSE, R^2 and OR were considered. Best model can be declared then, when R^2 is almost close to 1 with its best OR value is also close to 1.

2.8.3 SUPPORT VECTOR MACHINE

In this analysis, support vector machine (SVM) with different kernel functions like linear SVM (SVM-L), quadratic SVM (SVM-Q) and cubic SVM (SVM-C) was used to prediction the CBR of stabilized soil using different admixture at varying proportion. In SVM analysis, lime (%), QD (%) or RHA (%), CP (days), OMC (%) and MDD (kN/m^3) as well as CBR (%) were selected as input and target, respectively. In SVM analysis, to select the best model, the RMSE, R^2 and MAE were considered. When R^2 value is the near about 1, root mean square error (RMSE) and mean absolute error (MAE) value is near about zero, then it can call best fitted model of SVM.

3.0 RESULTS AND DISCUSSIONS

The soft computing systems like SLR, MLR and SVM with different kernel function are SVM-L, SVM-Q and SVM-C were performed for the prediction of CBR of stabilized soils and hence discussed in the following articles.

3.1 STABILIZED SOILS WITH ADMIXTURES

In the laboratory, the stabilized soils were prepared using QD with lime and RHA with lime at varying mixing proportions and hence discussed in the following articles.

3.1.1 QUARRY DUST WITH LIME

The variation of dry density in relation to the changing of moisture content of stabilized soil with QD and lime is shown in Figure 1. Figure 1 depicts that dry density increases with the increasing of QD and lime content in soil at a certain amount of moisture content. For a particular amount of QD like 50%, the stabilized soil with 6 % lime content showed comparatively the higher values of dry density due to more additive power of admixtures than that of stabilized soil with other less amount of QD content as shown in Figure 1(c).

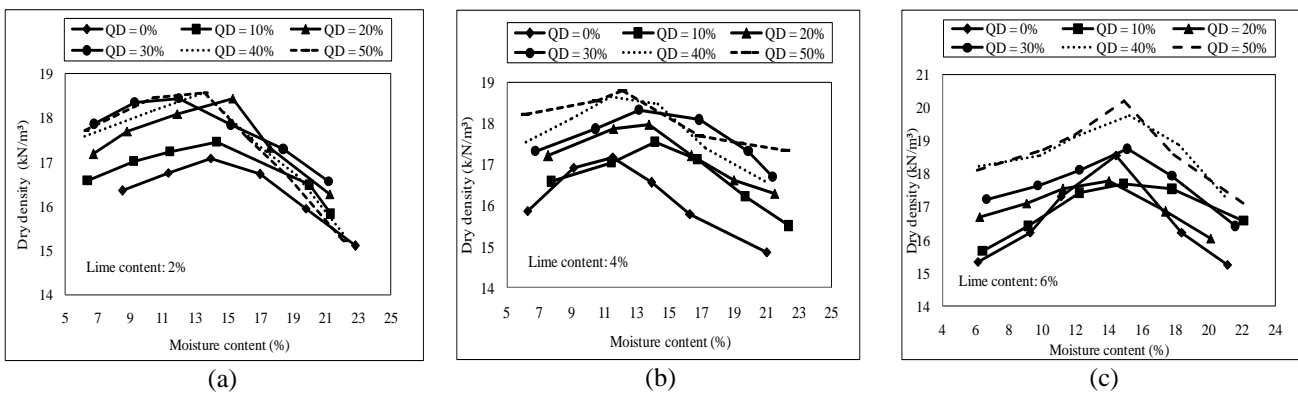


Figure 1: Effect of QD content on compaction curve for (a) 2% lime content, (b) 4% lime content and (c) 6% lime content

Figure 2 shows the variation of MDD of stabilized soil with different percentages of QD and lime. MDD is an important parameter to calculate the CBR of stabilized soils.

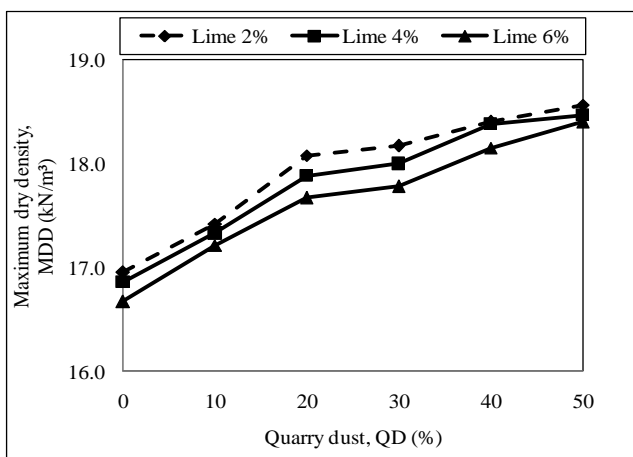


Figure 2: Variation of MDD with QD and lime content.

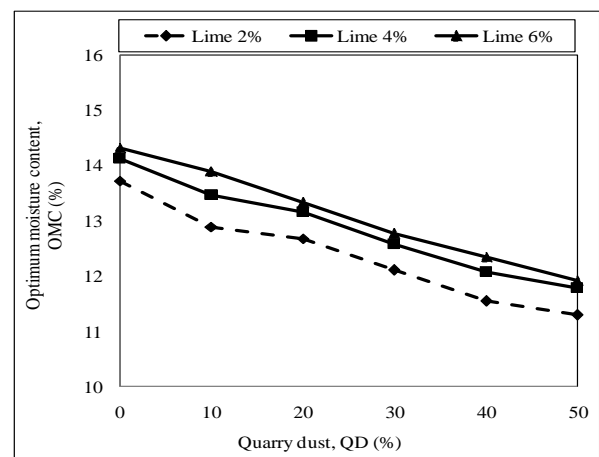


Figure 3: Variation of OMC with QD and lime content.

The MDD of stabilized soil decreases with the increasing of lime content as shown in Figure 2. In addition, MDD increases in relation to the increasing of QD content in soil. Figure 2 also shown that for a particular

mixing content of QD (30%), the value of MDD decreases with the increasing of lime content. Moreover, for a particular amount of lime content (6%), the value of MDD increases in relation to the adding of QD in stabilized soil. In addition, Figure 3 shows the variation of OMC of stabilized soil with different percentages of QD and lime. OMC is an important parameter to determine the CBR of stabilized soils. The OMC of stabilized soil increases with the increasing of lime content as shown in Figure 3. In addition, OMC decreases in relation to the increasing of QD content in stabilized soil. Figure 3 also shown that for a particular mixing content of QD (30%), the value of OMC increases with the increasing of lime content. Moreover, for a particular mixing amount of lime content (6%), the value of OMC decreases in relation to the adding of QD in stabilized soil.

The deviation of MDD and OMC in stabilized soil with QD (0 to 50%) and lime 2% is shown in Figure 4. The OMC decreases, while MDD increases with the increasing of QD content with a particular amount of lime (2%) as shown in Figure 4. A research conducted by [15] and stated that MDD decreases, while OMC increases with the increasing of admixture like RHA in soil. In this study, OMC and MDD of stabilized soil with QD showed the inverse behavior of stabilized soil with RHA due to the inherent properties of admixtures of QD and RHA. The findings in this study agreed well with the results postulated by [15].

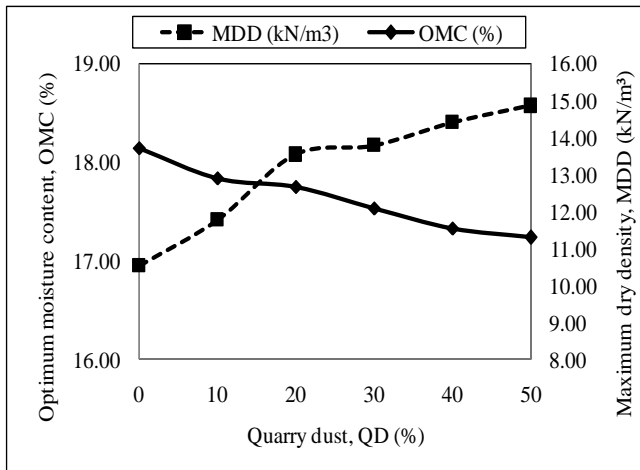


Figure 4: Variation of MDD and OMC with QD (%) and 2% lime.

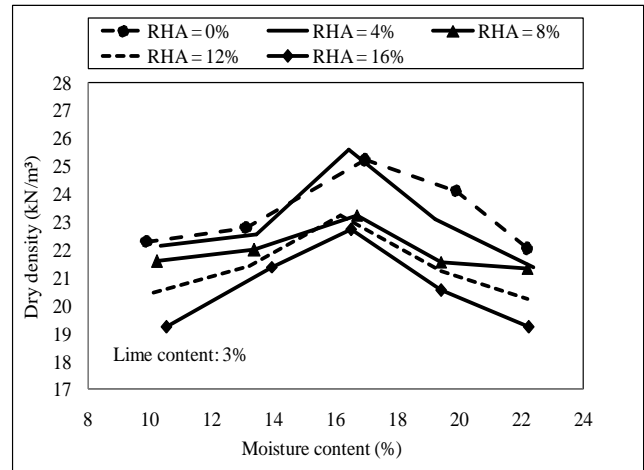


Figure 5: Effect of RHA content on dry density and moisture content.

3.1.2 RICE HUSK ASH WITH LIME

The effect of RHA content with 3% lime on the compaction curve of stabilized soil with RHA and lime is shown in Figure 5. Figure 5 reveals that dry density decreases for the increasing of RHA content with soil at certain amount of moisture content and then decreases. According to [16] the dry density values with moisture contents for soil samples with different percentage of additives are varied. The findings of this study are agreed well with the results by [16].

The MDD of stabilized soil decreases with the increasing of lime content as shown in Figure 6 (a). In addition, MDD decreases in relation to the increasing of RHA content in soil. Figure 6 (a) also shows that for a particular mixing content of RHA (8%), the value of MDD decreases with the increasing of lime content. Moreover, for a particular mixing amount of lime content (5%), the value of MDD decreases in relation to the adding of RHA in stabilized soil. Moreover, the OMC of stabilized soil increases with the increasing of lime content as shown in Figure 6 (b). In addition, OMC increases in relation to the increasing of RHA content in stabilized soil. Figure 6 (b) also shows that for a particular mixing content of OMC (8%), the value of OMC increases with the increasing of lime content. Moreover, for a particular mixing amount of lime content (5%), the value of OMC increases in relation to the adding of RHA in

stabilized soil. So, Figure 6 (c) illustrates the deviation of MDD and OMC in stabilized soil with RHA (0 to 16%) and lime of 4%. The MDD decreases while OMC increases with the increasing of RHA.

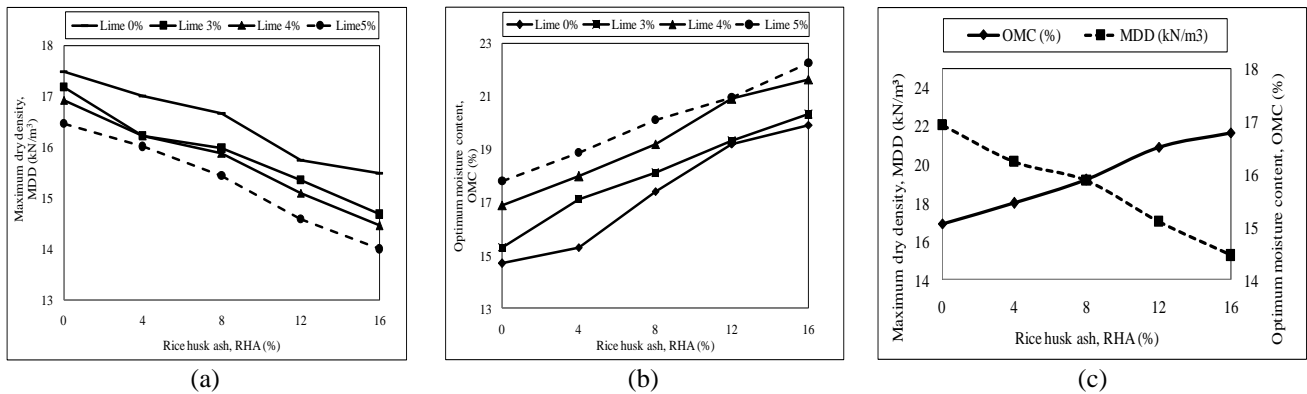


Figure 6: (a) Variation of MDD with RHA and lime (b) Variation of OMC with RHA and Lime (c) Variation of MDD and OMC with RHA (%) and 4% lime

3.1.3 VARIATION OF CALIFORNIA BEARING RATIO WITH ADMIXTURES

In the laboratory, stabilized soil with different admixtures like QD and RHA at varying mixing proportions and curing period was prepared. The CBR of stabilized soils was measured and the results of CBR of stabilized soils are hence discussed in the following articles.

3.1.3.1 Stabilized Soil with Quarry Dust and Lime

The results of CBR of stabilized soil with different mixing content of QD and lime at varying curing period of 0, 7 and 28 days is provided in Table 2.

Table 2: Results of CBR of stabilized soil with QD and lime at varying curing periods

QD content (%)	Lime content (%)	CBR (%) for different curing period (days)		
		0	7	28
0	2	28.70	33.34	57.66
10	2	32.92	40.21	69.30
20	2	35.17	45.32	73.20
30	2	38.86	51.31	78.65
40	2	42.82	61.10	87.25
50	2	40.36	56.64	81.89
0	4	29.03	44.67	62.12
10	4	30.12	46.21	73.55
20	4	39.80	53.78	79.00
30	4	53.68	62.32	87.81
40	4	77.54	83.27	98.26
50	4	66.35	74.50	91.22
0	6	28.87	39.80	59.89
10	6	31.52	41.14	71.50
20	6	37.48	44.77	76.22
30	6	46.27	59.55	83.50
40	6	60.18	74.19	91.75
50	6	53.35	69.13	87.21

Figure 7 shows the variation of CBR with different percentage of QD and lime at the curing period 0 days. It is observed that CBR goes on increasing up to 4% of lime, further decreases with adding lime. For a particular amount of lime, CBR increases with the increasing of QD in soil. The CBR increases up

to 40% of QD, further addition of QD decreases the values of CBR irrespective of the percentage of lime. The CBR increases to 77.54% from 28.70%, when the percentage of lime is 4%, QD is 40% and curing period is 0 days (Figure 7). The decline in CBR after a peak value at 40% QD may be connected with the decrease in the clay proportions which plays the role of the bonding agent at the lower percentage of QD. In addition, Figure 8 shows the variation of CBR with different percentage of QD and lime at the curing period of 7 days. It is observed that CBR goes on increasing up to 4% of lime, further decreases with adding lime with soil. For a particular mixing amount of lime content, CBR increases with the increasing of QD content. The CBR increases up to 40% addition of QD, further addition of QD decreases the CBR irrespective of the percentage of lime. The CBR increases to a value of 83.27% from 33.34%, when the percentage of lime is 4%, QD is 40% and curing period is 7 days.

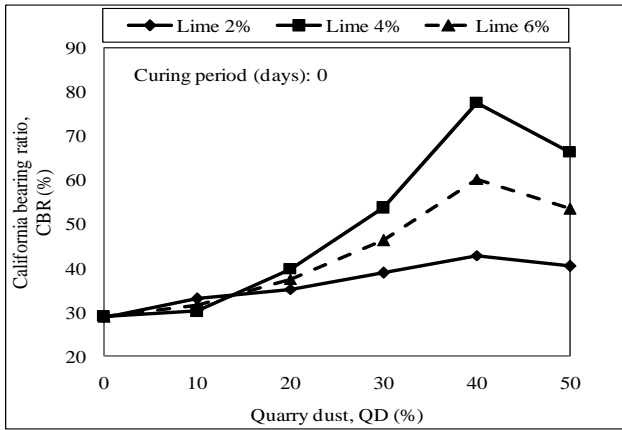


Figure 7: Stabilized soil with QD and lime at curing period of 0 days

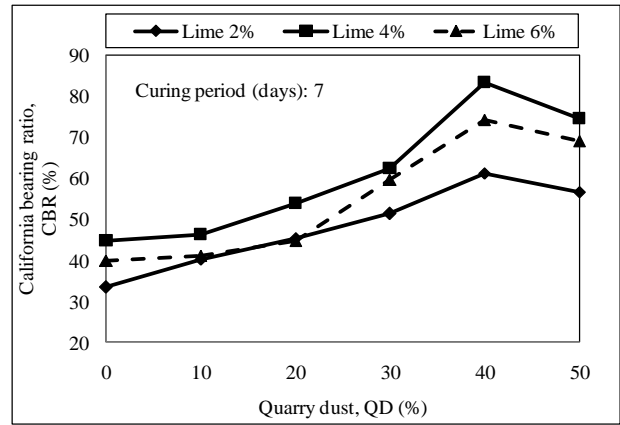


Figure 8: Variation of CBR of stabilized soil with QD and lime at curing period of 7 days.

3.1.3.2 Stabilized Soil with RHA and Lime

Figure 9 shows the variation of CBR of stabilized soil with different percentage of RHA and lime at the curing period of 0 days. It observed that CBR of stabilized soil goes on increasing up to 4% of lime, further decreases with adding lime with soil. For a particular mixing amount of lime content, CBR increases with increasing of RHA content in soil. The CBR increases up to 12% addition of RHA, further addition of RHA decreases CBR irrespective the percentage of lime. The CBR increases to a value of 50.1% from 5.1%, when the percentage of lime is 4%, RHA is 12% and curing period is 0 days as shown in Figure 9. The reason for increment in CBR may be because of the gradual formation of lime compounds in the soil by the reaction between the RHA and some amounts of CaOH present in soil and lime present. The decrease in CBR at RHA content of 16% may be due to extra RHA that could not be mobilized for the reaction which consequently occupies spaces within the sample. A research conducted by [12] stated that the CBR increases in relation to the increasing of RHA content in soil up. The result of this study agreed well with the researcher [12]. Figure 10 shows the variation of CBR of stabilized soil with different percentage of RHA and lime at the curing period of 28 days. It observed that CBR of stabilized soil goes on increasing up to 4% of lime, further decreases with adding lime with soil. For a particular mixing amount of lime content, CBR increases with the increasing of RHA content in stabilized soil. The CBR increases up to 12% addition of RHA, further addition of RHA decreases the CBR values irrespective of the percentage of lime. The CBR increases to a value of 58.41% from 13.43%, when the percentage of lime is 4%, RHA is 12% and curing period is 28 days as shown in Figure 10. The results of CBR of stabilized soil with RHA and lime depicted that the optimum content of RHA 12% was considered to get better CBR of stabilized soil for any curing period. The reason for increment in CBR may be because of the gradual formation of lime compounds in the soil by the reaction between the RHA and some amounts of Ca (OH)₂ present in soil and lime present.

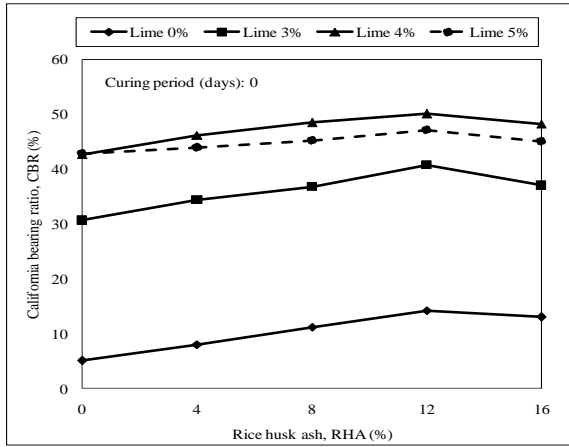


Figure 9: Variation of CBR of stabilized soil with RHA and lime at curing period of 0 days.

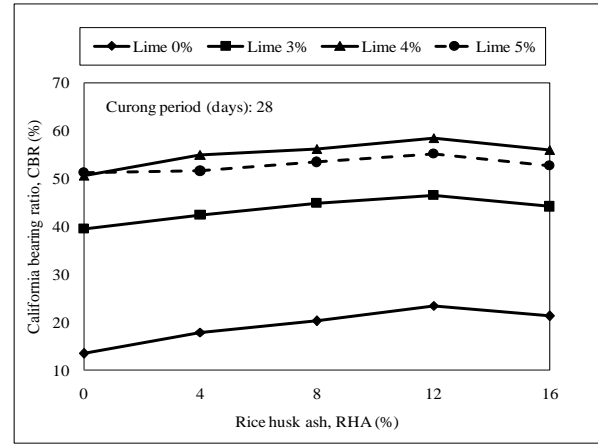


Figure 10: Stabilized soil with RHA and lime at curing period of 28 days

3.2 SOFT COMPUTING SYSTEMS

The soft computing systems like simple linear regression (SLR), multiple linear regressions (MLR), different algorithms of Levenberg-Marquardt neural network (LMNN), Bayesian regularization neural network (BRNN) and scaled conjugate gradient neural network (SCGNN) of ANN's back propagation as well as support vector machine (SVM) with different kernel functions like linear SVM (SVM-L), quadratic SVM (SVM-Q) and cubic SVM (SVM-C) applied for the prediction of CBR values of stabilized soils and hence discussed in the following articles.

3.2.1 SIMPLE LINEAR REGRESSION

In simple linear regression (SLR) analysis, QD (%), lime (%), CP (days), OMC (%) or MDD (kN/m³) as well as observed CBR considered as independent and dependent variables, respectively, of stabilized soil with QD and lime at different curing period of 0, 7 and 28 days. Moreover, RHA (%), lime (%), CP (days), OMC (%) or MDD (kN/m³) as well as observed CBR considered as independent and dependent variables, respectively, of stabilized soil with RHA and lime at different curing period of 0, 7 and 28 days.

3.2.1.1 Stabilized Soil with QD and Lime

In SLR analysis, QD (%), lime (%), CP (days), OMC (%) or MDD (kN/m³) as well as observed CBR considered as independent and dependent variables, respectively, at different curing period of 0, 7 and 28 days. After analysis, the value of R² was found at different curing periods depicted in Table 3. In Table 3, it is observed the best R² of 0.596 when independent variable of QD (%) and dependent variable as observed CBR (%) for curing period of 0 days. The best R² was found to be 0.722 when independent variable was QD (%) and dependent variable as observed CBR (%) for curing period 7 days. Similarly, for curing period 28 days, the best R² was found to be 0.798 with independent variable QD (%) and dependent variable as observed CBR (%).

Table 3: Performance analysis of SLR for stabilized soil with QD and lime at various curing period

Group	Dependent variable	Independent variables	R ² at varying curing period (days)		
			0	7	28
A	Observed CBR	lime (%)	0.037	0.04	0.018
B		QD (%)	0.596	0.722	0.798
C		OMC (%)	0.411	0.505	0.64
D		MDD (kN/m ³)	0.507	0.602	0.768

The predicted CBR of stabilized soil was correlated with all the variables independently and it was observed that CBR increases in relation to the increasing of QD (%) shown in Figure 11. The SLR analysis provided the best R^2 was 0.798 (shown in Group B) for curing period 28 days when QD (%) have taken as an independent variable. A researcher [7] stated that all the test results consisting of gravel, sand, fine grained, liquid limit, plastic limit, OMC or MDD as independent variable and CBR is dependent variable that's analyzed by statistical method of least regression. The best linear fitting approximation equations having maximum R^2 values are determined. Where independent variable used as FG, G and MDD separately on one dependent variable is CBR for different equations and plots. The findings of this study are agreed well with the results published by researcher [7].

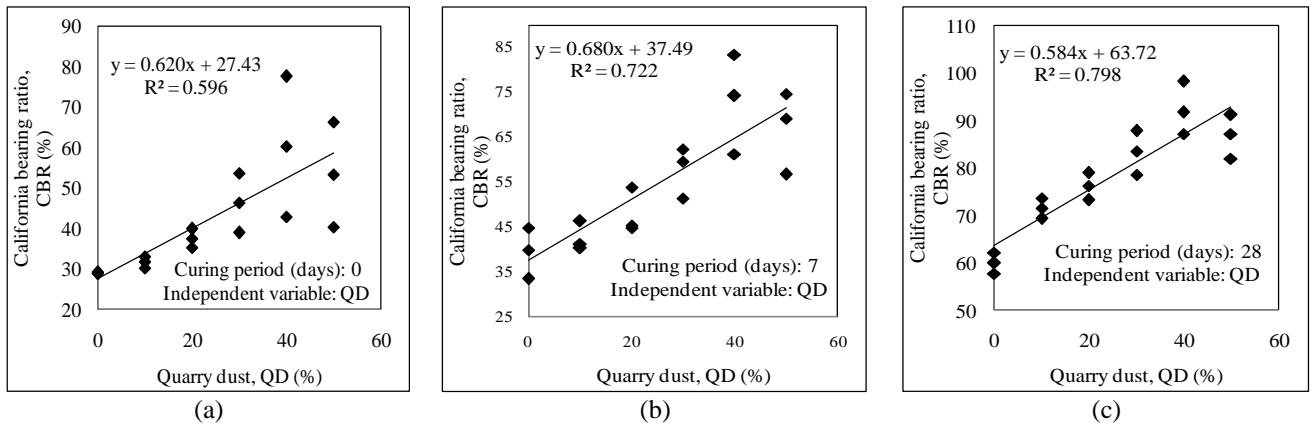


Figure 11: Changes of CBR with the variation of QD (%) in stabilized soils.

Table 4: Developed equations for predicting CBR of stabilized soils with QD and lime at varying curing periods

Correlation of predicted CBR	Equation No.	R^2	Curing period (days)	Figure No.
$CBR = 0.62 QD + 27.43$	3	0.596	0	Figure 11 (a)
$CBR = 0.68 QD + 37.48$	4	0.722	7	Figure 11 (b)
$CBR = 0.584 QD + 63.72$	5	0.798	28	Figure 11 (c)

In SLR analysis, the best linear fitting approximation equations having maximum value of R^2 were determined from the curing periods of 0, 7 and 28 days and can be expressed in Equations 3, 4 and 5, respectively. After analysis of SLR, the developed equations were selected as best based on R^2 for predicting CBR of stabilized soil with QD at varying curing periods provided in Table 4. From Table 4, it is clear that since best R^2 was found to be 0.798 by SLR analysis, therefore the best prediction of CBR at 28 days curing period can be determined by the Equation 5 where QD (%) has taken as an independent variable.

3.2.1.2 STABILIZED SOIL WITH RHA AND LIME

In SLR analysis, RHA (%), lime (%), CP (days), OMC (%) or MDD (kN/m^3) as well as observed CBR considered as independent and dependent variables, respectively at different curing period 0, 7 and 28 days. After analysis, the value of R^2 was found at different curing periods shown in Figure 12. From Figure 12 it is observed that, for 0 days curing the best R^2 is found to be 0.905 when independent variable is lime (%) and dependent variable as observed CBR (%). For curing period of 7 days, the best R^2 was found to be 0.901 when independent variable is Lime (%) and dependent variable as observed CBR (%). For curing period of 28 days, the best R^2 was found to be 0.908 when independent variable is Lime (%) and dependent variable as observed CBR (%).

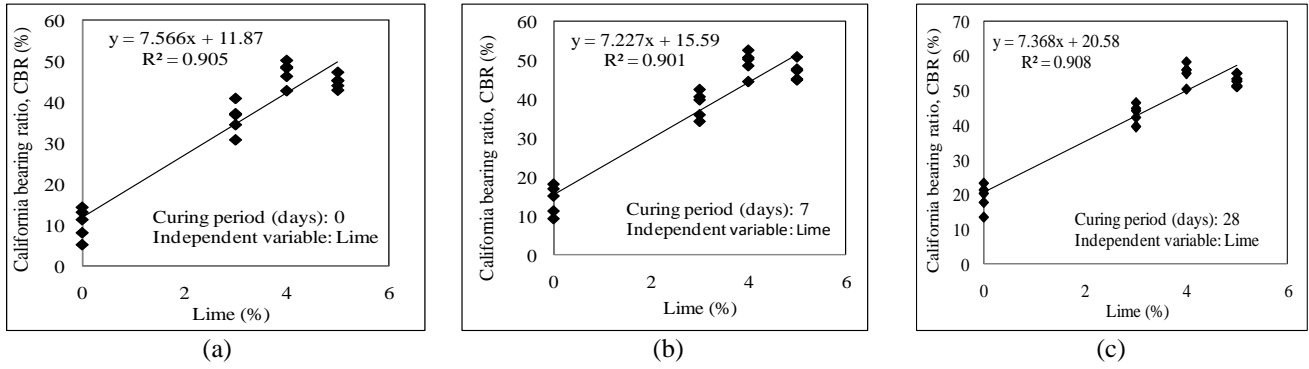


Figure 12: Changes of CBR with the variation of Lime (%) in stabilized soils.

In this study, in SLR analysis the best linear fitting approximation equations having maximum value of R^2 were determined from the curing periods of 0, 7 and 28 days and can be expressed in Equations 6, 7 and 8 respectively. After analysis of SLR, the developed equations were selected as best based on R^2 for predicting CBR of stabilized soil with RHA at varying curing periods provided in Table 5. Equation (8) can be taken as satisfactory for the prediction of CBR and more reliable equations need to be evolved for best values of R^2 .

Table 5: Developed equations for predicting CBR of stabilized soils with QD and lime at varying curing periods

Correlation of predicted CBR	Equation No.	R^2	Curing period (days)	Figure No.
$CBR = 7.566 \text{ Lime} + 11.87$	6	0.905	0	Figure 12 (a)
$CBR = 7.566 \text{ Lime} + 15.59$	7	0.901	7	Figure 12 (b)
$CBR = 7.566 \text{ Lime} + 20.58$	8	0.908	28	Figure 12 (c)

3.2.2 MULTIPLE LINEAR REGRESSION

In multiple linear regression (MLR) analysis, QD (%), lime (%), CP (days), OMC (%) and MDD (kN/m^3) as well as observed CBR considered as independent and dependent variables, respectively of stabilized soil with QD and lime at different curing period of 0, 7 and 28 days. Moreover, RHA (%), lime (%), CP (days), OMC (%) and MDD (kN/m^3) as well as observed CBR considered as independent and dependent variables, respectively of stabilized soil with RHA and lime at different curing period of 0, 7 and 28 days. The analysis of MLR for stabilized soils is described in the following articles.

3.2.2.1 STABILIZED SOIL WITH QD AND LIME

In MLR analysis, QD (%), lime (%), CP (days), OMC (%) and MDD (kN/m^3) as well as observed CBR considered as independent and dependent variables, respectively at different curing period of 0, 7 and 28 days. The results of R^2 by MLR analysis are provided at different curing period in Table 6.

Table 6: Performance analysis of MLR for stabilized soil with QD and lime at various curing period

Group	Dependent variable	Independent variables	R^2 at varying curing period (days)		
			0	7	28
A	Observed CBR	QD, lime, CP, OMC, MDD	0.663	0.787	0.872
B		QD, lime, OMC, MDD	0.663	0.787	0.871
C		Lime, OMC, MDD	0.628	0.741	0.870
D		QD, OMC, MDD	0.663	0.786	0.853
E		QD, lime, OMC	0.651	0.781	0.82
F		QD, lime, MDD	0.640	0.766	0.863
G		QD, lime,	0.633	0.763	0.817
H		OMC, MDD	0.533	0.619	0.792

The values of 0.663, 0.787 and 0.872 were found for R^2 at curing period of 0, 7 and 28 days for the independent variables in group A (QD, lime, CP, OMC, MDD). After that the independent variables were eliminated one or more and rearranged successively at various combination of variables designated as group B, C, D, E, F, G and H to get best R^2 of stabilized soils with QD and lime (Table 6). The MLR analysis was carried out by taking all the independent variables in consideration at first and thereafter eliminating one or more forming various combinations to get the best R^2 .

From Table 6, the selected best R^2 was 0.872 at curing period of 28 days in group A (QD, lime, CP, OMC, MDD) as compared to other groups of B, C, D, E, F, G and H. In addition, predicted model for CBR containing five variables and giving significant value of R^2 derived by MLR analysis is given by Equation (9), where MDD is in (kN/m^3) and all other parameters are in %.

$$CBR = -262.723 + 2.322 * Lime - 0.333 * QD + 0 * CP - 0.214 * OMC + 18.839 * MCD \quad (9)$$

when R^2 is 0.872.

Equation (9) can be taken as satisfactory for the prediction of CBR and more reliable equations need to be evolved for better values of R^2 . Moreover, the best prediction of CBR at curing period of 28 days can be determined by use this equation.

3.2.2.2 STABILIZED SOIL WITH RHA AND LIME

In MLR analysis, RHA (%), lime (%), CP (days), OMC (%) and MDD (kN/m^3) as well as observed CBR considered as independent and dependent variables, respectively at different curing period of 0, 7 and 28 days. The results of R^2 by MLR analysis are provided at different curing period in Table 7. The values of 0.949, 0.950 and 0.946 were found for R^2 at curing period of 0, 7 and 28 days for the independent variable in group A (RHA, lime, CP, OMC, MDD). After that the independent variables were eliminated one or more and rearranged successively at various combination of variables designated as group B, C, D, E, F, G and H to get best R^2 of stabilized soils with RHA and lime (Table 7).

Table 7: Performance analysis of MLR for stabilized soil with RHA and lime at various curing period

Group	Dependent variable	Independent variables	R^2 at varying curing period (days)		
			0	7	28
A	Observed CBR	RHA, lime, CP, OMC, MDD	0.949	0.950	0.946
B		RHA, lime, OMC, MDD	0.949	0.949	0.946
C		lime, OMC, MDD	0.925	0.925	0.926
D		RHA, OMC, MDD	0.79	0.79	0.795
E		RHA, lime, OMC	0.93	0.931	0.927
F		RHA, lime, MDD	0.947	0.948	0.946
C		RHA, lime	0.928	0.929	0.927
D		OMC, MDD	0.34	0.351	0.331

From Table 7, selected the best R^2 is 0.95 for curing period of 7 days shows as group A (RHA, lime, CP, OMC and MDD) as compared to other B, C, D, E, F, G and H. In addition, the predicted model for CBR containing five variables and giving significant value of R^2 derived by MLR is given by Equations (10), where MDD is in (kN/m^3) and all other parameters are in %.

$$CBR = -228.643 + 10.516 * Lime - 2.582 * RHA + 0 * CP - 0.366 * OMC + 13.918 * MCD \quad (10)$$

when R^2 is 0.95.

Equation (10) can be taken as satisfactory for the prediction of CBR and more reliable equations need to be evolved for best values of R^2 . Moreover, the best prediction of CBR at curing period of 7 days can be determined by use this equation.

3.2.3 ARTIFICIAL NEURAL NETWORK

In this study, ANN was performed on stabilized soil with different admixtures at varying curing periods. The ANN was implemented to select the best fitted model such as Levenberg-Marquardt neural network (LMNN), Bayesian regularization neural network (BRNN) and scaled conjugate gradient neural network (SCGNN). The number of hidden layers and neurons were varied to find out the best structure of ANN modeling. In order to compute the most appropriate ANN architecture for modeling, the number of neurons in the hidden were tried to predict the best CBR of stabilized soils. The number of hidden neurons in hidden layer was varied as 2, 4, 6, 8, 10, 12, 15, 20, 25 and 30. In this study, the hidden layer ranges from 2 to 30 provided the good results of R^2 . Moreover, when increased the number of neurons in hidden layer from 2 to 10 in interval 2, then increase R^2 consequently and hence discussed in the following articles.

3.2.3.1 STABILIZED SOIL WITH QD AND LIME

In this study, the algorithms of LMNN, BRNN and SCGNN through ANN model has been evaluated based on R^2 and OR to predict the CBR of stabilized soil with QD and lime. In ANN analysis, QD (%), lime (%), CP (days), OMC (%) and MDD (kN/m^3) as well as CBR (%) were considered as independent and dependent variable, respectively. To get the best performance of LMNN, BRNN and SCGNN, it has been eliminated one or more independently and rearranged at various combinations. The results of OR and R^2 of LMNN analysis are provided in Table 8. The values of 1.231 and 0.987 were found for OR and R^2 , respectively, for the independent variable in group A (QD, lime, CP, OMC, MDD). In addition, the values of 0.769 and 0.966 were found for OR and R^2 respectively, for the independent variables in group B (QD, lime, OMC and MDD). After that the independent variables were eliminated one or more and rearranged successively at various combination of variables designated as group C, D, E, F, G and H to get best R^2 of stabilized soils with QD and lime (Table 8).

Table 8: Performance of LMNN for stabilized soil with QD and lime

Group	Dependent variable	Independent variables	Mean square error (MSE)		Over fitting ratio (OR)	Determination coefficient (R^2)
			Training	Testing		
A	Observed CBR	QD, lime, CP, OMC, MDD	8.415	12.750	1.231	0.987
B		QD, lime, OMC, MDD	5.937	3.510	0.769	0.966
C		lime, OMC, MDD	4.218	3.293	0.884	0.945
D		QD, OMC, MDD	5.972	3.612	0.778	0.984
E		QD, lime, OMC	2.198	2.882	1.145	0.992
F		QD, lime, MDD	1.857	2.566	1.175	0.987
G		QD, lime	12.937	4.681	0.602	0.961
H		OMC, MDD	10.091	27.968	1.665	0.840

From Table 8, it can be observed that the group E (QD, lime and OMC) showed the best R^2 with 0.992 which is almost close to 1 with its best OR 1.145 (also close to 1). Therefore, group E (QD, lime and OMC) was considered as best of LMNN as compared to other groups of A, B, C, D, F, G and H. A research conducted by [17] stated that in the five different models the number of input as independent variables changes from seven to two and the target (dependent variable) was CBR as observed CBR. As well as the best model select depend on its OR and R^2 . The findings of this study are agreed well with the results postulated by [17].

3.2.3.2 STABILIZED SOIL WITH RHA AND LIME

The results of OR and R² of BRNN analysis are provided in Table 9. The values of 1.103 and 0.998 were found for OR and R², respectively, for the independent variable in group A (RHA, lime, CP, OMC, MDD). After that the independent variables were eliminated one or more and rearranged successively at various combination of variables designated as group B, C, D, E, F, G and H to get best R² of stabilized soils with RHA and lime (Table 9). From Table 9, it can be observed that the group A (RHA, lime, CP, OMC, MDD) showed the best R² with 0.998 which is almost close to 1 with its best OR 1.103 (also close to 1). Therefore, group A (RHA, lime, CP, OMC, MDD) is considered as best of LMNN as compared to B, C, D, E, F, G and H.

Table 9: Performance of BRNN for stabilized soil with RHA and lime

Group	Dependent variable	Independent variables	Mean square error (MSE)		Over fitting ratio (OR)	Determination coefficient (R ²)
			Training	Testing		
A		RHA, lime, CP, OMC, MDD	2.32	2.823	1.103	0.998
B		RHA, lime, OMC, MDD	4.564	3.441	0.868	0.996
C	Observed	lime, OMC, MDD	1.849	2.83	1.237	0.992
D	CBR	RHA, OMC, MDD	12.398	6.847	0.743	0.948
E		RHA, lime, OMC	7.458	5.160	0.832	0.997
F		RHA, lime, MDD	7.117	4.268	0.774	0.969
G		RHA, lime	7.4	4.174	0.751	0.969
H		OMC, MDD	10.034	4.226	0.649	0.444

3.2.4 SUPPORT VECTOR MACHINE

The support vector machine (SVM) analysis is also an important part for the prediction of CBR of stabilized soil using two or more independent variable such as QD (%), lime (%), CP (days), OMC (%) and MDD (kN/m³) at different curing period of 0, 7 and 28 days. Other independent variable such as RHA (%), lime (%), CP (days), OMC (%) and MDD (kN/m³) as well as dependent variable CBR (%) (as observed CBR) at different curing period of 0, 7 and 28 days were also considered in SVM analysis. The SVM modeling was implemented to select the best fitted like Linear support vector machine (SVM-L), Quadratic support vector machine (SVM-Q) Cubic support vector machine (SVM-C). The analysis of SVM is discussed in the following articles.

3.2.4.1 STABILIZED SOIL WITH QD AND LIME

In this study, the performance of different kernel functions like SVM-L, SVM-Q and SVM-C through SVM model has been evaluated based on RMSE, R² and MAE. In SVM analysis, QD (%), lime (%), CP (days), OMC (%) and MDD (kN/m³) as well as CBR (%) were considered as independent and dependent variables (as observed CBR), respectively. To get the best performance of SVM-L, SVM-Q and SVM-C, it has been eliminated one or more independent variables and rearranged at various combination. The results of RMSE, R² and MAE of SVM-L analysis are provided in Table 10. The values for RMSE, R² and MAE were found as 5.38, 0.77 and 4.53, respectively, for the independent variables in group A (QD, lime, CP, OMC, MDD). In addition, the values of 5.34, 0.77 and 4.48 were found for RMSE, R² and MAE, respectively, for the independent variables in group B (QD, lime, OMC and MDD).

After that the independent variables were eliminated one or more and rearranged successively at various combination of variables designated as groups C, D, E, F, G and H to get best R² of stabilized soils with QD and lime (Table 10). From Table 10, it can be observed that the group E (QD, lime and MDD) showed the best R² with 0.79 which is almost close to 1 with its best RMSE 5.19 (lowest value) and MAE 4.24 (lowest value). Therefore, group E (QD, lime and MDD) was considered as best of SVM-L as compared to other groups of A, B, C, D, F, G and H.

Table 10: Performance of SVM-L for stabilized soil with QD and lime

Group	Dependent variable	Independent variables	RMSE	R ²	MAE
A		QD, lime, CP, OMC, MDD	5.38	0.77	4.53
B		QD, lime, OMC, MDD	5.34	0.77	4.48
C		lime, OMC, MDD	5.25	0.78	4.32
D	Observed CBR	QD, OMC, MDD	5.57	0.75	4.51
E		QD, lime, MDD	5.19	0.79	4.24
F		QD, lime, OMC	5.28	0.78	4.36
G		QD, lime	5.96	0.72	4.85
H		OMC, MDD	5.86	0.73	4.73

3.2.4.2 STABILIZED SOIL WITH RHA AND LIME

From analysis SVM-C, the results of RMSE, R² and MAE of SVM-C analysis are provided in Table 11. The values of 2.37, 0.97 and 2.00 were found for RMSE, R² and MAE, respectively, for the independent variable in group A (RHA, lime, CP, OMC, MDD). After that the independent variables were eliminated one or more and rearranged successively at various combination of variables designated as group B, C, D, E, F, G and H to get best R² of stabilized soils with RHA and lime (Table 11). From Table 11, it can be observed that the group A (RHA, lime, CP, OMC, MDD) showed the best R² with 0.97 which is almost close to 1 with its best RMSE 2.37 (lowest value) and MAE 2.00 (lowest value). Therefore, group A (RHA, lime, CP, OMC, MDD) is considered as best of SVM-Q as compared to B, C, D, E, F, G and H.

Table 11: Performance of SVM-C for stabilized soil with RHA and lime

Group	Dependent variable	Independent variables	RMSE	R ²	MAE
A		RHA, lime, CP, OMC, MDD	2.37	0.97	2.0
B		RHA, lime, OMC, MDD	2.64	0.97	2.23
C		lime, OMC, MDD	2.41	0.97	2.17
D	Observed CBR	RHA, OMC, MDD	8.93	0.62	7.42
E		RHA, lime, OMC	3.01	0.96	2.58
F		RHA, lime, MDD	2.94	0.96	2.32
G		RHA, lime	2.94	0.96	2.32
H		OMC, MDD	5.01	0.95	2.65

3.3 OPTIMUM CONTENT OF ADMIXTURES

In this study, the stabilized soils were prepared using QD with lime and RHA with lime. The values of maximum CBR for stabilized soil with QD (40%) and lime (4%) were obtained as 77.54, 83.27 and 98.26% at curing period of 0, 7 and 28 days respectively, provided in Table 12.

Table 12: Obtained results of CBR of stabilized soil with QD and RHA

Stabilized soils with	Optimum content of admixtures	CBR (%) at varying curing period (days)		
		0	7	28
QD and lime	QD (40 %) Lime (4 %)	77.54	83.27	98.26
RHA and lime	RHA (12 %) Lime (4 %)	50.1	52.5	58.41

Moreover, the values of maximum CBR were obtained of 50.1, 52.5 and 58.41% for stabilized soil with RHA (12%) and lime (4%) at curing period of 0, 7 and 28 days, respectively. The maximum CBR (98.26%) was found for stabilized soil with QD and lime at curing period 28 days than other mixing

content and curing periods used in this study. Therefore, the higher CBR was found for stabilized soil with QD and lime than that of stabilized soil with RHA and lime.

3.4 FINAL SELECTION OF MODEL OF THIS ANALYSIS

The values of R^2 were found as 0.798, 0.872, 0.995 and 0.90 for SLR, MLR, ANN and SVM, respectively, for prediction of CBR of stabilized soil with QD and lime (Table 13). Moreover, the values of R^2 were found as 0.908, 0.95, 0.998 and 0.97 for SLR, MLR, ANN and SVM, respectively, for prediction of CBR of stabilized soil with RHA and lime.

From stabilized soil with QD and lime, the best R^2 was found 0.995 from ANN analysis as compared to SLR, MLR and SVM analysis. Moreover, from stabilized soil with RHA and lime, the best R^2 was found 0.998 by ANN as compared to SLR, MLR and SVM analysis. Therefore, ANN modeling gets its superior priority as the best performer to predict CBR of stabilized soil using QD and lime as well as RHA and lime. A research conducted by [18, 19, 20] as well as found the best model of ANN as compared to SLR, MLR and SVM. That means, the findings of this study was near about the findings of both researchers. Finally, the findings of this research are clearly agreed with these research that conducted by [18, 19, 20].

Table 13: Final models for analysis of stabilized soil with admixtures

Admixture	R^2 of SLR		R^2 of MLR		R^2 of ANN		R^2 of SVM		Selected model	
	Present study	Literature	Present study	Literature	Present study	Literature	Present study	Literature	Present study	Literature
QD and lime	0.798	--	0.872	0.933	0.995	0.981	0.90	0.98	ANN	ANN
RHA and lime	0.908	0.624	0.95	0.882	0.998	0.985	0.97	--	ANN	ANN
Reference of literature	-	Bhatt et al., 2014	--	(Sabat, 2013) and (Bhatt et al., 2014)	--	(Sabat, 2013) and (Ali et al., 2016)	--	Sabat, 2015	--	Sabat, 2013

4.0 CONCLUSION

Result reveals OMC of stabilized soil with QD and lime decreases, while, OMC increases in case of stabilized soil with RHA and lime. In addition, MDD of stabilized soil with QD and lime increases, while, MDD decreases in case of stabilized soil with RHA and lime. The optimum content 40% and 4% was found for QD and lime, respectively, at varying curing periods to obtain better CBR of stabilized soil with QD and lime. Moreover, the optimum content of RHA was found 12% and lime of 4% at varying curing periods to obtain better CBR of stabilized soil with RHA and lime. The optimum contents of QD and RHA with lime can be used to stabilize soils with further trial. The result of ANN analysis reveals that QD, lime and OMC were the best independent variables for the stabilization of soil with QD, while, RHA, lime, CP, OMC and MDD for stabilized soil with RHA. In addition, SVM proved QD and lime as well as RHA, lime, CP, OMC and MDD were the best independent variables for the stabilization of soil with QD and RHA, respectively. The observed CBR and selected independent variables can be expressed by a series of developed equation of reasonable degree of accuracy and judgement from SLR and MLR

analysis. The model ANN showed comparatively the better values of CBR with satisfactory values of prediction parameters as compared to SLR, MLR and SVM for the prediction of CBR of stabilized soils. Therefore, the selected optimum content of admixtures and newly developed techniques of soft computing systems will further be used of other researchers to stabilize soil easily and then predict CBR of stabilized soils.

5.0 ACKNOWLEDGEMENT

The authors gratefully acknowledged the financial, logistics and technical support provided by Khulna University of Engineering & Technology (KUET), Khulna, Bangladesh for the completion of this research successfully. Special thanks to Engr. Animesh Chandra Roy, Post-graduate student, Department of Civil Engineering, KUET, for his valuable time and kind efforts throughout the research periods.

REFERENCES

- [1] Venkatasubramanian, C. and Dhinakaran, G. 2011. ANN Model for Predicting CBR from Index Properties of Soils, *International Journal of Civil and Structural Engineering*, Integrated Publishing Association (IPA), 2 (2): 605-611.
- [2] Joel, M. and Agbedi, I. 2011. Mechanical-Cement stabilization of laterite for use as flexible pavement material, *Journal of Material in Civil Engineering*, Vol.23, No.2, pp.146-152.
- [3] Hebib, S. and Farrell, E.R. 1999. Some Experiences of Stabilizing Irish Organic Soils. *Proceeding of Dry Mix Methods for Deep Soil Stabilization* (pp. 81-84).
- [4] Rajasekaran, G., and Narasimha Rao, S. 2000. Strength characteristics of lime-treated marine clay. *Proceedings of the Institution of Civil Engineers-Ground Improvement*, 4(3), 127-136.
- [5] Dash, S. K. and Hussain, M. 2011. Lime stabilization of soils: reappraisal. *Journal of materials in civil engineering*, 24(6), 707-714.
- [6] Taskiran, T. 2010. Prediction of California bearing ratio (CBR) of fine grained soils by AI methods, *Advances in Engineering Software*, Vol.41:886-892.
- [7] Bhatt, S., Jain, P. K., & Prades, M. 2014. Prediction of California Bearing Ratio of Soils Using Artificial Neural Network. *American International Journal of Research in Science, Technology, Engineering & Mathematics*, 156-16.
- [8] Sudhir, B. and Pradeep, K. J. 2014a. Prediction of California Bearing Ratio of Soils Using Artificial Neural Network. *American International Journal of Research in Science, Technology, Engineering & Mathematics*. ISSN (Print): 2328-3491, ISSN (Online): 2328-3580, ISSN (CD-ROM): 2328-3629.
- [9] Sudhir, B. and Pradeep, K. J. 2014b. Prediction of California Bearing Ratio of Soils Using Artificial Neural, *Transportation Research Record* (1219), 56-67.
- [10] Samui, P., Das, S. K. and Sabat, A. K. 2011. Prediction of field hydraulic conductivity of clay liners using an artificial neural network and support vector machine. *International Journal of Geomechanics*, 12(5), 606-611.
- [11] Afrin, H. 2017. A Review on Different Types Soil Stabilization Techniques. *International Journal of Transportation Engineering and Technology*, 3(2), 19.
- [12] Jay, p., Kusum. K. and Vijay, K. 2017. Stabilization of Soil Using Rice Husk Ash. *International Journal of Innovative Research in Science, Engineering and Technology*, Vol. 6, Issue 7, July 2017.
- [13] Rakaraddi, P. G., and Gomarsi, V. 2015. Establishing relationship between CBR with different soil properties. *International journal of research in engineering and technology*, 4(2), 182-188.
- [14] Smarten, (2018). The SVM Classification Analysis and How Can It Benefit Business Analytics. (Source, <https://www.elegantjbi.com/blog/what-is-svm-classification-analysis-and-how-can-it-benefit-business-analytics.htm>, October 16, 2018).
- [15] Rajkumar, C. and Meenambal, T. (2017). Artificial neural network modelling and economic analysis of soil subgrade stabilized with flyash and geotextile. *Indian journal of GEO Marine Science*. Vol. 46 (07), July 2017, 1454-1461.
- [16] Sarapu, D. 2016. Potentials of Rice Husk Ash for Soil Stabilization, *International Journal of Geomechanics*, 12(5), 606-611.
- [17] Al-Joulani, N. 2012. Effect of stone powder and lime on strength, compaction and CBR properties of fine soils. *Jordan Journal of Civil Engineering*, 6(1), 1-16.
- [18] Sabat, A. K. 2013. Prediction of California bearing ratio of a soil stabilized with lime and quarry dust using artificial neural network. *Electronic Journal of Geotechnical Engineering*, 18, 3261-3272.
- [19] Sabat, A. K. 2015. Prediction of California bearing ratio of a stabilized expansive soil using artificial neural network and support vector machine. *Electron. J. Geotech. Eng*, 20, 981-991.
- [20] Ali, B., Rahman, M. A., and Rafizul, I. M. 2016. Prediction of California Bearing Ratio of Stabilized Soil using Artificial Neural Network. *Proceedings of the 3rd International Conference on Civil Engineering for Sustainable Development (ICCESD 2016)*, (ISBN: 978-984-34-0265-3).