Correlation of CBR Values with Soil Index Properties by Regression Model using Soft Computing Techniques

Heena Malhotra, Janmeet Singh, Himanshu Jaiswal

Abstract: The spatial variation of soil properties is beyond the designer's control. Designer often feel discomfort before reaching at any conclusion and totally rely on the soil testing. This soil investigation takes much longer time and resources of a project. So geotechnical engineers usually attempts to develop empirical equations. But these empirical equations are more specific to the location & type of soil. However the empirical relation is useful for future projects coming in the vicinity. In road construction, civil engineers always encounter difficulties in obtaining representative CBR value for design of pavement. The type of soil is not the only parameter which affects the CBR value, but it also varies with different soil properties possessed by the soil. Laboratory CBR test requires relatively large effort to conduct the test and it is time consuming. Currently, many road construction projects and railway constructions are undergoing in the country. In light of this, the output of the proposed correlation will provide road authorities, railway authorities, consultants and contractors preliminary background information on the value of CBR, for a localized sub-grade material, from soil index properties with a benefit of time saving and without incurring any additional cost for carrying out laboratory CBR test. As a result, our present study aims to find the correlation between CBR values with soil index properties. So to develop correlation, Single line regression (SLR) & Multiple line regression (MLR) is done to correlate CBR value with soil index properties and their precision is examined by Statistical data analysis tool. Accordingly, 100 disturbed samples were collected from different location of Haryana district and required laboratory test have been conducted in order to establish an equation of CBR as a function of grain size parameters, atterberg limit by considering the effect of an individual soil properties and effect of combination of soil properties on the CBR value. The developed correlation lead to a regression value of R^2 = 0.729, using SLR, while MLR generated relatively an improved value of R^2 = 0.650. After validating the established correlation with other empirical equation developed by other researchers, it was observed that correlation of CBR value with soil Indian properties is more applicable for preliminary characterizing the soil strength.

Keywords: California Bearing Ratio (CBR), Regression, Index Properties

I. INTRODUCTION

During the early 1920's, California Bearing Ratio (CBR) test was developed by O. J. Porter for the California Highway Department to evaluate the bearing capacity of pavement materials in laboratory conditions. California Bearing Ratio (CBR) is a common and comprehensive test currently practiced in the design of pavement to assess. The stiffness modulus and shear strength of sub-grade material so as to determine the thickness of overlying pavement layers. Since then, several countries have developed or adopted pavement design methods based on the CBR value of the materials. The CBR value is defined as the ratio between the applied load and the standard load of standard crushed rock for the plunger to reach the same depth.

$$CBR = \frac{Applied\ load}{Standard\ load} \times 100 \qquad (1)$$

The CBR test is time-consuming and is infrequently performed due to the equipment needed and the fact that the field moisture content keeps changing over time. Type of soil is not the only parameter which affects the CBR value, but it also varies with different soil properties possessed by the soil. Over the years, many correlations have been developed for the prediction of CBR by various researchers. A method is proposed for correlating CBR values with the Liquid Limit, Plastic Limit, Plasticity Index, Optimum Moisture Content, and Maximum Dry Density. The correlation is established in the form of an equation of CBR as a function of different soil properties by the method of regression analysis and then comparison is done between the experimental results and calculated results.

In the current study, the CBR test was performed in the laboratory on some fine-grained sub-grade soils collected from various locations in Haryana. Based on the test results, a satisfactory empirical correlation was found between the CBR and the index properties of the experimental soils.

II. METHODOLOGY OF THE STUDY

Primarily, in order to address the intended objectives of the study, basic theories and descriptions of CBR test in general and in relation to soil index property of sub-grade soil is reviewed. Subsequently, previous works of different researchers with regard to prediction of CBR value from basic soil index properties were assessed. Statistical regression analyses of test results are carried out and correlations are developed and also analyzed to fit the test results. Under the discussions of the obtained results the suitability of the developed correlations are examined. Finally, generalized conclusions and recommendations are made.

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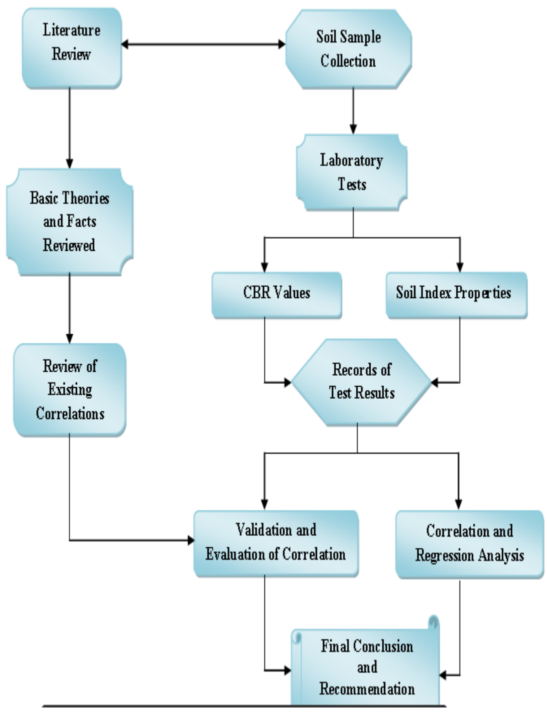

Figure 1: Methodology of the Study

III. EXISTING CORRELATIONS

Many researchers and agencies developed relationships between CBR with soil index parameters on the basis of samples obtained from a specific region and soil type. General relationships are also developed using universally accepted soil classification systems, basically based on the Unified Soil Classification System (USCS) and American Association of State Highway and Transportation Officials (AASHTO) systems. These correlation methods take a general approach and attempt to encompass many or all possible soil types.

3.1. Universal Approaches Based on Soil Classification Systems

The Unified Soil Classification System is a standardized technique for classifying soils for engineering purposes. Within this system, soils are classified based on the distribution of their grain sizes and the plasticity characteristics of the cohesive material. It should be stressed that the USCS is a systematic and repeatable classification strictly based on test measurement values defined in the ASTM standard. As such, the USCS class of a soil is inherently tied to the soil properties by which it is defined. In the USCS system, soils are divided in three categories; coarse-grained (either gravel or sand), fine-grained (either silt or clay) and highly organic soils as shown in Table 1.

Guidelines for choosing CBR values based solely on USCS soil type are found throughout different literature. A variety of USCS class soils are associated with a range of CBR values by different researchers and research institutes. A summary of reported values from several of these sources is shown in Table 2. Generally, these are consistent for each soil type, with minor differences among the reported values. Part of this variation may be due to the fact that some refer to compacted soils, others refer to field-measured CBR values, while some do not specify test conditions.

Table 1: Symbols in the Unified Soil Classification System

Symbols	G	S	M	C	O	Pt	H	L
Description	Gravel	Sand	Silt	Clay	Organic Clay/ Slit	Peat	High Plastic	Low Plastic

Table 2: Typical California Bearing Ratio Values Based on Unified Soil Classification

US CS Soil Type	USA CE, US Army & Air Force	Yoder & Witczalk	US Army, Air Force & Navy and PCA	Rollings & Rollings	NCHRP
GW	**40-80**	**60-80**	**60-80**	**60-80**	**60-80**
GP	**30-60**	**35-60**	**25-60**	**35-60**	**35-60**
GM	**20-60**	**40-80**	**20-80**	**40-80**	**30-80**
GC	**20-40**	**20-40**	**20-40**	**20-40**	**20-40**
SW	**20-40**	**20-40**	**20-40**	**20-50**	**20-40**
SP	**Oct-40**	**15-25**	**25-Oct**	**25-Oct**	**15-30**
SM	**Oct-40**	**20-40**	**Oct-40**	**20-40**	**20-40**
SC	**20-May**	**20-Oct**	**20-Oct**	**20-Oct**	**20-Oct**
ML	**15 or less**	**15-May**	**15-May**	**15-May**	**16-Aug**
CI	**15 or less**	**15-May**	**8-Apr**	**8-Apr**	**15-May**
OL	**5 or less**	**8-Apr**	**8-Apr**	**8-Apr**	**--**
MH	**10 or less**	**8-Apr**	**5-Mar**	**5-Mar**	**8-Feb**
CH	**15 or less**	**5-Mar**	**5-Mar**	**5-Mar**	**5-Jan**
OH	**5 or less**	**5-Mar**			**--**
Pt	**--**	**--**	**--**	**< 1**	**--**
CL-ML	**--**	**--**	**--**	**--**	**--**
GW-GM	**--**	**--**	**--**	**--**	**35-70**
GW-GC	**--**	**--**	**--**	**--**	**20-60**

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GP-GM	--	--	--	--	**25-60**
GP-GC	--	--	--	--	**20-50**
GC-GM	--	--	--	--	
SW-SM	--	--	--	--	**15-30**
SW-SC	--	--	--	--	**25-Oct**
SP-SM	--	--	--	--	**15-30**
SP-SC	--	--	--	--	**25-Oct**
SC-SM	--	--	--	--	--

3.2. AASHTO Group Index Value as Indicator of Suitability of Sub-Grade

Group index value (GI) is an indicator of suitability of sub-grade soil for highway construction. Different soil class under AASHTO classification are generally rated for sub-grade suitability from excellent to good for coarse graded material and good to poor for fine graded soil. This parameter used as a general guide to the load bearing capacity of a soil. The group index is a function of the liquid limit, the plasticity index and the amount of material passing 0.075mm sieve size.

$$GI = (F-35)\,[0.2+0.005(w_1-40)]+0.01(F-15)(I_P-10) \quad (2)$$

Where,

F= Percentage passing sieve no. 200 (size 0.075 mm), whole number

W_1= Liquid limit, expressed as a whole number

I_p = Plasticity Index, expressed as a whole number

IV. CBR PREDICTION & VALIDATION BY DIFFERENT RESEARCHERS

Soil properties such as particle size distribution, atterberg limits, density and moisture content were collected for the analysis and substituted into the existing correlations to find the estimated CBR values. The estimated CBR values which derived from the existing correlations were compared with the CBR values obtained from the laboratory. Comparison results were reported and discussed in the study to evaluate the appropriateness of the correlation cohesive soil CBR value is correlated with plasticity and liquidity index (Black: 1962), liquid limit and gradation characteristics of soil (Vinod and Cletus; 2008). Pradeep Muley and Jain (2013) developed a correlation to predict CBR of stone dust mixed poor soil. Roy et.al; 2010 and Hakari and Nadgauda; 2013 correlated the CBR value by using presumptive design chart and Nomography as per IRC SP: 37-2007. Patel et.al (2010), Venkatasubramanian and Dhinakaran (2011), Ramasunnarao and Siva Sankar (2013), Akshay (2013), and Dilip Kumar Tulukdar (2014) had developed multiple liner regression analysis models (MLRA) for correlating CBR with index properties of soil.

In the present paper, an attempt is made to bring up the correlations of CBR with soil index properties. These types of correlations can help the designer to choose appropriate CBR value and cross verify the CBR value obtained from the laboratory testing. Along with the soil test data, some of the existing correlations are made use for further improvement of the correlations. Existing correlations for CBR are made use to validate the laboratory CBR values The existing correlations for CBR were developed based on the soil parameters such as liquid limit, plasticity index and OMC by:

Agarwal and Ghanekar (1970)developed a correlation between CBR values with the basic index properties such as Liquid Limit (LL) and Plasticity Index (PI). However, it is felt that exact information about soil LL and PI are essential to make use of the correlations for prediction of CBR. Further for prediction of CBR of a soil, they made a correlation between CBR, OMC and LL also was proposed. Instead, finally they found an improved correlation when they included the optimum moisture content and liquid limit. The correlation is defined as below.

$$CBR = 2\text{-}16 \log(OMC) + 0.07(LL) \quad (3)$$

where,

OMC = Optimum Moisture content and LL= Liquid limit

Patel and Desai (2010) had proposed a correlation between plasticity index, maximum dry density and optimum moisture content:

$$CBR = 43.907-0.093(PI) - 18.78\,(MDD) - 0.3081(OMC) \quad (4)$$

V. REGRESSION ANALYSIS AND CORRELATIONS: METHODOLOGY ADOPTED

Regression analysis is a statistical technique that is very useful in the field of engineering and science in modeling and investigating relationships between two or more variables. The method of regression analysis is used to develop the line or curve which provides the best fit through a set of data points. This basic approach is applicable in situations ranging from single linear regression to more sophisticate nonlinear multiple regressions. The best fit model could be in the form of linear, parabolic or logarithmic trend. A linear relationship is usually practiced in solving different engineering problems because of its simplicity.

In this research work, an attempt is made to apply single linear regression model and multiple linear regression models to characterize the strength of sub-grade soil from soil index parameters using a statistical approach. The general representation of a probabilistic single and multiple linear regression models are presented in the following forms:

$$Y= \beta_0 +\beta_1 +\varepsilon \quad (5.a)$$

$$Y= \alpha_0 +\alpha_1 x_1+\alpha_2 x_2 \ldots\ldots + \alpha_n x_n+\varepsilon \quad (5.b)$$

Where, the slope (β_1) and intercept (β_0) of the single linear regression model are called regression coefficients. Similarly, coefficients α_0, α_1, α_2 and α_n are termed multiple regression coefficients. The appropriate way to generalize this to a probabilistic linear model is to assume that the actual value of Y is determined by the mean value function (the linear model)

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Plus the random error term, ε. The basic assumption to estimate the regression coefficients of the single and multiple regression models is based on the least square method.

5.1. Single Linear Regression Analysis (SLRA)

To establish relation between soaked CBR and different soil properties, graphs are plotted with CBR against different soil parameters and suitable trend line is drawn with higher correlation coefficient. Correlation quantifies the degree to which dependent and independent variables are related. Linear regression quantifies goodness of fit with R^2 value. R^2 value provides a measure of how well future outcomes are likely to be predicted by the model. Any correlation with R^2 value more than 0.80 will be viewed as a best fit.

5.2. Correlation Between CBR and Different Soil Index Properties

The resulting regression analysis after correlating CBR with index properties is expressed by the following single linear equation with its corresponding correlation coefficients:

Model 1:

CBR= 6.30(MDD) – 9.93, R^2= 0.89 (6.a)
CBR= 0.1759(PI) +0.9763, R^2= 0.91 (6.b)
CBR= 0.1951(OMC) +0.043, R^2= 0.72 (6.c)
CBR= 0.1422(LL) – 1.8153, R^2= 0.55 (6.d)

Model 2:

CBR= 11.341(MDD) – 27.503, R^2= 0.79 (7.a)
CBR= 0.2977(PI) +6.9729, R^2= 0.91 (7.b)
CBR= 0.7403(OMC) +2.9083, R^2= 0.72 (7.c)
CBR= 0.2894(LL) – 13.297, R^2= 0.34 (7.d)

The fine-grained soils data used in the analysis have optimum moisture content within the range of 9.8% to 24.8% and maximum dry density of 14.5 kN/m^3 to 20.5 kN/m^3. It is observed that the maximum dry density will be lower if the optimum moisture content is getting higher. As the maximum dry density can be correlated with the optimum moisture content, it is a good indication that these soil properties can be used to find a CBR correlation with these soil properties. The details of the statistical output indicates that the relationship developed between soil index properties and CBR is significant as α <0.05 as shown in Model-1 & Model-2.

5.3. Multiple Linear Regression Analysis

To develop the models of multiple linear regression analysis soaked CBR value is considered as independent variable and soil properties such as Gravel (G), Fines (F), Sand(S), LL, PL, MDD and OMC are considered as the dependent variables. MLRA has been carried out by considering soaked CBR value as the independent variable and the rest of soil properties as dependent variables. MLRA can be carried out using standard statistical software like data analysis tool in order to derive the relationship statistically. During analyzing the multiple linear regressions, after going through a number of alternative combinations of predictors the following results are obtained for the 100 samples and the significant relationships are presented hereunder:

CBRs = fn (LL, PL, MDD, OMC) (8)

The objective function for applying genetic algorithm in this research study will be formulated as follows:
Y is directly proportional to the variables x_1, x_2, x_3, x_4 & x_n.
So, the equation created will be
$y= b_0+b_1x_1+ b_2x_2 +b_3x_3 +b_4x_4 \ldots\ldots b_nx_n$ (9)
where, y = California bearing ratio(%)

5.4. Correlation between CBR with MDD and OMC

The resulting regression analysis after correlating CBR with MDD and OMC is expressed by the following multiple linear equations with its corresponding correlation coefficients:

Model 1(a)

CBR = 59.11MDD- 4.53OMC+ 0.924, R^2= 0.68, (10.a)

Model 2(a)

CBR = 12.93MDD- 4.53OMC+0.3.282, R^2= 0.62, (10.b)

The details of the statistical output of Model 1(a) and 2(a) indicates that the relationship developed between CBR with MDD and OMC is significant as α <0.05. Besides the R^2 value of the multiple regressions analysis is improved than the R^2 value of the individual parameters.

Table 3: Evaluation of the Developed and Existing Correlations

Sample No.	Actual CBR Value [A]	Developed Correlation		NCHRP	
		Predicted CBR Value [B]	Variation (%) [B-A]*100/A	Predicted CBR Value [C]	Variation (%) [C-A]*100/A
1	2.9	5.1	75.86	4.8	65.52
2	2.6	3.8	47.29	3.9	51.16
3	6.0	7.9	31.23	3.1	-48.50
4	3.0	4.7	57.19	4	33.78
5	2.7	3.8	39.71	5.5	102.21
6	2.6	4.9	85.61	4.4	66.67
7	2.4	5.1	108.45	7.8	218.80
8	5.0	6.9	38.28	5.6	12.22
9	3.9	4.8	23.08	4.8	23.08
10	2.1	3.9	87.37	2.3	10.50
AVG	3.33	5.09	59.41	4.62	53.54

As a preliminary validation of the correlations developed and depicted in Table3, the CBR values resulting from these correlations were compared to the ranges of CBR values recommended for materials defined by the USCS classification system in Table 2. It is important to note that the CBR ranges recommended in Table 1 for the USCS materials were not used as a data source to develop the CBR correlations in this report. Therefore, it is a valid source for validation of the results obtained. The Table 3 shows the CBR calculated by the correlations and the CBR ranges calculated by equation 3, 4, 6 & 7 and by experimental methods. All of the CBR calculated values fall inside the range recommended, and therefore the correlations may be viewed as being quite reliable and consistent between all of the hierarchical sources of data used in the analysis.

VI. CONCLUSION

Field CBR testing is a time-consuming operation requiring a skilled operator, and can be hazardous for the evaluation teams in hostile environments. Limited amounts of published CBR data are available. Engineers always experience difficulties in obtaining representative CBR values for design. Due to limited budgets and poor planning conditions, insufficient soil investigation data are obtained in many cases. On the other hand, the laboratory CBR test is not only laborious and time consuming, but, sometimes, the results are not accurate due to the sample disturbance and poor quality of the laboratory testing conditions. Therefore, the development of prediction models might be useful and become a base for the judgment of the validity of the CBR values. Therefore these equations can be applicable for preliminary characterization of soil strength.

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