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DEVELOPMENT OF EMPIRICAL CORRELATIONS BETWEEN INDEX AND STRENGTH PROPERTIES FOR INDIGENOUS SUBGRADE SOILS

[a] Zakirullah*, [b] Kashif Riaz, [c] Muhammad Bilal, [d] Naveed Ahmad

[a, b,c,d](Department of Civil Engineering ,University of Engineering and Technology, Taxila)

* Corresponding author: Email ID: zakir6897@gmail.com

Abstract-The California Bearing Ratio (CBR) is an important design parameter for the subgrade layer in a flexible pavement structure. Determination of CBR value is a very common laboratory test to estimate the stiffness modulus and shear strength of sub-grade soil for the pavement design. CBR test is technically an extensive and time-consuming process and may lead to delay in execution of construction projects and thus cause an increase in construction costs. Therefore, it is extremely important for the geotechnical engineer to develop a predictive model for quick assessment of geo-material behavior which is used in civil infrastructures. In this study, an attempt has been made to develop regression models both Single and Multiple linear Regression Analysis (SLRA & MLRA) to determine the soaked CBR value from soil basic properties like Liquid limit, Plastic limit, Plasticity index, optimum moisture content, and Maximum Dry Density of some subgrade sample gathered from twenty-one different locations of Rawalpindi Division, Pakistan. From both SLRA and MLRA models coefficient of correlation, the R^2 value is found in between (0.80 –0.98) indicating a very good correlation between soaked CBR and soil basic properties. Predicted CBR values were also compared with actually calculated values and a very good agreement was found between the two.

Keywords- SLRA, MLRA, Predictive, LL, PL, PI, OMC, MDD, soaked CBR.

1 Introduction

The transportation systems usually act as a backbone of a country. The Road network covers a large portion of the transportation system, as most of the freight is transported through roads. One of the primary elements in the road networks is the pavement. The performance of the road pavement depends upon the strength of the subgrade material. Subgrade serves as a suitable foundation of the pavement structure, which is a compacted layer of natural local soil deposit from the borrow pits. Load from the moving vehicles on the road surface is ultimately transferred to the subgrade that may be a natural soil deposit of compacted fill material. [1] The suitability of subgrade soil is typically evaluated before the beginning of construction activity starts. Geographical variations in soil properties from one location to another make it to carry out investigation for its suitability for the intended purpose. [2] Statistical empirical correlations play a vital role in civil engineering analysis and designs.

The correlation model development is advantageous and acts as a foundation for the judgment of the validity of the CBR values. In past, many researchers have developed the correlation model for the prediction of CBR value through some of the basic soil properties obtained from Atterberg's limits test and compaction tests like LL, PL, PI, MDD, and OMC. Some prediction models for the determination of the CBR value from literature are presented in Table 1.

Table 1- Correlations of CBR with Soil Index properties

Ref No	Proposed correlations	No. of Materials used	Coefficient of Determinations (R^2)	Remarks
3	CBR= -0.01(LL)-0.425(PI)+1 CBR=O.79(Cu) + 8.5 CBR=0.7Cu +0.045MDD +3.4	59	0.9 0.8 0.8	Fine and coarse grain soil
4	CBR= -4.8353–1.56856(OMC) +4.6351(MDD)	20	0.82	Fine Grained Soils
5	CBR = 0.0262 (L.L) + 0.0283 (O.M.C) 0.142+ (%fines) +1.043(M.D.D)17.029	11	0.84	Well graded sand containing silt
6	CBR = – 0.728(PL) - 0.221(SL) – 0.341(MDD+ 1.126(OMC) +43.012 CBR=1.492(PL)-0.58(SL)–0.05(MDD) +0.398(OMC)+39.06	5	0.86 to 0.99	NA
7	CBR = - 0.172 (PI)+0.404 (MDD) - 0.089 (OMC) +3.51 CBR = 0.151 (FF)+0.045(PI) + 14.58	NA	NA	Fine Grained Soils
8	CBR = 1.04 (PL)+13.56 CBR = 0.22 (LL)+28.87 CBR = 50.28 (MMD)-70.22 CBR = 9.42 (SG)+10.91 CBR =10.43 (SG)+56.19	8	NA	lateritic soil(A-2-4)
9	CBR= [Fs+264PI^2-56PI-5](1.44-4.23PI) CBR =(8.44-16.1PI) [Fi+488PI^2-314PI+45]	24	NA	Fine Grained Soils (Silty Clay)
10	Log10(CBR) = 0.29(GM) - 0.024(PI) +1.23	NA	NA	Base coarse material
11	CBR = 11.805 - 0.126 (LL) + 0.234 (PL) -0.246(SL)	12	% Error=-25	Alluvial soil
12	CBR=-(0.014LL)- (0.015PI) +(0.011OMC) +(2.100MDD) -0.258	8	0.97	Fine Grained soils
13	CBR=2.19+0.062(FF) +0.0888(LL) CBR=17.029+0.142(FF)+0.0262(LL)+0.0283(OMC) +1.043(MDD	11	0.082 0.836	Well graded sand containing silt
14	CBR_{10}= -0.728(PL) -0.221(SL) 0.341(MDD)+1.126(OMC)+43.012 CBR_{30}= - 1.492(PL) -0.58(SL) -0.05(MDD) - 0.398(OMC)+39.0 CBR_{56}= -2.682(PL)+0.467(SL)+1.073(MDD)-0.233(OMC) -58.406	5	0.82 to 0.9	Fine grained soils
15	CBR=35.23$e^{-0.5(LL)}$	10	0.967	Fine and coarse grain soil

Where: CBR(%) = California Bearing Ratio , CBR(10,30,56)=CBR for 10,30 and 56 blows, Cu =Coefficient of Uniformity (Cu), LL(%)= Liquid Limit, PL(%)=Plastic Limit, PI(%)=Plasticity Index, OMC(%)= Optimum moisture content, MDD(%)=Maximum Dry Density, SG = Specific gravity; FF=% Fines; SL = shrinkage limit, F=Fines, %; S=Sand, %; G=Gravel, %Fi=initial state factor; Fs=soaking state factor.

2 MATERIALS AND METHODOLOGY

2.1 *Sample Collection*

Cumulatively twenty-one disturbed soil samples out of which 6 were collected from Rawalpindi (RWP), 5 from Attock (ATG), 5 from Chakwal (CHK), and 5 samples were collected from Jhelum (JMR) of the Rawalpindi Division, Pakistan having latitude 32.5˚N to 34.0˚N and longitude 72˚E to 74˚E at a depth of about 1m from the ground surface.

Figure 1: Study districts included in the Rawalpindi Division.

2.2 *Methodology*

Twenty-one different types of soil samples were collected from the district of Rawalpindi, Attock, Chakwal, and Jhelum. Soil samples were taken with the help of different sampling equipment's and almost 50 kg of soil sample was collected from each district site and then stored in plastic bags to avoid the loss of moisture content of the soil. Different means of transport were adapted for the transportation of samples depending upon site distance from the laboratory. All the Soil samples have been tested in the laboratory as per the specification of AASHTO to determine soil index and strength properties. Atterberg's limits test was conducted to obtain the value of liquid limit, plastic limit, and plasticity index of the soil. Grain size analysis was conducted by sieving the different types of soil samples through a set of sieves to obtain the values of % fines, % gravels, and % sands other particle size distribution characteristics of the soil. Modified proctor tests were used to determine the maximum dry density and optimum moisture content. Soaked CBR value obtains on the base of modified proctor test, soil sample compacted in the CBR mold according to MDD and OMC. Table.2 shows the laboratory testing program for this research study. Both single linear regression analysis and multiple linear regression analysis techniques are used for empirical relation and investigating the correlation between two or more variables.

Table 2: Laboratory Testing Program

S.NO	Test Names	Standard (AASHTO)
1	Grain Size Analysis	AASHTO T-88
2	Atterberg Limits	AASHTO T,89 T 90
3	AASHTO Soil Classification System	AASHTO M-145
4	Modified Proctor Test	AASHTO T-180
5	Soaked CBR Test	ASHTO T-193

3 RESULTS AND DISCUSSION

All 21 soil samples were tested for the development of empirical correlations between soil index properties and CBR according to AASHTO standards. A summary of the experimental results of the tested soil sample is given in Table 3. The grain size distribution of different soils showed that soil samples can be classified into fine-grained soil and coarse-grained soil. The gravel percentage ranges from 0-47, sand=1-78% and Fines (silt & clay) =21-98%. From Atterberg limit test results it was observed that the soil liquid limit lies in a range of 21-33%, plastic limit =17-21% and shrinkage limit 5-12%. Modified proctor test results of soil samples showed that OMC was ranging from 8-13% and maximum dry density 119-134 Ib/ft3. Soaked CBR test results indicated that overall CBR values were ranging from 5-11%. Soil samples were classified as A-4, A-3, A-6, and A-2-4 according to the AASHTO soil classification system.

Table 3-Results of Laboratory Test for Soil Samples

Soil Type	Sample ID	LL	PL	PI	GRIAN SIZE DISTRIBUTION			Compaction Characteristics		Soaked CBR value
AASHTO		%	%	%	Gravel (%)	Sand (%)	Fines, (%)	OMC (%)	γd_{max} (lb./ft^3)	%
A-4	RWP-1	30	19	10	1	3	96	13	121	6
A-4	RWP-2	28	20	8	6	5	88	13	125	7
A-4	RWP-3	29	20	9	6	8	86	12.5	120	6
A-4	CHK-1	24	17	7	1	34	65	9.5	129	10
A-4	CHK-2	27	19	8	3	7	90	12	129	8
A-4	RWP-4	23	17	6	0	42	58	9	128	8
A-4	ATG-1	28	19	5	0	4	96	11	126	8
A-4	ATG-2	30	21	9	0	2	98	12	119	6
A-4	RWP-5	25	18	6	3	6	91	10	130	9
A-4	ATG-3	26	17	9	2	5	93	10	128	8
A-4	RWP-6	29	20	9	1	2	97	12	122	7
A-4	CHK-3	28	19	8	0	3	97	12	125	7
A-6	ATG-4	33	22	12	0	2	98	15	119	5
A-4	CHK-4	30	21	10	0	8	92	13	120	6
A-6	CHK-5	31	20	11	0	28	72	14	122	6
A-2-4	JMR-1	25	18	7	15	46	39	11	132	10
A-2-4	JMR-2	28	17	8	48	30	23	13	133	9
A-3	JMR-3	23	NP	NP	17	64	19	9	135	10
A-2-4	JMR-4	21	NP	NP	0	78	22	9	134	10
A-2-4	ATG-5	26	NP	NP	2	72	26	11	127	8
A-2-4	JMR-5	28	NP	NP	0	78	22	13	120	7

4 Linear Regression Analysis (LRA)

The Linear Regression Analysis technique is used to formulate the correlation between CBR and other soil basic properties. The single linear regression analysis (SLRA) has one X-axis and one Y-axis variable. So CBR is taken as the dependent variable and plotted on Y-axis while soil basic properties like Liquid Limit, Plastic Limit, Plasticity Index, Optimum Moisture Content, and Maximum Dry Density are taken as independent variables and plotted on X-axis and then simple scatter graph is plotted on Microsoft Excel and the then suitable trend line is chosen based on the coefficient of determination of higher value. The multiple linear regression Analysis has one Y-axis and two or more X-axis variables. So for MLR by using statistical software SPSS version 2013 in which soaked CBR taken is a Dependent variable and other soil index properties like LL, PL, PI, OMC, and MDD are the Independent variables.

4.1 Single Linear Regression Analysis Models for CBR

In the SLRA model were chosen suitable scatter trend line and drawn scatter graph between soaked CBR and soil basic properties (LL, PL, and MDD) is presented fromFig.2 to Fig.4, and their correlations as shown in Table 5.The strength of these correlations were checked on basis of the coefficient of correlation R^2 according to criteria proposed by pellinen in Table 4.

From Fig.2 there is linear relationship exists between soaked CBR and Liquid Limit and it notice from this Fig with an increase in the liquid limit of soil soaked CBR value tends to decrease. The empirical correlation between soaked CBR and Liquid limit is presented in Table .5. It has regression coefficient, R2 = 0.8509. Fig.2 and (1) from Table.5 indicating very little scatter and good correlations according to criteria proposed by Pellinen in Table 4.

From Fig.3 there is are linear relationship exists between soaked CBR and Plastic Limit and.it notices from this Fig with an increase in the Plastic limit of soil soaked CBR value tends to decrease. The empirical correlation between soaked CBR and PL is presented in Table 4. It has a coefficient of correlation (R2) = 0.8085. Similarly, Fig.3 and (2) from Table 5, indicating very little scatter and good correlations according to criteria proposed by Pellinen in Table 4.

It is observed from Fig.4 that there are linear relationship exists between soaked CBR and MDD. It notices from this Fig as maximum dry density increases also CBR values increases. The correlation between soaked CBR and MDD is presented in Table 5. It has coefficient correlation, R2 = 0.9134. Fig.4 and (3) from Table 5 indicating very little scatter and good correlations according to criteria proposed by Pellinen in Table 4.

Table 4- Criteria for goodness of fit statistical parameters [16]

S.NO	Criteria	coefficient of correlation R^2
i.	Excellent	>0.9
ii.	Good	0.7-0.89
iii.	Fair	0.4-0.69
iv.	Poor	0.2-0.39
v.	Very Poor	<0.2

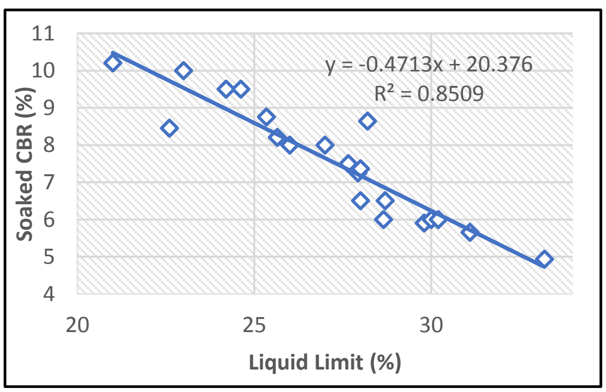


Fig. 2: Correlation between LL and Soaked CBR

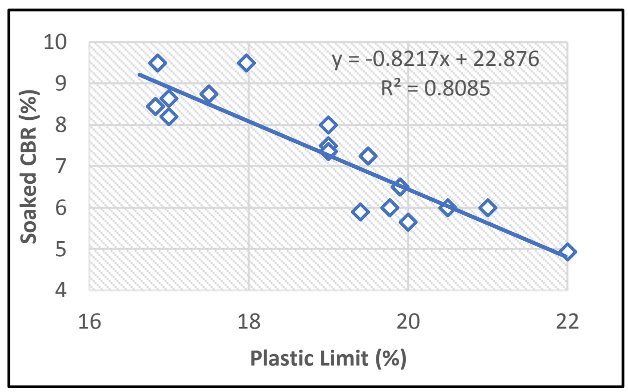


Figure 3: Correlation between PL and Soaked CBR

4.2 *Multiple Linear Regression Analysis Models for CBR*

In the MLRA by using IBM SPSS statistics software as a solver tool and soaked CBR taken as dependent variables and remaining soil properties as independent variables. With help of SPSS software were calculated acceptable empirical relation which as shown in Table 6.

Soaked CBR = (LL, PL, PI, OMC, and MDD)

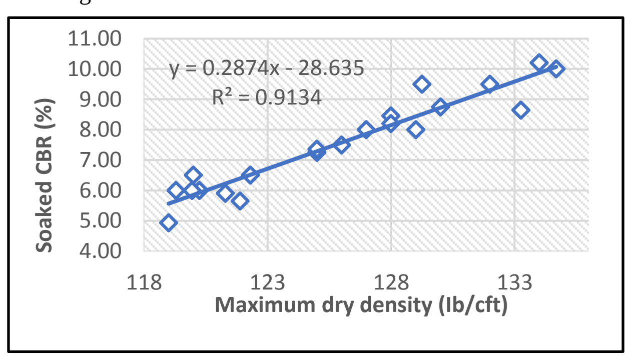


Figure 4: Correlation between MDD and soaked CBR

Table 5-Single Linear Regression

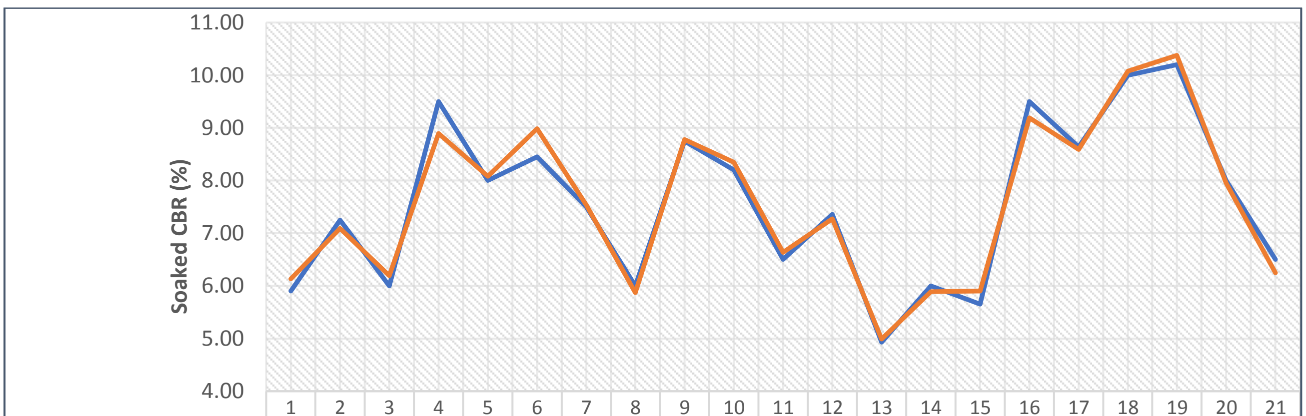
Equation No	Correlation	R^2
1	CBR= -0.4713(LL) + 20.37	0.8509
2	CBR= -0.8217(PL) + 22.876	0.8085
3	CBR= 0.2874(MDD)- 28.635	0.9134

Table 6-Multiple Linear Regression

Equation No	Correlation	R^2
4	CBR= -0.151(LL) + 0.019(PL) -0.048(PI) +0.180(MDD) -9.706	0.975
5	CBR= -0.159(LL)-0.127(OMC) +0.179(MDD)-9.191	0.977
6	CBR= -0.026(PL)-0.761(OMC) +16.720	0.760
7	CBR= -0.235(LL) + 0.172(MDD) - 7.724	0.975
8	CBR= -0.337(OMC) +0.207(MDD)-14.574	0.971

5 Validity of Regression Analysis Models

To check the validity of Regression Analysis Models by comparison between experimental soaked CBR and predicted Soaked CBR values. Predicted soaked CBR values were obtained on the basis of MLRA correlation from Table 6.
Eq.5 presents the correlation between Soaked CBR values and LL, OMC, and MDD. Based on (5) were calculated predicted Soaked CBR values. It is observed from Fig.5 that the predicted CBR values are very close to Experimental soaked CBR values and the coefficient of regression from (5) is (R^2)=0.977.



	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
Expermental CBR	5.90	7.25	6.00	9.50	8.00	8.45	7.50	6.00	8.75	8.20	6.50	7.36	4.93	6.00	5.65	9.50	8.64	10.00	10.20	8.00	6.5
Predictive CBR	6.13	7.09	6.19	8.89	8.08	8.98	7.54	5.87	8.78	8.35	6.64	7.27	4.99	5.89	5.90	9.19	8.59	10.08	10.38	7.95	6.25
%Error	3.79	-2.23	3.08	-6.86	1.03	5.95	0.48	-2.22	0.34	1.76	2.09	-1.22	1.20	-1.89	4.31	-3.39	-0.59	0.78	1.70	-0.58	-4.01

Fig.5: comparison b/w Experimental CBR and Predictive CBR for LL, OMC, and MDD

Eq.5 indicating a very good correlation according to criteria proposed by Pellinen in Table 4 and percentage error is less than 4%.Which can be successfully used for preliminary prediction of CBR value for locally available soils in Rawalpindi Division., Pakistan for sub-grade soils.

6 CONCLUSION

Following conclusions can be drawn from the conducted study:

- The present study's empirical relations can be used for the successful prediction of soaked CBR value for locally available soils in Rawalpindi Division., Pakistan.
- From Fig.2 through Fig.4 shows the effects of plasticity and compactions parameter on the soaked CBR value when Soaked CBR value tends to increases with the increase in the Maximum Dry Density. But soaked CBR values decrease with the increase in the Liquid limit, Plastic limit, Optimum moisture content, and Plasticity index.
- It is observed from the multiple linear regression models that is very small differences between the experimental soaked CBR values and predicted soaked CBR values and the coefficient of correlation R^2 is found above 0.80. This indicates is a very good relationship exists between soaked CBR value and soil basic properties according to criteria proposed by Pellinen in Table 4.

For the comprehensive model to make for Pakistani soils to predict CBR value from soil index properties by collecting more number of soil samples and types of soil from different locations of Pakistan.

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