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Experimental Study to Correlate Soaked CBR with Index and Engineering Properties of Black Cotton Soil of Madhya Pradesh

Pravin Kumar Kushwaha[1], Hemant Kumar Mahiyar[2]
M.E. Transportation Engineering, CE & AMD, S.G.S.I.T.S. Indore, Madhya Pradesh, India[1]
Professor, CE & AMD, S.G.S.I.T.S. Indore, Madhya Pradesh, India[2]

Abstract: California Bearing Ratio is main design input in pavement construction to predict the shear strength and stiffness modulus of subgrade materials. Technically, the California Bearing Ratio value can be carried out in the laboratory or in the field. But due to time consuming and high cost for conventional CBR testing, prediction of the CBR value from other geotechnical properties of soil become profitable.

In the present study, soaked value of CBR has been correlated with index and engineering properties for black cotton soil. The empirical correlation has been developed among the test results using Simple and Multiple Linear Regression Analysis from thirty five numbers of black cotton soil samples collected from eight districts of Madhya Pradesh, India. The soil properties studied are Specific Gravity, Liquid Limit, Plastic Limit, Free Swell Index, Unconfined Compressive Strength and Swelling Pressure are correlate with soaked CBR. Also, relationships for prediction of Unconfined Compressive Strength and Swelling from index properties were observed using simple and multiple linear regression analysis.

Keywords: CBR, UCS, SP, LL, PL, FSI, Correlation, Regression.

I. Introduction

Presently the infrastructure of India's is growing rapidly. In Civil Engineering works like the construction of highways, buildings, dams and other structure, proper analysis of the soil is important to ensure that these structures are safe and free from endue settling and fall. Soil formation and character are complex in nature and varies from place to place and over the time, therefore the exact prediction of its engineering behavior is in the interest of civil engineering field. The California Bearing Ratio (CBR) is a general and comprehensive test prevalent in the design of the pavements to evaluate the shear strength and stiffness modulus of subgrade materials to determine the thickness of the overlaying pavement layers. This test has been used for the decades and is familiar with the parties involved in the interpretation of the result, as a road design and construction. Civil Engineers in road construction always face difficulties in obtaining representative California Bearing Ratio value for the design of the pavement. Soil type is not the only parameter that affects the CBR value, but also varies with the soil properties obtained by the soil.

The California Bearing Ratio (CBR) is an indirect measure, which represents the comparison of strength of subgrade, sub-base and base course materials to the strength of the standard crushed rock quoted in percentage value. This method was originally developed by the California Division of Highway in 1930's as part of its study on pavement failure during World War II to assess the relative stability of fined rock material. Laboratory CBR testing requires a relatively large effort to carry out the test and is time consuming. The alternative method could be correlating the test results of CBR value with index and engineering properties of soil. These tests are more economical and faster than the CBR test. Several attempts have made on the prediction of the California Bearing Ratio (CBR) value from the other geotechnical properties of soil. Therefore, determining factors that affect the soil strength and deriving their relation with the CBR value in the representative sample may be considered as a good idea of soil behavior.

The present experimental work shall provide an overview to get correlation between CBR value with index and engineering properties of soil. Previous researches and investigation in the correlation of CBR with the other geotechnical properties of Black Cotton soil is limited to only particular districts and inadequate number of sample. Hence, objective of present research is focused on increasing the study area and number of samples.

At present, many projects of roads and railway constructions are undergoing in India. In light of it, the developed correlation will be useful to provide to the road authority, railway authority, contractors and consultant for the

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initial background information about CBR value for a locally available subgrade material from other geotechnical properties with the benefit of time and additional cost saving from carrying out CBR test in laboratory.

II. Experimental Investigation

This study consists of laboratory testing and analysis of the results. In this study, index and engineering properties of black cotton soil determined in laboratory as per Indian Standard (IS) specifications. The investigation steps are summarized as follows:

1. Thirty five numbers black cotton soil samples extracted from a depth of about 50 cm below the ground surface (both disturbed & undisturbed) and collected from eight district of Madhya Pradesh, India. These districts are Indore, Raisen, Bhopal, Sidhi, Dewas, Ujjain, Dhar and Jabalpur.

S.NO.	Sp.Gravity	Grain Size Analysis					Atterberg's Limit				FSI(%)	Proctor Test		CBR		Field		UCS(kg/sq.cm)		SP(kg/sq.cm)		K(e-07)(cm/s)
		Gravel(%)	Sand(%)	Silt(%)	Clay(%)	IS Classification	LL(%)	PL(%)	PI(%)	SL(%)		OMC(%)	MDD(gm/cc)	Unsoaked(%)	Soaked(%)	Moisture(%)	Density(gm/cc)	UDS	RMD	UDS	RMD	
1	2.61	7	7	70	16	MH	70	36	34	14	64	21	1.57	9.3	1.8	16.14	1.76	2.88	1.25	0.411	0.369	2.90
2	2.69	1	9	78	12	CH	63	31	32	16	57	18	1.64	5.3	2.2	12.67	1.67	3.63	1.67	0.483	0.282	1.56
3	2.64	5	17	66	13	CI	46	23	23	12	37	16	1.69	7.9	3.3	17.00	1.69	5.34	1.91	0.357	0.195	2.12
4	2.58	0	18	70	12	CH	57	27	30	13	51	19	1.72	5.6	2.9	18.97	1.99	7.60	1.77	0.251	0.261	4.01
5	2.65	3	21	61	15	CH	56	25	31	17	60	18	1.63	5.8	2.6	19.41	1.50	1.52	1.80	0.315	0.214	7.12
6	2.65	7	4	68	21	CH	57	26	31	13	59	19	1.67	7.9	3	11.30	1.94	1.31	1.64	0.478	0.249	8.18
7	2.67	1	13	69	17	CH	56	26	30	10	41	16	1.69	10.3	2.7	12.23	1.47	2.17	1.55	0.529	0.287	9.49
8	2.66	2	17	69	13	CH	52	27	25	8	40	18	1.68	5.8	3.4	14.46	2.07	3.69	1.76	0.366	0.175	9.34
9	2.61	6	14	73	7	CI	41	20	21	12	31	16	1.74	6.3	4.1	12.97	1.76	1.97	1.94	0.460	0.165	2.31
10	2.51	1	5	83	11	MH	65	36	29	15	55	19	1.68	4.9	2.2	17.85	1.91	2.83	1.61	0.363	0.264	5.75
11	2.59	4	17	57	22	CH	54	23	31	11	33	16	1.67	8.4	3.5	13.86	1.66	3.60	1.83	0.591	0.177	3.10
12	2.70	2	15	61	22	CI	45	22	23	10	34	18	1.72	9.9	4.0	17.34	1.39	1.54	2.15	0.599	0.156	8.60
13	2.71	3	10	80	7	CH	51	25	26	10	37	18	1.60	7.7	3.4	18.25	1.69	3.36	1.78	0.371	0.208	4.12
14	2.69	3	7	67	23	MH	61	38	23	13	57	21	1.55	5.2	1.7	19.72	1.89	2.82	1.47	0.211	0.371	4.75
15	2.68	3	14	63	20	CI	45	22	23	12	38	18	1.70	7.5	3.9	18.42	1.64	7.11	1.94	0.342	0.175	8.50
16	2.66	5	18	67	10	CH	59	30	29	9	53	18	1.70	7.2	2.4	15.39	1.98	3.84	1.51	0.355	0.237	2.00
17	2.67	4	15	64	17	CI	49	25	24	17	37	18	1.77	8.3	3.2	15.64	1.31	1.90	1.64	0.458	0.197	2.31
18	2.64	3	12	70	14	CI	47	21	26	13	49	19	1.55	6.0	3.0	11.68	1.51	3.42	1.73	0.538	0.199	8.55
19	2.59	5	5	77	13	CH	66	34	32	15	67	19	1.61	7.5	1.9	21.35	1.72	2.28	1.41	0.147	0.371	6.33
20	2.65	3	10	69	17	MH	59	32	27	13	39	19	1.58	6.0	2.1	13.83	1.98	4.22	1.64	0.399	0.294	7.44
21	2.62	0	20	60	20	CH	63	28	35	18	61	21	1.55	5.2	2.5	19.30	1.95	2.82	1.47	0.260	0.288	4.75
22	2.68	2	19	63	16	CI	48	27	21	13	40	18	1.73	5.8	3.1	19.11	1.74	4.18	1.82	0.363	0.221	3.97
23	2.68	1	15	76	7	CI	50	23	27	12	48	18	1.73	5.0	3.0	18.23	1.75	4.65	2.03	0.242	0.189	3.72
24	2.64	2	7	71	20	MH	65	39	26	11	67	18	1.63	4.2	1.8	22.16	1.44	1.45	1.75	0.093	0.207	7.67
25	2.66	1	6	62	31	MH	64	37	27	17	55	21	1.55	9.2	2.0	21.03	1.97	6.19	1.65	0.278	0.263	8.43
26	2.67	4	13	68	16	MH	54	31	23	13	57	18	1.73	5.1	2.3	18.04	1.98	3.71	1.56	0.264	0.197	3.97
27	2.64	1	2	81	16	MH	53	35	18	13	58	18	1.64	10.4	2.4	16.51	1.89	3.54	1.54	0.221	0.285	6.90
28	2.70	0	31	65	4	CI	45	24	21	8	30	15	1.65	7.7	3.4	16.30	2.11	2.59	1.79	0.307	0.098	4.55
29	2.71	5	8	60	17	CI	44	26	18	13	37	18	1.67	9.4	3.7	9.84	1.98	2.17	2.08	0.513	0.184	8.23
30	2.68	3	10	70	17	MI	48	28	20	10	41	16	1.64	7.0	3.5	18.70	1.99	2.10	1.81	0.259	0.241	7.82
31	2.52	1	9	75	15	MH	58	31	27	15	64	18	1.58	8.1	1.9	13.04	2.02	2.31	1.31	0.415	0.416	9.45
32	2.49	4	8	71	17	MH	60	30	30	13	50	16	1.63	6.1	2.9	16.95	1.58	2.43	1.88	0.255	0.196	9.40
33	2.64	0	4	85	11	CH	51	24	27	8	39	18	1.64	9.5	3.3	15.58	1.44	4.18	1.81	0.513	0.201	7.12
34	2.58	2	21	51	26	MH	53	31	22	16	50	18	1.63	7.3	2.8	11.23	2.03	2.44	1.72	0.465	0.239	7.49
35	2.54	1	2	78	20	MH	62	36	26	12	58	21	1.49	8.3	2.5	13.13	1.49	3.01	1.45	0.500	0.195	1.29

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2. The collected soil samples tested for Specific Gravity, Grain Size Analysis, Attreberg's Limit, Standard Proctor, Permeability, Free Swell Index, Swelling Pressure, Unconfined Compressive Strength (both disturbed & undisturbed), and California Bearing Ratio (CBR) as per IS 2720 and test results are summarized in Table 2.1.

III. DATA ANALYSIS, REGRESSION AND CORRELATIONS

After the determining the properties of black cotton soil were completed for each samples, the results have been examined to determine which index properties of black cotton soil showed stronger correlation with the CBR, UCS & Swelling Pressure (SP) value. In this study, Specific Gravity, Liquid Limit (LL), Plastic Limit (PL) and Free Swell Index (FSI) considered as independent variables and Unconfined Compressive Strength, Swelling Pressure and California Bearing Ratio value considered as dependent variables.

Initially to carry out the analysis of thirty five samples using regression analysis, a scatter plot is generated by using the excel spread sheet and shown in figure 3.1 in order to identify the relationship between the independent variables and dependent variables, so as to identify the model or equation that the best suited for the test results.

The scatter diagrams show that, although there is no simple curves that exactly passes through all the points but there is a reasonable indication that, all points spread around the straight line, especially when CBR value plotted with liquid limit, plastic limit, FSI, swelling pressure and UCS, and when UCS value plotted with liquid limit and swelling pressure and when swelling pressure value plotted with liquid limit and FSI. The above mentioned scatter diagram shows an approximately linear variation therefore, a linear model presenting to correlate the subject parameters.

In this research work, the simple linear regression and multiple linear regression models has used to predict the soaked CBR from the index and engineering properties of soil. The generalised form of single and multiple regression models have represented by equation (1) and (2).

Simple Linear Regression: $Y = C + aX + u$ ………………..(1)
Multiple Linear Regression:
$Y = C + a_1X_1 + a_2X_2 + a_3X_3 + \ldots\ldots + a_nX_n + u$ …… (2)
Where,

Y = Dependent Variable
X = Independent Variable
C = the intercept
a = Slope
u = Regression residual

The appropriate method to generalize this to a probabilistic linear model is to assume that experimental value of predictor (Y) determined by the mean value function (linear model) and random error (ε). The basic assumptions to determine the regression coefficient for the single and multiple regression models based upon the least square method. During the development of regression model taking the assumption that if p-value ≤ 0.05 (i.e. statistically significant) and coefficient of determination (R^2) is more than 0.70 i.e. 70% then it represent the significant relationship between the variables(s). For this study, Microsoft Excel 2010 has used to investigate the properties of soil to develop empirical model using regression. The statistical information of the independent variables and dependent variables have presented in Table 3.1

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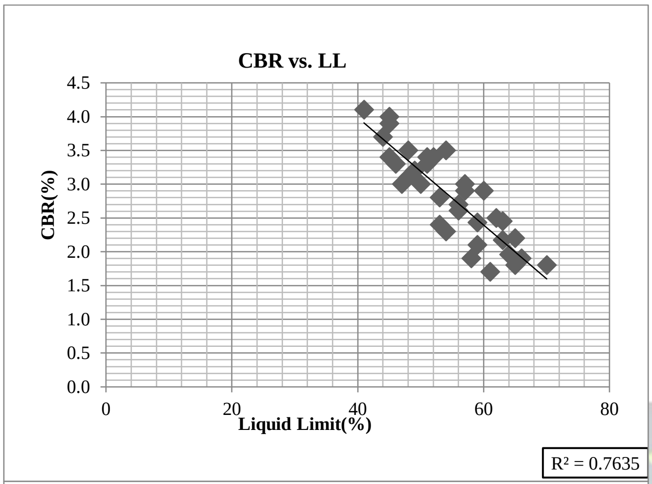

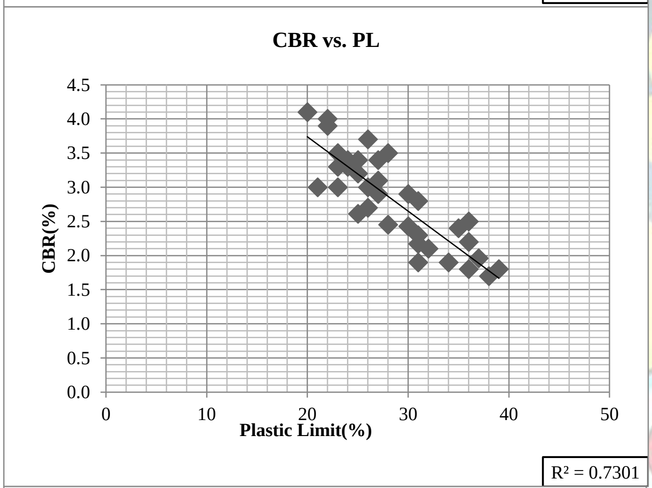

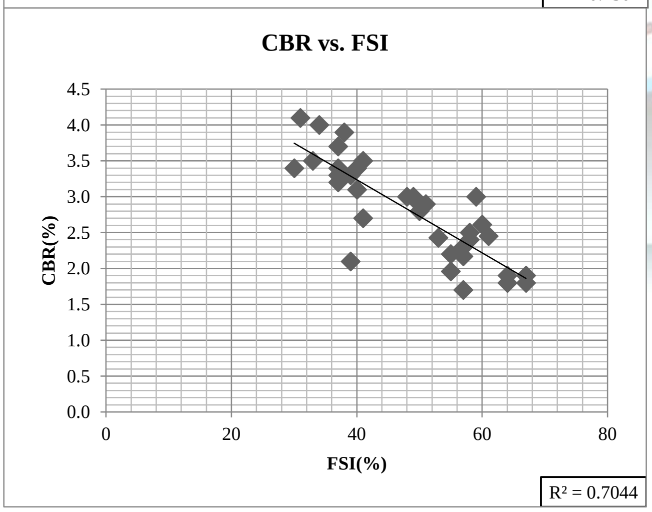

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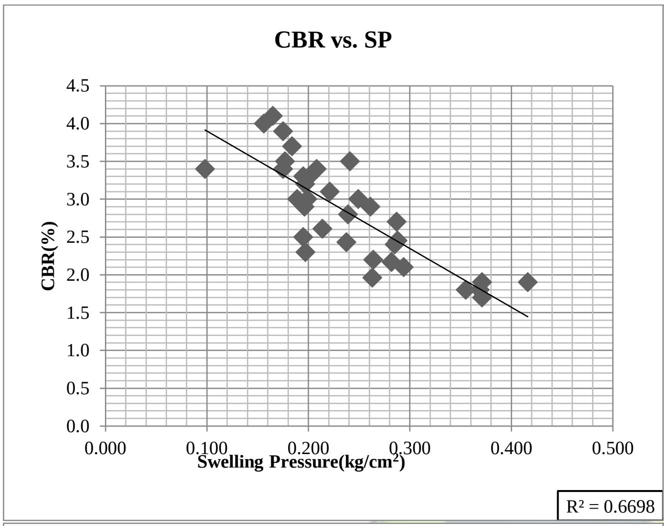

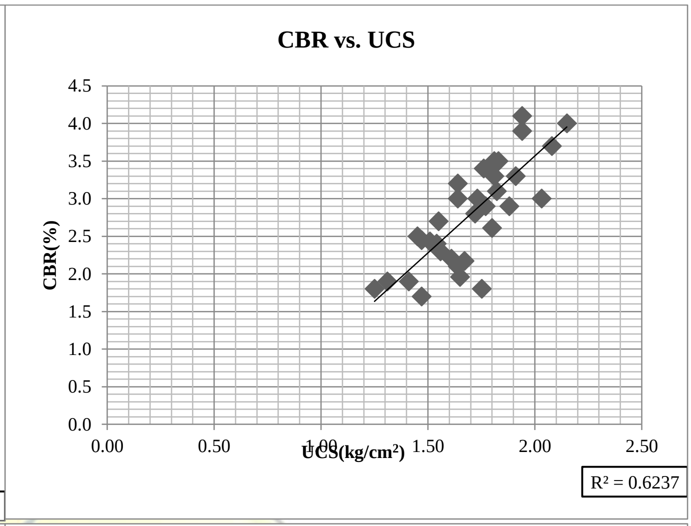

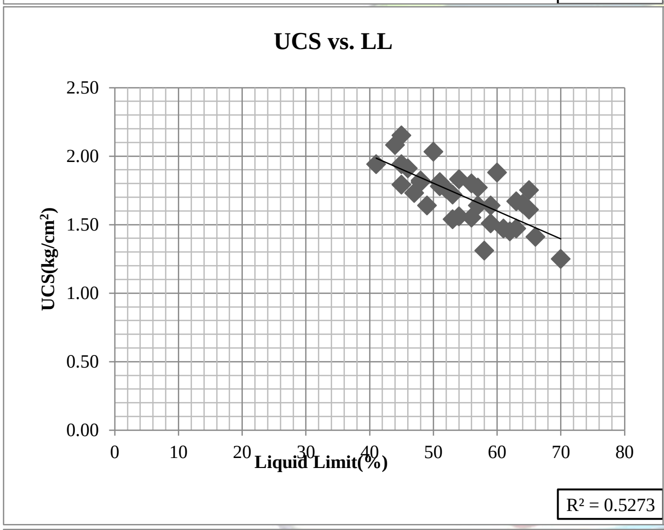

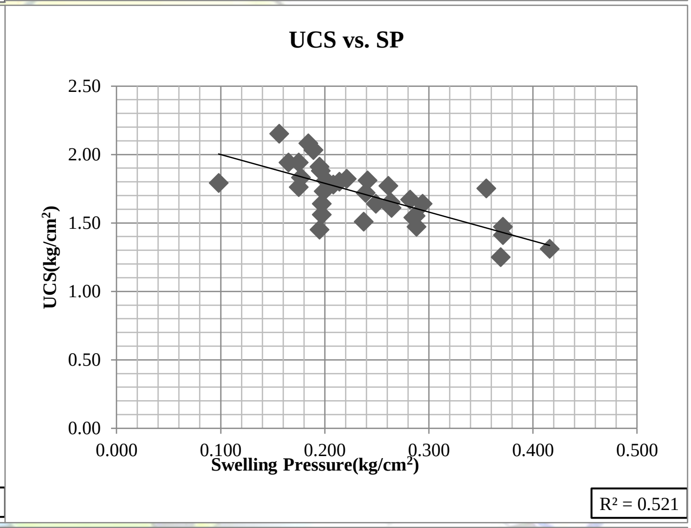

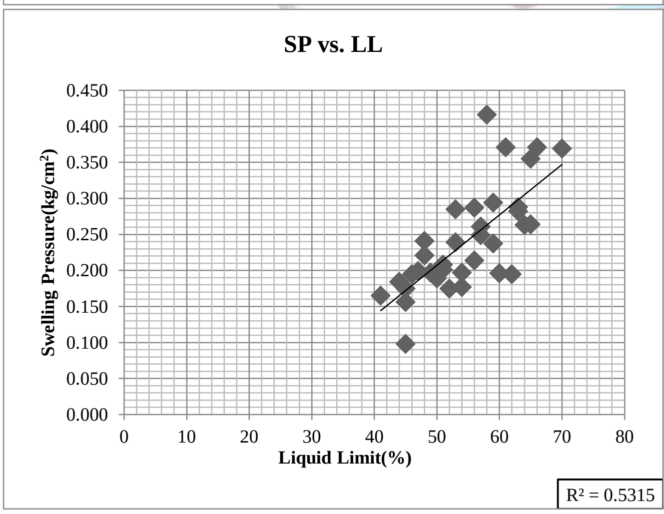

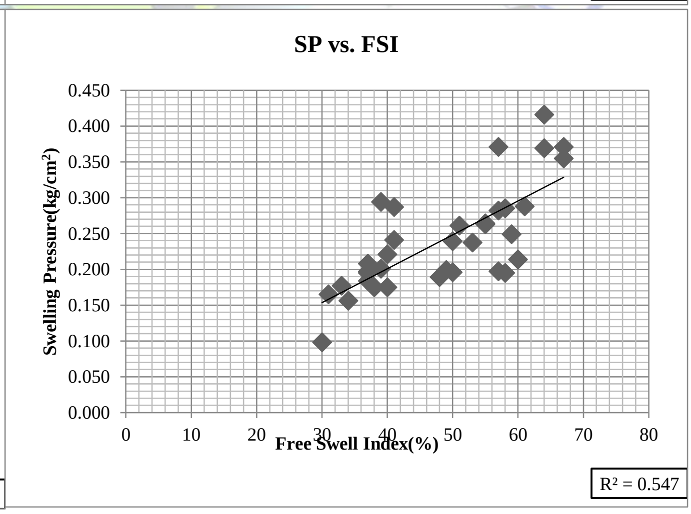

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Fig. 3.1: Scatter Diagram

After performing simple and multiple linear regression analysis on test results of black cotton soil, models that are statistically significant to predict the dependent variable, summarised in Table 3.2.

Table 3.1: Statistical Information of Independent and Dependent Variables

Variable Type	Variable Name	Unit of Measurement	Number of sample	Ranges Min.	Ranges Max.	Mean	Standard Deviation
Dependent Variable	CBR (soaked)	%	35	1.70	4.10	2.81	0.67
	UCS (on proctor value)	kg/cm^2	35	1.25	2.15	1.70	0.21
	Swelling Pressure (on proctor value)	kg/cm^2	35	0.098	0.416	0.240	0.071
Independent variables	Specific Gravity	-	35	2.49	2.71	2.64	0.06
	Liquid Limit	%	35	41	70	54.77	7.34
	Plastic limit	%	35	20	39	28.54	5.24
	Plasticity Index	%	35	18	35	26.23	4.36
	Shrinkage Limit	%	35	8	18	12.71	2.65
	Free Swell Index	%	35	30	67	48.40	11.02
	OMC	%	35	15	21	18.17	1.54
	MDD	gm/cc	35	1.49	1.77	1.65	0.07

Table 3.2: Summary of the Regression Analysis

Regression Type	Model Name [Equation]	Coefficient of Determination (R^2)	Significance Order
Dependent variables - CBRs, **Independent Variables** - LL, PL, FSI, UCS, SP			
SLRA	Model 1 (CBRs/LL) [CBR = 7.173 – 0.079*(LL)]	0.763	2
	Model 2 (CBRs/PL) [CBR = 5.922 – 0.109*(PL)]	0.730	3
	Model 3 (CBRs/FSI) [CBR = 5.276 – 0.051*(FSI)]	0.704	4
	Model 4 (CBRs/SP) [CBR = 4.667 – 7.771*(SP)]	0.669	5
	Model 5 (CBRs/UCS) [CBR = - 1.582 + 2.575*(UCS)]	0.623	6
MLRA	Model A (CBRs/LL, PL, FSI) [CBR = 6.687 – 0.029*(LL) – 0.046*(PL) – 0.019*(FSI)]	0.860	1
Dependent variables - UCS, **Independent Variables** - LL, PL, FSI, SP			
SLRA	Model 6 (UCS/LL) [UCS = 2.817 – 0.020*(LL)]	0.527	2
	Model 7 (UCS/PL) [UCS = 2.438 – 0.025*(PL)]	0.430	4
	Model 8 (UCS/FSI) [UCS = 2.322 – 0.013*(FSI)]	0.460	3
	Model 9 (UCS/SP) [UCS = 2.250 – 2.308*(SP)]	0.580	1

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Dependent variables - Swelling Pressure, Independent Variables - LL, PL, FSI, CBR_S			
SLRA	Model 10 (SP/LL) [SP = -0.143 + 0.007*(LL)]	0.531	4
	Model 11(SP/PL) [SP = - 0.027 + 0.009*(PL)]	0.489	5
	Model 12 (SP/FSI) [SP = 0.011 + 0.005*(FSI)]	0.546	3
	Model 13 (SP/UCS) [SP = 0.666 – 0.252*(UCS)]	0.583	2
MLRA	Model D (SP/UCS, CBR_S) [SP = 0.601 - 0.146*(UCS) - 0.041*(CBR_S)]	0.645	1

SLRA=Simple linear Regression analysis, MLRA=Multiple linear regression analysis, LL=Liquid limit, PL=Plastic limit, FSI=Free swell index, SP=Swelling pressure, UCS=Unconfined compressive strength, CBR_S=Soaked CBR

IV. Results And Discussions

In the regression analysis, the coefficient of determination (R^2) and p-value (Proportioning Value) are important parameters that represent the strength of relationship between the variable(s). In the regression output any p-value less the significance level ($\alpha = 0.05$) indicate that the data used in the study is statistically significant and normally distributed.

Hence, depending upon the significance order best models to **predicting the CBR** value are *Model 1* (from SLRA using index properties) and *Model A* (from MLRA using index properties).

Model 1:

CBR = 7.173 – 0.079*(LL) ; with $R^2 = 0.763$

Model A:

CBR = 6.687 – 0.029*(LL) – 0.046*(PL) – 0.019*(FSI) ; with $R^2 = 0.860$

In addition, depending upon the significance order best models to **predicting the UCS** are *Model 6* (from SLRA using index properties) and *Model* 9 (from SLRA using engineering properties).

Model 6:

UCS = 2.817 – 0.020*(LL) ; with $R^2 = 0.527$

Model 9:

UCS = 2.250 – 2.308*(SP) ; with $R^2 = 0.580$

In addition, depending upon the significance order best models to **predicting the Swelling Pressure** are *Model 12* (from SLRA using index properties), *Model 13* (from SLRA using engineering properties) and *Model D* (from MLRA using engineering properties).

Model 12:

SP = 0.011 + 0.005*(FSI) ; with $R^2 = 0.546$

Model 13:

SP = 0.666 – 0.252*(UCS) ; with $R^2 = 0.583$

Model D:

SP = 0.601 - 0.146*(UCS) - 0.041*(CBR_S) ; with $R^2 = 0.645$

Table 4.1 show the experimental and pridicted value of soaked CBR and and figure 4.1(a) and figure 4.1(b) show the variations between them.

Table 4.1: Experimental and Predicted CBR value

Sample Number	Experimental value of CBR (Soaked) (%)	Using Model 1		Using Model A	
		Predicted value of CBR (Soaked) (%)	% Difference in value	Predicted value of CBR (Soaked) (%)	% Difference in value
1	1.8	1.6	11	1.8	0
2	2.2	2.2	0	2.4	-9
3	3.3	3.5	-6	3.6	-9
4	2.9	2.7	7	2.8	3
5	2.6	2.7	-4	2.8	-8
6	3	2.7	10	2.7	10
7	2.7	2.7	0	3.1	-15
8	3.4	3.1	9	3.2	6
9	4.1	3.9	5	4.0	2
10	2.2	2.0	9	2.1	5
11	3.5	2.9	17	3.4	3

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12	4.0	3.6	10	3.7	8
13	3.4	3.1	9	3.4	0
14	1.7	2.4	-41	2.1	-24
15	3.9	3.6	8	3.6	8
16	2.9	2.4	17	2.6	10
17	3.3	3.1	6	3.4	-3
18	2.8	3.0	-7	2.8	0
19	2.5	2.3	8	2.1	16
20	2.4	2.5	-4	2.6	-8
21	3.2	3.3	-3	3.4	-6
22	3.0	3.5	-17	3.4	-13
23	1.9	2.0	-5	1.9	0
24	2.1	2.5	-19	2.8	-33
25	2.5	2.2	12	2.4	4
26	3.1	3.4	-10	3.3	-6
27	3.0	3.2	-7	3.3	-10
28	1.8	2.0	-11	1.7	6
29	2.0	2.1	-5	2.1	-5
30	2.3	2.9	-26	2.6	-13
31	2.4	3.0	-25	2.4	0
32	3.4	3.6	-6	3.7	-9
33	3.7	3.7	0	3.5	5
34	3.5	3.4	3	3.2	9
35	1.9	2.6	-37	2.4	-26

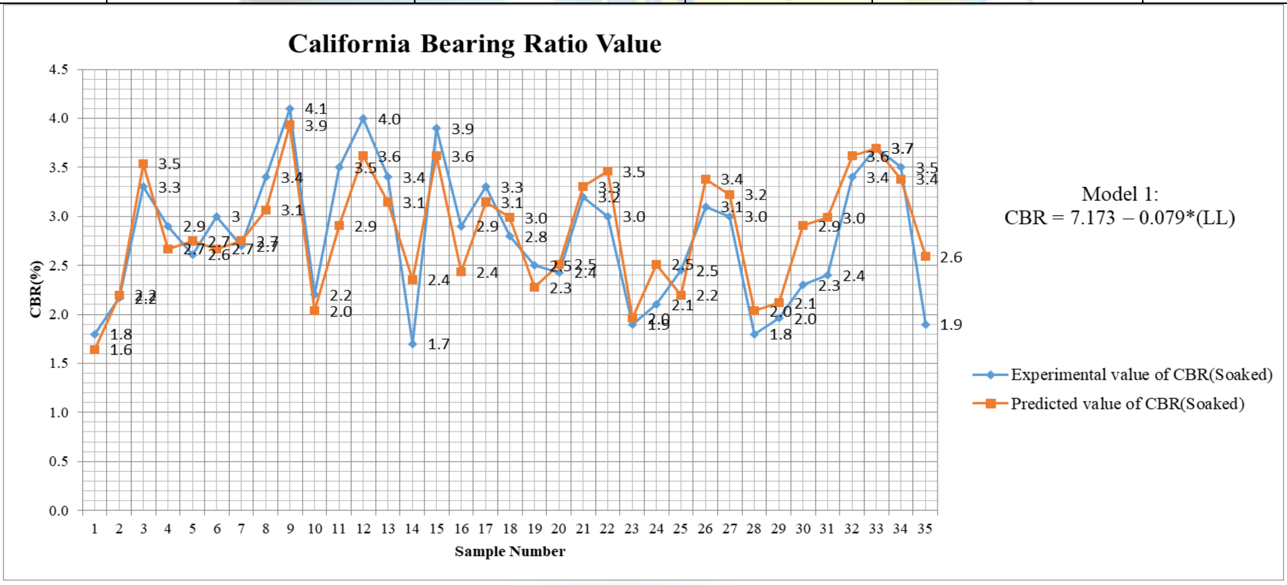

Fig. 4.1(a): Variation in Experimental and Predicted CBR Value for Model 1

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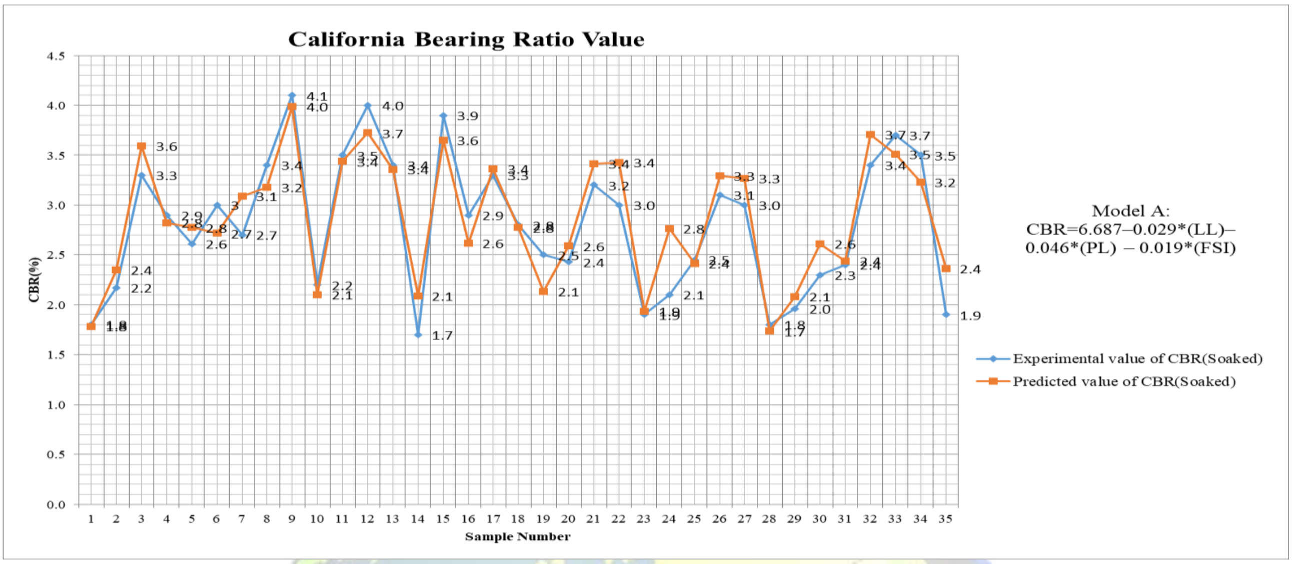

Fig. 4.1(b): Variation in Experimental and Predicted CBR Value for Model A

V. CONCLUSION

1. Among the all Simple Linear Regression Analysis (SLRA) to predict the CBR, correlation between CBR and Liquid Limit (LL) has shown the better result and represented by following equation:
   $CBR = 7.173 – 0.079*(LL)$; with $R^2 = 0.763$
2. Relatively an improved correlation than the simple linear regression is obtained when multiple linear regression is used to predict the CBR as given below:
   $CBR = 6.687 – 0.029*(LL) – 0.046*(PL) – 0.019*(FSI)$; with $R^2 = 0.860$
3. Prediction of UCS using simple regression with the parameters viz. liquid limit and swelling pressure gives better result among the all other parameters.
4. Prediction of UCS and swelling pressure using the multiple linear regression with the parameters viz. liquid limit, plastic limit and free swell index have found statistically insignificant.
5. However, the swelling pressure has better correlated with the free well index, UCS and soaked CBR.

For preliminary design purpose, the above correlation might be used, if soil is Black Cotton soil and the predicted CBR value lies in the range of 1.6% to 4.5%. Otherwise, a detailed laboratory test performed according to IS specification to calculate the actual CBR value.

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