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Development of Regression Equations to Predict C.B.R of Black Cotton Soils of Karnataka, India

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Abstract

California Bearing Ratio (CBR) is a measure of strength of soil and is often used as a design parameter for the design of Roads. It is a difficult parameter to comprehend and hence attempts have been made in the literature to correlate the CBR of soils with simple soil parameters (Index properties) like Plasticity characteristics, Grain size characteristics. The determination or prediction of CBR for Expansive soils (Indian Black cotton soils) is even more challenging job for the Civil Engineers. In the present investigation an attempt has been made to establish the regression equations to predict the CBR value of Indian Black cotton soils based on their field strength properties as well with the index properties. For this purpose samples from 26 different locations representing Black cotton soils are collected and tested in the laboratory for various properties including test for CBR. Also Standard Penetration Tests (SPT) and Dynamic Cone Penetration Tests (DCPT) are conducted at the location of soil sample collection. Based on these laboratory and field test results attempts are made to develop regression equation using the statistical analysis (SPSS Software). The regression equations so developed indicated good correlation co-efficient and are presented in this paper.

Keywords: CBR, Index properties, Black cotton soils, Standard Penetration Test, Dynamic cone penetration Test, SPSS.

INTRODUCTION

Industrialization and the rapid urbanization have called for the rapid growth in infrastructure development. The development of infrastructure includes the development of good accessibility in the form of roads and other facilities. The design and construction procedure for the construction of road ways are very well established. California Bearing Ratio (CBR) is generally used for the design of pavements, as it is a parameter indicating the strength of the soil. To determine the CBR value of soils Standard procedures have been established in different Codes. Most of the test methods often involve laborious test procedure to establish the CBR values fairly but are time consuming. For the Quick estimation of CBR value, attempts have been made to correlate the CBR with the basic index properties of the soil such as liquid limit, plasticity index, grain size distribution etc. Such efforts have resulted in the development of correlation equations, suitable only for a set of soils.

CBR being a measure of strength of soils, it becomes appropriate to correlate this strength parameter with the field Strength parameter. Standard penetration test is one of the popular methods used in the field for measurement of strength and is often performed in routine geotechnical investigation. If a good correlation between the Felid SPT 'N' value and the laboratory CBR value is established, it becomes very handy in estimating the CBR values quickly. In the literature there are few or scanty evidence of such a correlation between the CBR and the SPT "N" value, Hence in the present investigation, it is planned to make an attempt to establish a relationship between the CBR value and the SPT 'N' value, considering other soil parameters.

LITERATURE REVIEW

Various researchers have contributed immensely to develop the prediction equations for CBR using different soil properties. CBR test procedure was originally developed in 1929 in the state of California, USA by Roads Department of the State (Yoder, 1975). In India the laboratory test procedure for the determination of CBR is well established and the test procedure is outlined in IS – 2720 (Part 16) – 1985 (Reaffirmed 1997). Generally, the laboratory CBR test is conducted on soaked soil sample compacted at their maximum dry unit weight and Optimum Moisture content (i.e., MDD and OMC, as determined in Standard / Modified Proctor test as appropriate) The CBR test would take about 5 to 7 days.

Based on grain size of soils (NCHRP), Plasticity characteristics of soils (Carter and Bentley 1991, Noorjahan Begum and Binu Sharma. 2014, Naveen B Shirur and Santosh G Hiremath 2014, Compaction characteristics of soils (Carter and Bentley 1991, Noorjahan Begum and Binu Sharma. 2014, Naveen B Shirur and Santosh G Hiremath 2014, have established the regression equations to predict the values of CBR. Likewise Parampreet Kaur,et.al 2012, Smith and Pratt 1983, Wu 1987, Harison

1989, Websteret.al 1992, Webster, et.al 1994, Kleyn 1992, Livneh et .al., 1992, Ese et.al 1994, Coonse 1999, Sahoo and Sudhakar Reddy 2009, Rakareddy and Vijay Gomarsi 2015, have attempted to establish the relationship of CBR with the field strength parameters.

OBJECTIVES OF THE PRESENT STUDY

The objective of the present investigation is,

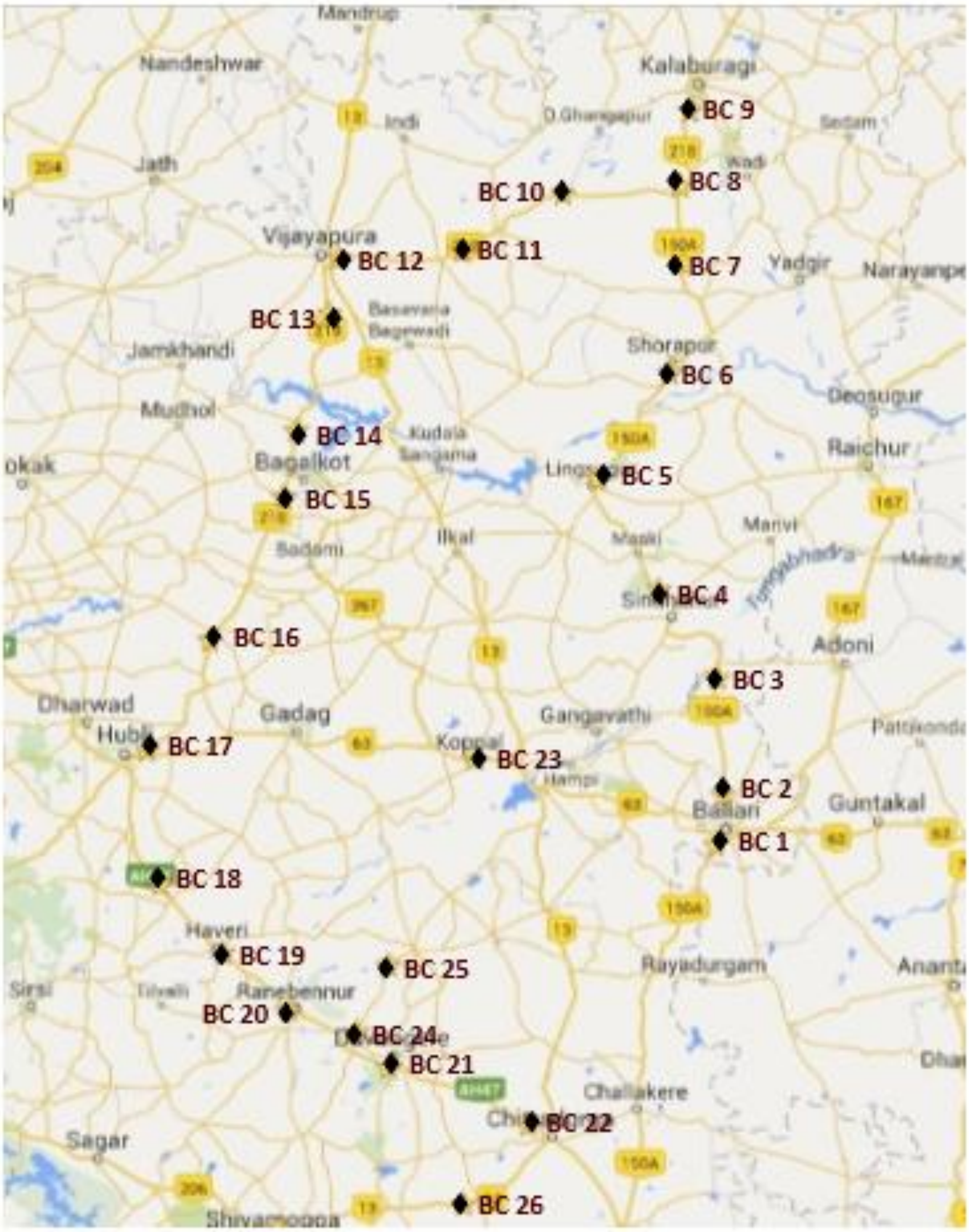
- To develop correlation equations between Index properties of Black cotton soil and the CBR
- To develop regression equation to predict the CBR of Black cotton soil based on field SPT "N" value
- To compare the predicted CBR values (by developed regression equation) with the laboratory determined CBR values.

MATERIALS AND METHODS

Black Cotton soils from different parts of Karnataka state, India are tested in the present investigation, to develop regression equations for the prediction of CBR values. A vast area of the state of Karnataka has the Expansive soil deposits, locally known as "Black Cotton Soil" and is covered in an area of about 1,02,725 sq Km. Black cotton soil in this area is generally grayish brown to black in color and occur from 0.5m to 10m deep and have high compressibility.

The locations of existence of Black cotton soils are identified and the soil samples are collected and transported to the laboratory. Also at the time of soil sample collection Standard Penetration tests (IS 2131-1981(Re affirmed in1992) and Dynamic Cone penetration tests (ASTM 6951-3(2003)) are conducted. The collected soil samples are subjected to various laboratory tests to determine Particle size distribution (IS–2720: (Part 4) – 1985 (Reaffirmed 1997), Atterberg limits (IS–2720: (Part 5) – 1985 (Reaffirmed 1997)), Compaction Characteristics (IS–2720 (Part 7) – 1985 (Reaffirmed 1997)) and California Bearing Ratio (IS–2720 (Part 16) – 1985 (Reaffirmed 1997)).

The locations selected for Testing in the present investigation is shown in Map – 1 and is summarized in Table.1



Map – 1. Locations for BC soil sampling

Methodology adopted

The proposed methodology involves conducting the Standard Penetration Test and Dynamic Cone penetration test, as per the relevant standards, and collecting undisturbed and representative soil samples for laboratory testing from different parts of Karnataka state. The laboratory tests to be conducted also include Soaked CBR tests. The laboratory test results are presented in Table 2.

Regression analysis

Attempts are made to correlate the CBR values with the Index properties of the soil Viz., Liquid limit. Plasticity Index, Activity of the soil. Further attempts are also made to obtain the correlation equation between CBR and Standard / Modified Compaction Characteristics of the soils. Linear regression equations, Multiple linear regression equations are tried with different software programme. After several trials the statistical package **SPSS** is used for regression analysis in the present study.

RESULTS AND DISCUSSION

Correlation of CBR with Index properties

Table 2 presents the Index properties of the soil samples tested. Based on the test results, the following is the range of values for the tested Black cotton soils of Karnataka.

a. Liquid Limit - 41% to 74%

b. Plastic limit - 19% to 32%

c. Shrinkage limit - 8% to 14%

d. Clay Size - 15% to 36%

e. Silt Size - 18% to 50%

f. Classification of soil - CH (Inorganic Clay with high Compressibility)

Method adopted to develop Regression equations:

Soil sample selection / grouping: As it can be seen from Table 2, the soils from several locations have almost the same Liquid limit values but slightly different characteristics (Like Plasticity Index, activity and CBR). Hence the soil samples having the same liquid limit are grouped together and the average Index property of such group is used for correlation equation development. For example Sample No. BC7, BC8 and BC19 exhibited the same value of Liquid limit and hence they are grouped together. Similarly their Plasticity Index values are averaged and used in the correlation equation development. The same procedure is followed with reference to other laboratory and field properties of the soils. The grouping of this is shown in Table 2.

Table 2: Properties of B.C Soil Used For Regression

Sample No.	Liquid limit, w_L %	Plasticity Index, %	Activity %	Compaction Characteristics		Soaked CBR %	SPT 'N' mm/blow	DCPT 'N' mm/blow
				MDD (g/cc)	OMC (%)			
BC10	74	49	1.72	1.43	24	2.06	17.93	2.36
BC23	74							
BC20	71	46	1.83	1.45	23	2.62	1 7.23	2.29
BC7	70	42	1.61	1.57	19	2.71	16.81	2.09
BC8	70							
BC19	70							
BC17	69	40	1.75	1.55	22	2.82	15.09	2.20
BC3	69							
BC9	68	41	1.37	1.55	23	2.91	13.25	1.75
BC18	67	41	2.05	1.5	22	3.0	12.50	1.82
BC1	66	40	1.72	1.55	21	3.11	11.81	1.56
BC21	66							
BC26	66							
BC16	65	40	1.25	1.5	21	3.23	10.00	1.67
BC13	63	38	1.41	1.5	21	3.35	9.50	1.32
BC2	59	32	1.33	1.65	19.5	3.42	6.58	2.61
BC5	58	31	1.31	1.5	19	3.54	6.66	2.60
BC12	58							
BC24	58							
BC4	57	30	1.36	1.6	22	3.61	5.97	2.24
BC15	56	29	0.91	1.5	20	3.72	4.69	2.32
BC25	49	21	0.84	1.6	19	4.02	4.20	1.80
BC22	45	20	0.83	1.7	18	4.21	3.98	1.67
BC14	44	19	0.9	1.7	17	4.32	3.12	1.81
BC11	43	16	0.73	1.72	18	4.45	2.73	1.50
BC6	41	16	0.62	1.75	17.5	4.60	2.35	1.50

Note :

i. The sample are arranged based on their liquid limit values, in the descend order.

ii. Samples having same liquid limit are grouped together and average value for other properties is assigned to each group.

iii. iii) MDD: Maximum Dry Density, OMC: Optimum Moisture Content CBR : California Bearing Ratio, SPT : Standard Penetration test ‘N’ Value DCPT : Dynamic Cone Penetration ‘N’ value

Correlation techniques: Attempts are made to correlate the CBR values with the Index properties of the soil Viz., Liquid limit, Plasticity Index, Activity of the soil. Linear regression equations, multiple regression equations are tried to arrive at different correlation equation using SPSS software’s. This is

Followed by manual analysis of the test data. The two (Manual and the software based correlations) are matched well and subsequent correlations are carried out with SPSS software

Correlation Equation:

$$CBR = 5.540 - 0.064*Ip \quad (1)$$

With R^2 = 0.957

$$CBR = 5.343 – 1.465*A \quad (2)$$

With R^2 = 0.787

$$CBR = 5.545 – 0.040*A – 0.063* Ip \quad (3)$$

With R^2 = 0.957

Where,

CBR = California Bearing Ratio, IP = Plasticity Index

A = Activity

Explanation : Attempts are made to correlate the index properties viz., Plasticity Index and Activity of the soil samples tested with the Soaked CBR values of the soil samples. Attempts are also made to correlate grain size (mainly Clay and Silt content) of the soil samples with the Soaked CBR values but such correlations did not yield good results as indicated by very low values of regression co-efficient (R^2). Hence, this is not considered for presentation. As can be seen from equation (1) to equation (3), the correlation of CBR with Plasticity Index and Activity results in better values of R^2.

The predicted CBR values by different correlation equations with the laboratory CBR values are plotted in Fig 1 to Fig 3. Fig 1 is the correlation based on Plasticity Index (Equation 1), Fig 2 is the correlation based on Activity (Equation 2) and Fig 3 is the correlation based on both Plasticity Index and Activity (Equation 3). As demonstrated by these figures, the correlation between CBR and Plasticity Index as well as Plasticity Index and Activity is better than that with the Activity alone.

Table 1: Identification of Soil Sample Location.

Sample No.	**Latitude**	**Longitude**	**Location**
BC1	15.0949444	76.89058333	Anakundi
BC2	15.2436944	76.90838889	Somasamudra
BC3	15.5885000	76.894000	Siraguppa
BC4	15.8473611	76.7144444	Agadaddini pai camp
BC5	16.1745833	76.53441667	Lingasaguru
BC6	16.4867778	76.74858333	Kavadimatti
BC7	16.4867778	76.78969444	Madarkki
BC8	16.8076389	76.78655556	Jevargi
BC9	17.0330833	76.81019444	Sitnoor
BC10	17.2554742	76.43411111	Jeratagi
BC11	16.8440833	76.13000	Devarhippargi
BC12	16.8220000	75.991667	Bijapur
BC13	16.6625833	75.76219444	Vanavanahalli
BC14	16.3188056	75.63772222	Bilagi
BC15	16.1219167	75.59516667	Hoskere cross
BC16	15.6977222	75.3785	Nargunda
BC17	15.3771111	75.18925	Hubli
BC18	14.9806944	75.22775	Shiggon
BC19	14.7794444	75.41394444	Haveri
BC20	14.6081389	75.61577778	Ranibennur
BC21	14.4346667	75.90830556	Davanagere
BC22	14.2695278	76.33072222	Margatta
BC23	15.3491890	76.167492	Koppal
BC24	14.7408920	75.911069	Harihara
BC25	14.5447960	75.817834	Dhiganthi
BC26	14.0339760	76.134757	Holalkere

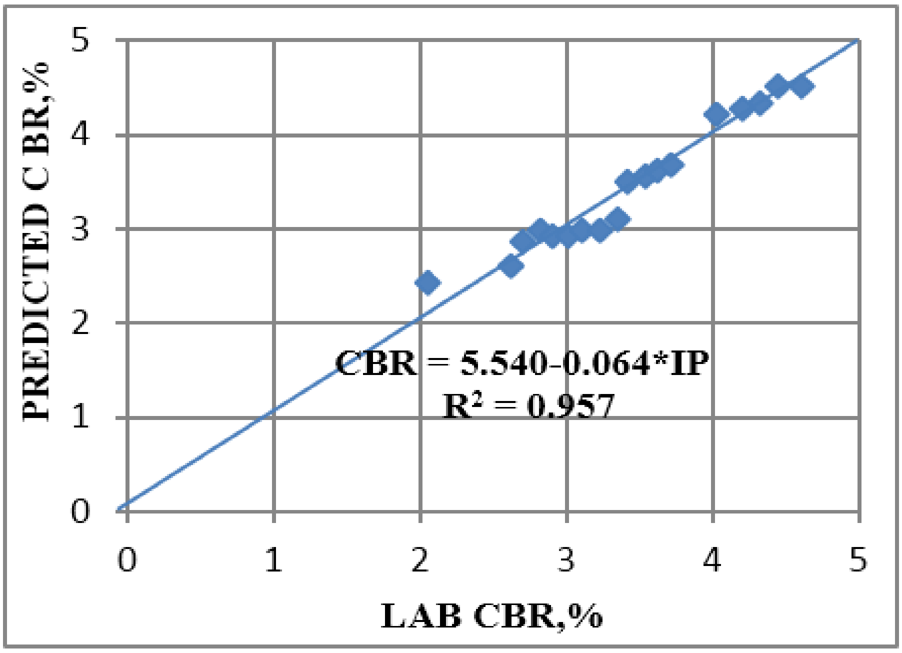


Fig 1. Correlation of CBR with Plasticity Index

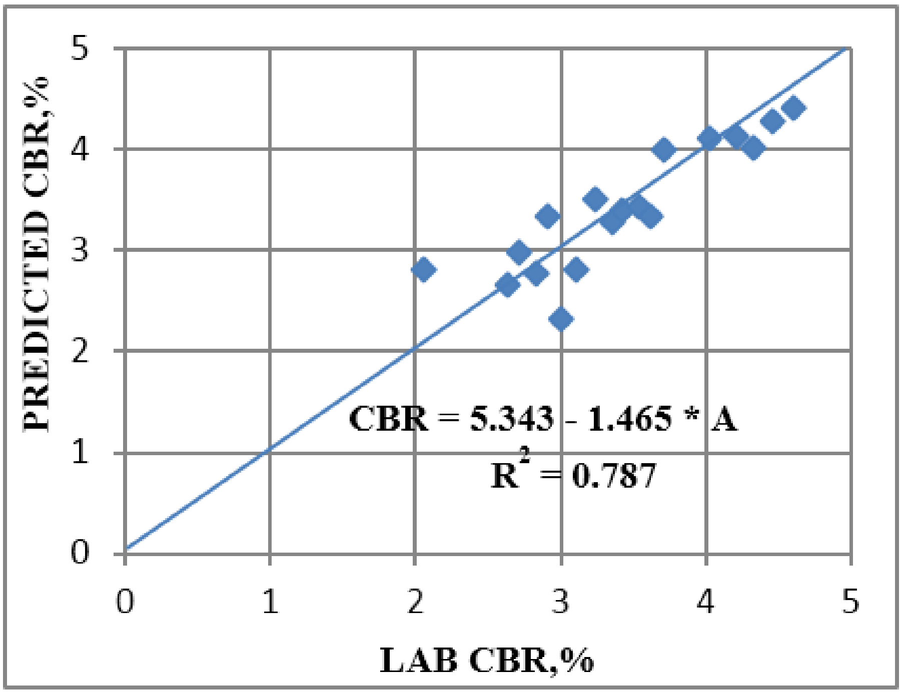


Fig 2. Correlation of CBR with Activity

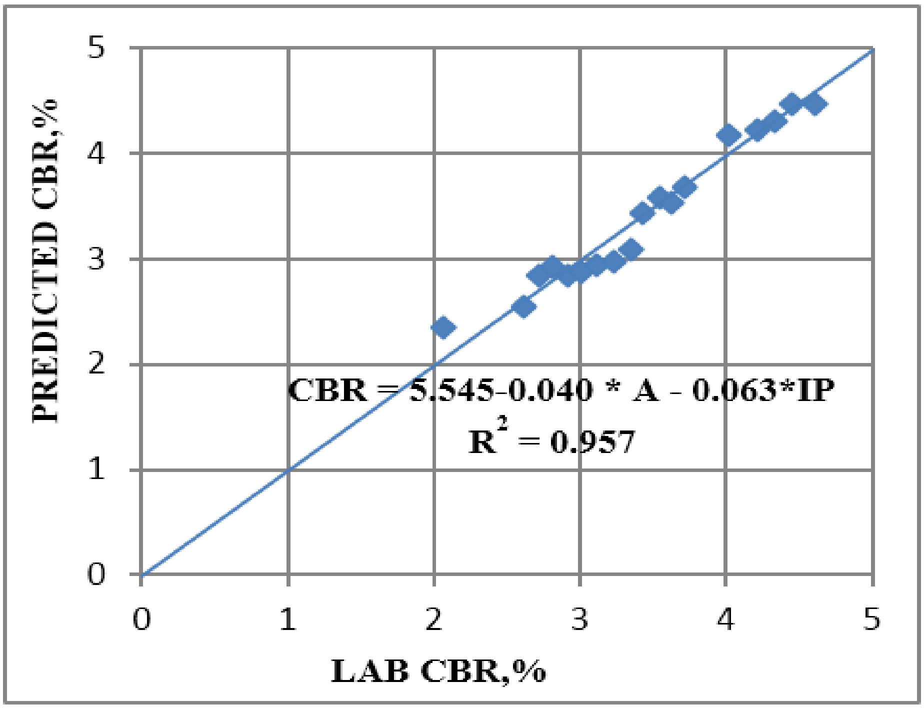


Fig 3. Correlation of CBR with IP and Activity

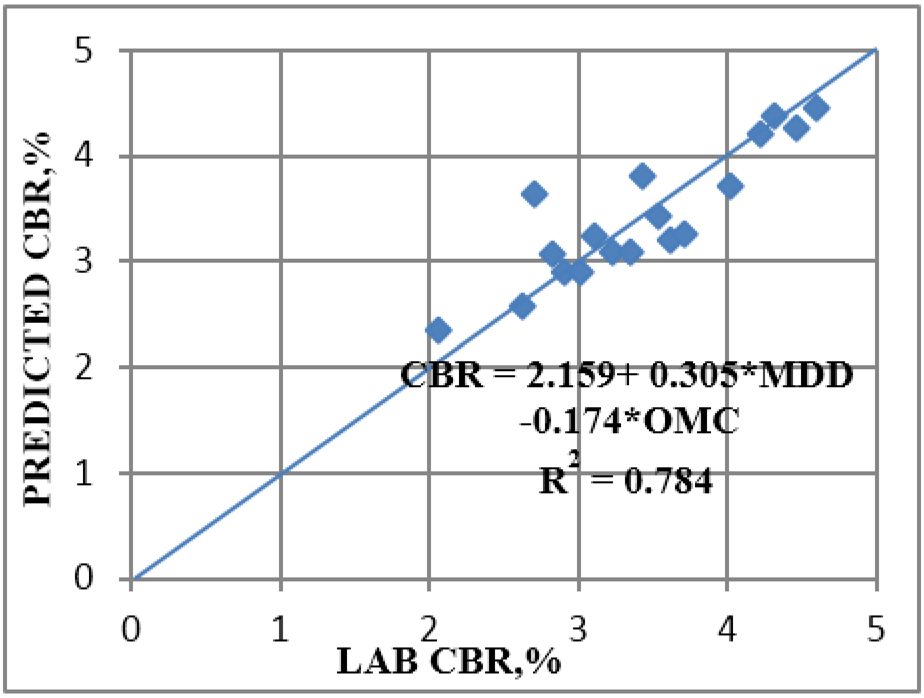


Fig 4. Correlation of CBR with, MDD, OMC

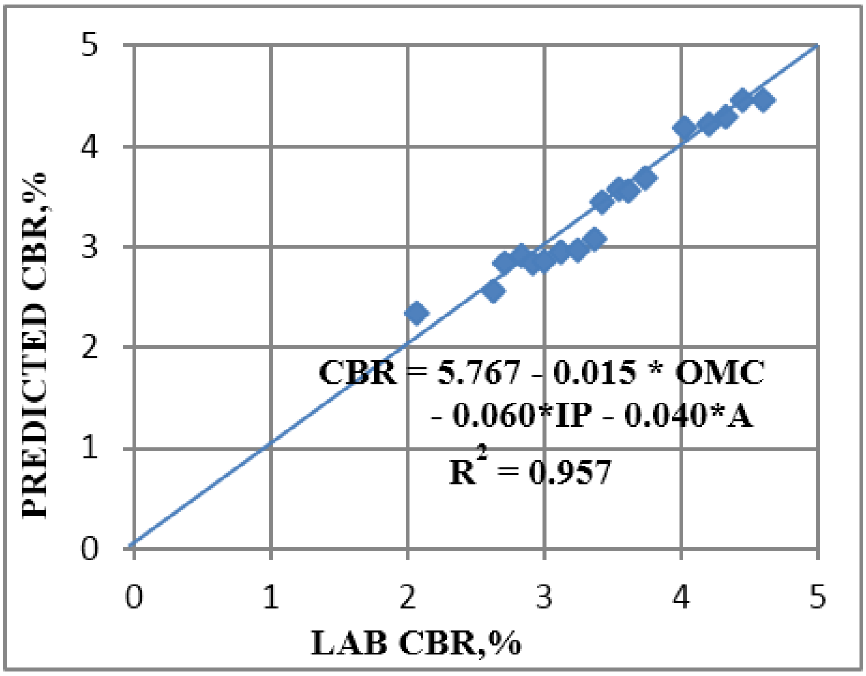


Fig 5. Correlation of CBR with IP, Activity,OMC

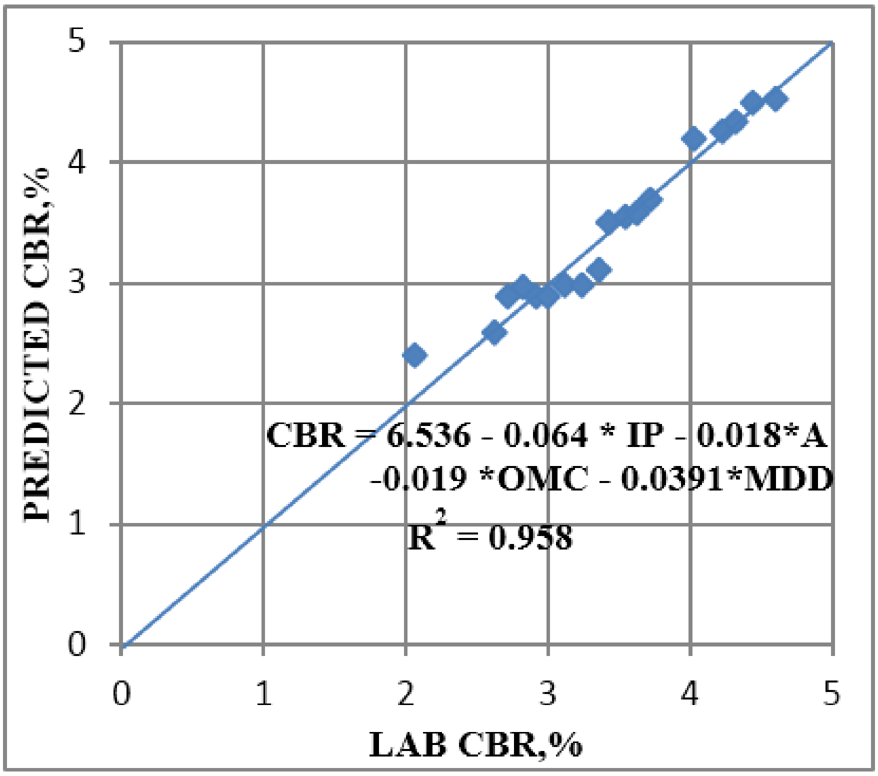


Fig 6. Correlation of CBR with IP, Activity,OMC,MDD

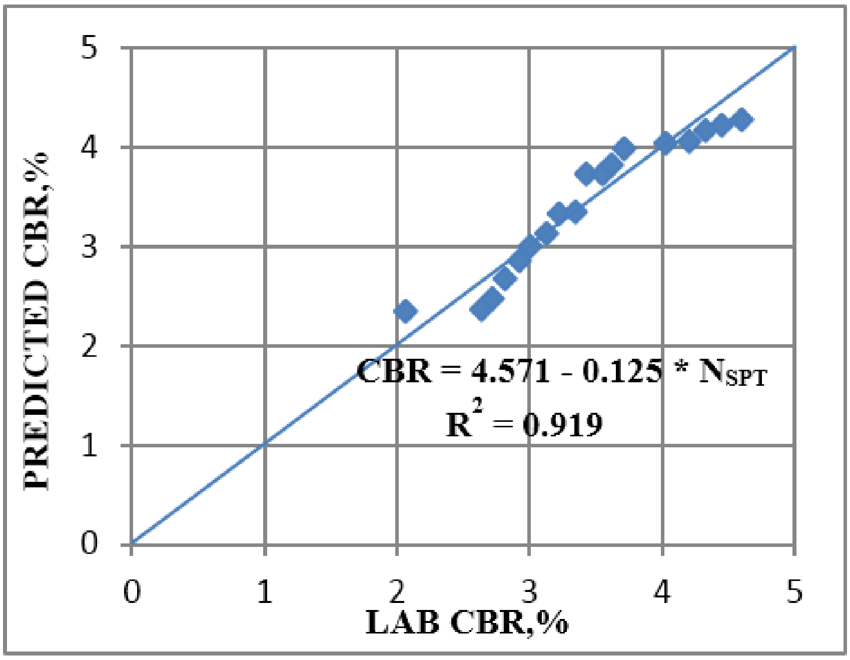


Fig 7. Correlation of CBR with SPT 'N'

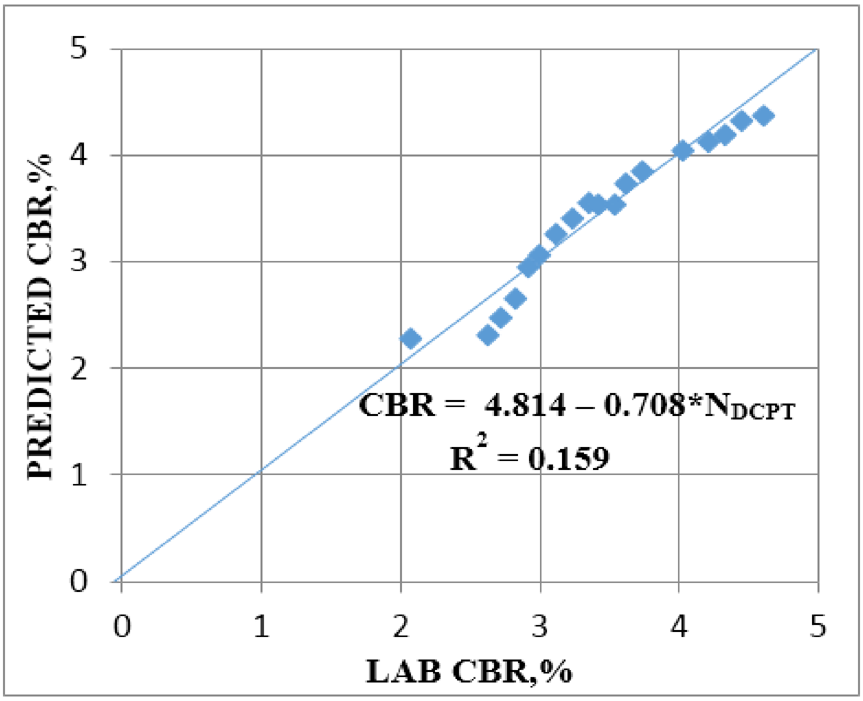


Fig 8. Correlation of CBR with DCPT 'N'

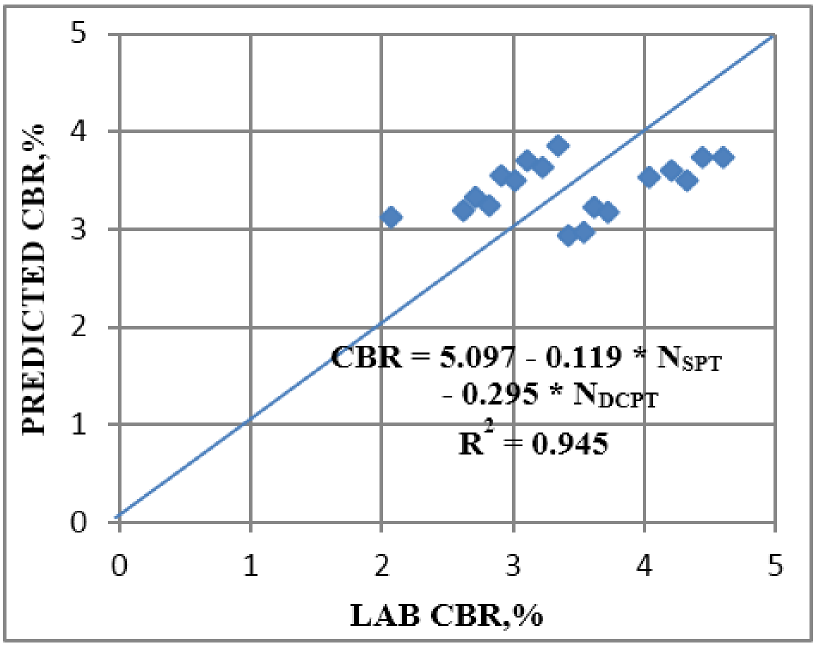


Fig 9. Correlation of CBR with SPT 'N' and DCPT 'N'

Correlation of CBR with Compaction Characteristics

The Compaction characteristics (Maximum dry unit weight and Water Content), good indicators of strength of soils, are used to develop the correlation equations with CBR. The compaction characteristics of the soils tested along with their Soaked CBR values are indicated in Table 2.

Correlation Equation:

$$CBR = 2.159 + 3.052*MDD - 0.174*OMC \quad (4)$$

With $R^2 = 0.784$

$$CBR = 5.767 - 0.015*OMC - 0.060*Ip - 0.040*A \quad (5)$$

With $R^2 = 0.957$

$$CBR = 6.536 - 0.064*Ip - 0.018*A - 0.019*OMC - 0.391*MDD$$

With $R^2 = 0.958$ (6)

Where,

CBR = California Bearing Ratio

IP = Plasticity Index

A = Activity

OMC = Optimum Moisture Content

MDD = Maximum Dry Density

Explanation: Attempts are made to correlate the Compaction characteristics viz., Maximum Dry Density (MDD) and Optimum Moisture Content (OMC) with the Soaked CBR values of the soil samples. Such correlation (Equation. 4) yielded a low value of regression co-efficient ($R^2 = 0.784$). To improve on the regression coefficient Activity and Plasticity Index of the soil samples are used in addition to MDD and OMC for regression analysis. Equation (5) and Equation (6) presents the regression between CBR and MDD/ OMC along with Activity and Plasticity Index. Activity and Plasticity Index are chosen for this regression, as they bear a good relationship with CBR (demonstrated in previous section). With such regression, the R^2 value is increased to about 0.96.

The predicted CBR values by different correlation equations with the laboratory CBR values are plotted in Fig 4 to Fig 6. Fig 4 is the correlation based on MDD and OMC (Equation 4), Fig 5 is the correlation based on OMC, Activity and Plasticity Index (Equation 5) and Fig 6 is the correlation based on MDD, OMC, Activity and Plasticity Index (Equation 6).

As demonstrated by these figures, the correlation between CBR with MDD and OMC is better, if other properties viz., Activity and Plasticity Index is used.

Correlation of CBR with SPT ‘N’ Value and DCPT ‘N’ Value

Field strength tests viz., Standard Penetration Tests (SPT) and Dynamic Cone Penetration Tests (DCPT) are conducted in the field at the location of soil sample collection. The tests are conducted as per the specifications of respective Indian Standard Codes. The “N” Values in both the tests conducted are expressed in terms of mm/penetration.

i) Regression Equation:

$$CBR = 4.571 - 0.125 * N_{SPT} \quad (7)$$

With $R^2 = 0.919$

$$CBR = 4.810 - 0.706 * N_{DCPT} \quad (8)$$

With $R^2 = 0.159$

$$CBR = 5.100 – 0.119*N_{SPT} – 0.296*N_{DCPT} \quad (9)$$

With $R^2 = 0.945$

Where,

CBR = California Bearing Ratio

N_{SPT} = SPT ‘N’ value

N_{DCPT} = DCPT ‘N’ value

Explanation : Equation 7 presents the regression equation between CBR and the SPT ‘N ‘ value, with an R^2 value of 0.921.The SPT ‘N’ values are expressed in terms of mm/blow and are corrected for overburden pressure. The value of R^2 is satisfactory, considering the uncertainties in the field measurement of SPT ‘N’ value. Further, attempts are made to correlate CBR values with the DCPT ‘N’ values, being expressed as mm/blow. Equation 8 presents the regression equation for CBR and DCPT ‘N’ value. This correlation yielded a very low value of R^2 (= 0.159) indicating that the prediction is poor. Further, to improve the correlation with DCPT ‘N’ value, attempts are made to correlate DCPT ‘N’ value and SPT ‘N’ value together with the CBR. Both SPT and DCPT are conducted at the same depth and both are expressed in terms of mm/blow. Equation 9 presents the resulting regression equation with an R^2 value of 0.948.

The predicted CBR values by different correlation equations with the laboratory CBR values are plotted in Fig 7 to Fig 9. Fig 7 is the correlation based on SPT ‘N’ value (Equation 7), Fig 8 is the correlation based on DCPT ‘N’ value (Equation 8) and Fig 9 is the correlation based on both SPT ‘N’ and DCPT ‘N’ values. (Equation 9).

As demonstrated by these figures, the correlation between DCPT ‘N’ value and the CBR is very poor. The correlation of CBR with SPT ‘N’, SPT ‘N’ and DCPT ‘N’ values yielded good result indicating the strength of regression analysis.

CONCLUSIONS

Based on the laboratory and field test results presented and subsequent to the regression analysis, the following conclusions are drawn.

The soil selected for testing, in the selected area, is generally classified as “CH” – Inorganic clay with high compressibility. The laboratory measurement of different properties, confirmed that the soil samples are medium to Highly Expansive in nature (Indian Black Cotton soil).

Based on the results of 26 Black cotton soil samples tested, the following regression equations are arrived at.

a) **Using Index properties**

CBR = 5.540 - 0.064*I_p

With R^2 = 0.957

CBR = 5.343 – 1.465*A

With R^2 = 0.787

CBR = 5.545– 0.040*A – 0.063*I_p

With R^2 = 0.957

b) **Using Compaction Characteristics**

CBR = 2.159+ 3.052*MDD – 0.174*OMC

With R^2 = 0.784

CBR = 5.767 – 0.015*OMC– 0.060*Ip

–0.040*A

With R^2 = 0.957

CBR = 6.536– 0.064*Ip– 0.018*A– 0.019*OMC

– 0.391*MDD

With R^2 = 0.958

c) **Using SPT and DCPT results**

CBR = 4.571 – 0.125*N_{SPT}

With R^2 = 0.919

$CBR = 5.100 – 0.119*N_{SPT} – 0.296*N_{DCPT}$

With $R^2 = 0.945$

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