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 coefficient 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 roadways 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.

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

<table>
<thead>
<tr>
<th>Sample No.</th>
<th>Liquid limit, ( w_l ) %</th>
<th>Plasticity Index, %</th>
<th>Activity %</th>
<th>Compaction Characteristics</th>
<th>Soaked CBR %</th>
<th>SPT ‘N’ mm/blow</th>
<th>DCPT ‘N’ mm/blow</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>MDD (g/cc)</td>
<td>OMC (%)</td>
<td></td>
<td></td>
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<tr>
<td>BC10</td>
<td>74</td>
<td>49</td>
<td>1.72</td>
<td>1.43</td>
<td>24</td>
<td>2.06</td>
<td>17.93</td>
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<tr>
<td>BC23</td>
<td>74</td>
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<td>BC20</td>
<td>71</td>
<td>46</td>
<td>1.83</td>
<td>1.45</td>
<td>23</td>
<td>2.62</td>
<td>17.23</td>
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<td>BC7</td>
<td>70</td>
<td>42</td>
<td>1.61</td>
<td>1.57</td>
<td>19</td>
<td>2.71</td>
<td>16.81</td>
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<tr>
<td>BC8</td>
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<tr>
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<td>BC9</td>
<td>68</td>
<td>41</td>
<td>1.37</td>
<td>1.55</td>
<td>23</td>
<td>2.91</td>
<td>13.25</td>
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<td>BC18</td>
<td>67</td>
<td>41</td>
<td>2.05</td>
<td>1.5</td>
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<td>66</td>
<td>40</td>
<td>1.72</td>
<td>1.55</td>
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<td>3.11</td>
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<td>BC26</td>
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<td>1.25</td>
<td>1.5</td>
<td>21</td>
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<td>10.00</td>
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<td>9.50</td>
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<td>BC2</td>
<td>59</td>
<td>32</td>
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<td>6.58</td>
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<td>31</td>
<td>1.31</td>
<td>1.5</td>
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<td>3.54</td>
<td>6.66</td>
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<td>0.91</td>
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<td>4.69</td>
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<td>44</td>
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<td>0.9</td>
<td>1.7</td>
<td>17</td>
<td>4.32</td>
<td>3.12</td>
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<tr>
<td>BC6</td>
<td>41</td>
<td>16</td>
<td>0.62</td>
<td>1.75</td>
<td>17.5</td>
<td>4.60</td>
<td>2.35</td>
</tr>
</tbody>
</table>

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) (1)
With $R^2 = 0.957$

(CBR = 5.343 – 1.465*A) (2)
With $R^2 = 0.787$

(CBR = 5.545 – 0.040*A – 0.063* Ip) (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.

<table>
<thead>
<tr>
<th>Sample No.</th>
<th>Latitude</th>
<th>Longitude</th>
<th>Location</th>
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<tr>
<td>BC1</td>
<td>15.0949444</td>
<td>76.89058333</td>
<td>Anakundi</td>
</tr>
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<td>BC2</td>
<td>15.2436944</td>
<td>76.90838889</td>
<td>Somasamudra</td>
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<td>76.894000</td>
<td>Siraguppa</td>
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<td>15.8473611</td>
<td>76.7144444</td>
<td>Agadaddini pai camp</td>
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<td>Madarkki</td>
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<td>BC8</td>
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<td>76.78655556</td>
<td>Jevargi</td>
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Development of Regression Equations to Predict C.B.R of Black Cotton Soils

Fig 1. Correlation of CBR with Plasticity Index

Fig 2. Correlation of CBR with Activity
Fig 3. Correlation of CBR with IP and Activity

\[ CBR = 5.545 - 0.040 \times A - 0.063 \times IP \]
\[ R^2 = 0.957 \]

Fig 4. Correlation of CBR with MDD, OMC

\[ CBR = 2.159 + 0.305 \times MDD - 0.174 \times OMC \]
\[ R^2 = 0.784 \]
Development of Regression Equations to Predict C.B.R of Black Cotton Soils...

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

\[
\text{CBR} = 5.767 - 0.015 \times \text{OMC} - 0.060 \times \text{IP} - 0.040 \times \text{A} \\
\Rightarrow R^2 = 0.957
\]

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

\[
\text{CBR} = 6.536 - 0.064 \times \text{IP} - 0.018 \times \text{A} - 0.019 \times \text{OMC} - 0.0391 \times \text{MDD} \\
\Rightarrow R^2 = 0.958
\]
Fig 7. Correlation of CBR with SPT ‘N’

\[ \text{CBR} = 4.571 - 0.125 \times N_{\text{SPT}} \]
\[ R^2 = 0.919 \]

Fig 8. Correlation of CBR with DCPT ‘N’

\[ \text{CBR} = 4.814 - 0.708 \times N_{\text{DCPT}} \]
\[ R^2 = 0.159 \]
**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:**

\[
CBR = 2.159 + 3.052 \times \text{MDD} - 0.174 \times \text{OMC}
\]  
\(R^2 = 0.784\)  
\(\text{Equation 4}\)

\[
CBR = 5.767 - 0.015 \times \text{OMC} - 0.060 \times \text{Ip} - 0.040 \times \text{A}
\]  
\(R^2 = 0.957\)  
\(\text{Equation 5}\)

\[
CBR = 6.536 - 0.064 \times \text{Ip} - 0.018 \times \text{A} - 0.019 \times \text{OMC} - 0.391 \times \text{MDD}
\]  
\(R^2 = 0.958\)  
\(\text{Equation 6}\)

Where,

- **CBR** = California Bearing Ratio
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:

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

With $R^2 = 0.919$

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

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 R² = 0.957

CBR = 5.343 – 1.465*A

With R² = 0.787

CBR = 5.545– 0.040*A – 0.063*I_p

With R² = 0.957

b) **Using Compaction Characteristics**

CBR = 2.159+ 3.052*MDD – 0.174*OMC

With R² = 0.784

CBR = 5.767 – 0.015*OMC– 0.060*I_p

–0.040*A

With R² = 0.957

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

– 0.391*MDD

With R² = 0.958

c) **Using SPT and DCPT results**

CBR = 4.571 – 0.125*N_{SPT}

With R² = 0.919
CBR = 5.100 – 0.119*N_{SPT} – 0.296*N_{DCPT}
With \( R^2 = 0.945 \)

REFERENCES


[8] IS–2720 (Part 16) – 1985 (Reaffirmed 2002) Methods Of Test For Soils; Part 16 Laboratory Determination Of CBR (Second Revision) Bureau of Indian standards, New Delhi,


