NEW STATISTICAL MODELS FOR THE PREDICTION OF SOAKED CALIFORNIA BEARING RATIO OF SOIL FROM DIFFERENT SOIL PROPERIES

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ABSTRACT: California Bearing Ratio (CBR) value determines the subgrade soil strength and is widely used for the design of flexible pavement. But in reality, evaluation of four day soaked CBR is an expensive and time consuming test, (approximately 8-10 working days) and to obtain a reliable CBR value for a long stretch very large number of tests to be done. So preliminary estimation of CBR is necessary to go ahead with the design work. Hence there is arising a need to find a simple, easier and quicker method of determining the soaked CBR value based on index properties and other parameters which can be determined easily at the same time, less time consuming. The present study is undertaken to develop some regression-based models for estimating CBR values of fine as well as coarse grained soil separately considering three independent parameters like Plasticity Index (PI), 75µ finer and Maximum Dry Density (MDD) on a large number of soil samples collected from different road projects at various locations of Telengana state. Multiple linear regression models are developed using Microsoft excel software. The approximate CBR values thus obtained may be used for preliminary estimation around Telengana state only.

KEYWORDS: California Bearing Ratio, Soaked CBR value, Regression, Model, Co-efficient of determination (R^2).

1 INTRODUCTION

Flexible pavements are mostly used in Indian Highways. The design and performance of pavement mainly depends on subgrade soil strength. The California Bearing Ratio (CBR) test was developed in USA during 2nd World war and subsequently adopted as a standard empirical method of design of flexible pavement for the other countries. For new alignment CBR values should preferably be based on for remoulded samples prepared and compacted at Optimum moisture content and Maximum dry density determined from Modified proctor test with four days soaking. Soaked CBR highlights the worst soil strength the subgrade may face in its lifetime. In situ tests such as field CBR or Dynamic cone penetration test should be avoided as far as possible since the results of these tests are largely affected by the presence of any boulder /gravel/ foreign materials anticipated inside the soil. But the major disadvantage of CBR tests is that it is very laborious and time consuming (approximately 8-10 working days) and its repeatability is low. It is very difficult to perform CBR value for a long highway within short time causing delay in project and increases its cost.

CBR is not a fundamental material property and hence no theoretical relationship has been developed yet to correlate the CBR value with other soil parameters applicable in general. Hence there is arising a need to find a simple, easier and quicker method of determining the soaked CBR value based on index properties and other parameters of subgrade soil which can be determined easily at laboratory and at the same time, less time consuming to achieve economy in time and money.

2 AVAILABLE METHODS FOR PREDICTING CBR

Many researchers and Research Institutes have developed different co-relations between CBR and index properties based on soil type and classification based USCS(Unified Soil Classification System) and AASHTO (American Association of State Highway and Transportation Officials) system. In IRC:SP:72-2015 ,US Army Corps of Engineers(USACE), E.J.Yoder & M.W. Witczak, Rollings & Rollings and

National Cooperative Highway Research Programme of United States (NCHRP) various CBR values on the basis of soil classification tests are given. There is also a Nomograph for computing soaked CBR value from sieve analysis data. Moreover extensive number of correlation empirical equations have been developed by various researchers namely Satyanarayana Reddy & Pavani(2006), Venkatasubramanian and Dhinakaran (2011), Ramasunnarao and Siva Sankar (2013), Vinod and Reena(2008), Patel and Desai(2010), Yildirim & Gunaydin(2011) and Pradeep Muley and Jain(2013) which are applicable for a specific region and particular type of soil. A few widely used correlations are given in Table-1.

Table 1 Some well known correlations are as follows:

Sl.No	Equation/ Values for CBR	Reference
1a	CBR =5 for D_{60}<=0.01mm	NCHRP (non-plastic coarse grained soil)
1b	CBR = $28.09(D_{60})^{0.358}$	
1c	CBR = 95 for D_{60}>=30mm	
1d	$CBR = \frac{75}{1+0.728(wPI)}$	NCHRP (plastic, fine grained soil)
2a	2-3 for CH,MH	IRC:SP:72-2015
2b	4-5 for ML,MI,CL,CI	
2c	6-10 for SC,SM	
2d	<2 for Expansive clay	

D_{60} =Diameter on grain size distribution curve where 60 percent particles are finer.
wPI is Weighted Plasticity Index

3 OBJECTIVES OF PRESENT STUDY:

The present study is undertaken to develop some regression-based models for estimating CBR values of fine as well as coarse grained soil separately considering three independent parameters like Plasticity Index (PI), % finer than 75µ sieve (FC) and Maximum Dry Density (MDD) on a large number of soil samples collected from different road projects at various locations of Telengana state. The black cotton soil, which is widely available at this region, is also addressed separately. All the tests have been carried out in our own laboratory. Multiple linear regression models are developed using Microsoft excel software. The approximate representative soaked CBR values thus obtained may be used for preliminary design around Telengana state only.

4 DATA COLLECTION

4.1 Soil Selection, Sampling and Laboratory Testing

Different soil samples are collected either from a trial and Borrow pit at nearby locations of the proposed alignment of highway at suitable intervals having a depth of excavation of 1.00-1.50m. The Particle size distribution, Liquid limit (LL), Plastic limit (PL), Optimum moisture content (OMC), Maximum dry density (MDD) and CBR values are determined in our own laboratory. All these tests are as per IS 2720 Part I, II, IV, V, VIII and XVI specifications.

4.2 Geotechnical properties of collected soils:

Approximately 400 nos. of disturbed samples were analysed for our present work. Four types of soil are considered separately as (i) Type-A Expansible clayey soil i.e. Black cotton soil. (ii) Type-B normal clay (iii) Type-C silty sand with medium to low plasticity and (iv) Type-D silty sand with no plasticity.

Table 2 Geotechnical properties of studied soil in Telengana

Soil Type	Properties	Range	Median	Std. Dev.
A	FC	55-94	71	10.62
	PI	24-42	31	3.89
	MDD	1.62-2.00	1.86	0.10
B	FC	50-94	76.71	12.17
	PI	03-35	09	8.38
	MDD	1.60-2.12	1.80	0.09
C	FC	14-50	9.21	18.45
	PI	3-32	5.56	13
	MDD	1.82-2.18	0.065	2.09
D	FC	2.50-30	6.51	11.86
	MDD	1.92-2.21	0.07	2.16

5 BASIS OF MODELLING

Two major factors which should be considered in establishing an empirical formula are as follows:
1) The selection of critical soil parameters to be included – Reliability of any prediction depends on the relative importance of different factors controlling the output result. Three parameters are choosen for our analysis- a) % finer than 75 µ sieve , b)PI and c) MDD. CBR value decreases with increase in plasticity index for clayey soil. From the experience it is seen that for coarse grained soil decrease in % finer than 75 µ sieve and increase in Maximum dry density value increases the CBR value.
2) Selection of type of model i.e. simple and complicated. This selection is a difficult task and

depends on judgements. In our analysis linear model is selected for all cases.

6 STATISTICAL ANALYSIS AND MODEL DEVELOPMENT

Statistical Analysis (Multiple Linear Regression) was carried out using Microsoft Excel software for developing new correlations considering CBR as independent variable and other three parameters as dependent variable. Five well known statistical indices (a) Co-efficient of determination i.e. R^2, (b) Mean Absolute Percent Error (MAPE), (c) Root Mean Square Error (RMSE), (d) Mean Absolute Deviation (MAD), (e) F test were used in order to compare the performance and precision of the developed equation. It is to be noted that the closer the value of R^2 to 1.00 and lower the value of MAPE, RMSE, & MAD, the better the model performance. F-test is performed to determine the adequacy of the model. Analysis of variance (ANOVA) is employed with an F-distribution with degrees of freedoms for regression and Error/residual. 95% of level of confidence is taken. If calculated F value is greater than tabulated F value, null hypothesis is rejected and a real relation exists between dependent and independent variables i.e. model is valid.

Table 3. Comparison of different statistical parameters :

Soil Type	R2	MAPE	RMSE	MAD	F TEST/ FCRIT
A	0.973	13.282	0.611	0.491	497 / 2.83
B	0.921	23.257	3.191	2.397	460/ 2.68
C	0.946	20.228	4.275	3.527	846/ 2.66
D	0.986	9.401	2.801	2.239	1160/ 3.29

In comparison to the statistical parameters from the tables 3 it is observed that R-squared value is maximum and MAPE, RMSE & MAD values are quite low. Also calculated F value is considerably greater than tabulated F value.

This implies that the author's prediction appear to be in good agreement with the observed values and suggested as new empirical graphs in this study for determination of CBR in Telengana State.

On the basis of developed models the graphs for determining CBR values are as follows:

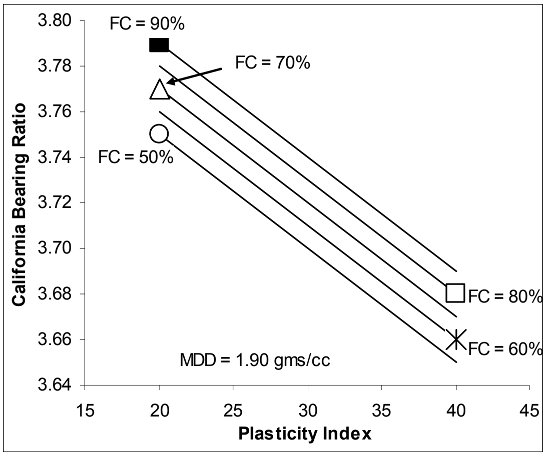

Fig. 1a. Black cotton soil- Variation of CBR with varying fine content for a particular MDD.

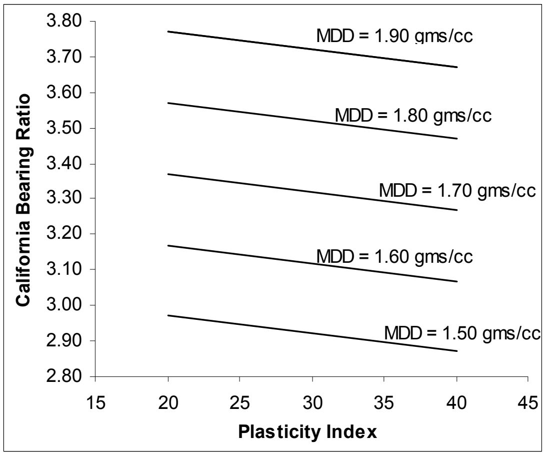

Fig. 1b. Black cotton soil- Variation of CBR with different MDD & plasticity index

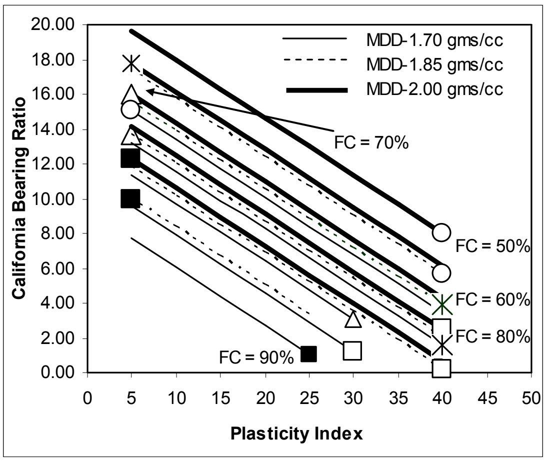

Fig. 2. Clayey soil (Other than Black cotton) - Variation of CBR with varying fine content, MDD & PI

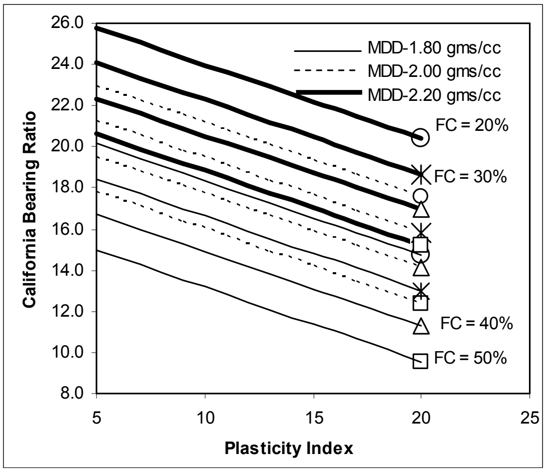

Fig. 3. Silty sand - Variation of CBR with varying fine content, MDD & PI.

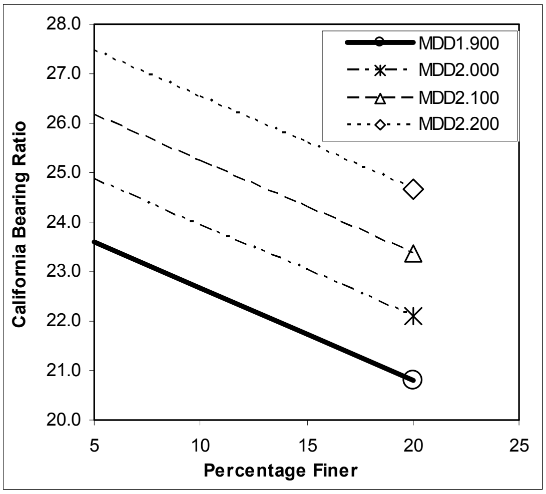

Fig. 4. Silty sand with no plasticity - Variation of CBR with varying fine content & MDD

We have proposed the following four sets of equations to determine soaked CBR value of Telengana State as follows:

For Black cotton soil:
CBR = 0.001FC - 0.0050PI + 2MDD (1)

For Clayey soil other than Black Cotton:
CBR = - 0.1841FC - 0.3329PI + 15.25MDD (2)

For sandy soil (SC type)
CBR = - 0.1723FC - 0.3609PI + 14.11MDD (3)

For sandy soil (SM type)
CBR = - 0.1865FC + 12.907MDD (4)

7 CONCLUSION

From the present study the following conclusions can be made for determination of soaked CBR value in Telengana state.

1) Correlaions which may exist between soaked CBR value and three parameters as a) % finer than 75 μ sieve , b) PI and c) MDD are determined using multiple linear regression [Ref. Eqn 1 to 4 & Fig 1 to 4]. The graphs as well as equations may be utilized for quick determination of soaked CBR value particularly useful for preliminary estimate.
2) For Black cotton soil CBR value changes for a negligible extent with increase in value of fine content from 50-90% keeping other factors constant [Refer Fig-1a & Fig-1b, Eq. 1].
3) For the clayey soil CBR value decreases considerably by increasing PI for a particular fine content and MDD.[Refer Fig-2, Eq.2].
4) For sandy soil CBR value increases with decrease in fine content and increase in MDD. [Refer Fig-3 & 4, Eq. 3 & 4].

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