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Predicting Soaked CBR Value of Fine Grained Soils Using Index and Compaction Characteristics

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ABSTRACT

California Bearing Ratio (CBR) value is an indicator of subgrade soil strength and is used often for design of flexible pavements. The conventional soaked CBR testing method is expensive and time consuming. To overcome this situation, it is appreciable to predict CBR value of subgrade soil with simple properties of soils such as index properties which include grain size analysis (% Gravel, % Sand, % Fines), Liquid Limit (LL), Plastic Limit (PL), and compaction characteristics; namely Maximum Dry Density (MDD) and Optimum Moisture Content (OMC). The present study aims at developing regression-based models for predicting soaked CBR value for fine-grained subgrade soils in terms of gran size analysis, LL, PL, MDD and OMC.

KEYWORDS: Soaked CBR value, Regression, Model, Coefficient of determination (R^2).

INTRODUCTION

A pavement is a relatively stable crust constructed over natural soil for supporting and distributing wheel loads and providing durable wearing surface. Pavement is usually built in several layers, and these are usually termed subgrade, subbase, base and surfacing. The design and the behaviour of flexible pavement depend mainly on the strength of subgrade soil, and hence it is necessary to assess its strength. The subbase/base thickness of pavement is governed by CBR value of subgrade soil along with some other parameters such as traffic intensity, climatic conditions,… etc. CBR test was introduced by California Highway Department, USA during the 2nd World War and subsequently adopted as a standard method of design in other parts of the world. CBR test is now an empirical test widely applied in design of flexible pavements over the world.

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The CBR test is essentially a penetration test, which can be carried out either in the laboratory or in the field. CBR value can be measured directly in the laboratory (ASTM, 2007) on soil samples acquired from site. The conventional CBR testing method is expensive, time consuming and its repeatability is low. To conduct CBR test on subgrade soil, a representative sample shall be collected, from which a remoulded specimen is prepared, compacted at predetermined OMC with standard proctor's (light) compaction. The specimen prepared is soaked for 4 days under water and penetration test is conducted. To obtain soaked CBR value of a soil sample, it takes about a week. CBR test is expensive, time consuming and laborious. Obtaining a proper idea about the soaked CBR of subgrade materials over total length of the road is very difficult. So, it is not really possible to take a large number of samples. In addition, CBR test in laboratory requires a large soil sample and is laborious as well as time consuming. This would result in serious delay in the progress of the project, since in most situations the materials for earth work construction come from highly variable sources. Any delay in construction inevitably leads to rise of project cost. To overcome this situation, it is better to predict CBR value of subgrade soil with easily determinable parameters. To exercise the right judgment during various phases of professional activities, the engineer is constantly required to predict. In fact, prediction is an integral component of practice (Nagaraj et al., 1994).

A few investigators (NCHRP, 2001; Satyanarayana and Pavani, 2006; Gregory and Cross, 2007; Vinod and Reena, 2008; Patel and Desai, 2010; Yildrim and Gunaydin, 2011) in the past developed models for estimating the CBR value on the basis of low cost, less time consumption and easiness to perform tests. Other investigators (Yildrim and Gunaydin, 2011; Wenkatasubramanian and Dhinakaran, 2011; Saklecha et al., 2012) used soft computing systems like Artificial Neural Networks for correlating CBR values with LL, PL, PI, OMC, MDD and Unconfined Compressive (UCC) strength values of various soils. In this investigation, an attempt has been made for correlating soaked CBR value of fine-grained soils with index properties such as Grain Size Analysis (% Gravel, % Sand, % Fines), Plasticity Characteristics (LL and PL) and Compaction Characteristics; namely MDD and OMC. The tests conducted for determining grain size, LL, PL, MDD and OMC are much cheaper and less-time consuming than soaked CBR test. The correlation is established in the form of an equation of soaked CBR value as a function of different soil properties by regression analysis.

Existing Models to Estimate CBR

Attempts have been made by several researchers to develop suitable correlation between CBR value of compacted soils and different soil characteristics. The details of the existing models proposed by several researchers and the parameters considered for developing those models are presented in Table 1. The statistical parameters such as coefficient of correlation (R), coefficient of determination (R^2) and standard error reported by earlier investigators are also presented in the Table 1.

Proposed Model for Estimating Soaked CBR Value

In this study, regression models, both simple linear and multiple linear, were developed for estimating soaked CBR value in terms of index and compaction characteristics. Data pertaining to soil properties used for developing models to estimate soaked CBR value is presented in Table 2. The index properties of soils show that all the soils used for developing models are fine-grained soils (ASTM, 2010). The range of parameters studied in this investigation is: Gravel=0-24%, Sand=0-40.14%, Fines (Silt+Clay) =50-100%, LL=24.6-94.0%, PL=11.9-36.0%, MDD=1.25-1.85g/cc, OMC=12.3-35.4%, soaked CBR=0.8-5.86%. A wide range of fine grained soils are selected while developing models to predict soaked CBR value of subgrade soil.

Simple Linear Regression Analysis (SLRA)

To develop the models, simple linear regression analysis and multiple linear regression analysis were carried out. Soaked CBR value is considered as independent variable and Gravel (G), Fines (F), Sand (S), LL, PL, MDD and OMC are considered as the dependent variables. Simple Linear Regression Analysis (SLRA) has been carried out to develop the correlation between individual soil property and soaked CBR value. SLRA can be carried out using standard statistical software like Data Analysis Tool Bar of Microsoft Excel in order to derive the relationship statistically. Statistical parameters of soaked CBR value predicted by various SLRA models are presented in Table 3.

From Table 3, it is noticed that model 6 has given a good performance as it has the highest coefficient of correlation (R)-value of 0.91, coefficient of determination (R^2)-value of 0.84 and least standard error of 1.23. Correlation and linear regression are not the same. Correlation quantifies the degree to which dependent and independent variables are related. Coefficient of correlation tells how much one variable tends to change when the other one does. When R is 0.0, there is no relationship. When R is 1, there is a good relation. Linear regression quantifies goodness of fit with r^2, sometimes shown in upper case R^2. R^2-value provides a measure of how well future outcomes are likely to be predicted by the model. Any correlation with R^2 value equal to 0.80 or above will be viewed as a best fit. Models 5, 1, 7, 2, 4 and 3 have performed in descending order by observing decreasing order of R-value and R^2-value.

Table 1. Models Proposed by Earlier Investigators

S.No.	Investigator	Parameters considered and their range	Model	Statistical parameter
1	(NCHRP, 2001)	non-plastic coarse-grained soils	CBR = 5%, if D_{60}≤0.01mm CBR=28.09$(D_{60})^2$, if 0.01mm≤D_{60}≤30mm CBR=95%, if D_{60}≥30mm	R^2=0.84
		plastic, fine-grained soils	$CBR = \frac{75}{1+0.728(wPI)}$	R^2=0.67
2	(Satyanarayana Reddy & Pavani, 2006)	FF=9.0-34.8%, LL=22-48%, MDD=1.90-2.32g/cc, CBR_s=12.8-56.8%	CBR_s=-0.388F-0.064LL+20.38MDD	R=0.96
3	(Gregory & Gross, 2007)	For cohesive soils	CBR = 0.09 c_u	-
		For cohesionless soils	$CBR=\frac{q_{ult}*100}{6895}$	-
4	(Vinod & Reena, 2008)	C=33-65%, LL=38.10-63.00%, CBR_s=8.9-30.4%	CBR_s= -0.889(W_{LM})+45.616 where, W_{LM} = LL (1 – C/100)	R=0.979
5	(Patel & Desai, 2010)	LL=52.98-70.78%, PL=17.09-26.8%, SL=8.03-19.5%, MDD=1.58-1.73g/cc, OMC=17.23-24.70%, PI=24.19-47.78%, CBRu=2.80-8.94%, CBRs=1.54-4.42%	CBR_u=17.009-0.0696Ip-.296MDD+0.0648OMC	% error=-2.5%
			CBR_s=43.907-0.093Ip-18.78MDD-0.3081OMC	% error=-5%
6	(Yildirim & Gunaydin, 2011)	G=0-78%, S=1-49%, F=10-99%, LL=20-89%, PL=11-43% MDD=1.21-2.18 g/cc, OMC=7.20-40.20%	CBR = 0.2353G+3.0798	R^2=0.86
			CBR=-0.1805F+18.508	R^2=0.80
			CBR=0.22G+0.045S+4.739MDD+0.122OMC	R^2=0.88
			CBR=0.62OMC+58.9 MDD+0.11LL+0.53PL-126.18	R^2=0.63

Where, CBR_s = Soaked California Bearing Ratio, CBR_u = Unsoaked California Bearing Ratio, D_{60} = Diameter at 60% passing from grain size distribution (in mm), w = Percentage passing No.200 U.S. sieve (in decimal), LL= Liquid Limit of soil (in percent) and C is fraction of soil coarser than 425micron (percent), PL=Plastic Limit, SL=Shrinkage Limit, Ip =PI=Plasticity Index, MDD=Maximum Dry Density, OMC = Optimum Moisture Content (%), c_u= undrained cohesion (kPa), q_{ult}=Ultimate bearing capacity (in kPa).

Table 2. Data Used for Developing Models to Estimate Soaked CBR Value

S. No.	Fines (%)	Sand (%)	Gravel (%)	LL (%)	PL (%)	Soil Type	Compaction Characteristics		Soaked CBR Value (%)
							OMC (%)	MDD (g/cc)	
1	62.50	37.50	0.00	54.80	27.40	CH	16.8	1.78	3.00
2	60.40	34.58	5.02	58.70	16.48	CH	17.0	1.64	1.47
3	94.40	5.60	0.00	60.60	30.60	CH	35.0	1.51	1.96
4	91.50	8.50	0.00	63.00	31.00	CH	35.0	1.25	1.26
5	94.40	5.60	0.00	72.70	30.50	CH	21.2	1.85	2.10
6	65.50	32.50	2.00	82.50	32.80	CH	19.6	1.58	0.80
7	89.00	11.00	0.00	94.00	36.00	CH	35.4	1.33	2.10
8	89.00	11.00	0.00	75.00	32.00	CH	28.0	1.47	2.43
9	91.00	9.00	0.00	48.00	26.00	CL	20.0	1.61	3.40
10	71.00	27.00	2.00	49.00	24.00	CL	19.6	1.69	4.13
11	52.00	39.00	9.00	59.00	34.00	CH	19.0	1.69	4.00
12	100.00	0.00	0.00	47.20	32.00	CL	23.0	1.55	4.90
13	60.00	18.00	22.00	24.60	15.30	CL	18.5	1.56	2.34
14	57.00	24.00	19.00	29.30	18.40	CL	18.2	1.71	2.55
15	57.00	19.00	24.00	26.00	11.90	CL	15.2	1.63	2.12
16	54.00	28.00	18.00	30.00	12.30	CL	14.2	1.82	3.14
17	83.00	17.00	0.00	36.50	20.90	CL	16.2	1.76	3.94
18	66.67	33.30	0.00	34.04	25.75	ML	18.9	1.52	5.86
19	61.50	35.50	3.00	45.20	22.30	CL	12.3	1.78	3.3
20	74.00	26.00	0.00	56.00	27.00	CH	24.8	1.51	3.89
21	79.00	21.00	0.00	59.00	31.00	MH	26.1	1.47	3.57
22	92.00	8.00	0.00	57.80	21.70	CH	22.0	1.58	1.5
23	87.00	13.00	0.00	32.60	20.60	CL	15.0	1.84	1.31
24	59.86	40.14	0.00	43.50	26.78	ML	21.6	1.61	3.27
25	97.00	3.00	0.00	69.00	33.00	CH	26.8	1.55	2

Multiple Linear Regression Analysis (MLRA)

MLRA has been carried out by considering soaked CBR value as the independent variable and the rest of soil properties as dependent variables. MLRA can be carried out using standard statistical software like Data Analysis Tool Bar of Microsoft Excel in order to derive the relationship statistically. Soaked CBR (CBR_s) may be expressed as given below:

$CBR_s = f(F, S, G, LL, PL, MDD, OMC)$

$$CBR_s=0.064F+0.082S+0.033G-0.069LL+0.157PL-1.810MDD-0.061OMC \quad \ldots\ldots (1)$$

Table 3. Models Developed from Simple Linear Regression Analysis

Type of RA	Model No.	Model	Statistical Parameters			
			R	R^2	Adjusted R^2	Standard Error
SLRA	1	CBR_s=0.035F	0.88	0.78	0.74	1.43
SLRA	2	CBR_s= 0.1085S	0.84	0.70	0.66	1.69
SLRA	3	CBR_s= 0.144G	0.40	0.16	0.12	2.85
SLRA	4	CBR_s=0.045LL	0.82	0.68	0.64	1.76
SLRA	5	CBR_s = 0.103PL	0.89	0.79	0.75	1.39
SLRA	6	CBR_s = 1.737MDD	0.91	0.84	0.80	1.23
SLRA	7	CBR_s = 0.116OMC	0.85	0.73	0.69	1.60

Table 4. Analysis of Variance (ANOVA) for Testing Significance of Regression

Source of Variation	*Degree of freedom (df)*	*Sum of Squares (SS)*	*Mean Square (MS)*	*F*= MS_R/MS_E
Regression	7	217.0522	MS_R =217.0522/7=31.007	=31.007/0.952 =32.542
Error or Residual	18	17.15102	MS_E =17.15102/18= 0.952	
Total	25	234.2032		

The statistical parameters indicate that the best performance can be obtained from MLRA rather than SLRA by showing the highest R-value of 0.96 and R^2-value of 0.92. Hence, the above model may be proposed for estimating soaked CBR value. To measure the adequacy of the proposed model for estimation of CBR value, F-test is performed according to the standard procedure (Montgomery and Runger, 2003). To test the significance of regressions, analysis of variance (ANOVA) was employed. This test follows an F-distribution with degree of freedom (d.o.f) ν_1=7 and ν_2=18 for CBR, so that the critical region will consist of a value exceeding 2.58. In this test, a 95% level of confidence was chosen. If the calculated F value is greater than the tabulated F value, the null hypothesis is rejected and there is a real relation between dependent and independent variables. Since the calculated F value (=32.542) is greater than the tabulated F value ($F_{0.05,\,7,\,18}$=2.58), the null hypothesis is rejected. Therefore, it is concluded that the model is valid.

Validity of the Proposed Model

The validity of the proposed model for prediction of soaked CBR value was verified by data of soil properties reported by few investigators. The results of the predicted and observed soaked CBR values are presented in Table 5. The soaked CBR value was predicted using the proposed regression model given by equation (1). It is found that the observed soaked CBR value and the predicted CBR values are close to each other. The proposed model should only be used along with good judgment and engineering experience to provide a rapid and cost-effective method of determining soaked CBR of subgrade soil.

Table 5. Validity of Proposed Model

Investigator	**(El-Rawi & Al-Samadi, 1995)**	**(El-Rawi & Al-Samadi, 1995)**	**(Mohanty et al., 2011)**	**(Reddy et al., 2011)**
Fines (%)	89	97	92.56	54
Sand (%)	11	3	7.44	43
Gravel (%)	0	0	0	3
LL (%)	52	51	33.45	42
PL (%)	29	24	22.24	22
OMC (%)	22.7	20.5	17	14.6
MDD (g/cc)	1.54	1.67	1.72	1.8
Predicted CBR_s Value (%)	3.38	2.42	3.57	3.50
Observed CBRs Value (%)	3.8	2.5	3.28	3.8
Ratio of Predicted CBR_s to Observed CBR_s	0.89	0.96	1.09	0.92

CONCLUSIONS

The following conclusions can be drawn from the results of the present study:

1. The statistical parameters indicate that the model developed by Simple Linear Regression Analysis (SLRA) for correlating soaked CBR value with Maximum Dry Density (MDD) has shown better performance.
2. The other models developed by SLRA for correlating soaked CBR value with Plastic Limit (PL), %Fines (F), %Sand (S), Liquid Limit (LL) and Optimum Moisture Content (OMC) have shown relatively good performances.
3. The statistical parameters indicate that better performance can be obtained from the model developed using Multiple Linear Regression Analysis (MLRA) by showing the highest R-value of 0.96 and R^2 - value of 0.92 and the lowest error of 0.97.
4. It was observed that the use of index properties such as grain size analysis (%Gravel, %Sand, %Fines), Plasticity Characteristics (LL, PL) and Compaction Characteristics; namely MDD and OMC appears to be reasonable in the estimation of soaked CBR value of fine grained soils.

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REFERENCES

ASTM D1883-07e2. 2007. Standard Test Method for CBR (California Bearing Ratio) of Laboratory-Compacted Soils, American Society for Testing of Materials, Pennsylvania, USA.

ASTM D2487-10. 2010. Standard Practice for Classification of Soils for Engineering Purposes (Unified Soil Classification System), American Society for Testing of Materials, Pennsylvania, USA.

El-Rawi, N.M. and Al-Samadi, M.M.Y. 1995. Optimization of Cement-Lime-Chemical Additives to Stabilize Jordanian Soils, *Journal of Islamic Academy of Sciences*, 8 (4): 167-174.

Gregory, G.H. and Cross, S.A. 2007. Correlation of CBR with Shear Strength Parameters, June 24-27, 1-14, *Proceedings of 9th International Conference on Low Volume Roads*, Austin, Texas.

Mohanty, B., Chauhan, M.S. and Mittal, S. 2011. California Bearing Ratio of Randomly Oriented Fiber Reinforced Clayey Subgrade for Rural Roads, Dec. 15-17, 611-614, *Proceedings of Indian Geotechnical Conference-2011*, Kochi, India.

Montgomery, D.C. and Runger, G.C. 2003. Applied Statistics and Probability for Engineers, 3rd Edn., John Wiley and Sons, Inc.

Nagaraj, T.S., Srinivasa Murthy, B.R. and Vatsala, A. 1994. Analysis and Prediction of Soil Behavior, First Edition, New Age International Publishers, New Delhi, India.

National Cooperative Highway Research Program (NCHRP). 2001. Guide for Mechanistic and Empirical–Design for New and Rehabilitated Pavement Structures, Final Document, Appendix CC-1: Correlation of CBR Values with Soil Index Properties, West University Avenue Champaign, Illinois, USA.

Patel, S.R. and Desai, M.D. 2010. CBR Predicted by Index Properties for Alluvial Soils of South Gujarat, Dec. 16-18, 79-82, *Proceedings of Indian Geotechnical Conference–2010*, India.

Reddy, C.N.V.S., Reddy, K.C. and Kumar, T.K. 2011. Reinforced Soil Mattress Approach for Flexible Pavements over Clay Subgrade, Dec. 15-17, 601-603, *Proceedings of Indian Geotechnical Conference-2011*, Kochi, India.

Saklecha, P.P., Katpatal, Y.B., Rathore, S.S. and Agarwal, D.K. 2012. ANN Modeling for Strength Characterization of Subgrade Soil in a Basaltic Terrain, *Proceedings of ICAMB-2012*, Jan. 9-11, 1215-1220, SMBS, VIT University, Vellore, India.

Satyanarayana Reddy, C.N.V. and Pavani, K. 2006. Mechanically Stabilised Soils-Regression Equation for CBR Evaluation, Dec. 14-16, 731-734, *Proceedings of Indian Geotechnical Conference-2006*, Chennai, India.

Venkatasubramanian, C. and Dhinakaran, G. 2011. ANN Model for Predicting CBR from Index Properties of Soils, *International Journal of Civil and Structural Engineering*, Integrated Publishing Association (IPA), 2 (2): 605-611.

Vinod, P. and Reena, C. 2008. Prediction of CBR Value of Lateritic Soils Using Liquid Limit and Gradation Characteristics Data, *Highway Research Journal*, IRC, 1 (1): 89-98.

Yildrim, B. and Gunaydin, O. 2011. Estimation of CBR by Soft Computing Systems, *Expert Systems with Applications*, ELSEVIER, 38 (2011): 6381-6391.