Prediction of CBR Value from Index Properties of Different Soils: Review

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Abstract: **A prediction is a vital tool in engineering used to take right decisions. It's very important for engineers to quickly predict the behaviour of geomaterials used in the infrastructures. California Bearing Ratio (CBR) test is a common laboratory test, performed to evaluate the shear strength and stiffness modulus of sub grade for the design of pavement. CBR test is a laborious test, therefore, it is vital to develop the models for quick assessment of CBR value. This study is an attempt to develop valid models to determine the CBR value from index properties of soil which are quicker to estimate from their standard method of testing. In this study authors developed predictive models using 59 set of soil samples containing both fine grained and coarse grained soil samples. Three models were developed and validity of these models was checked on 25 set of soil samples tested separately. Authors developed separate models for coarse grained soil and fine grained soils. These models were developed, based on liquid limit and plasticity index for fine grained soil, the coefficient of uniformity and maximum dry density for coarse grained soil.**

Index Terms **- Prediction, California Bearing Ratio, Fine Grained Soil, Coarse Grained Soil, Liquid limit, Plasticity index, Coefficient of Uniformity, Maximum Dry Density**

I. INTRODUCTION

Geotechnical engineers should play a vital role in planning and designing of infrastructures. A prediction is an important tool in engineering used to take right decisions. Therefore, it is very important for Geotechnical engineers to quickly predict the behavior of geo-materials used in the infrastructure. CBR is an important parameter used in designing a pavement. To determine the shear strength and stiffness modulus of subgrade to be used in design of pavement, California Bearing Ratio (CBR) is performed on subgrade material. CBR value can be directly assessed by California Bearing Ratio test. CBR test is laborious and tedious. It usually takes four days to complete a test. So for quick assessment of CBR value, it is required to correlate the CBR value with the quickly assessable properties of soils.

Different researchers have worked in this context. Various studies i.e. Black in 1962, Graft-Johnson & Bhatia in 1969, Agarwal and Ghanekar in 1970 and NCHRP in 2001 [i-iv] have focused the effect of geotechnical characteristics of soils and soil types on CBR values. Many researchers have made attempts to develop effective correlations for prediction of California Bearing Ratio (CBR) from index properties of soils. Black in 1962 aimed to develop an approximate method to quickly predict the CBR value. He established predictive models to predict CBR value based on Plasticity index [i]. Agarwal and Ghanekar in 1970 established a relation between CBR value and different index properties of soil [iii]. Following prediction model was proposed using liquid limit and optimum moisture content.

$$CBR = 2 - 16 \log(OMC) + 0.07LL \qquad (1)$$

Yildirim & Gunaydin (2011) proposed following correlation for CBR soaked value with index properties of fine grained soils [iv].

$$CBR=0.62OMC+58.9MDD+0.11LL+0.53PL-126.18 \qquad (2)$$

Nugroho et.al (2012) compared value of CBR given by un-soaked and soaked test and proposed following linear correlation of un-soaked and soaked CBR value with Index properties of soils [v].

$$\Delta CBR = 25+C_1-C_2LL-C_3PI + 3.5OMC \qquad (3)$$

Where C_1, C_2, C_3, are coefficients depend upon the clay fraction.

Prediction models for CBR value documented in the National Cooperative Highway Research Program (2001) of United States of America through the "Guide for Mechanical-Empirical Design of New and Rehabilitated Pavement Structures" are the most cited models [ii]. Prediction model based on plasticity index is quoted for fine grained soil and for coarse grained soil (wPI = 0) $D60$, diameter at 60% passing from grain size distribution is used as predictor.

$$CBR = \frac{75}{1 + 0.728\,wPI} \qquad (4)$$

$$CBR = 28.09 D_{60}^{\,0.358} \qquad (5)$$

TABLE I

SUMMARY OF THE LITERATURE MODELS CORRELATING CBR AND INDEX PROPERTIES OF SOILS

Equation	R^2	Remarks	Country	Reference
CBRu=17.009-0.0696(PI)-0.296(MDD) +0.0648(OMC)	Error =-2.5%	Fine Grained Soils	South Gujarat, India	[vi]
CBR=-18.78(MDD)+43.907-0.093(PI) - 0.3081(OMC)	Error =-2.5%	Fine Grained Soils	South Gujarat, India	[vi]
$CBR = 4.5 [(20-GI)/18]^2$	NA	Fine grained, cohesive soils with CBR ≤ 20%	Australia	[vii]
$CBR=96.3–17.8Log[(LSP)(P425)^{0.7}]$ 28.7Log(P200)	0.69	NA	South Africa	[vii]
$CBR=97.7–17.1Log[(PI)(P425)^{0.5}]–30.7Log(P200)$	0.66			
CBR=90– 47.4Log (P200)	0.59			
CBR = 13.56+1.04 (PL) CBR = 28.87+0.22 (LL) CBR = -70.22+50.28 (MMD) CBR = 10.91+9.42 (SG) CBRu= 65.31+0.8 (PL) CBRu= 83.19+0.031(LL) CBRu= 65.88+8.66 (MMD) CBRu = 56.19+10.43 (SG)	NA	lateritic soil (A-2-4)	Osogbo, Nigeria	[viii]
Log10(CBR) = 0.29(GM) - 0.024(PI) +1.23	NA	Base course material	NA	[ix]
CBR=0.064(F)+0.082(S)+0.033(G)-0.069(LL) +0.157(PL)-1.810(MDD)-0.061(OMC	0.92	Fine Grained Soil	India	[x]
$CBR=(1.44-4.23PI)[Fs+264PI -56PI-5]^2$ CBRu=(8.44-16.1PI)[Fi+488PI -314PI+45]	NA	Fine Grained Soils (Silty Clay)	Sudan	[xi]
CBR=-0.889(WLM)+45.616 where, WLM= LL (1 – P425/100)	0.979	NA	NA	[xii]
Where: CBR = California Bearing Ratio (soaked),%; wPI = Weighted Plasticity index; MDD=Maximum dry density; OMC=Optimum Moisture Content; GI=group index; CBRu = unsoaked CBR; LL = Liquid limit; PL = Plastic limit; PI=Plasticity index; SG = Specific gravity; LSP = Linear shrinkage P200 = passing No. 200 U.S. sieve, %; GM = grading modulus; P425 = passing sieve size 0.425 mm; F=Fines, %; S=Sand, %; G=Gravel, %; Fi=initial state factor; Fi=soaking state factor.				

II. METHODOLOGY

To achieve the objectives of the research study, soil samples of varying geotechnical characteristics were collected from different parts of Pakistan. Total 84 number of soil samples were collected from different projects among which 43 samples were of fine grained soil and 41 were of coarse grained soil. Fig. 1 shows testing program for the present study.
Among 84 tested samples, 59 samples test results were utilized for the development of correlations and 25 were utilized to check the validity of developed correlations. Correlations were developed separately for fine grained soils and coarse grain soils.

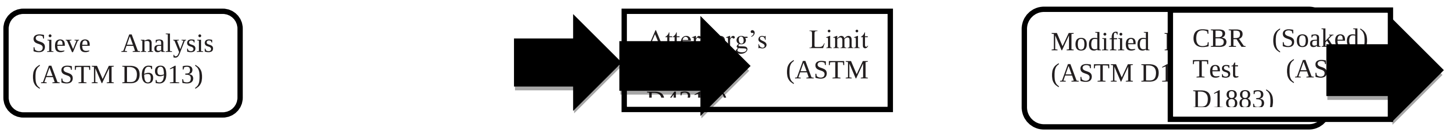

Fig. 1. Laboratory Testing Program [xix-xxii]

III. TEST RESULTS

All the soil samples were tested as per ASTM standards [xix-xxii]. 59 samples of soil were tested for the establishment of correlations. Summary of all test results is given in Table II.

TABLE II
LABORATORY TEST RESULT DATA

Classification Symbol	Number	LL	PI	Grain size distribution			Compaction Characteristics		Soaked CBR value
(USCS)		(%)	(%)	Gravel (%)	Sand (%)	Fines, F200 (%)	OMC (%)	γdmax 3 (lb/ft)	CBRs (%)
CL	16	23-41	9-19	1-28	3-34	66-99	12-15	114.5-123	3.8-9.5
ML	5	17-22	5-19	1-9	15-34	53-84	9-11	117-124	10.5-15
CL-ML	8	19-25	4-7	0-60	8-38	51-89	9-11	112.5-130	9-14
SP	6	0-0	0-0	0-2	91-99	1-9	12-15	103-120	7.5-11
SC	3	23-30	9-14	0-4	59-80	20-41	8-8.5	128-130	10-21
SM	19	0-21	0-0	0-26	52-84	12-40	8.5-11	108-121.5	8.1-35
SP-SM	2	18-19	0-0	0-0	92-94	6-8	8-11	103-131	7-21
Overall	59	0-41	0-19	0-26	3-99	1-99	8-15	103-130	3.8-35

Sieve Analysis of soil samples showed that soil samples can be classified among coarse grained soil samples and fine grained soil samples. Among fine grained soil samples percentage of gravel was ranging from 0-28%, sand 1-46% and fines(F200)51-99%, where among coarse grained soil samples percentage of gravel was ranging from 0-26%, sand 51-99% and fines(F200)1-41%.Atterberg's limit test results of soil samples showed that liquid limit is in a range of 0- 41%, The plastic limit is in a range of 0-21% and plasticity Index is in a range of 0-19%. Soil samples were classified as per Unified Soil Classification System. Samples were classified as CL, ML, CL-ML, SP, SC, SM and SP-SM. From modified compaction test results it was observed that OMC was ranging from 8-15% and maximum dry density 103-130 pcf. Soaked CBR test results revealed that overall CBR value was ranging from 3.8-35 [xviii]. For Fine grained soil samples this range was 3.8-15 and for coarse grained soil samples this range was 7-35.

IV. SOIL TEST RESULT ANALYSIS

Based on soil test results, different relationships were established. The strength of these relationships was checked from R2 value based on criteria proposed by Pellinen, and shown in Table II. Soil samples were classified majorly as fine grained soil samples having F200 greater than or equal to 50% and coarse grained soil samples having F200 less than 50%. It was observed that with an increase in fines the CBR value tends to decrease but strength of this relationship is very poor as shown in Fig. 1.

The relationship was also established between CBR soaked value, optimum moisture content and maximum dry density. It was observed there is a linear relationship between CBR soaked value and optimum moisture content for both fine grained and coarse grained soil as shown in Fig. 2. With an increase in optimum moisture content of soil CBR soaked tends to decrease. Similarly, a linear relationship was observed between CBR soaked value and maximum dry density as shown in Fig. 3. CBR soaked tends to increase with the increase in maximum dry density of soil.

Liquid limit and plasticity index are two very important index properties of fine grained soils. In the present study it was observed that with an increase in liquid limit and plasticity index, CBR soaked Value tends to decrease for fine grained soil as shown in Fig. 4 and 5. The value of R^2 is very high for both relationships 0.8482 and 0.8949 indicating very less scatter and good correlations. For coarse grained soil sample relationship was established between CBR soaked Value and D60 as shown in Fig. 6. The value of R2 is very low (R2 = 0.019) indicating high scatter in data and very poor relationship. Relationship between CBR soaked Value and coefficient of uniformity Cu was also established as shown in Figure 7. It was observed that with increase in the value of coefficient of uniformity Cu, CBR soaked Value tends to increase. A high value of R2 was observed (R2 = 0.810) indicating less scatter in data and good strength of correlation between Cu and CBR soaked value.

V. DEVELOPMENT OF PREDICTION MODELS

In order to develop valid prediction models correlating CBR soaked Value (%) and index properties of soils, different relationships were drawn between CBR soaked Value (%) and index properties of soils as discussed in previous section. The scatter diagrams of the soaked CBR and each of the index soil properties was drawn and presented in Fig. 2 through 8. For fine grained soil Fig. 5, 6 show relatively stronger correlations. The strength of these correlations is also indicated by R2 0.8482 and 0.8949 respectively. Similarly, for coarse grained soil Fig. 2, 8 show relatively stronger correlations. The strength of these correlations is also indicated by R2 0.639 and 0.810 respectively. A multiple regression modelling was then tried using the solver tool within SPSS and the goodness of fit statistics checked according to the conceptual criteria proposed by Pellinen, and shown in Table III was used to select the best model [xxiii]. Linear Regression estimates the coefficients of the linear equation, involving one or more independent variables that best predict the value of the dependent variable. Regression analysis gives the different equations by correlating CBR values with different groups of soil properties.

TABLE III
Criteria for goodness of fit statistical parameters [xxiii]

Criteria	R^2
Excellent	>0.9
Good	0.7-0.89
Fair	0.4-0.69
Poor	0.2-0.39
Very poor	<0.2

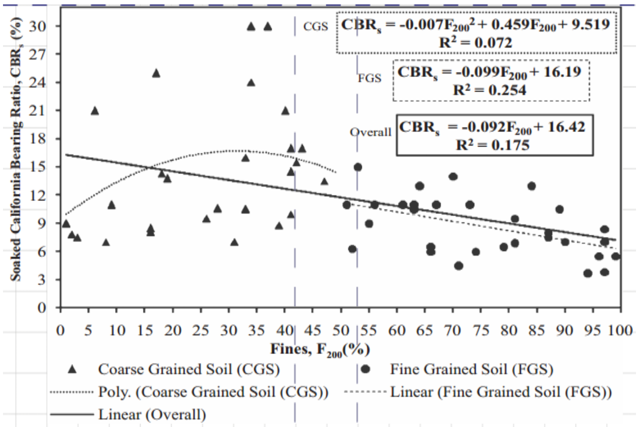

Fig. 2. Relationship between CBR soaked Value (%) and Percentage Fines (%)

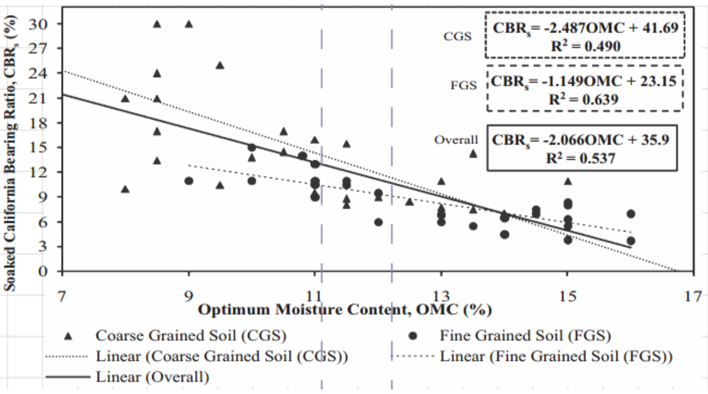

Fig. 3. Relationship between CBR soaked Value (%) and Optimum moisture content (%)

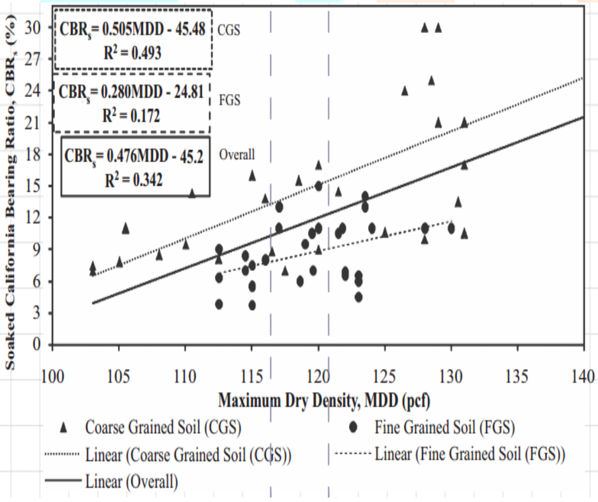

Fig. 4. Relationship between CBRsoaked Value (%) and Maximum dry density (pcf)

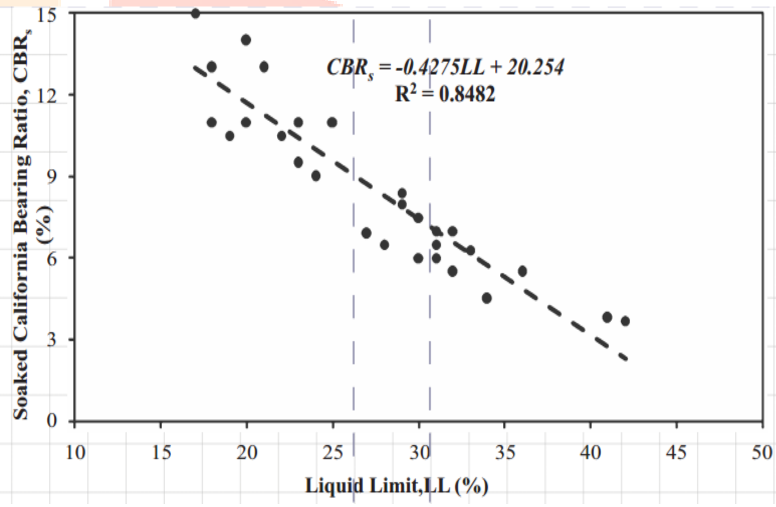

Fig. 5. Relationship between CBRsoaked Value (%) and Liquid limit (%)

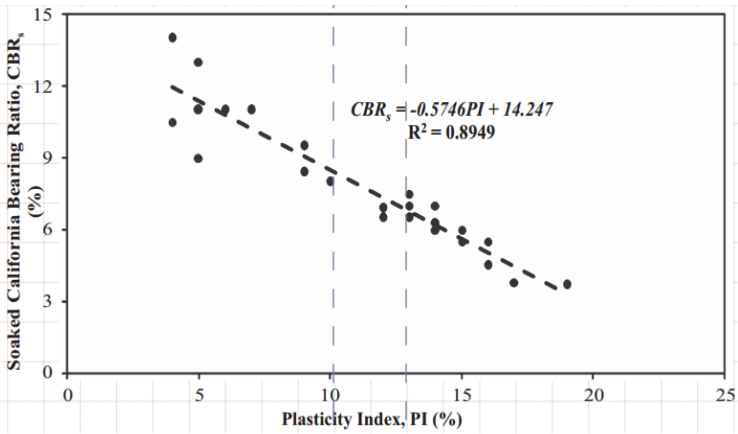

Fig. 6. Relationship between CBRsoaked Value (%) and Plasticity Index (%)

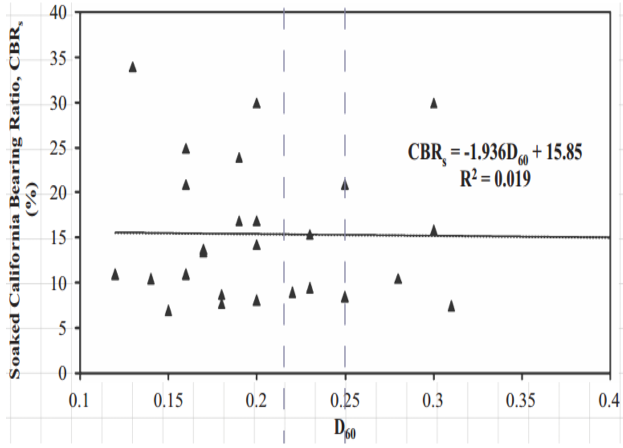

Fig. 7. Relationship between CBRsoaked Value (%) and D60 (%)

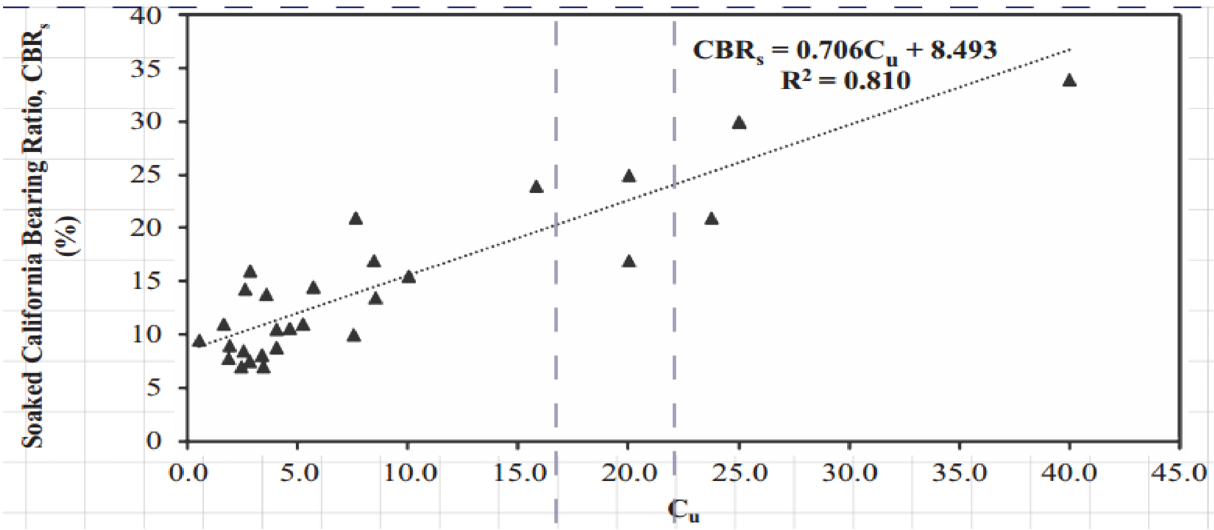

Fig. 8. Relationship between CBRsoaked Value (%) and Cu

Following correlations were developed for fine grained soils having F200≥50%;

$CBRs = -0.43LL + 20.52$ (R^2 =0.85) (6)

$CBRs = 0.58PI + 14.25$ (R^2 =0.85) (7)

$CBRs = -0.10LL - 0.425PI + 15.73$ (R^2 =0.9) (8)

Where for coarse grained soil having F200<50%;

$CBRs = 0.7C_u + 8.5$ (R^2 =0.8) (9)

$CBRs = 0.7C_u + 0.045MDD + 3.4$ (R^2 =0.8) (10)

Where;
CBRs is soaked value of California Bearing Ratio (%)
LL is Liquid Limit (%)
PI is Plastic Limit (%)
C_u is Coefficient of Uniformity
MDD is Maximum Dry Density (pcf)

VI. VALIDITY OF DEVELOPED MODELS

To check the validity of developed models a separate set of soil samples were tested. Test result summary of these samples are presented in Tables IV and V. Experimental values of CBR_S (%) are then plotted against predicted values of these CBR_S (%) by developed equations. Percentage error from 45^0-line (equality line) was calculated by given formula in equation 11;

Percentage Error = $\frac{100\%}{n} f(x) = a_0 + \sum_{i=1}^{n} \frac{(At-Pt)}{At}$ (11)

Where;
A_t =Actual value
P_t =Predicted value
n= Number of values

Validity was checked for all models (Eq. 6 to Eq. 10) developed in present study based on criteria described above. It was observed that among all the developed models equation 6 and equation 7 showed high degree of scatter around equality line. While equations 8, 9 and 10 showed less scatter around equality line as shown in Fig. 7, 8 and 9.

Based on the above discussion three models are proposed for the prediction of soaked CBR Value. The first model is for fine grained soils having F_{200}≥50%, whereas, the next two models are for coarse grained soil having F_{200}<50%.

Predictive Model	R^2	Percentage Error
$CBR_s = -0.10LL - 0.425PI + 1$	0.9	± 8%
$CBR_s = 0.7C_u + 8.5$	0.8	± 9%
$CBR_s = 0.7C_u + 0.045MDD + 3.4$	0.8	± 7%

Where;
CBRs is soaked value of California Bearing Ratio (%)
LL is Liquid Limit (%)
PI is Plastic Limit (%)
Cu is Coefficient of Uniformity
MDD is Maximum Dry Density (pcf)

Validity of correlation from literature is also checked for the same set of soil samples and compared with the models developed in present study. Different correlations for the prediction of CBRs value for fine grained soil in the literature (NCHRP, 2001 and Yildirim & Gunaydin, 2011) are also plotted in Fig. 8 for comparison with predictive model developed in present study for fine grained soil. It was observed that both of these correlations from the literature showed more deviation from equality line than the predictive model of the preset study, as shown in Fig. 7. Similarly, correlations for the prediction of CBRs value for coarse grained soil in the literature (NCHRP, 2001) is also plotted in Fig. 10 for comparison with the predictive model developed in the present study for fine grained soil. It appears that the model developed in the present study shows less percentage error than other model in literature, as shown in Fig. 10.

TABLE IV
VALIDITY DATA FOR FINE GRAINED SOILS

Soil Type	No. of Samples	Gravel (%)	Sand (%)	Fines, F_{200} (%)	LL	PI	CBR_s (%)
CL	8	0-14	3.0-37	61-89	27-34	12-18	4-7
ML	2	0-2	13-16	84-85	18-21	3-3	13.5-16.5
CL-ML	2	2-10	33-33	57-65	21-27	7-7	8.5-9.3

TABLE V
VALIDITY DATA FOR COARSE GRAINED SOILS

Soil Type	No. of Samples	Gravel (%)	Sand (%)	Fines, F_{200} (%)	C_u	MDD (lb/ft^3)	CBR_s (%)
SP	2	0	91-99	1-9	2-5	110-112	10.6-11
SM	8	0-27	42-91	1-43	0.5-40	110-137	9-34
SC	2	12-21	42-45	42-45	8.4-25	120-140	15-30

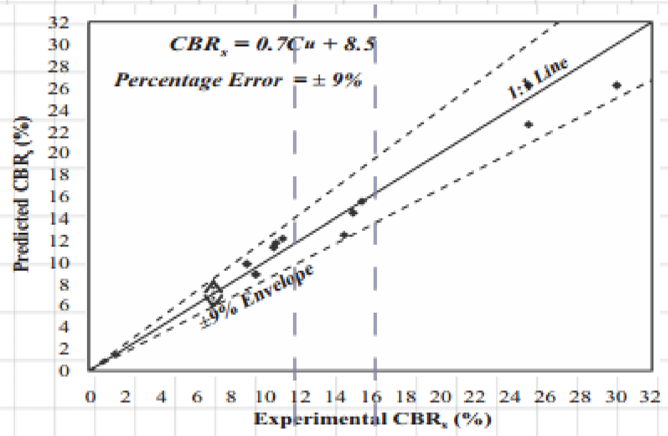

Fig. 9. Validity check for Eq. 9

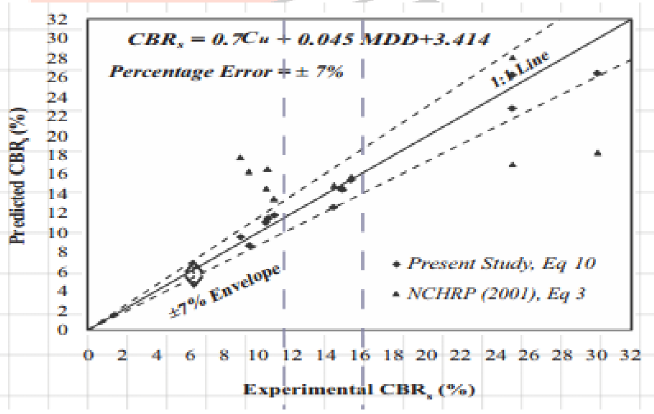

Fig. 10. Validity check for Eq. 1

VII. MODEL IMPLICATION

Because of the involvement of more than one variable in the predictive models the accurate prediction of the values of soaked CBR (%) becomes generally difficult. However, the predictive model presented in the present study are simple and can be effectively used for the prediction of the CBRS values for fine grained as well as coarse grained soils with reasonable accuracy. These models would be very useful in the quick evaluation of shear strength and stiffness modulus of sub grade at the site without performing the laboratory CBR tests. The prediction of shear strength and stiffness modulus of sub grade material will help in the selection of suitable subgrade material. Predictive curves are the graphical calculating chart, a 2D diagram designed to perform the approximate graphical computation of a mathematical model or function, used for the quicker estimation. For quick and easy computation, predictive curves are presented based on the models developed for fine grained and coarse grained soils, as shown in Fig. 11 and 12.

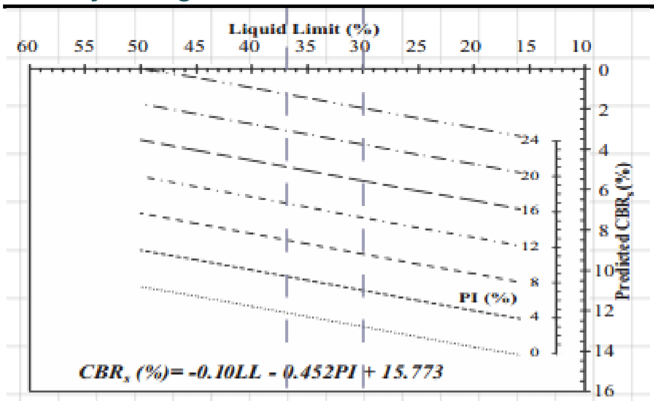

Fig. 11. Predictive Curve for Fine grained soils (Eq. 8)

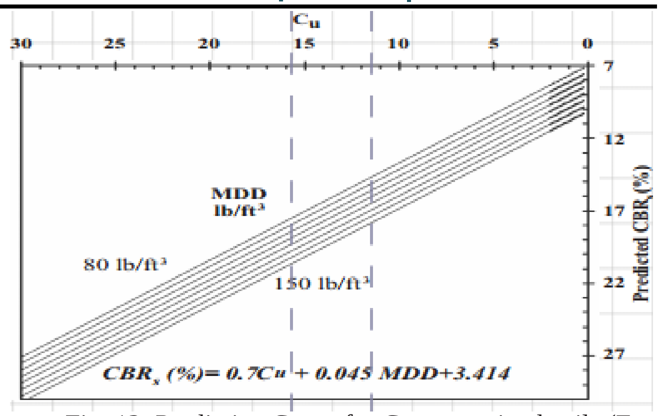

Fig. 12. Predictive Curve for Coarse grained soils (Eq. 10)

VIII. CONCLUSION

A number of soil samples are collected from different regions of Pakistan to develop predictive models for locally available soils. Models are developed for the prediction of CBR Soaked value for both fine grained and coarse grained soils. One model is developed for fine grained soil and two models are developed for coarse grained soil as follow. These models are proposed after checking their strength based on R value and validity on real scale data. Simplified predictive curves are also presented to determine the CBRsoaked values for fine grained and coarse grained soil from multiple regression models proposed in the present study. Models presented in the present study can be effectively used for preliminary prediction of CBRs value for locally available soils in Pakistan. However, such models can't be the replacement of actual tests.

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