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CORRELATION OF CBR VALUE WITH PARTICLES SIZE AND COMPACTION CHARACTERISTICS OF COHESIONLESS SOIL

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ABSTRACT

Coarse grains of soil particles play an important role in the geotechnical problems. Therefore, it is necessary to predict of CBR value from some physical properties that easy, low time consume, and limited facility for laboratory experiments. In this paper, an attempt has been conducted to correlate CBR value of coarse-grained soils based on some physical properties such as grain size analysis (percentage finer sieves 25, 9.5, 4.75, 2.36, 1.18, 0.3, and 0.075mm), particles fraction as Gravel (G), Sand (S), and Fines (F). Other parameters taken into consideration are Compaction Characteristics namely optimum moisture content (OMC) and maximum dry density (MDD). The tests conducted for determining grain size, MDD and OMC are easy cheaper and less time to consume than soaking CBR test. The correlation established was in the form of an equation of soaked CBR value as a function of different soil properties using regression analysis.

KEYWORDS: Regression; Correlation; Optimum Moisture Content; Maximum Dry Density

ربط قيم نسبة التحمل الكاليفورني مع التدرج الحبيبي وخصائص الرص للترب غير المتماسكة

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المستخلص

الحبيبات الخشنة للتربة تلعب دورا مهما في المسائل الجيوتقنية. لذلك دعت الحاجة الى استنباط قيم نسبة التحمل الكاليفورني من بعض الخصائص الفيزيائية البسيطة والتي تحتاج الى وقت قصير لإجرائها ومتطلبات محددة من الفحوصات المختبرية. في هذه الورقة تم اجراء محاولة لاستنباط قيم نسبة التحمل الكاليفورني للترب الخشنة من بعض الخصائص الفزيائية مثل التحليل الحبيبي، تفاصيل المكونات مثل الحصى، الرمل، المواد الناعمة. كذلك بالإضافة الى نتائج فحص الرص والتي تعطي الكثافة الجافة العظمى والمحتوى المائي الامثل. الفحوصات المستخدمة لإيجاد قيمة كل من الكثافة الجافة العظمى و المحتوى المائي الأمثل و نسب المكونات , الحصى , الرمل, المواد الناعمة هي فحوصات بسيطة و سهلة مقارنة بفحص نسبة التحمل الكاليفورني في حالة الغمر الاستنباط تم من خلال انشاء معادلة يكون فيها قيمة نسبة التحمل الكاليفورني كمتغير معتمد والخصائص الفيزيائية الأخرى كمتغيرات مستقلة.

1. INTRODUCTION

Subgrade strength is mostly, affected by the thickness of pavement, in highway design. California Bearing Ratio (CBR) is one of the methods to determine the subgrade strength. CBR test is laborious and time-consuming but still required for geotechnical design of engineering road structures. For area development projects, using fillings requires placement of such fillings in proper order for high strength and low compressibility. A Huge quantity of filling material is used for the construction of subgrade and CBR value for all such fill materials is a very important parameter and must be assessed. While high cost and time requirement for such testing, it generally becomes difficult to map the variation in their value along the alignment.

A few number of investigators predicted empirical formulae presented in the geotechnical literature that was developed to estimate the soaked CBR value for coarse-grained soils from the physical properties and compaction characteristics of soil. These models were developed to estimate CBR value depending on low cost, less time consumption basis. Such of this empirical formula was presented by NCHRP (2004). It was proposed as a best-fitted equation for correlated CBR value with the D_{60} for clean, coarse-grained soil. This correlation is shown in Table 1. Siddhartha et al. (2015) used two types of soil samples (CL-ML) to establish a correlation between CBR and some soil parameters. The soil samples used were mixed with varied sand content. A simple and multiple linear regression were developed to correlate CBR with MDD and percentage sand content. These empirical correlations are shown in Table 1. Naveen and Santosh (2014) proposed a correlation between CBR value and some index properties. They used twenty samples of plastic and non-plastic soil that were collected from different locations in India. Set of laboratory tests were conducted on the soil samples. A simple and multiple linear regression analysis were performed using index properties, and soaked CBR value. They concluded their work by many correlations as mentioned in Table 1. Saklecha P., et al. (2011) used simple and multiple linear regression analysis to develop correlation models. Physical and mechanical tests result like a moisture-density relationship, consistency limits, and CBR tests were used as a data set. They used 387 data sets of soil properties and corresponding CBR values. These models are shown in Table 1. Rakaraddi and Vijay (2001) used simple and multiple regression analysis models to correlate between some of the soil properties and CBR value. The empirical formulae that correlate CBR value with sieve analysis and compaction characteristics are shown in Table 1.

Table 1. Empirical formula developed by other researchers.

Researchers		Empirical formulae	R^2	Type of soil
NCHRP; 2004	Eq.1	$CBR = 5$ for $(D_{60} \leq 0.01\text{mm})$ $CBR = 28.09(D_{60})^{0.35}$ for $(0.01 < D_{60} < 30)$ $CBR = 95$ for $(D_{60} \geq 30\text{mm})$	0.84	Coarse-grained
Siddhartha et al; 2015	Eq.2	CBR = 2.456 + 0.107 $*$ % sand	0.98	Different types
	Eq.3	$CBR = 16.5235 + 0.1314 *$ % sand $- 8.3923 * MDD$	-	Different types
Naveen & Santosh; 2014	Eq.4	$CBR = 4.99 * MDD - 5.711$	0.78	Sand to fines
	Eq.5	$CBR = -0.2443 * OMC + 7.5264$	0.70	Sand to fines
	Eq.6	$CBR = -4.8353 - 1.56856 * OMC + 4.6351 * MDD$	0.82	Sand to fines
Saklecha et al; 2011	Eq.7	$CBR = 0.26\,OMC + 42.55\,MDD - 73.62$	0.47	Different types
	Eq.8	$CBR = -1.3407(OMC) + 28.623$	0.24	Different types
	Eq.9	$CBR = 38.38(MDD) - 61.95$	0.46	Different types
Rakaraddi & Vijay G.; 2001	Eq.10	$CBR = 63.09e^{-0.14OMC}$	0.86	Medium to coarse sand
	Eq.11	$CBR = -8.214MDD^2 + 41.68MDD - 42.36$	0.88	Medium to coarse sand
	Eq.12	$CBR = -0.26052OMC + 5.717093MDD$	0.94	Medium to coarse sand

However, the applicability and validity of the empirical formulae that developed by the researchers in the literature need to be tested. A comparison between the values of CBR that gained from laboratory test and values gained from formulae to check the applicability and limitations of these formulae.

2. PURPOSE AND SCOPE

The main purpose of this study is to develop a correlation to estimate CBR values of a soil from soil index properties test results and moisture-density relationships determined using the standard Proctor test. The objectives can by summarized as:

1. To verify the correlations found by the researchers on the results of soil samples proposed for the study. This verification is published by conducting by review on the correlations which proposed by other researchers.

2. To develop a correlation model to estimate CBR value by performing simple and multiple linear regression analyses to determine a recommended correlation of CBR value.
3. Taking a number of soil samples, which are tested by sieve analysis and compaction tests to compare the results gained from laboratory tests in order to evaluate the deviation with the results of the developed correlation.

3. DATABASE USED AND DESCRIPTION

The soil samples that used in this study were compiled from different size of materials. A thirty-six of disturbed soil samples were tested from different locations in Al-Najaf city that used for pavement construction projects during 2010 to 2016. The selected soil samples were tested for Socked CBR value, standard compaction, and sieve analysis. These tests were concluded in laboratory of Al-Najaf technical institute. All these tests were performed according to ASTM standards. The majority of the materials contained non-plastic cohesionless materials that used as fill material for road embankments as well as subbase and base course material. The Soil parameters used in the database where Optimum Moisture Content (OMC), Maximum Dry Density (MDD), effective size (D_{10}), The diameter corresponding to 60% finer in the particle size distribution (D_{60}), The diameter corresponding to 30% finer in the particle size distribution (D_{30}), The coefficient of curvature (Cc), The coefficient of uniformity (Cu), Gravel content (G), Sand content (S), Fines content (F), Percentage finer sieve 25mm (%F25mm), Percentage finer sieve 9.5mm (%F9.5mm), Percentage finer sieve 4.75mm (%F4.75mm), Percentage finer sieve 2.36mm (%F2.36mm), Percentage finer sieve 1.18mm (%F1.18mm), Percentage finer sieve 0.3mm (%F0.3mm), Percentage finer sieve 0.075mm (%F0.075mm) In order to assess the adequacy of the database, descriptive statistics of each dataset presents in the database were determined. (Table 1) presents the descriptive statistics of each variable. While the histogram distribution of the database is shown in Fig. 1. According to the results that appear in Table 1 and 2, it can be concluded that the database consists of an available range of data. Therefore, this database can be used for the comparison of the performance of existing empirical formulae with the exact value.

Table 2: Statistical parameters of database.

	Sieve opening (mm)							Compaction		CBR value
	25	9.5	4.75	2.36	1.18	0.3	0.075	OMC	MDD	
Maximum value	100	90	75	75	63	29	17	15	2.280	44
Minimum valu	75	40	28	28	17	8	5	4	2.070	30
Range	25	50	47	47	46	21	12	11	0.210	14
Mean	86.3	64.5	52.2	51.8	41.6	16.3	10.8	9.8	2.201	36.3
Median	86	66	54	53	43	15	11	10	2.202	36
Standard dev.	5.56	7.77	7.30	7.05	7.06	2.08	2.65	2.8	0.017	0.67

Table 3. Result of redraw the database.

	G	S	F	D_{10}	D_{30}	D_{60}	Cc	Cu
Maximum value	72	64	17	0.75	4.75	17	16.29	300
Minimum value	25	22	5	0.04	0.18	0.55	0.02	7.33
Range	47	42	12	0.71	4.57	16.45	16.27	292.66
Mean	48.37	41.31	10.8	0.09	1.17	8.26	2.91	113.92
Median	48	42	11	0.07	1	7.3	1.87	100
Std. deviation	7.25	7.42	2.65	0.05	0.58	2.78	2.40	56.72
Units	%	%	%	mm	mm	mm	-	-

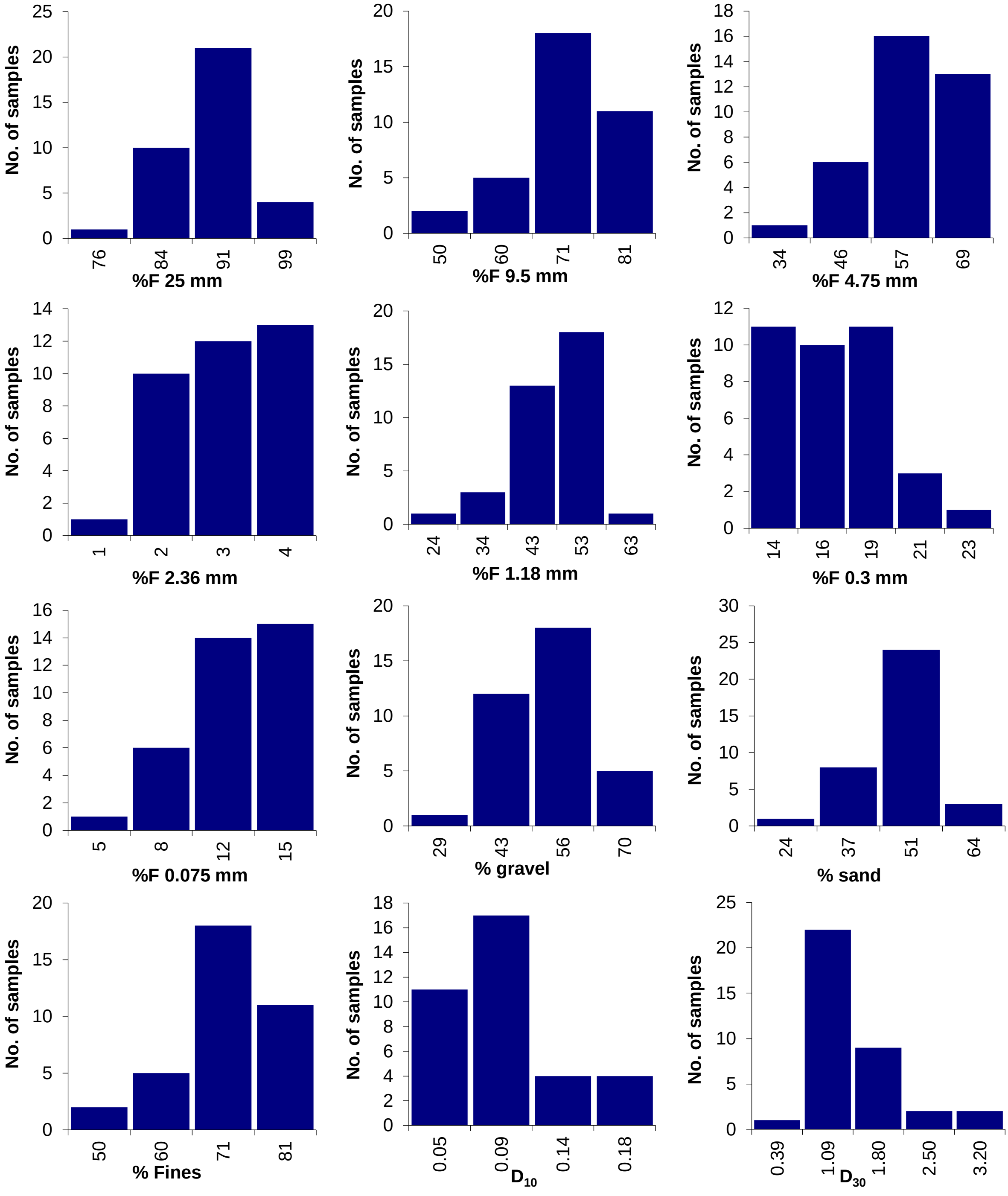

Fig. 1. The result of Histogram distribution of the database.

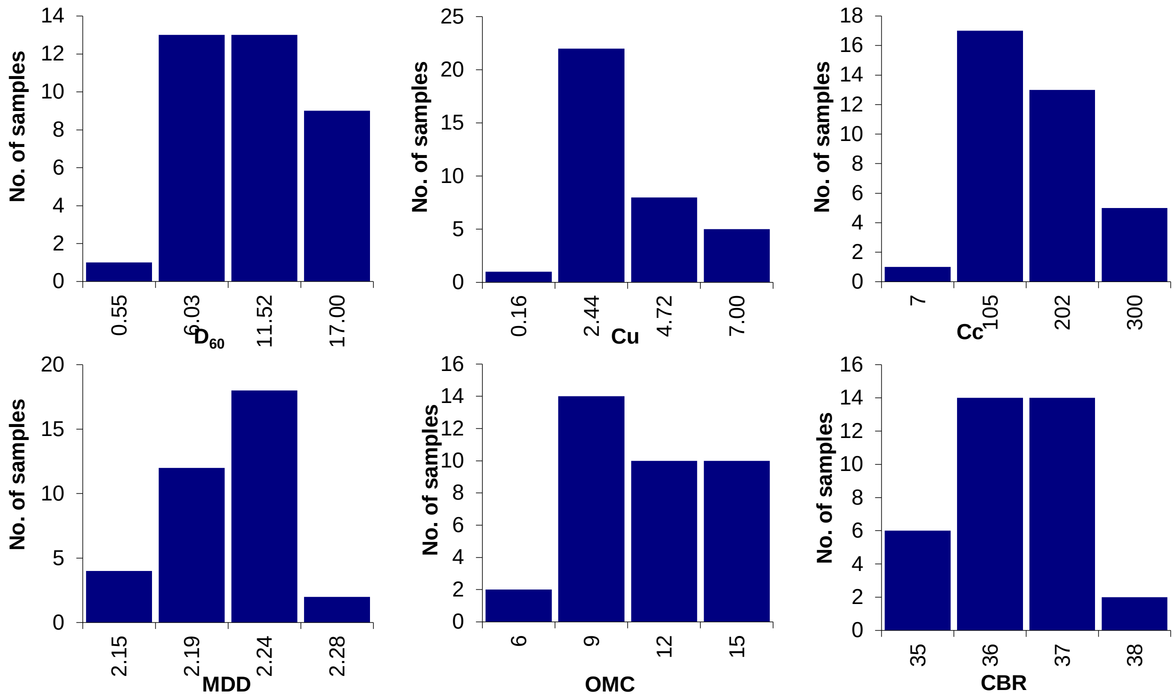

Fig. 1. Continued …

4. RESULTS AND DISCUSSIONS

4.1. VERIFY THE CORRELATIONS FOUND BY THE RESEARCHERS

The verification of the empirical formulae developed by other researchers is done by applying these formulae using the database mentioned in the study. The results of the verification are shown in Fig. 2. The results of the verification are presents that the empirical formula (Eq.4) proposed by Naveen and Santosh (2014), and the empirical formulas Eq.7 & Eq.8 proposed by Saklecha et al. (2011) are closest results from experimental result of the CBR value.

4.2. Regression Analysis

Regression analysis is a statistical process used to estimate the relationships between variables. It is used to understand which one of the dependent variables are related to the independent variable and to explore the forms of these relationships. Both simple linear regression analysis (SLRA) and multiple linear regression analysis (MLRA) were developed in this study to estimate soaked CBR value based on some of the physical properties and compaction characteristics using the selected database. The correlation between some soil properties and CBR value in simple correlations had been reported to predict CBR value with less time consumption.

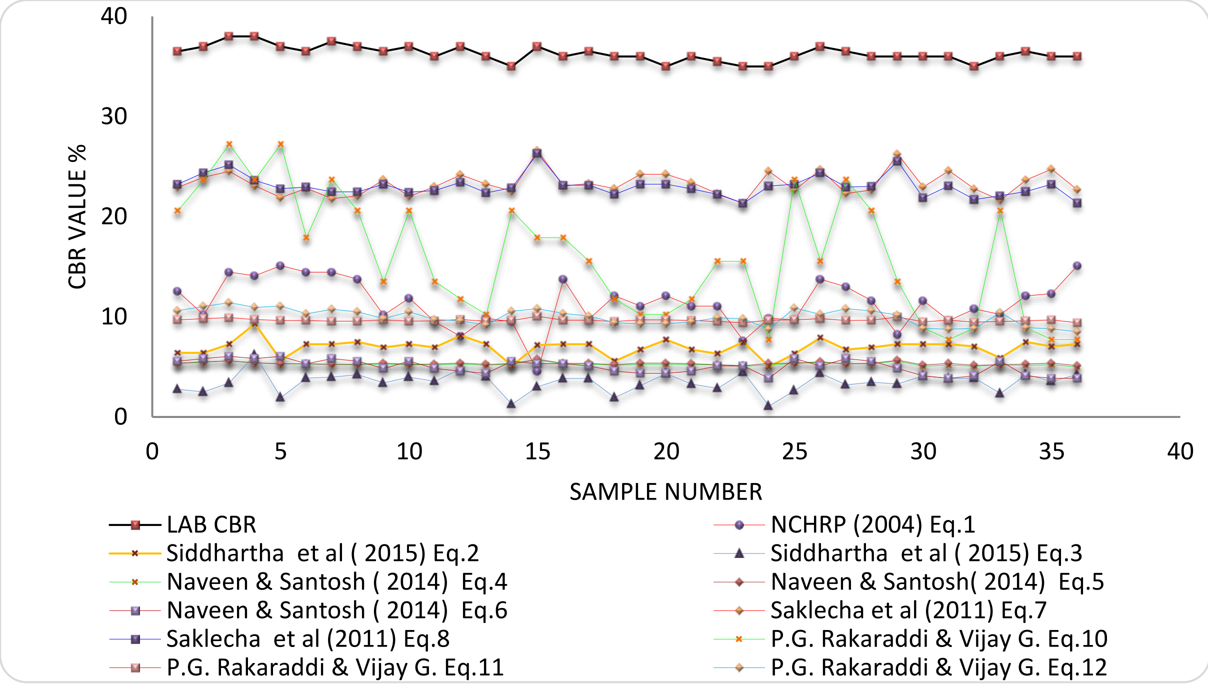

Figure 2: The result of application of database in the formulae developed by other researchers

4.2.1. Simple Linear Regression Analysis (SLRA)

Simple linear regression is the most basic type of regression and commonly used predictive analysis. The main idea of this analysis is to examine two things: the first is a set of predictor variables do a good accuracy in predicting an outcome value of the variable, the second, which are variables, in particular, are significant predictors of the dependent variable. To establish a simple linear regression between CBR and some soil parameters, a plotted of a suitable trend line along each point is drawn. The accuracy of this correlation depends on the dependent variable. It is measured by determining the value of R2. The coefficient of determination R2 is a number that indicates the proportion of the variance in the dependent variable that is predictable by the independent variable. The correlation with R2 value more than 0.80 will be view as acceptable correlation. To develop the models of the simple linear regression analysis soaked CBR value is considered as the dependent variable and the percentage passing, particle fractions, and compaction characteristics are consider as the independent variables. The correlation is done between individual soil properties with soaked CBR values. It was carried out by using Data Analysis Tool Bar in Microsoft Excel to derive the relationship statistically. The statistical parameters of the soaked CBR value predicted by various SLRA models are present in Fig. 3 to Fig.16 below and the correlation and coefficient of determination are a list in Table 4. In Table 4, it is noticed that model 3 has given the highest coefficient of determination (R2=0.28) and model 12 have given the lowest coefficient of determination

(R2=0.02). While other physical properties are neglected because it were given insignificant value of coefficient of determination (R2≤0.01) in SLRA.

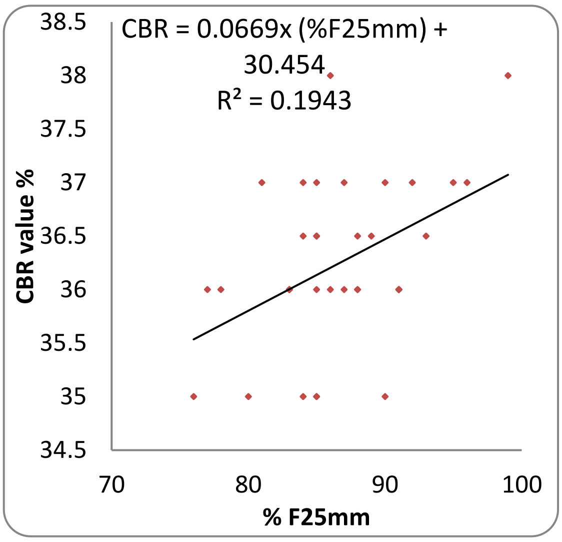

Fig. 3. $\boldsymbol{CBR}$ **vs** $\%(\boldsymbol{F\ 25mm})$**.**

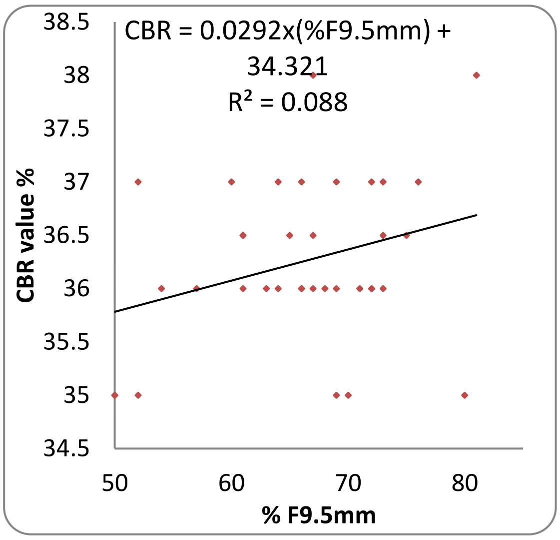

Fig. 4. $\boldsymbol{CBR}$ **vs** $\%(\boldsymbol{F\ 9.5mm})$**.**

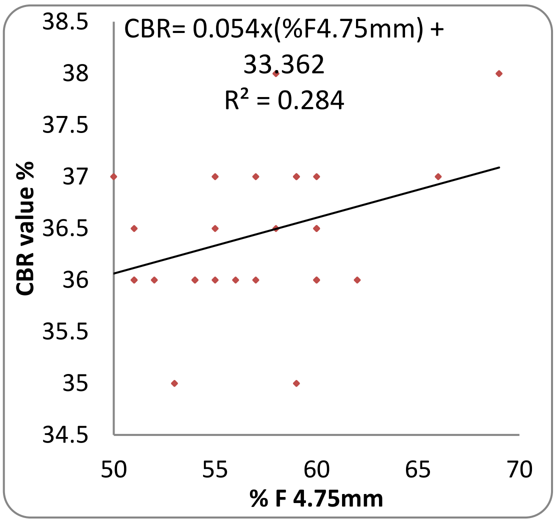

Fig. 5. $\boldsymbol{CBR}$ **vs** $\%(\boldsymbol{F\ 4.75mm})$**.**

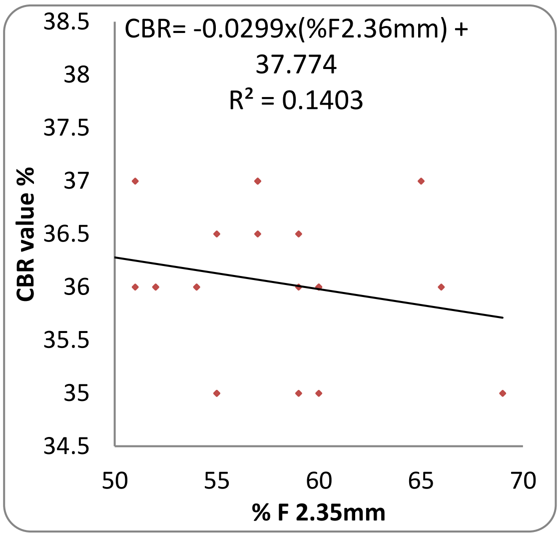

Fig. 6. $\boldsymbol{CBR}$ **vs** $\%(\boldsymbol{F\ 2.36mm})$**.**

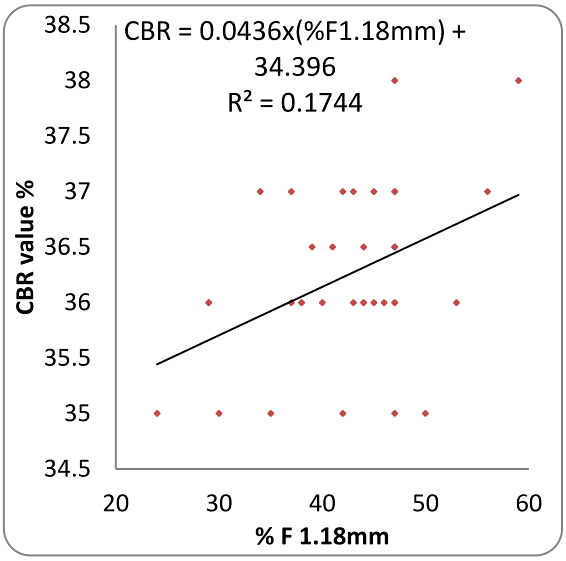

Fig. 7. ***CBR*** **vs %(** ***F*** **1.18*mm*).**

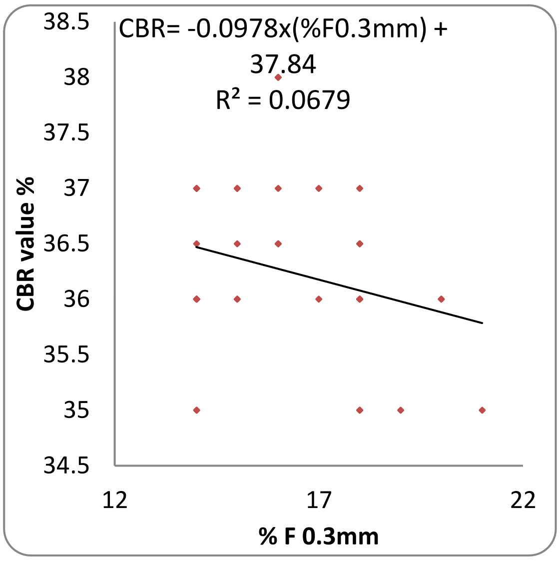

Fig. 8. ***CBR*** **vs %(** ***F*** **0.3*mm*).**

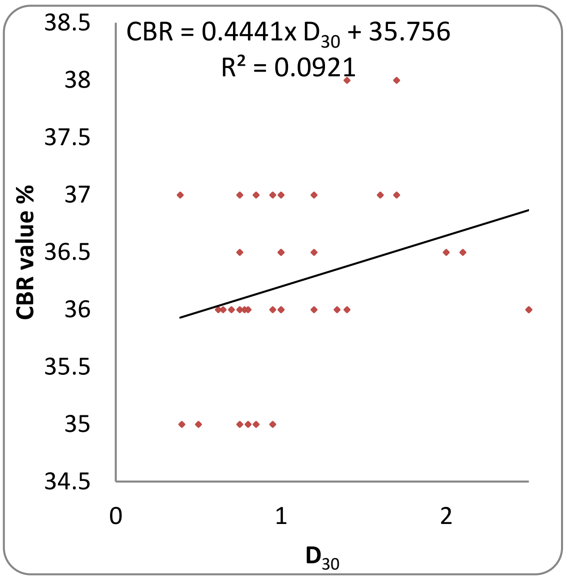

Fig. 9. CBR **vs** D_{30} **mm.**

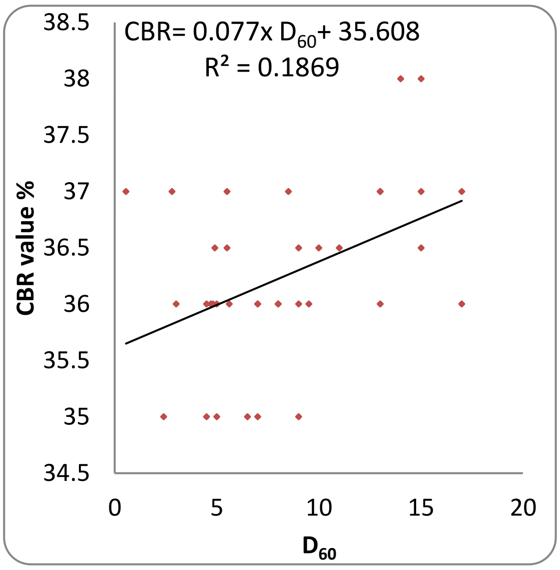

Fig. 10. CBR **vs** D_{60} ***mm*.**

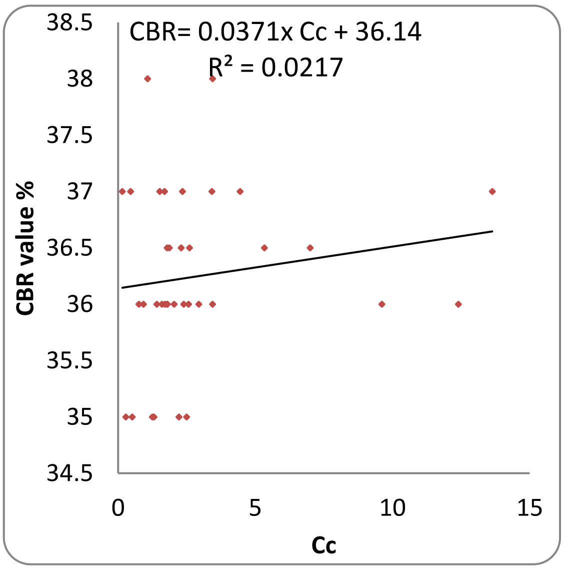

Fig. 11. CBR **vs Cc.**

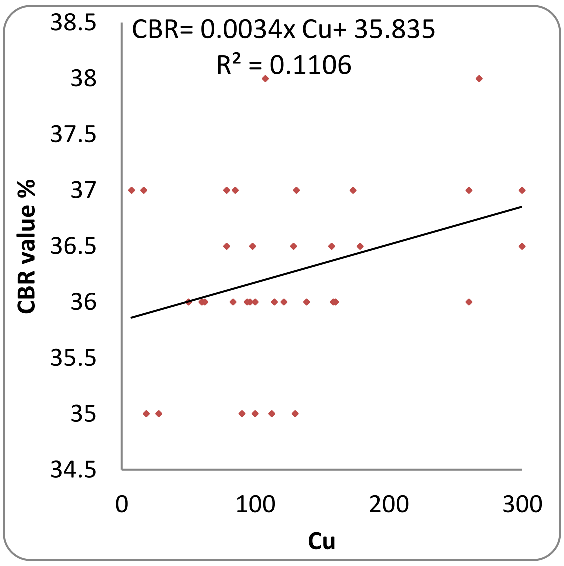

Fig. 12. CBR **vs Cu.**

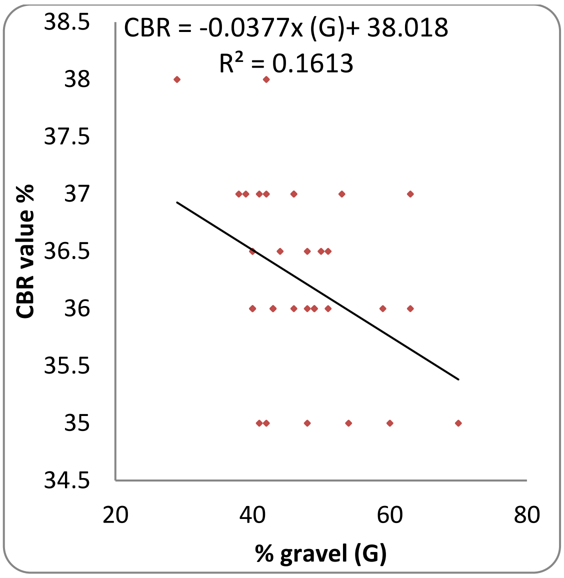

Fig. 13. CBR **vs % gravel.**

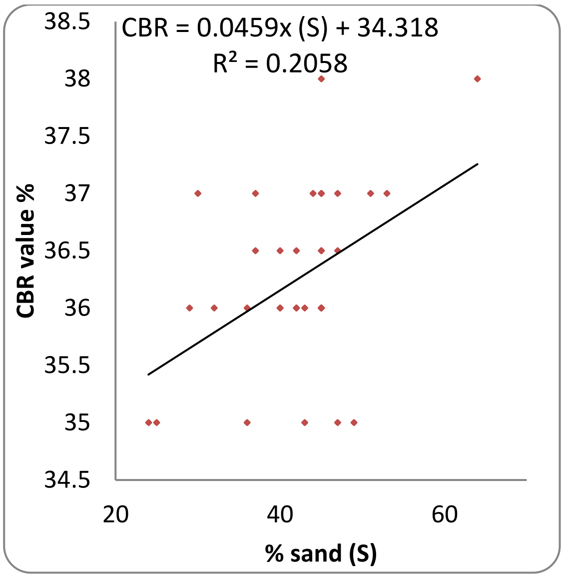

Fig. 14. CBR **vs % sand.**

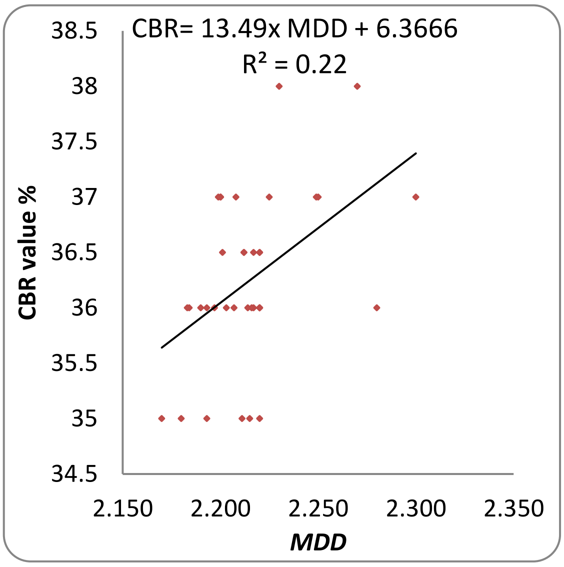

Fig. 15. CBR **vs** MDD.

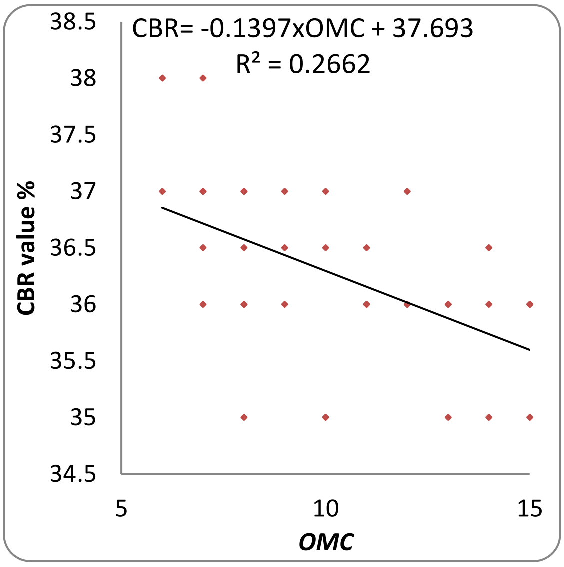

Fig. 16. CBR **vs** OMC.

4.2.2. Multiple Linear Regression Analysis(MLRA)

To develop the models of multiple linear regression analysis, CBR value is considered as the dependent variable and soil properties such as percentage passing ($\%F25$, $\%F9.5$, $\%F4.75$, $\%F2.36, \%F1.18, \%F0.3), G, S, F, D_{10}, D_{30}, D_{60}, Cc, Cu,$ $MDD, and\ OMC$ are considered as independent variables. Four models (Table 5) with different soil properties selected from the database were developed for correlations. Statistical parameter like coefficient of determination (R^2) values is calculated. The predicted CBR values with actual CBR values gained from the database were plotted and best linear fit curves are drawn to find the variation between the predicted value and the exact value. It is noticed that model 1 has given a good performance as it has the highest coefficient of determination (R^2=0.95) and model 4 gave a poor performance as it has the lowest coefficient of determination (R^2=0.85) in MLRA.

Table 4: Summary of developed (SLRA) to evaluate CBR value.

Model	Independent variable	R^2	Regression Equation
1	$\%F25mm$	0.19	$CBR = 0.0669 * (\%F25mm) + 30.454$
2	$\%F9.5mm$	0.08	$CBR = 0.0292 * (\%F9.5mm) + 34.321$
3	$\%F4.75mm$	0.28	$CBR = 0.054 * (\%F4.75mm) + 33.362$
4	$\%F2.36mm$	0.14	$CBR = -0.0299 * (\%F\ 2.36mm) + 37.774$
5	$\%F1.18mm$	0.17	$CBR = 0.0436 * (\%F1.18mm) + 34.396$
6	$\%F0.3mm$	0.06	$CBR = -0.0978 * (\%F0.3mm) + 37.84$
7	G	0.16	$CBR = -0.0377 * (G) + 38.018$
8	S	0.20	$CBR = -0.0122 * (F) + 36.384$
9	D_{30}	0.09	$CBR = 0.4441 * D30 + 35.756$
10	D_{60}	0.18	$CBR = 0.077 * D60 + 35.608$
11	Cc	0.11	$CBR = 0.0034 * Cu + 35.835$
12	Cu	0.02	$CBR = 0.0371 * Cc + 36.14$
13	OMC	0.26	$CBR = -0.1397 * OMC + 37.693$
14	MDD	0.22	$CBR = 13.49 * MDD + 6.3666$

$\%\boldsymbol{F25mm} = \boldsymbol{percentage\ finer\ sieve\ with\ opening\ equal\ to\ 25\ mm}$

The derivation of the developed empirical formulae depending on the principle of choosing the higher coefficient of determination in the single linear regression analysis, because of any one of physical soil property that are directly effect on the value of CBR are also indirectly effect on the value of CBR in multiple linear regression analysis. Therefore; the coefficient of determinations of model 1 and model 2 are closest when the value of D_{10} neglected in model 2. Other physical property that ignored in multiple linear regression analysis depending on the invaluable coefficient of determination that added.

Table 5: Summary of developed (MLRA) to evaluate CBR value.

MLRA	Independent variables	R^2	Developed empirical formula
Model 1	$\%F$ (25, 9.5, 4.75, 2.36, 1.18, 0.3mm), $OMC, MDD, G, S, F, D_{10}, D_{30}, D_{60}, Cu, Cc$	0.95	$CBR = 36.83 + 0.0196 * \%F25 - 0.066 * \%F9.5 + 0.102 * \%F4.75 - 0.0184 * \%F2.36 - 0.061 * \%F1.18 - 0.180 * \%F0.3 - 2.076 * MDD - 0.141 * OMC + 0.078 * G + 0.1141 * S + 0.13 * F - 6.335 * D_{10} - 0.207 * D_{30} + 0.036 * D_{60} + 0.012 * Cc - 0.004 * Cu$
Model 2	$\%F$ (25, 9.5, 4.75, 2.36, 1.18, 0.3mm), $OMC, MDD, G, S, F, D_{10}, D_{30}, D_{60}$	0.93	$CBR = 39.97 + 0.0146 * \%F25 - 0.052 * \%F9.5 + 0.108 * \%F4.75 - 0.006 * \%F2.36 - 0.063 * \%F1.18 - 0.204 * \%F0.3 - 3.689 * MDD - 0.162 * OMC + 0.075 * G + 0.1001 * S + 0.127 * F - 3.46 * D_{10} - 0.159 * D_{30} + 0.019 * D_{60}$
Model 3	$\%F$ (25, 9.5, 4.75, 2.36, 1.18, 0.3mm), $OMC, MDD, G, S, F, Cu, Cc$	0.91	$CBR = 42.91 + 0.0137 * \%F25 - 0.05 * \%F9.5 + 0.106 * \%F4.75 - 0.0179 * \%F2.36 - 0.055 * \%F1.18 - 0.183 * \%F0.3 - 3.562 * MDD - 0.16 * OMC + 0.041 * G + 0.059 * S + 0.12 * F - 0.009 * Cc - 0.001 * Cu$
Model 4	$\%F$ (25, 9.5, 4.75, 2.36, 1.18, 0.3mm), OMC, MDD	0.85	$CBR = 42.91 + 0.005 * \%F25 - 0.054 * \%F9.5 + 0.115 * \%F4.75 - 0.013 * \%F2.36 - 0.053 * \%F1.18 - 0.15 * \%F0.3 - 2.012 * MDD - 0.178 * OMC$

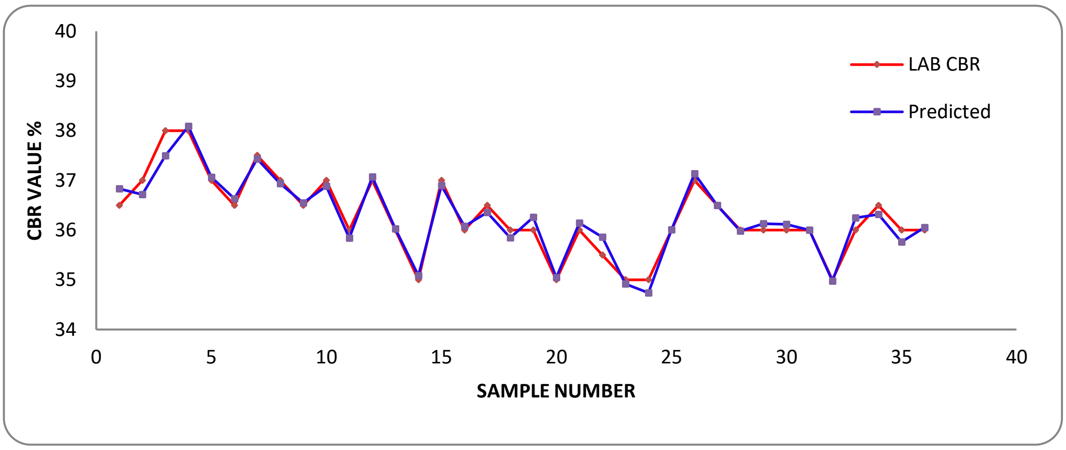

Fig. 17. Comparison between Lab. and predicted CBR value gained from MLRA1.

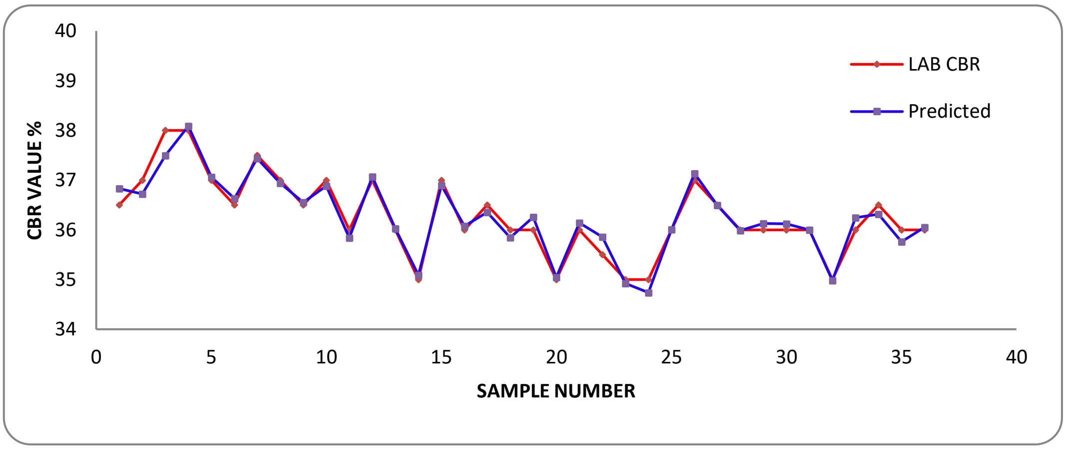

Fig. 18. Comparison between Lab. and predicted CBR value gained from MLRA2.

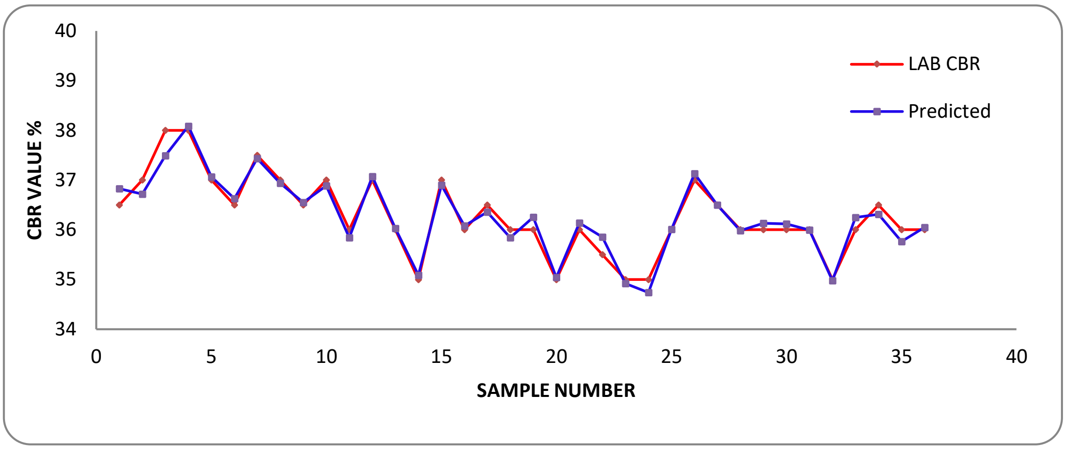

Fig. 19. Comparison between Lab. and predicted CBR value gained from MLRA3.

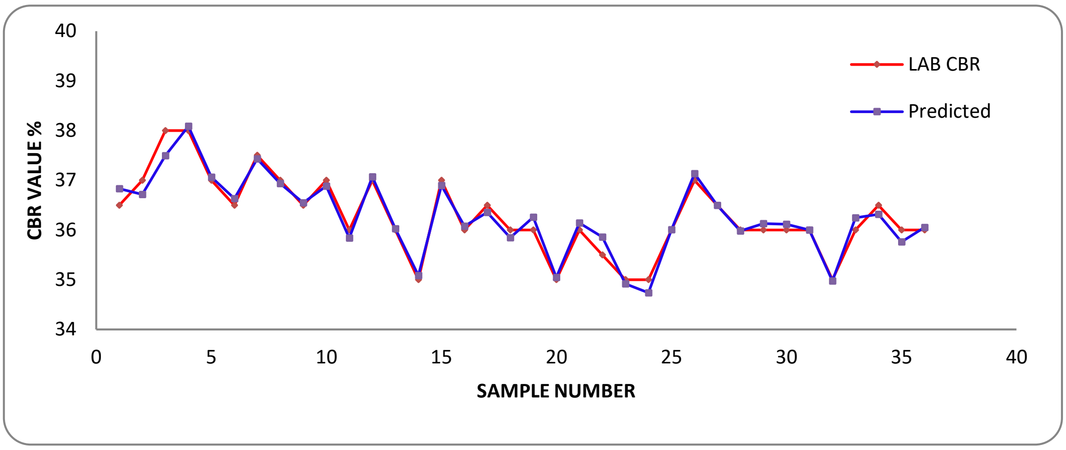

Fig. 20. Comparison between Lab. and predicted CBR value gained from MLRA4.

5. CONCLUSIONS

Depending on the results and discussions presented previously, the following points may be concluded:

1. Some of empirical formulae closest from experimental result of CBR value such as the empirical formula (Eq.4) proposed by Naveen and Santosh (2014), and the empirical formulae (Eq.7 & Eq.8) proposed by Saklecha et al. (2011).

2. The results of CBR which are proposed by the researchers are less than and equal to twenty results of the laboratory CBR value. In addition, some of the empirical formulae proposed were based on the limited number of physical tests.

3. The statistical parameters of MLRA indicated that model 1 gives the best performance by showing the highest (R^2) of 0.95.

4. From SLRA the coarse grain particles are more governing than others are because the correlation of the CBR value significantly depends on of the value of $D_{60}, \% G, \% S$.

5. The CBR correlated with the moisture-density relationship, particle fraction, the uniformity coefficient, the curvature coefficient, and percent finer per sieve equation generated developed an empirical formula, which was derived by MLRA with R^2=0.95 provides good value.
6. Multiple linear regression analysis gives better correlation results than the simple correlation using index properties.

It is recommended that using ANN technique in the prediction of CBR value from the available database with minimum time consumption and maximum accuracy.

6. LIST OF SYMBOLS

Symbol	Detail	Symbol	Detail
MDD	Maximum dry density	$\%F25mm$	Percent of particles passing 25mm sieve
OMC	Optimum moisture content	$\%F9.5mm$	Percent of particles passing 9.5mm sieve
Cc	Coefficient of curvature	$\%F4.75mm$	Percent of particles passing 4.75mm sieve
Cu	Coefficient of uniformity	$\%F2.36mm$	Percent of particles passing 2.36mm sieve
CBR	California bearing ratio	$\%F1.18mm$	Percent of particles passing 1.18mm sieve
R^2	Coefficient of determination	$\%F0.3mm$	Percent of particles passing 0.3mm sieve
G	gravel	MLRA	multiple linear regression analysis
S	sand	D_{30}	Diameter of particle meet 60% passing
F	fines	D_{60}	Diameter of particle meet 60% passing
D_{10}	Effective size	SLRA	Single linear regression analysis

7. REFRENECES

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