CORRELATION BETWEEN CBR VALUES AND INDEX PROPERTIES OF SUBGRADE SOILS: IN THE CASE OF BODITI TOWN

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ABSTRACT

The suitability and stability of soil is usually evaluated before its use in construction of pavement. Proper analysis is necessary to ensure that Civil engineering infrastructures such as roads, buildings, rails, dams, etc. remain safe and free to withstand settlement and collapse. This paper presents the results of the correlation between California Bearing Ratio (CBR) and index properties of sub-grade soils in the Boditi town. CBR (California Bearing Ratio) test is performed to evaluate stiffness modulus and shear strength of subgrade soils. However, CBR test is laborious and time consuming, particularly when soil is highly plastic. In order to solve this limitation, it may be appropriate to correlate CBR value of soil with its index properties like grain size analysis, Atterberg limits, and compaction characteristics such as MDD (Maximum Dry Density) and OMC (Optimum Moisture Content). SLRA (Single Linear Regression Analysis) and MLRA (Multiple Linear Regression) based Models were utilized. It is seen that MLRA gave better correlations up to R^2 *of about 0.984. It is observed that the Soaked CBR value can be predicted with confidence from LL (Liquid Limit), PI (Plasticity Index) and percent finer while un-soaked CBR value can be obtained from LL, plasticity index and MDD. Laboratory tests were carried out to determine soaked CBR, LL, PL, PI, MDD and OMC on soil samples collected from different parts of town. A correlation relationship between CBR and soil index properties were developed using non-linear and multiple linear regression analysis. Standard Minitab 16 and Microsoft Excel 2019 software package were used for the analysis.*

Keywords: *Index Properties, Single Linear Regression Analysis, Multiple Linear Regression Analysis, Predicted California Bearing Ratio, Regression Analysis and Correlation Analysis, Coefficient of Determination.*

1. 1. INTRODUCTION

The suitability and stability of soil is usually evaluated before its use in construction of pavement. Proper analysis is necessary to ensure that Civil engineering infrastructures such as roads, buildings, rails, dams, etc. remain safe and free to withstand settlement and collapse. Geographical variability in soil conditions from one location to another makes it difficult to predict the behavior of soil. As a result, soil conditions at every site must be thoroughly investigated for proper design [1]. A subgrade soil on which the whole structure of the flexible pavement consists of a number of layers including pavement rests and for this, CBR is one of the most widely sub-bases, base course, surfacing etc. which ultimately used methods. This method is mainly used to determine lies on subgrade. Basically, subgrade is not the physical the stiffness modulus and shear strength of the subgrade part of the pavement but it is considered as the functional soil and helps in designing the thickness of each layer of pavement [3-4]. If the subgrade has higher CBR value, this means that it has more strength and will be able to bear more traffic load coming over it and ultimately the thickness of pavement layers will be small and vice versa [5].

The soaked CBR value of the subgrade soil is of great importance, which is required to be determined as it helps in assessing the swelling potential and almost the actual strength of subgrade soil over the entire road length. Though this conventional method helps in evaluating the strength of the subgrade soil by obtaining its soaked CBR value, but it is quite time consuming and laborious method and also its reproducibility is low [2]. Moreover, this test is costly as it involves a high-level technical supervision and quality control assessment. Therefore, more samples are required to be tested in order to achieve better accuracy and to obtain proper idea about the soaked CBR value of subgrade materials over the entire length of the road which is quite difficult because it is difficult to take large number of samples. This would result in serious delay in the progress of the project, since in most situations the materials for earthwork construction come from highly variable sources. Any delay in construction inevitably leads to rise of project cost [1,4-6].

In Ethiopia, most of the road networks consist of flexible pavement which is made up of different layers such as sub-grade, sub - base, base course and surface layer. The design and performance of this pavement mainly depend on the strength of sub-grade material. Sub-grade is the bottom-most layer that serves as the foundation of a road pavement and the wheel load from the pavement surface is ultimately transferred to the sub-grade [7]. The California Bearing Ratio (CBR) test is an empirical method of design of flexible pavement. The bearing capacity of the soil beneath highways, airfield runways and other pavement systems are of great importance to the integrity of the pavement. This bearing capacity changes from time to time and can vary from place to place within a given area. The thickness of subgrade depends on CBR value, subgrade that has lower CBR value will have thicker pavement compared with the sub grade that has higher CBR value and vice versa.

1.2 Objective of the Study

1.2.1 General Objective

The main objective of this thesis is to find correlation between California Bearing Ratio with soil index properties of subgrade soils recovered from different parts of town.

1.2.2 Specific Objectives

- To check and come up with a correlation between CBR values and soil index properties of subgrade soils.
- To validate and evaluate the developed correlation using a control test results.

2.LITERATURE REVIEW

2.1 California Bearing Ratio (CBR)

The California Bearing Ratio (CBR), defined as the ratio of the resistance to penetration of a material to the penetration resistance of a standard crushed stone base material. California Bearing Ratio is the main design input in pavement construction to assess the stiffness modulus and shear strength of subgrade material. The method was developed by the California Division of Highways as part of their study in pavement failure at World War II. With an intention to adopt a more simplified test method to measure the stiffness modulus and shear strength of subgrade soil a simple test that can be used as an index test was devised. This is where CBR test comes into frame in measurement of subgrade strength. The CBR test is a simple strength test that compares the bearing capacity of a material with that of a well graded standard crushed stone base kept in California Division of Highways Laboratory [8]. This means that the standard crushed stone material should have a CBR value of 100%. The resistance of the crushed stone under standardized conditions is well established. Therefore, the purpose of a CBR test is to determine the relative resistance of the subgrade material under the same conditions. The test is an index test; thus, it is not a direct measure of stiffness modulus or shear strength. The CBR test is essentially a measure of the shearing resistance of a soil at a known moisture and density conditions. The method of evaluating CBR is standardized in AASHTO T 193 and ASTM D 1883.

The design of pavement thickness in road construction requires the strength of subgrade soil, sub-base and base-course material to be expressed in terms of California Bearing Ratio, so that a stable and economic design achieved. A road section for which a pavement design is undertaken should be sub-divided into subgrade areas where the subgrade CBR can be reasonably expected to be delineated uniform, i.e. without significant variations, in order to utilize it in the design of pavement thickness. On the other way, the value of CBR is an indicator of the suitability of natural subgrade soil as a construction material. If the CBR value of subgrade is high, it means that the subgrade is strong and as a result, the design of pavement thickness can be reduced in conjunction with the stronger subgrade. Conversely, if the subgrade soil has low CBR value it indicates that the thickness of pavement shall be increased in order to spread the traffic load over a greater area of the weak subgrade or alternatively, the subgrade soil shall be subjected to treatment or stabilization [9].

3.METHODOLOGY

3.1Single Linear Regression Analysis

A SLRA provides an attempt to develop a correlation between two variables only in which one is the response (dependent) variable and other is the explanatory (independent) variable. In this research work, CBR is the dependent variable and each individual index properties of soil are independent variable. Graph is plotted between CBR and index properties of soils and a suitable trend line is drawn through the plotted points for obtaining the value of coefficient of determination (R^2). The value of R^2 provides a measure of how well the future outcomes are likely to be predicted by the model [10]. Generally speaking, any correlation greater than 0.88 is usually considered as a best fit.

3.2Multiple Linear Regression Analysis

A MLRA provides an attempt to develop a correlation between more than two variables. One is the response (dependent variable) and others are explanatory (independent) variables. In this research work, CBR is the dependent variable and all other IP are independent variables. In the equation, CBR value is the function of all other index properties. Mathematically:

CBR = f (%F, LL, PI, OMC, MDD) ……………………………. (1)

The equation will be created as follows:

$Y = b_o + b_1x_1 + b_2x_2 + b_3x_3 + b_4x_4 + \ldots\ldots B_nx_n$………………… (2)

Where b_o, b_1, b_2, b_3, b_4, b_n are constants, Y is CBR and, x_1, x_2, x_3, x_4, x_n are soil properties considered for analysis. The values of these constants can be obtained by using Data Analysis Tool bar of Microsoft Excel and then putting these values with their corresponding soil properties in order to obtain a suitable equation [10].

4. LABORATORY TEST

The samples for this research work have been collected from different section of town. Seven (7) samples have been collected from depths of about 2-3 feet and laboratory tests for LL, PL, PI, particle size distribution, OMC, MDD and CBR values (both soaked and unsoaked) have been performed on these samples at Geotechnical Laboratory, according to AASHTO and ASTM specifications [11-14]. The soil classifications of these samples have been done according to AASHTO method. The results are given in **Table 1** along with % finer passing from #200 sieve (%F) for each sample.

5.RESULTS AND DISCUSSION

Table 1 summarizes the results of different soil properties from the experiments conducted in the laboratory for seven samples collected from different locations. Sample Nos. 3 and 4 were classified as A-4 soils and such soils have very less presence in Jamshoro. Therefore, these samples are not considered for developing correlations. The range of other soil properties studied in this research work are: PL = 16.49-29.14%, PI = 20.31-29.26% [5]. The graphs representing laboratory test results for above samples are presented below. Fig. 1 presents the PSD of the soil samples tested. It is observed that the range of % finer considered for developing correlations by neglecting curves of sample 3 and 4 because of their irregular behavior comes out to be 58.709-84.794%. Further, the diameters of particles corresponding to 10% (D_{10}), 30% (D30) and 60% (D_{60}) passing are plotted for all samples through which Cu (Coefficient of Uniformity) and Cc (Coefficient of Curvature) is determined which helps in determining whether the soil is well graded or poorly graded. Table 2 presents the D_{10}, D_{30}, D_{60}, together with the Cu and Cc. The Cu is the ratio of D_{60} by D_{10} given by Equation (3):

$Cu = D_{60}/D_{10}$…………………………………………… (3)

Whereas, the Cu is the ratio of square of D_{30} by product of D_{60} and D_{10} and is given by Equation (4):

$Cc = (D_{30})^2/ (D_{60}*D_{10})$ ………………………………… (4)

If Cu is greater than 4-6 and Cc lies between 1 and 3, the soil is well graded otherwise it is poorly graded.

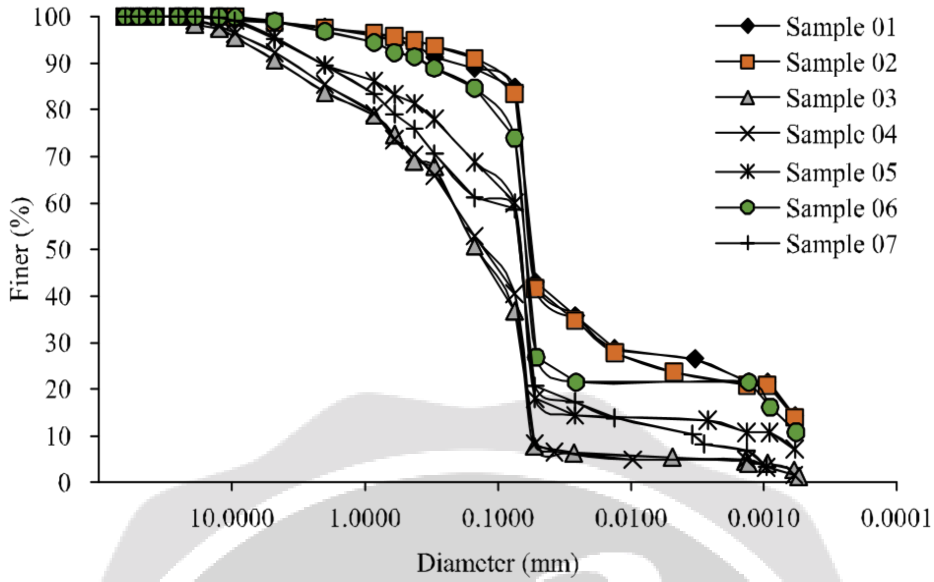

Fig. 1. Particle size distribution curves for all soil samples

Sample No	%F	Cu	Cc	LL (%)	PL (%)	PI (%)	Compaction Characteristics		CBR values		**AASHTO Classification**
							OMC (%)	MDD(g/cc)	Unsoaked (%)	Soaked (%)	
1	84.15	133.3	9.48	63	31.2	32	24.5	1.32	33.5	8.42	A-7-5 (poorly graded
2	87.5	125.0	11.2	71	30.7	40	27.8	1.17	41.3	17.89	A-7-5 (poorly graded
3	91.06	3.79	0.38	77	34.8	42.2	24.8	1.37	64.17	33.74	A-7-5 (poorly graded
4	88.25	4.0	0.35	87	42.2	45	27.4	1.18	11.95	4.558	A-7-5 (poorly graded
5	92.9	88.89	50.00	86	41.9	44	24.2	1.33	22.06	13.30	A-7-5 (poorly graded
6	85.15	108.3	77.56	69	29.4	39.6	28.7	1.20	15.6	10.02	A-7-5 (poorly graded
7	90.25	22.86	12.87	65	31	34	24.5	1.31	45.19	19.80	A-7-5 (poorly graded

TABLE 1 LABORATORY TEST RESULTS FOR SOIL SAMPLES

Fig. 2 shows LL curves showing LL corresponding to 20 mm penetration for all the soil samples tested in the laboratory. Curve of Sample-7 gives the highest liquid limit of about 58.40% and curve of Sample-3 gives the least liquid limit value of 21.70%. As Samples 3 and 4 were neglected in developing correlations, the least LL is considered to be 36.80% corresponding to Sample-5. Thus, the range of LL considered for developing correlations is

36.80-58.40%. Fig. 3 shows compaction curves with their peak points representing OMC and MDD of all the soil samples. Neglecting the results of Samples 3 and 4, the lowest MDD comes out to be 1.740 gm/cm^3 for Sample-7 and highest MDD is 2.025 gm/cm^3 for Sample-5. Thus, the range considered is 1.740-2.025 gm/cm^3. Similarly, the lowest OMC observed from the graph is 10.50% for Sample5 and the highest is 15.50% for Sample-7. Thus, the range of OMC considered is 10.50-15.50%. Fig. 4 shows load penetration curves, which help in determining the Unsoaked CBR values at 2.5and 5mm penetration respectively for all soil samples. The highest of both penetrations is considered as the CBR value of that particular sample. From Fig. 4, it has been observed that the range of Unsoaked CBR value considered for developing correlations is 15.571-45.185%.
Fig. 5 shows load penetration curves, which help in determining the Soaked CBR values at 2.5 and 5mm penetration respectively for all soil samples. From the graph, it has been observed that the range of Soaked CBR value considered for developing correlations is 8.418-19.805%.

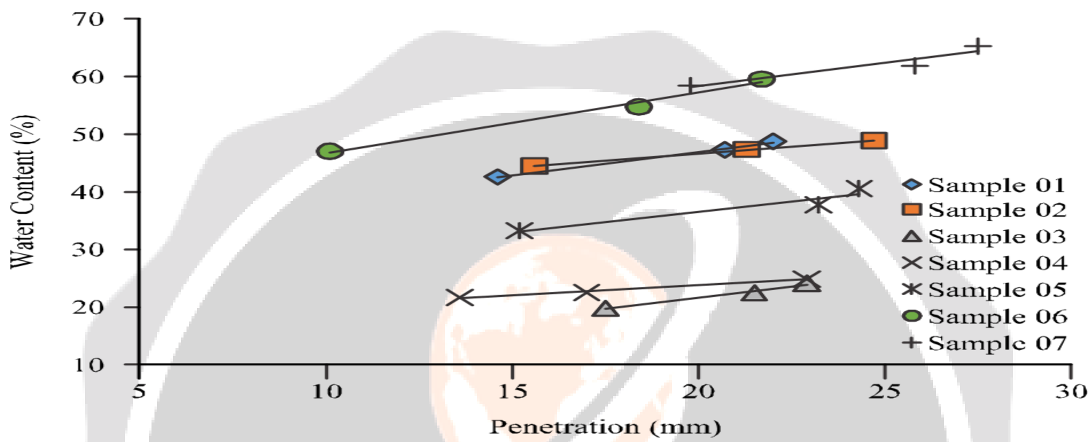

Fig. 2. Liquid limit curves for all soil samples

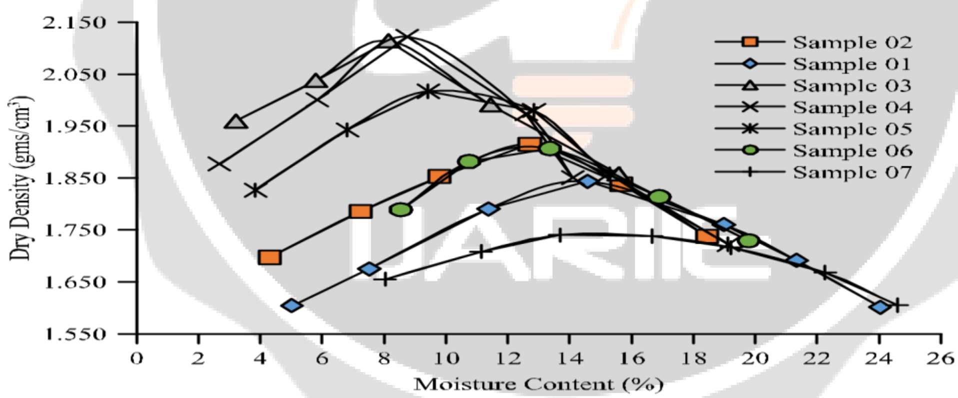

Fig. 3. Compaction curves for all soil samples

Sample No.	D_{10}	D_{30}	D_{60}	Cu	Cc	Soil Type
1	0.00045	0.016	0.06	133.33	9.48	Poorly Graded
2	0.00048	0.018	0.06	125.0	11.25	
3	0.058	0.07	0.22	3.79	0.38	
4	0.055	0.065	0.22	4.0	0.35	
5	0.0008	0.06	0.074	92.50	60.81	
6	0.0006	0.055	0.065	108.33	77.56	
7	0.0035	0.06	0.08	22.86	12.86	

5.1CORRELATIONS/MODELS

The table of laboratory test results along with the graphs is presented in section 3. Now, correlations/models are developed in the form of linear equations between CBR values and various index properties first by SLRA and then collectively by MLRA.

5.1.1Correlations By Single Linear Regression Analysis

The correlations by SLRA were developed and are described in Model 1- 11 (Fig. 6-16) indicating linear relationship between the variables. Some models gave very low values of reliability R2. However, in this paper, all models are shown:

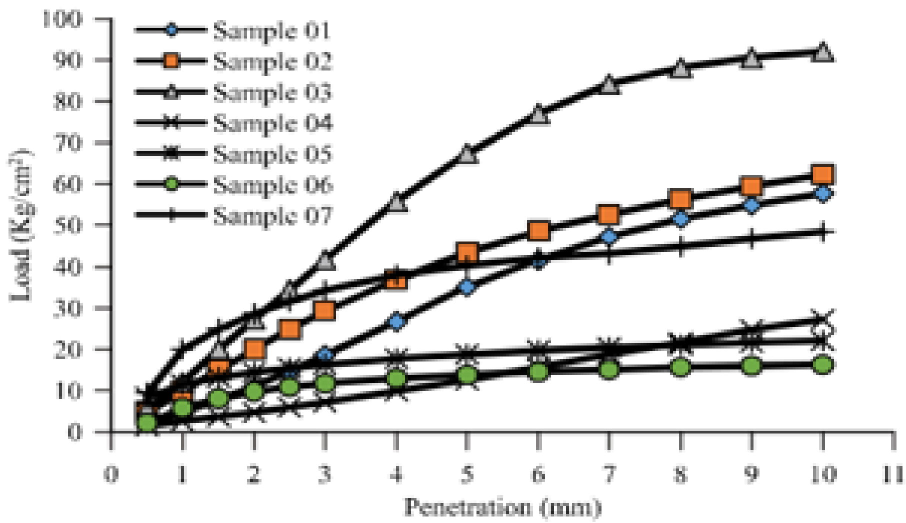

Fig. 4. Load-penetration curves for determining unsoaked CBR for all samples

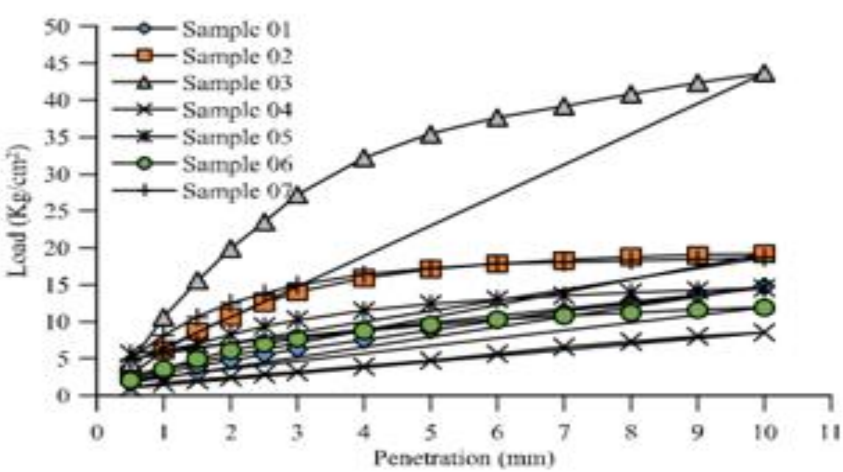

Fig. 5. Load-penetration curves for determining soaked CBR of all soil samples

Model-1: Correlation of Unsoaked California Bearing Ratio (CBR_U) With Liquid Limit:

Fig. 6 represents a graph, which shows a correlation between unsoaked CBR and LL for all soil samples. The mathematical relation between the two parameters is shown in Equation (5). It can be seen that the reliability factor R_2 obtained from this equation is only 0.0413.

CBR_U=0.2896(LL) + 17.274 R^2 = 0.0413 …………………………. (5)

Model-2: Correlation of Unsoaked California Bearing Ratio with Plasticity Index:
Fig. 7 represents a graph, which shows a correlation between unsoaked CBR and PI for all soil samples. The mathematical relation between the two parameters is shown in Equation (6). It can be seen that the reliability factor R_2 obtained from this equation is only 0.0268.
CBRU= 0.5519(PI) + 17.489 R^2 = 0.0268…………………………. (6)

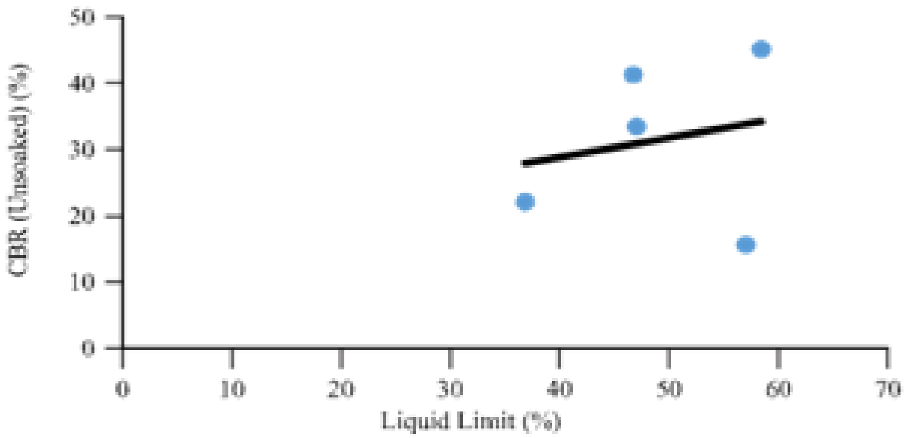

Fig. 6. Relationship of unsoaked CBR with liquid limit

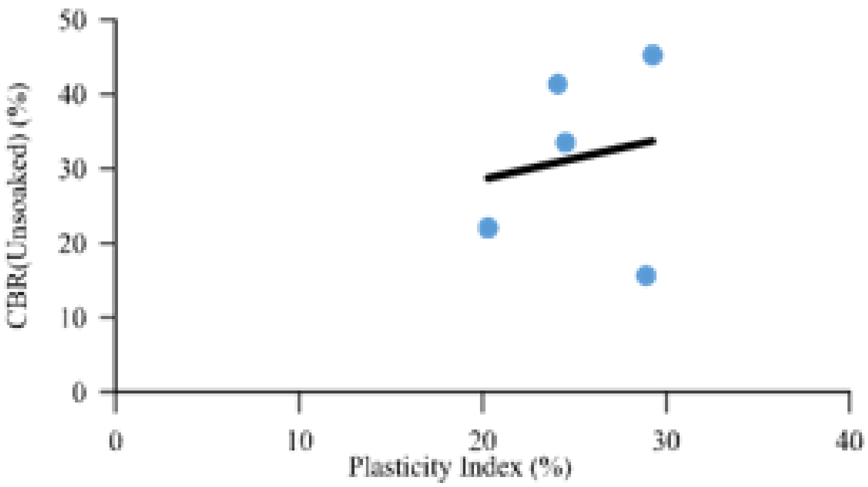

Fig. 7. Relationship of unsoaked CBR with plasticity index

Model-3: Correlation of Unsoaked California Bearing Ratio with Optimum Moisture Content:
Fig. 8 represents a graph, which shows a correlation between unsoaked CBR and OMC for all soil samples. The mathematical relation between the two parameters is shown in Equation (7). It can be seen that the reliability factor R2 obtained from this equation is 0.3812, which is still not significant.
CBR_U= 4.0282(OMC) – 21.807 R^2 = 0.3812…………………………. (7)
Model-4: Correlation of Unsoaked California Bearing Ratio with Maximum Dry Density:
Fig. 9 represents a graph, which shows a correlation between unsoaked CBR and MDD for all soil samples. The mathematical relation between the two parameters is shown in Equation (8). It can be seen that the reliability factor R2 obtained from this equation is 0.4413, which is still not significant.

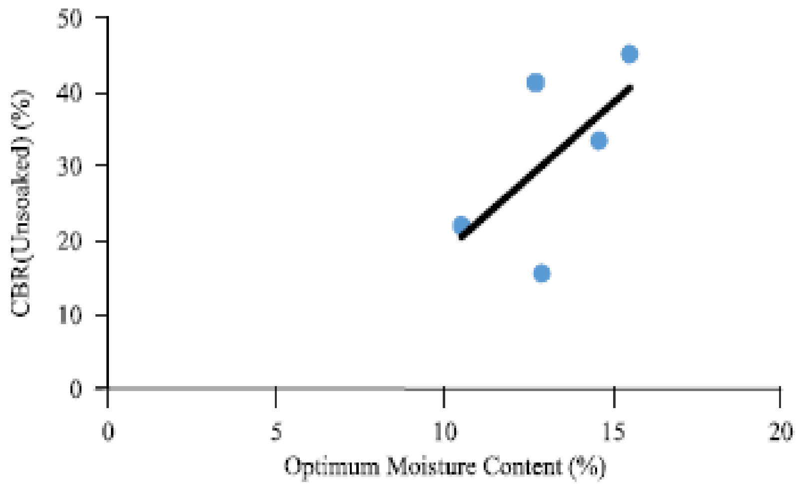

Fig. 8. Relationship of unsoaked CBR with optimum moisture content

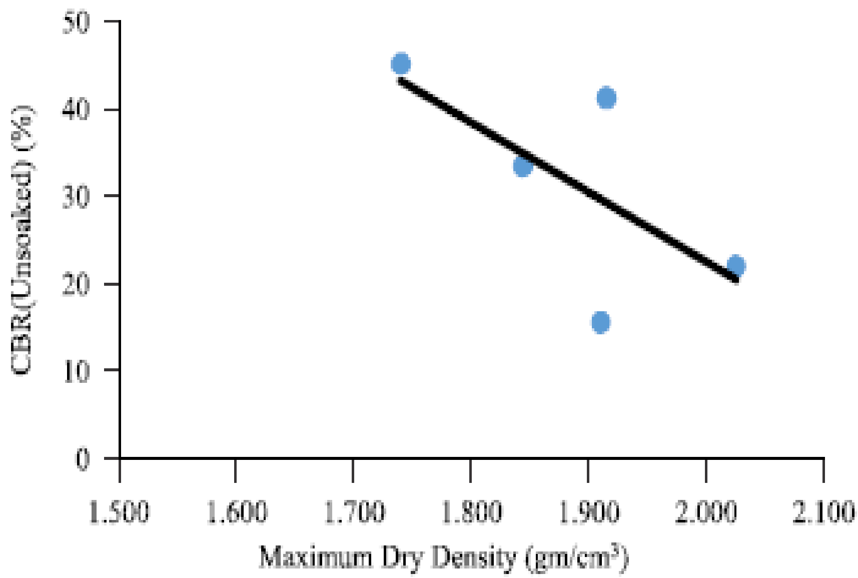

Fig. 9. Relationship of unsoaked CBR with maximum dry density

CBR_U= -79.67(MDD) + 181.84 R^2 = 0.4413………………………... (8)

Model-5: Correlation of Unsoaked California Bearing Ratio with %Finer Passing From #200 Sieve (%F):

Fig. 10 represents a graph which shows a correlation between unsoaked CBR and % finer passing from #200 sieve for all soil samples. The mathematical relation between the two parameters is shown in Equation (9). It can be seen that the reliability factor R2 obtained from this equation is only 0.0034.

CBR_U=0.0587(%F) + 27.276 R^2 = 0.0034…………….………… (9)

Model-6: Correlation of Soaked California Bearing Ratio (CBR_S) With Liquid Limit:

Fig. 11 represents a graph, which shows a correlation between soaked CBR and LL for all soil samples. The mathematical relation between the two parameters is shown in Equation (10). It can be seen that the reliability factor R_2 obtained from this equation is only 0.0373.

CBR_S= 0.1077(LL) + 8.5882 R^2 = 0.0373…………………………. (10)

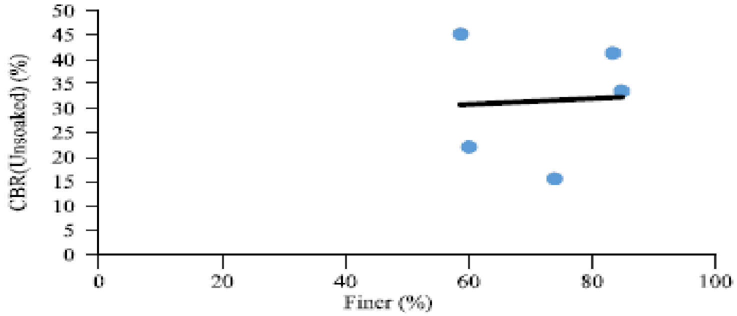

Fig. 10. Relationship of unsoaked CBR with % finer

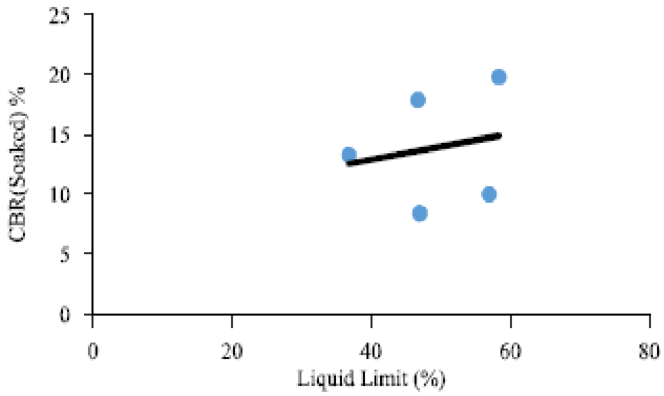

Fig. 11. Relationship of soaked CBR with liquid limit

Model-7: Correlation of Soaked California Bearing Ratio with Plasticity Index:

Fig. 12 represents a graph, which shows a correlation between soaked CBR and PI for all soil samples. The mathematical relation between the two parameters is shown in Equation (11). It can be seen that the reliability factor R^2 obtained from this equation is 0.0261.

CBR_S=0.2131(PI) + 8.4678 $R^2 = 0.0261$……………………….. (11)

Model-8: Correlation of Soaked California Bearing Ratio with Optimum Moisture Content:

Fig. 13 represents a graph, which shows a correlation between soaked CBR and OMC for all soil samples. The mathematical relation between the two parameters is shown in Equation (12). It can be seen that the reliability factor R2 obtained from this equation is only 0.0328.

CBR_S=0.4624(OMC) + 7.7621 $R^2 = 0.0328$………………… (12)

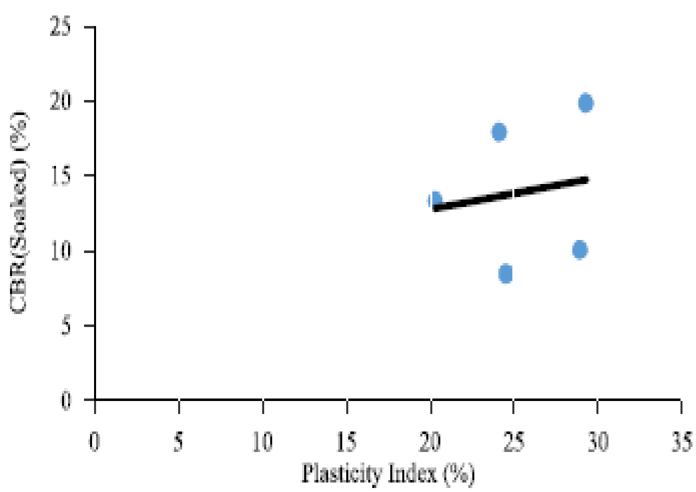

Fig. 12. Relationship of soaked CBR with plasticity index

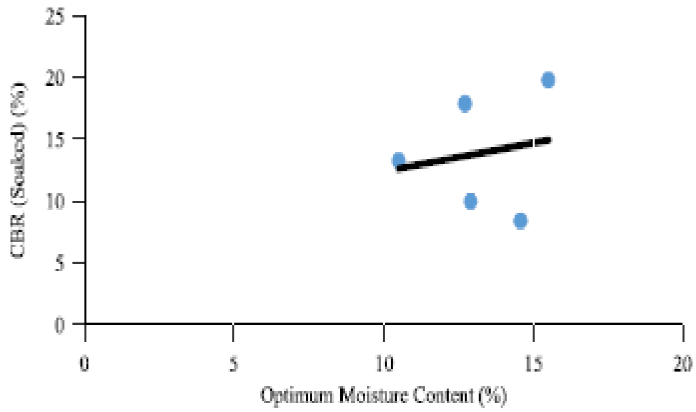

Fig. 13. Relationship of soaked CBR with optimum moisture content

Model-9: Correlation of Soaked California Bearing Ratio with Maximum Dry Density:

Fig. 14 represents a graph, which shows a correlation between soaked CBR and MDD for all soil samples. The mathematical relation between the two parameters is shown in Equation (13). It can be seen that the reliability factor R2 obtained from this
equation is 0.1136.

CBR_S = -15.81(MDD)+ 43.715 R^2 = 0.1136……………………… (13)

Model-10: Correlation of Soaked California Bearing Ratio with % Finer Passing From #200 Sieve (%F):

Fig. 15 represents a graph, which shows a correlation between soaked CBR and % finer passing from #200 sieve for all soil samples. The mathematical relation between the two parameters is shown in Equation (14). It can be seen that the reliability factor R2 obtained from this equation is 0.1806 which is still not significant.

CBR_S=-0.1681(%F) + 26.02 R^2 = 0.1806……………………… (14)

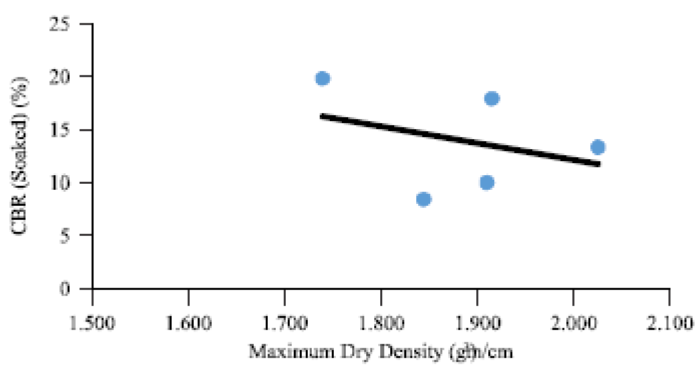

Fig. 14. Relationship of soaked CBR with maximum dry density

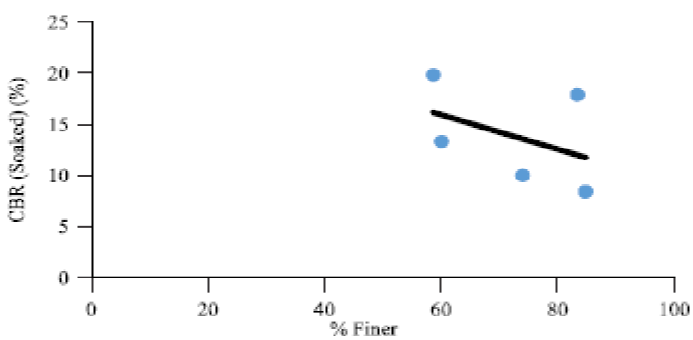

Fig. 15. Relationship of soaked CBR with % finer

Model-11: Correlation of Soaked California Bearing Ratio (CBR_S) With Unsoaked California Bearing Ratio:
Fig. 16 represents a graph, which shows a correlation between soaked CBR and unsoaked CBR for all soil samples [15]. The mathematical relation between the two parameters is shown in Equation (15). It can be seen that the reliability factor R^2 obtained from this equation is 0.5153 which is still not significant.

CBR_S=0.2807(CBRU) + 5.0352 R^2 = 0.5153………………………. (15)

A brief summary of the developed SLRA models for both Soaked and Unsoaked CBR are given in Table 3.

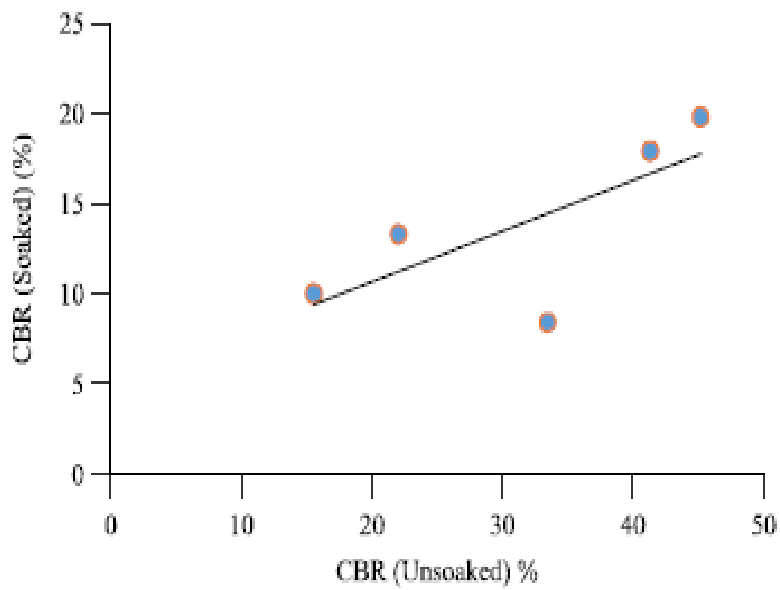

Fig. 16. Relationship of soaked CBR with unsoaked CBR

From the above developed SLRA models for unsoaked CBR, based on the values of coefficient of determination (R^2), it has been noted that Model-4 provides a better correlation with MDD with value of R2 = 0.4413. Similarly, for soaked CBR, Model-10 provides a better correlation with % Finer with value of R^2 = 0. 1806.On the other hand, the correlation between soaked and unsoaked CBR has been found to be a better correlation with a value of R^2 = 0.5153.

5.2 Correlations by Multiple Linear Regression Analysis

This analysis has been performed by taking CBR as function of more than one independent variables [Equation (1)]. Now, the equations which have been obtained through MLRA by adopting Microsoft Excel solution are given in Table 4 along with their model number. From the above developed MLRA models for Soaked CBR, based on the values of coefficient of determination (R^2) and Adjusted Coefficient of Determination (Adj R^2), it has been noted that Model-13 provides a better correlation with LL, PI and % Finer with value of R^2 = 0.984 and Adjusted R^2 = 0.935. Similarly, for Unsoaked CBR, correlations/models

developed are shown in Table 5. From the above developed MLRA models for Unsoaked CBR, based on the values of coefficient of determination (R^2) and Adjusted Coefficient of Determination (Adj R^2), it can be noted that Model-32 provides a better correlation of Unsoaked CBR with LL, PI and MDD with value of R^2= 0.971 and Adjusted R^2 = 0.884.

Model No.	**Correlation/Model**	**R^2**
1	**CBRU= 0.2896(LL) + 17.274**	**0.0413**
2	**CBRU= 0.5519(PI) + 17.489**	**0.0268**

3	**CBRU= 4.0282(OMC) - 21.807**	**0.3812**
4	**CBRU= -79.67(MDD) + 181.84**	**0.4413**
5	**CBRU=0.0587(%F) + 27.276**	**0.0034**
6	**CBRS= 0.1077(LL) + 8.5882**	**0.0373**
7	**CBRS=0.2131(PI) + 8.4678**	**0.0261**
8	**CBRS=0.4624(OMC) + 7.7621**	**0.0328**
9	**CBRS = -15.81(MDD)+ 43.715**	**0.1136**
10	**CBRS=-0.1681(%F) + 26.02**	**0.1806**
11	**CBRS=0.2807(CBRU) + 5.0352**	**0.5153**

TABLE 3. DEVELOPED CORRELATIONS FOR UNSOAKED AND SOAKED CBR VALUES (SLRA)

6. VALIDATION ANALYSIS

From section 4, it is observed that high reliability for CBR prediction is observed from MLRA instead of SLRA. So now, equations of MLRA are utilized for obtaining relation between predicted and actual CBR (Table 6). Also, the graph is plotted to show the difference in values between experimental and predicted CBR for each sample. For Soaked CBR: CBRS =11.2525(LL)-26.4144(PI)-0.3024(%F) +153.7175(16) R^2= 0.984, Adj R^2= 0.935 Now, the graph between predicted and actual CBR (Soaked) along with line of equality is presented in Fig, 17. The trend line in Fig. 17 shows that the ratio of predicted to actual CBR value is 1 i.e. P/A =1. Points above this line of equality indicate those samples whose predicted CBR value is higher than their actual CBR value and vice versa. From Fig. 17, it is observed that predicted CBR values of Sample-1, 6 and 7 slightly deviate from the line of equality while the remaining samples predicted CBR values scatters near the line of equality. The difference between experimental/actual and predicted CBR values is graphically shown below:

Fig. 18 represents difference in values of predicted and actual CBR value in soaked condition for each soil sample in a graphical format. It can be seen that predicted CBR values of Samples 2, 5 and 6 under estimate their actual CBR values, but for Sample 1 and 7, predicted CBR values over estimate their actual CBR values. Fig. 18 depicts the results of Soaked CBR value obtained from laboratory results as well as model.

Model No.	Correlation/Model	R^2
1	CBRS = 7.9602(LL)-18.5855(PI)+94.8082	0.478
2	CBRS = 0.0729(LL)+0.2140(OMC)+7.4679	0.040
3	CBRS = 60.1486-0.0954(LL)-22.0345(MDD)	0.125
4	CBRS = 0.0992(LL)-0.1655(%F) +20.9566	0.212
5	CBRS = 0.0824(PI)+0.3456(OMC)+7.2138	0.035
6	CBRS =66.5421-0.2981(PI)-23.8927(MDD)	0.135
7	CBRS = 0.1836(PI)-0.1651(%F) +21.1395	0.200
8	CBRS= 537.9573-10.4525(OMC)-204.4219(MDD)	0.726
9	CBRS = 0.6217(OMC)-0.1812(%F) +18.7382	0.239
10	CBRS = 54.7316-15.3367(MDD)-0.1650(%F)	0.287

11	CBRS=9.1437(LL)-21.0468(PI)-0.8825(OMC)+110.8469	0.524
12	CBRS = 7.9210(LL)-18.5035(PI)-0.4965(MDD)+95.5896	0.478
13	CBRS =11.2525(LL)-26.4144(PI)-0.3024(%F) +153.7175	0.984
14	CBRS = 589.7867-0.1925(LL)-10.8470(OMC)-224.1055(MDD)	0.773
15	CBRS = 18.8030-0.0064(LL)+0.6442(OMC)-0.1819(%F)	0.239
16	CBRS = 73.0295-0.1057(LL)-22.2298(MDD)-0.1663(%F)	0.302
17	CBRS = 596.3103-0.5054(PI)-10.8681(OMC)-225.6242(MDD)	0.787
18	CBRS =19.9079-0.1233(PI)+0.8015(OMC)-0.1870(%F)	0.243
19	CBRS =81.3928-0.3450(PI)-24.6802(MDD)-0.1686(%F)	0.316
20	CBR(Soaked) = 938.5039-19.3692(OMC)-366.2257(MDD)+0.3156(%F)	0.917

TABLE 4. DEVELOPED CORRELATIONS FOR SOAKED CBR VALUE (MLRA)

Model No.	Correlation/Model	R^2
21	CBRU = 293.4964+25.4466(LL)-59.5422(PI)	0.734
22	CBRU = 6.8302(OMC)-0.8217(LL)-18.4886	0.529
23	CBRU = 374.0235-1.1153(LL)-152.4578(MDD)	0.685
24	CBRU = 0.2930(LL)+0.0663(%F) +12.3209	0.046
25	CBRU = 6.9941(OMC)-2.0923(PI)-7.8884	0.560
26	CBRU = 392.0103-2.7448(PI)-154.0842(MDD)	0.720
27	CBRU = 0.5640(PI)+0.0678(%F) +12.2863	0.031
28	CBRU = 474.0850-6.1806(OMC)-191.1960(MDD)	0.474
29	CBRU = 4.0517(OMC)-0.0268(%F)-20.1844	0.382
30	CBRU = 0.0751(%F)-79.8853(MDD)+176.8267	0.447
31	CBRU = 19.5963(LL)-47.3755(PI)+4.3622(OMC)+214.2133	0.904
32	CBRU = 17.3174(LL)-42.5467(PI)-102.9336(MDD)+455.5159	0.971
33	CBRU = 28.4911(LL)-66.7818(PI)-0.2796(%F) +347.9718	0.800
34	CBRU = 795.1081-1.1925(LL)-8.6238(OMC)-313.1128(MDD)	0.748
35	CBRU = 7.0988(OMC)-0.8712(LL)-0.1136(%F)-11.4105	0.541
36	CBRU = 369.2812-1.1115(LL)-152.3859(MDD)-0.0612(%F)	0.689
37	CBRU = 809.8604-2.9083(PI)-8.5721(OMC)-313.1981(MDD)	0.782
38	CBRU = 1.0451-2.2370(PI)+7.3149(OMC)-0.1316(%F)	0.576
39	CBRU = 387.9331-2.7319(PI)-153.8680(MDD)+0.0463(%F)	0.722
40	CBRU = 1443.6615-27.7645(OMC)-582.8637(MDD)+0.7639(%F)	0.645

TABLE 5. DEVELOPED CORRELATIONS FOR UNSOAKED CBR VALUE (MLRA)

Sample No.	Actual CBR Value (%)	Predictive CBR Value (%)	Difference in Values
1	8.418	9.262	-0.844
2	17.892	17.396	0.496
5	13.302	13.161	0.141
6	10.002	9.363	0.639
7	19.805	20.225	-0.420

` TABLE 6. VALIDATION OF DEVELOPED CORRELATION FOR SOAKED CBR`

For Unsoaked CBR,

CBR_U = 17.3174(LL)-42.5467(PI)-102.9336(MDD)+455.5159………………… (17)

R^2= 0.971, Adj R_2 = 0.884

Now, the graph between predicted and actual CBR (Unsoaked) along with line of equality is presented in Fig. 19. It is observed that predicted CBR values of Sample 1, 5 and 7 slightly deviate from the line of equality while the remaining samples predicted CBR values scatters near the line of equality. Moreover, the predicted CBR values of Sample 1, 2 and 6 are higher than their actual CBR values while the predicted CBR values of Sample 5 and 7are lower than their actual CBR values (Table 7).

The difference between experimental/actual and predicted CBR values is shown graphically below:

Fig. 20 represents difference in values of predicted and actual CBR value in unsoaked condition for each soil sample in a graphical format. It can be clearly seen that predicted CBR values of Sample 5 and 7 under estimate their actual CBR values, but for Sample 1, 2 and 6, predicted CBR values over estimate their actual CBR values.

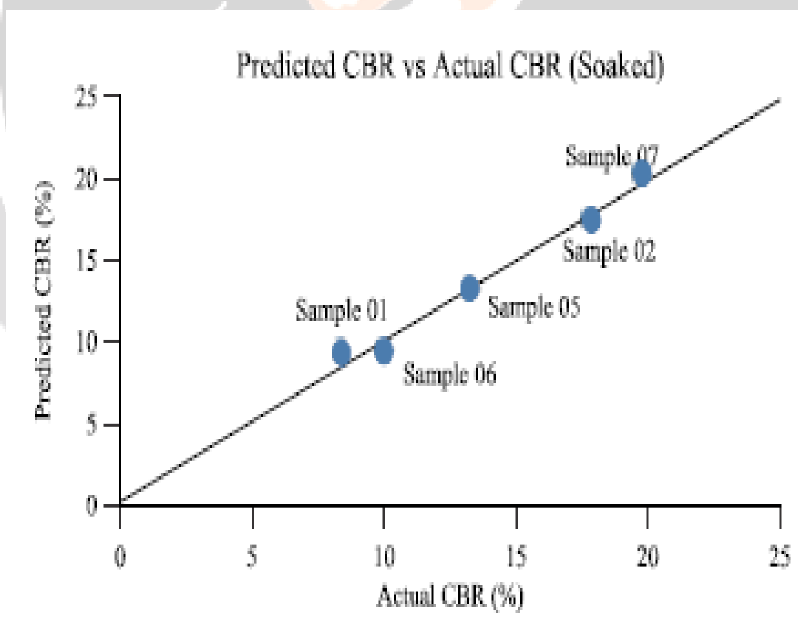

Fig. 17. Graph of predicted vs actual CBR in soaked condition

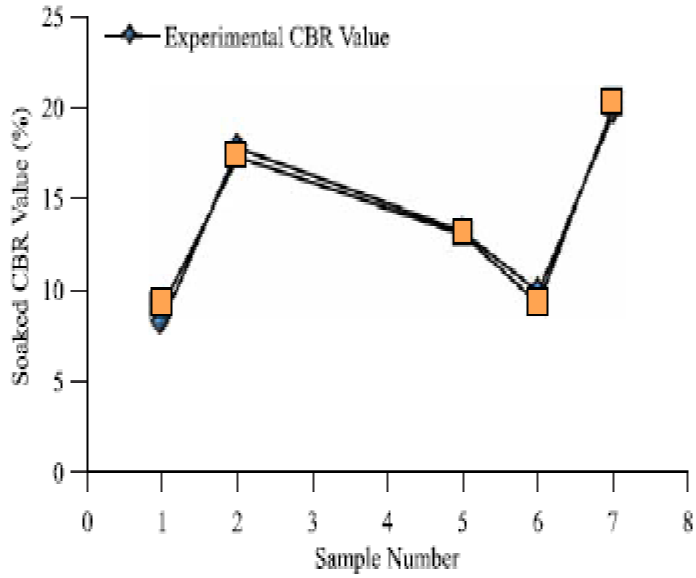

Fig. 18. Graph of CBR value vs sample number in soaked condition

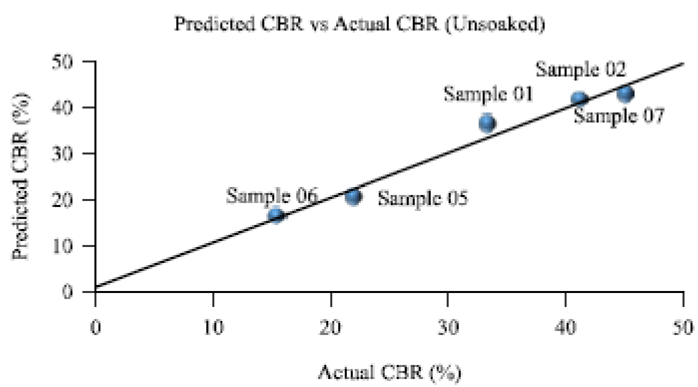

Fig. 19. Graph of predicted vs actual CBR in unsoaked condition

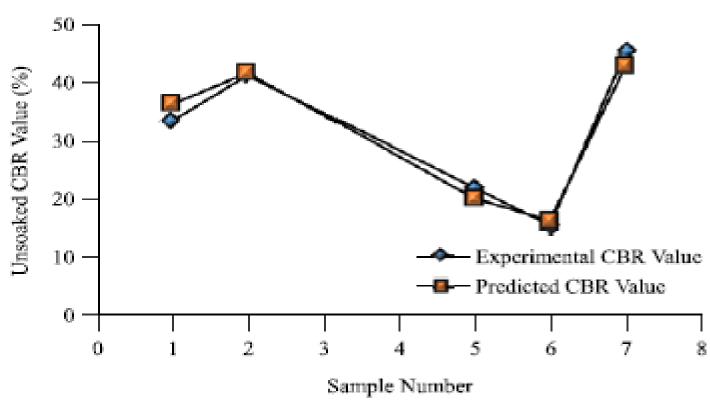

Fig. 20. Graph of CBR value vs sample number in unsoaked condition

Sample No.	Actual CBR Value (%)	Predictive CBR Value (%)	Difference in Values
1	33.465	36.379	-2.914
2	41.310	41.745	-0.435

5	22.059	20.232	1.827
6	15.571	16.405	-0.834
7	45.185	42.831	2.354

TABLE 7. VALIDATION OF DEVELOPED CORRELATION FOR UNSOAKED CBR Difference in Values

6. CONCLUSION

From the results of the research, the following conclusions can be drawn:

(i) Based on the above laboratory tests, no any reliable SLRA relationship exists for predicting Soaked as well as Un-Soaked CBR value from index properties.

(ii) The highest coefficient of determination obtained for Soaked CBR is 0.1806 while correlating Soaked CBR with % finer, and the highest coefficient of determination obtained for Un-Soaked CBR is 0.4413 while correlating Un-Soaked CBR with MDD.

(iii) Un-Soaked CBR value provides a relationship with MDD through SLRA with coefficient of determination R^2= 0.4413, which is not suitable.

(iv) The correlation of Soaked CBR with LL, PI and %Finer by utilizing MLRA approach gives a good relationship with R2 = 0.984 which is CBR (Soaked) = 11.2525(LL) - 26.4144(PI) - 0.3024(%F) + 153.7175 The correlation of Un-Soaked CBR with LL, PI and MDD by utilizing MLRA approach gives a good relationship with R^2 = 0.971, CBR (Un-Soaked) = 17.3174(LL) - 42.5467(PI) - 102.9336(MDD) + 455.5159

(vi) It is observed that CBR values decreases with increase in PI and increases with increase in LL.

(vii) From the developed correlation, it can be seen that the Soaked CBR value is largely dependent on LL and PI of soil whereas, the effect of % Finer is minor.

(viii) For Unsoaked CBR, the values are largely dependent on LL, PI and MDD.

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