PREDICTING THE CALIFORNIA BEARING RATIO VALUE OF LOW COMPRESSIBLE CLAYS WITH IT'S INDEX AND COMPACTION CHARACTERISTICS.

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Abstract

Geotechnical engineers usually attempt to develop empirical equations specific to a certain region and soil type. The distinctive nature of soil properties in-situ is that it is divergent spatially and seasonally beyond the designer's control. However, these empirical equations are more reliable for the type of soil where the correlation is origin. Coming from this background, this study attempted to find the correlation between California Bearing Ratio(CBR) values with soil index properties specific to clay subgrade soils of low compressibility(CL). The study examined the possibility of single linear regression analysis and multiple non-linear regression analysis in predicting the CBR value with soil index properties. Specific to this research, statistical software (XLSTAT) is employed to investigate the significance of individual independent variables. The correlation is established in the form of an equation of CBR as a function of Atterberg limits and compaction parameters by considering the effect of an individual soil properties and effect of a combination of soil properties on the CBR value. The developed correlation consisted a moderate determination coefficient of R^2 = 0.658 using single regression analysis, while multiple regression analysis generated relatively an improved correlation of R^2 = 0.934 for CL soils.

Keywords: UCBR, regression models, liquid limit, plastic limit, linear shrinkage, plasticity index, optimum moisture content and maximum dry density, coefficient of correlation,

Introduction

Road transportation system is an important element in the physical development of a nation. In developing countries of the world, the road network is probably the most widely used of the several means of transportation, and it is an important index of the development that touches the lives of both rural and urban dwellers. In fact roads have been described as causes as well as consequences of civilization (O'Flaherty, 1973). Flexible pavement consists of different layers such as sub-grade, subbase, base course and surface layer. Sub-grade is the bottom most layer. The performance of flexible pavementmainly depends on thestrength of sub-grade material. Theload from the pavement surface is ultimately transferred to sub-grade via the base and sub-base of the pavement. The sub-grade is designedsuch that the stress transferred should not exceed elasticlimit. Hence, the suitability and stability of sub-gradematerial is evaluated before construction of pavement.Soaked California bearing ratio (CBR) value (%) isconsidered as strength parameter in design of sub-grade (Rakaraddi and Gomarsi, 2015).

To obtain the soaked CBR value of a soil sample is laborious, time taking and it takes about a week thereby making CBR test expensive. Furthermore, the results sometimes are not accurate due to poor quality of skill of the technicians testing the soil samples in the laboratory (Roy, Chattopadhyay and Roy, 2010). As a result, only a limited number of CBR test could be performed per kilometre length of the proposed road to be constructed. Such limited number of CBR test results may not generally reveal the variation in the CBR values over the length of the road to enable rational, economic and safe construction. This could be avoided only if a large number of soil sample are taken. But such a procedure will increase the project cost and time. To overcome these difficulties, an attempt has been made in this study to predict the CBR value statistically with the liquid limit (LL), Plastic Limit (PL), Plasticity Index (PI), Maximum Dry Density (MDD) and Optimum Moisture Content (OMC) of soil. This is because these tests are simple and can be completed with less period of time.

Cohesive soil CBR value is correlated with plasticity and liquidity index (Black, 1962), liquid limit and gradation characteristics of soil (Vinod and Cletus; 2008). Muley and Jain (2013) developed a correlation to predict CBR of stone dust mixed with poor soil. Hakari and Nadagouda,(2013) correlated the CBR value by using presumptive design chart and Nomography as per IRC SP: 37-2007. Patel and Desai (2010), Venkatasubramanian and Dinakaran (2011), Ramasunnarao and Sankar (2013), Akashaya (2013), and Tulukdar (2014) had developed Multiple Liner Regression Analysis models (MLRA) for correlating CBR with index properties of soil. Aderinola et al(2017) correlated the CBR value of high compressible clay(CH) soil with it's index and compaction characteristics and discovered that single regression analysis produced a fairly good correlation while multiple regression analysis produced an improvement on the single regressioncorrelation. This study therefore sought to find out the relationship between the CBR value , the index and compaction characteristics if the clay soil is oflow compressibility(CL).

Methodology

Simple Relation

To establish a relation between unsoaked CBR and different soil properties, graphs was plotted with CBR against different soil parameters and suitable trend line was drawn with higher correlation coefficient. Correlation quantifies the degree to which dependent and independent variables are related. Linear regression quantifies goodness of fit with R^2 value. 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 greater than 0.80 were considered as a best fit.

Multiple Polynomial Regression Analysis

To develop the models of multiple linear regression analysis, the unsoaked CBR value was considered as independent variable andsoil properties such as Shrinkage Limit(SL), Liquid Limit(LL),Plastic Limit(PL),Plasticity Index(PI), Maximum Dry Density(MDD) and OPTIMUM Moisture Content (OMC) were considered as the dependentvariables. MPRA was carried out using the statistical software XLSTAT, an add-in for Microsoft Excel in order to derive the relationshipstatistically.

Materials

Samples test results were collected for low compressible clay (CL soils) from various locations in Akure, Ondo State, Nigeria. The results contained the CBR value (BS 1377), Optimum Moisture Content and Maximum Dry Density (Modified Proctor Compaction, BS 1377), Shrinkage Limit, Plastic Limit, Liquid Limit and Plasticity Index (BS 1377).

Results and Conclusion

The results obtained for the CL soils are exclusively given in Table 1.

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Table 1: Properties of CL soil samples

SAMPLE	TYPE	SL (%)	PL (%)	LL (%)	PI (%)	MDD (kg/m^3)	OMC (%)	UCBR (%)
1	CL	11.5	21.3	31.3	10.00	1960	14.4	30
2	CL	12.0	21.3	33.5	12.20	1890	16.4	26
3	CL	12.0	19.6	31.0	11.40	1928	15.3	29
4	CL	9.1	19.1	27.7	8.65	1995	13.4	31
5	CL	11.0	11.9	34.3	22.45	1443	31.6	7
6	CL	7.2	15.1	32.1	17.00	1512	26.4	11
7	CL	12.0	16.7	30.1	13.43	2203	17.6	32
8	CL	13.4	12.9	25.8	12.89	1867	20.2	27
9	CL	13.9	9.2	28.1	18.90	2107	10.1	14
10	CL	7.7	18.5	33.2	14.75	1648	17.6	17
11	CL	9.6	19.4	31.8	12.45	1779	18.0	25
12	CL	10.6	19.3	33.0	13.70	1779	18.0	24
13	CL	10.6	19.2	34.2	15.00	1749	18.8	25
14	CL	13.0	19.7	26.3	6.60	2067	12.7	31
15	CL	13.0	19.9	27.4	7.50	2051	13.3	30
16	CL	13.0	20.0	27.4	7.45	2048	13.4	30
17	CL	12.5	20.9	28.1	7.20	2064	12.8	32
18	CL	11.0	21.9	32.6	10.70	1899	18.2	22
19	CL	11.0	22.8	33.2	10.40	1924	17.4	25
20	CL	13.9	19.4	23.3	3.90	2073	12.5	34
21	CL	11.0	21.2	33.2	12.00	1952	16.5	26
22	CL	11.0	22.4	32.4	10.05	1927	17.3	25
23	CL	11.0	20.8	33.1	12.35	2113	11.2	31
24	CL	11.5	19.1	31.7	12.65	1986	15.4	27
25	CL	12.5	20.4	29.1	8.70	1980	15.6	25
26	CL	11.5	20.2	31.1	10.90	1974	15.8	27
27	CL	13.4	21.4	28.8	7.40	2046	11.2	32
28	CL	12.0	19.2	30.8	11.65	1994	12.6	32
29	CL	12.0	21.2	32.4	11.20	1987	12.8	32
30	CL	12.0	21.2	31.4	10.25	1990	12.7	32
31	CL	10.6	20.4	33.5	13.15	2001	12.4	31
32	CL	13.4	21.4	26.2	4.80	2035	11.5	35
33	CL	13.0	21.1	27.4	6.30	2024	11.8	32
34	CL	12.0	21.2	31.4	10.25	1857	16.4	28

Simple Linear Regression Analysis

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In Figures 1 to 6, the relationship between unsoaked CBR and different soil properties are plotted and mathematical equation was generated.

The variation between unsoaked CBR and shrinkage limit is shown in Figure 1 and the suitable trend line is given by the equation

UCBR = 3.734 + 2.001SL... (1).

with $R^2 = 0.237$

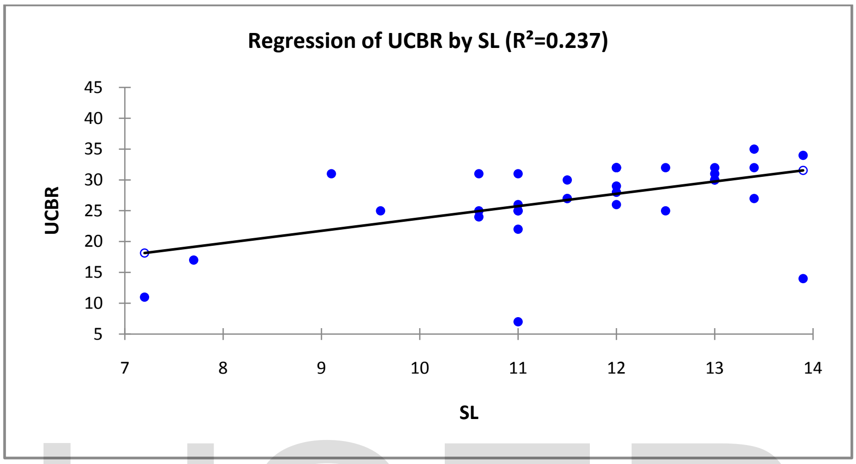

Figure 1: Scatter Plot and Regression Line for UCBR versus.SL

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The variation between unsoaked CBR and plastic limit is shown in Figure 2 and the suitable trend line is given by the equation

U*CBR = 0.912 + 1.345PL* .... (2)

with $R^2 = 0.391$.

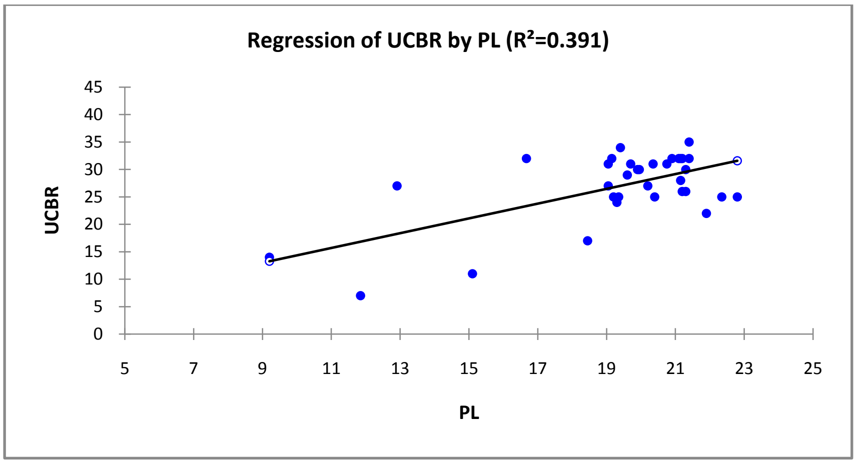

Figure 2: Scatter Plot and Regression Line for UCBRversus. PL

The variation between unsoaked CBR and Liquid limit is shown in Figure 3 and the suitable trend line is given by the equation

UCBR = 57.485–1.001LL .... (3)

with R^2 = 0.194.

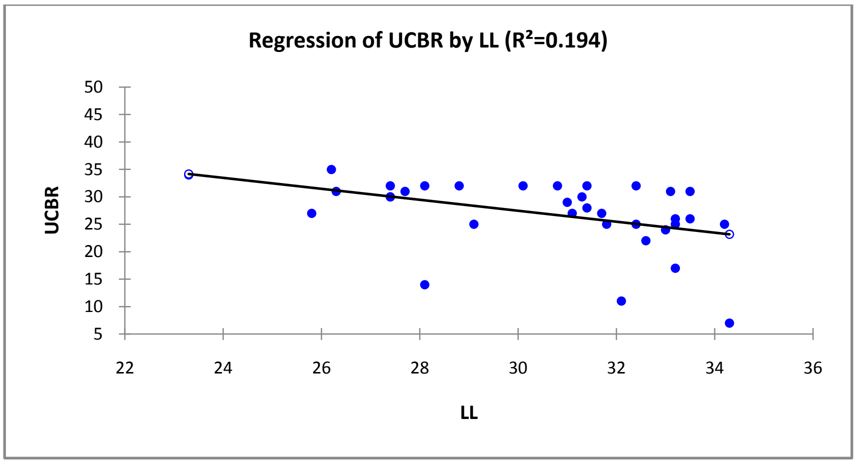

Figure 3: Scatter Plot and Regression Line for UCBRversus. LL

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The variation between soaked CBR and Plasticity Index is shown in Figure 4 and the suitable trend line is given by the equation

UCBR = 42.077 -1.358PI .... (4)

with R^2 = 0.658.

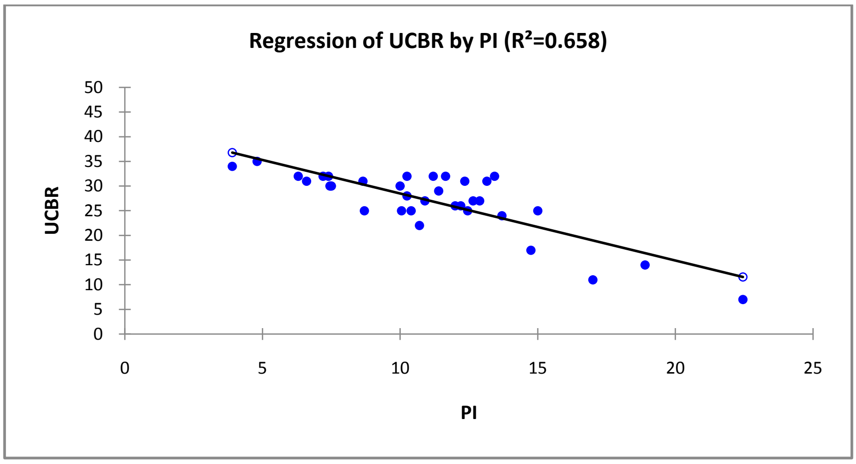

Figure 4: Scatter Plot and Regression Line for UCBRversus. PI

The variation between soaked CBR and Maximum Dry Density is shown in Figure 5 and the suitable trend line is given by the equation

$CBR = -32.287 + 0.031MDD$ .... (5)

with $R^2 = 0.595$.

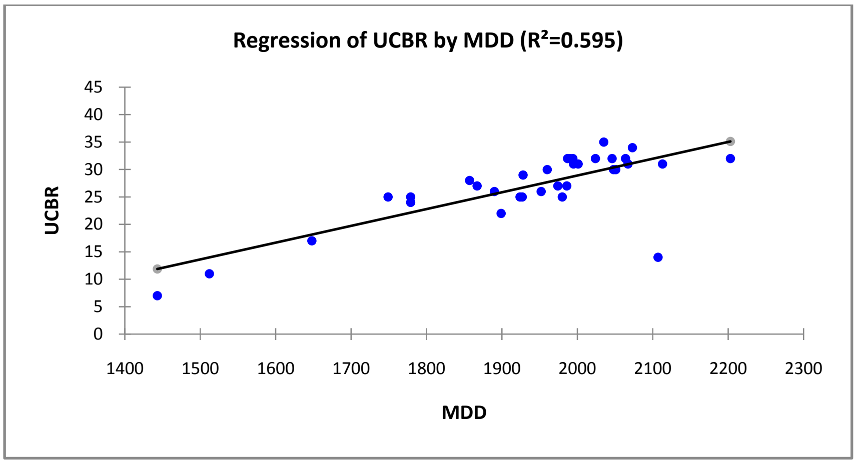

Figure 5: Scatter Plot and Regression Line for UCBRversus. MDD

The variation between soaked CBR and Optimum Moisture Content is shown in Figure 6 and the suitable trend line is given by the equation

$CBR = 44.508 - 1.122OMC$ .... (6)

with $R^2 = 0.569$.

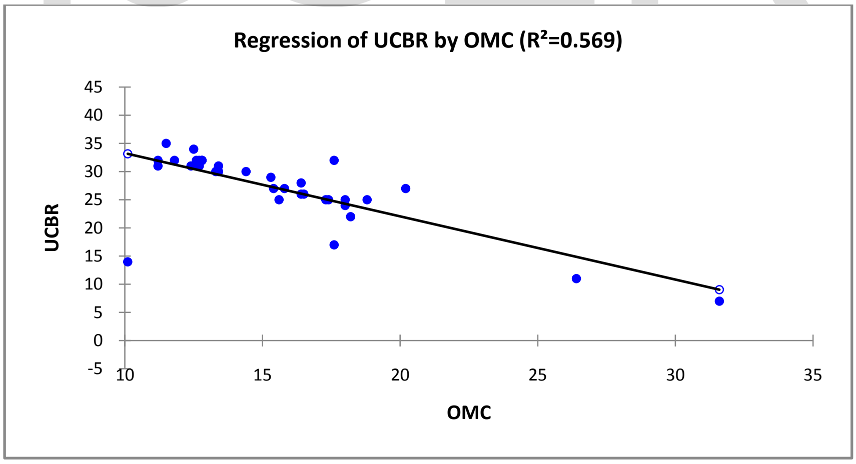

Figure 6: Scatter Plot and Regression Line for UCBRversus. OMC

The summary of the coefficient of correlation of different lines plotted in Figures 1 to 6 is given in Table 2.

Table 2: Coefficient of Correlation for UCBR with different Soil parameters

Regression Type	Correlation of UCBR with	R	R^2
Single Linear Regression Analysis	SL	0.487	0.237
	PL	0.625	0.391
	LL	-0.440	0.194
	PI	-0.811	0.658
	MDD	0.771	0.595
	OMC	-0.754	0.569

Multiple Polynomial Regression Analysis

By correlating unsoakedUCBR with SL, LL, PI and OMC, the mathematical equation generated isgiven thus:

$$UCBR = 144.633 + 13.361SL - 10.793LL + 3.529PI - 3.326OMC - 0.612SL^2 + 0.168LL^2 - 0.182PI^2 + 0.080OMC^2 \quad \ldots\ldots \quad (7)$$

With $R^2 = 0.885$.

Figure 7 is plotted with respect to laboratory UCBR value obtained for different CLsoil samples used for validation and predicted UCBR value (obtained fromequation-7)

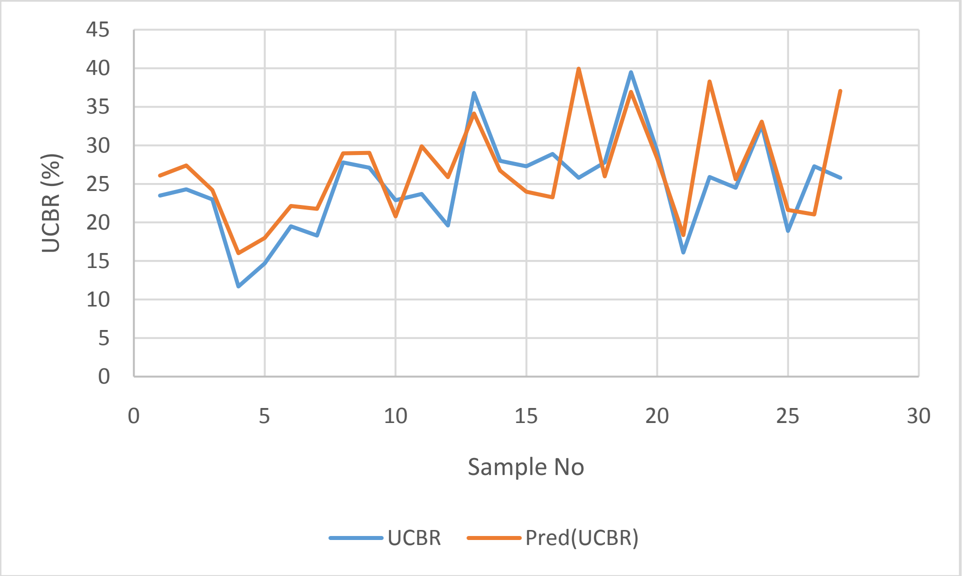

Figure 7: Predicted UCBR of Equation 7 and Laboratory UCBR

By correlating unsoaked CBR with SL, PL, LL and MDD, the mathematical equation generated isgiven thus:

$$UCBR = -77.951 + 5.254SL + 6.075PL - 3.122LL + 0.056MDD - 0.210SL^2 - 0.171PL^2 + 0.052LL^2 - 0.00001MDD^2 \quad \text{.........} \quad (8)$$

With $R^2 = 0.912$.

Figure 8 is plotted with respect to laboratory UCBR value obtained for different CLsoil samples used for validation and predicted UCBR value (obtained fromequation-8).

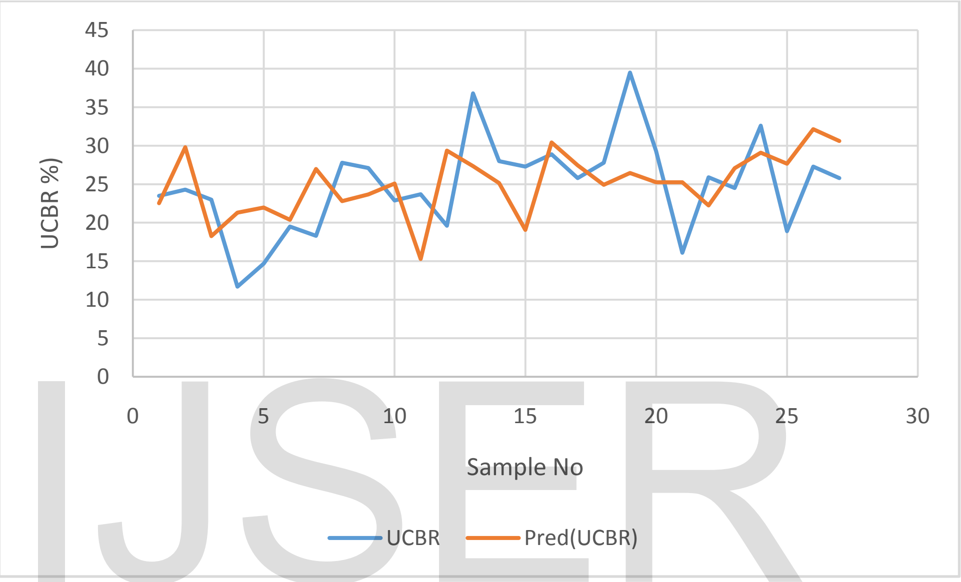

Figure 8: Predicted UCBR of Equation 8 and Laboratory UCBR

By correlating unsoaked CBR with SL, LL, PI, MDD and OMC, the mathematical equation generated is given below.

$$UCBR = 537.888 + 23.632SL - 13.351LL + 4.869PI - 0.432MDD - 1.921OMC - 1.047SL^2 + 0.205LL^2 - 0.241PI^2 + 0.00011MDD^2 + 0.021OMC^2 \quad \text{.........} \quad (9)$$

With $R^2 = 0.926$.

Figure 9 is plotted with respect to laboratory UCBR value obtained for different CLsoil samples used for validation and predicted UCBR value (obtained fromequation-9).

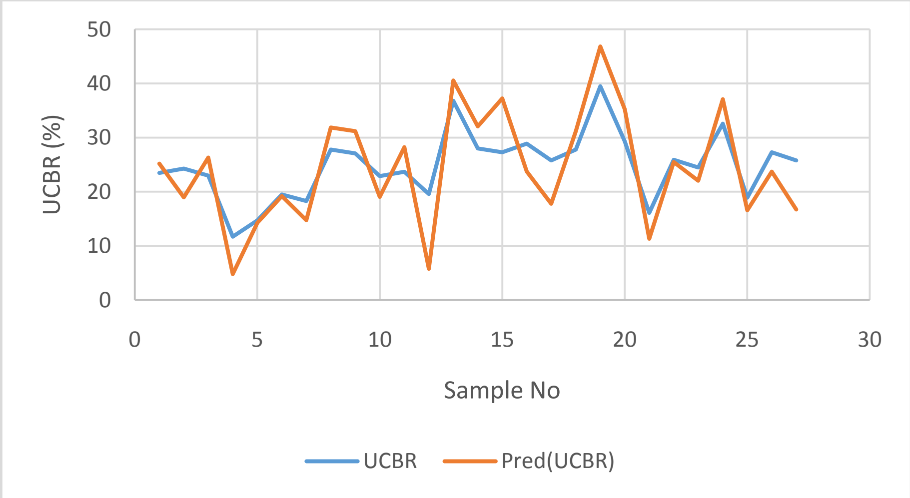

Figure 9: Predicted UCBR of Equation 9 and Laboratory UCBR

By correlating unsoaked CBR with SL, PL, LL, PI and OMC, the mathematical equation generated isgiven below.

$$UCBR = 56.735 + 11.489SL + 2.637PL - 5.072LL - 2.911OMC - 0.493SL^2 - 0.153PI^2 + 0.121LL^2 - 0.135PI^2 + 0.065OMC^2 \quad \ldots\ldots \quad (10)$$

With $R^2 = 0.927$.

Figure 10 is plotted with respect to laboratory UCBR value obtained for different CLsoil samples used for validation and predicted UCBR value (obtained fromequation-10).

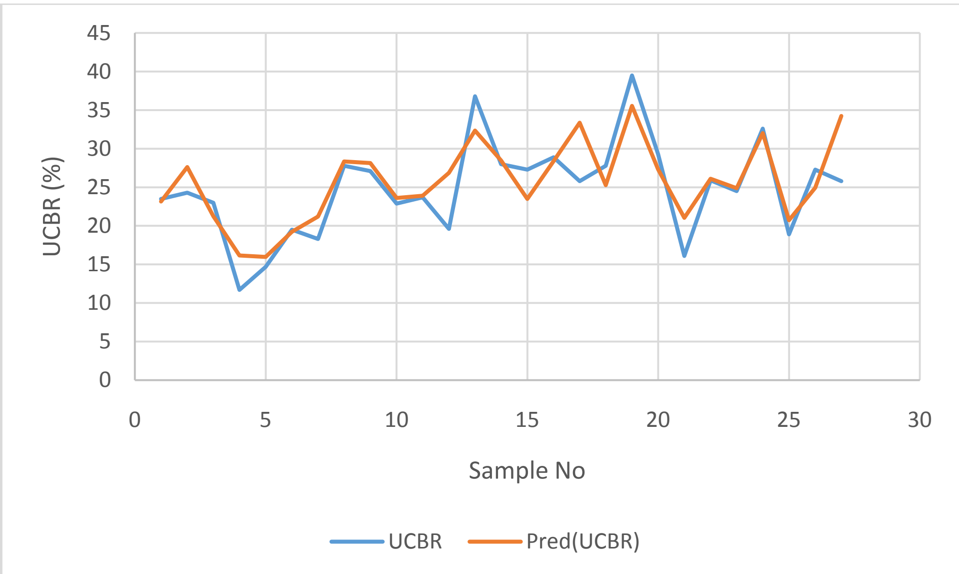

Figure 10: Predicted UCBR of Equation 10 and Laboratory UCBR

By correlating unsoaked CBR with SL, PL, LL, PI, MDD and OMC, the mathematical equation generated isgiven below.

$$UCBR = 268.772 + 15.883SL + 0.001PL - 6.549LL - 0.199MDD - 2.299OMC - 0.691SL^2 - 0.1PL^2 - 0.157LL^2 + 0.175PI^2 + 5 \times 10^{-5} \times MDD^2 + 0.042OMC^2 \quad ..... \quad (11)$$

With $R^2 = 0.934$.

Figure 11 is plotted with respect to laboratory UCBR value obtained for different CLsoil samples used for validation and predicted UCBR value (obtained fromequation-11).

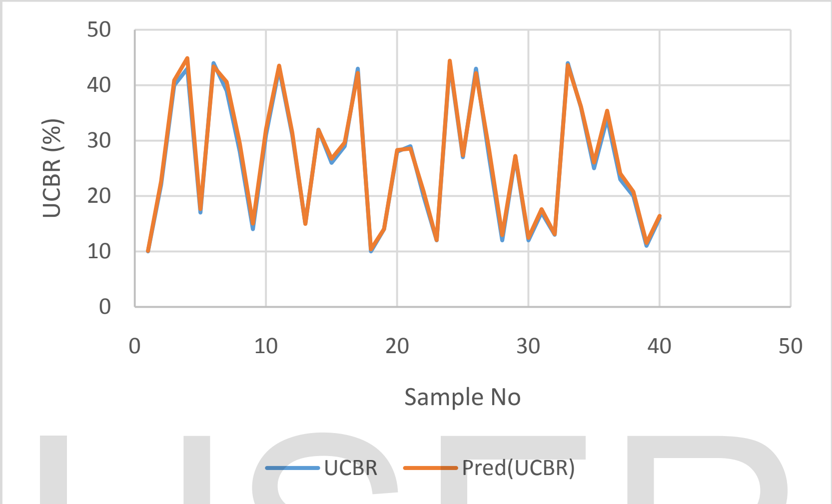

Figure 11: Predicted UCBR of Equation 11 and Laboratory UCBR

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Conclusion

With reference to the results and discussions, the following conclusions may be deduced:

1. Among the single linear regression analyses, the UCBR can be reasonably predicted from PIusing the most fitted model

   $$UCBR = 42.077 - 1.358PI$$

   with $R^2 = 0.658$.

2. Among the multiple non-linear regression analyses, the correlations between UCBR with SL, PL, LL, PI, MDD and OMC yield the most fitted model for CL soils, and it is given by:

   $$UCBR = 268.772 + 15.883SL + 0.001PL - 6.549LL - 0.199MDD - 2.299OMC - 0.691SL^2 - 0.1PL^2 - 0.157LL^2 + 0.175PI^2 + 5 \times 10^{-5} \times MDD^2 + 0.042OMC^2$$

   with $R^2 = 0.934$

3. In the light of the above, a combination of soil index properties correlates better with strength characteristic of CBR than individual soil properties.
4. For preliminary design purposes the above correlation might be used, if the predicted CBR value is within the range of 8% to 35%. Otherwise, a detailed laboratory test should be carried out to obtain the actual CBR value.

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