# CORRELATION OF CALIFORNIA BEARING RATIO VALUE OF CLAYS WITH SOIL INDEX AND COMPACTION CHARACTERISTICS

**Aderinola, Olumuyiwa Samson[1], Oguntoyinbo, Emmanuel[2], Quadri Ajibola Ibrahim[3]**

**[1]osaderinola@yahoo.com, [3]aiquadri@futa.edu.ng**

*Civil Engineering Department, Federal University of Technology Akure, Ondo State, Nigeria P.M.B 704*

***Abstract***

*The unique nature of soil properties as it appears naturally is that it is divergent spatially and seasonally beyond the designer's control. Geotechnical engineers usually attempt to develop empirical equations specific to a certain region and soil type. However, these empirical equations are more reliable for the type of soil where the correlation is origin. As a result, this study attempted to find the correlation between CBR values with soil index properties specific to clay subgrade soils. The study has examined the feasibility of single linear regression analysis and multiple non-linear regression analysis in correlating 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 entailed a moderate determination coefficient of $R^2$ = 0.933using single regression analysis, while multiple regression analysis generated relatively an improved correlation of $R^2$ = 0.959 for CH soils. After validating the developed correlation with control test results, it was noted that the correlation of CBR value with soil index properties is more applicable for characterizing the strength of subgrade soils.*

**Keywords:** *UCBR, regression models, plasticity index, optimum moisture content and maximum dry density, coefficient of correlation, fat clays (CH soils).*

## 1.0 Introduction

Road is necessary for transportation and economic development of a nation. Most of the road networks in a country consist of flexible pavement. Flexible pavement consists of different layers such as sub-grade, sub-base, base course and surface layer. Sub-grade is the formation layer. Design and performance of flexible pavementmainly depends on thestrength of sub-grade material. Theload from the pavement surface is ultimately transferred from the sub-base to thesub-grade. The sub-grade is designedsuch that the stress transferred should not exceed elasticlimit. Hence, the suitability and stability of sub-grademateriasl are evaluated before construction of pavement.Soaked California bearing ratio (CBR) value (in %) isconsidered as strength parameter in design of sub-grade (Rakaraddi and Gomarsi, 2015).

To obtain soaked CBR value of a soil sample, it takes about a week, making CBR test expensive, time consuming and laborious. 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 optimal construction. This could be avoided only if a large number of soil samples 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 correlate 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, 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. This study is using statistical software (XLSTAT) to predict the CBR value from the index properties of clay soil.

## 2.0 Methodology

### 2.1 Simple Relation

To establish relation between unsoaked CBR and different soil properties, graphs are plotted with CBR against different soil parameters and suitable trend line is 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 predictable outcome by the model. Any correlation with $R^2$ value more than 0.80 will be viewed as a best fit.

### 2.2 Multiple Polynomial Regression Analysis

To develop the models of multiple linear regression analysis, the unsoaked CBR value is considered as dependent variable andsoil properties such as SL, LL,PL, PI, MDD and OMC are considered as the independentvariables. MPRA is to be carried out using the statistical software XLSTAT, an add-in for Microsoft Excel in order to derive the relationshipstatistically.

### 2.3 Materials

Different samples test results were collected for fat clay (CH soils) from various locations of 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).

## 3.0 Results and Dicussion

The results obtained for the CH soil tests are exclusively given in Table 1.

**Table 1: Test Results for the Properties of CH soil samples**

| SAMPLE | TYPE | SL (%) | PL (%) | LL (%) | PI (%) | MDD (kg/m$^3$) | OMC (%) | UCBR (%) |
|---|---|---|---|---|---|---|---|---|
| 1 | CH | 7.7 | 22.2 | 64.5 | 42.30 | 1399 | 30.6 | 10 |
| 2 | CH | 7.7 | 21.9 | 66.3 | 44.45 | 1364 | 31.6 | 9 |
| 3 | CH | 7.2 | 22.2 | 68.2 | 46.05 | 1329 | 32.6 | 8 |
| 4 | CH | 8.2 | 22.5 | 57.9 | 35.40 | 1494 | 27.8 | 14 |
| 5 | CH | 8.7 | 23.1 | 54.1 | 31.00 | 1532 | 26.7 | 15 |
| 6 | CH | 8.2 | 22.3 | 62.0 | 39.75 | 1420 | 29.6 | 10 |
| 7 | CH | 8.7 | 21.3 | 55.9 | 34.60 | 1497 | 27.7 | 12 |
| 8 | CH | 8.7 | 22.2 | 62.7 | 40.55 | 1430 | 29.6 | 11 |
| 9 | CH | 8.3 | 23.1 | 58.2 | 35.10 | 1469 | 28.5 | 12 |
| 10 | CH | 8.2 | 21.2 | 59.6 | 38.45 | 1395 | 30.7 | 9 |
| 11 | CH | 7.7 | 21.4 | 64.3 | 42.90 | 1398 | 30.9 | 10 |
| 12 | CH | 8.7 | 23.2 | 58.3 | 35.15 | 1427 | 29.7 | 10 |
| 13 | CH | 9.1 | 22.9 | 56.2 | 33.30 | 1494 | 27.8 | 13 |
| 14 | CH | 2.5 | 24.9 | 61.2 | 36.35 | 1325 | 32.7 | 8 |
| 15 | CH | 8.7 | 23.1 | 51.8 | 28.75 | 1529 | 26.8 | 13 |
| 16 | CH | 8.2 | 23.1 | 50.8 | 27.70 | 1546 | 26.3 | 14 |
| 17 | CH | 7.7 | 28.2 | 62.2 | 34.05 | 1756 | 20.2 | 20 |
| 18 | CH | 12.0 | 42.8 | 61.4 | 18.60 | 2072 | 11.1 | 34 |
| 19 | CH | 7.7 | 24.6 | 53.4 | 28.85 | 1549 | 27.0 | 12 |
| 20 | CH | 7.7 | 26.3 | 50.4 | 24.10 | 1532 | 27.5 | 8 |
| 21 | CH | 7.7 | 26.6 | 53.8 | 27.25 | 1572 | 26.3 | 14 |
| 22 | CH | 5.8 | 24.7 | 62.4 | 37.70 | 1360 | 31.4 | 7 |
| 23 | CH | 5.8 | 25.2 | 66.3 | 41.14 | 1310 | 33.4 | 5 |
| 24 | CH | 5.8 | 24.1 | 64.0 | 39.90 | 1465 | 32.4 | 7 |
| 25 | CH | 5.8 | 24.3 | 63.4 | 39.10 | 1380 | 31.7 | 7 |
| 26 | CH | 6.8 | 24.8 | 58.3 | 33.50 | 1492 | 27.3 | 8 |
| 27 | CH | 7.7 | 24.0 | 50.8 | 26.80 | 1627 | 22.7 | 19 |
| 28 | CH | 6.8 | 23.3 | 52.8 | 29.50 | 1616 | 23.0 | 19 |
| 29 | CH | 7.2 | 21.9 | 54.5 | 32.65 | 1601 | 23.4 | 19 |
| 30 | CH | 7.2 | 21.4 | 53.3 | 31.90 | 1612 | 23.1 | 19 |
| 31 | CH | 7.7 | 24.4 | 50.8 | 26.45 | 1664 | 21.6 | 21 |
| 32 | CH | 7.2 | 20.2 | 53.5 | 33.30 | 1612 | 23.1 | 18 |
| 33 | CH | 7.2 | 20.4 | 52.7 | 32.30 | 1649 | 22.1 | 21 |
| 34 | CH | 7.7 | 25.8 | 50.8 | 25.00 | 1671 | 21.4 | 21 |
| 35 | CH | 7.7 | 22.2 | 64.5 | 42.30 | 1399 | 30.6 | 10 |
| 36 | CH | 7.1 | 21.9 | 66.3 | 44.45 | 1364 | 31.6 | 8 |
| 37 | CH | 7.2 | 22.4 | 68.4 | 46.05 | 1329 | 32.6 | 8 |
| 38 | CH | 8.2 | 22.5 | 57.9 | 35.40 | 1494 | 27.8 | 13 |

| SAMPLE | TYPE | SL (%) | PL (%) | LL (%) | PI (%) | MDD ($kg/m^3$) | OMC (%) | UCBR (%) |
|---|---|---|---|---|---|---|---|---|
| 39 | CH | 8.7 | 23.1 | 54.1 | 31.00 | 1532 | 26.7 | 15 |
| 40 | CH | 8.2 | 22.3 | 62.0 | 39.75 | 1450 | 29.6 | 12 |
| 41 | CH | 8.7 | 21.3 | 55.9 | 34.60 | 1497 | 27.7 | 13 |
| 42 | CH | 8.7 | 22.2 | 62.7 | 40.55 | 1430 | 29.6 | 10 |
| 43 | CH | 8.7 | 23.1 | 58.2 | 35.10 | 1469 | 28.5 | 12 |
| 44 | CH | 8.2 | 21.2 | 59.6 | 38.45 | 1395 | 30.7 | 10 |
| 45 | CH | 7.7 | 21.4 | 64.3 | 42.90 | 1388 | 30.9 | 9 |
| 46 | CH | 8.7 | 23.2 | 58.3 | 35.15 | 1427 | 29.7 | 11 |
| 47 | CH | 9.1 | 22.9 | 56.2 | 33.30 | 1494 | 27.8 | 12 |
| 48 | CH | 8.2 | 22.3 | 62.0 | 39.75 | 1420 | 29.9 | 9 |
| 49 | CH | 7.7 | 24.3 | 52.4 | 28.15 | 1543 | 23.7 | 17 |
| 50 | CH | 7.7 | 24.6 | 53.4 | 28.85 | 1519 | 24.3 | 17 |
| 51 | CH | 7.7 | 25.2 | 54.2 | 29.05 | 1460 | 25.8 | 16 |
| 52 | CH | 7.7 | 26.3 | 50.4 | 24.10 | 1399 | 26.7 | 15 |
| 53 | CH | 7.7 | 26.6 | 52.4 | 25.80 | 1322 | 28.6 | 13 |
| 54 | CH | 7.7 | 26.6 | 53.8 | 27.25 | 1479 | 24.7 | 17 |
| 55 | CH | 7.7 | 26.6 | 52.5 | 25.90 | 1575 | 22.3 | 18 |

## 3.1 Simple Linear Regression Analysis

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 as shown in equation (1)

$$UCBR = - 0.871 + 1.803SL \quad (1)$$

with $R^2 = 0.183$.

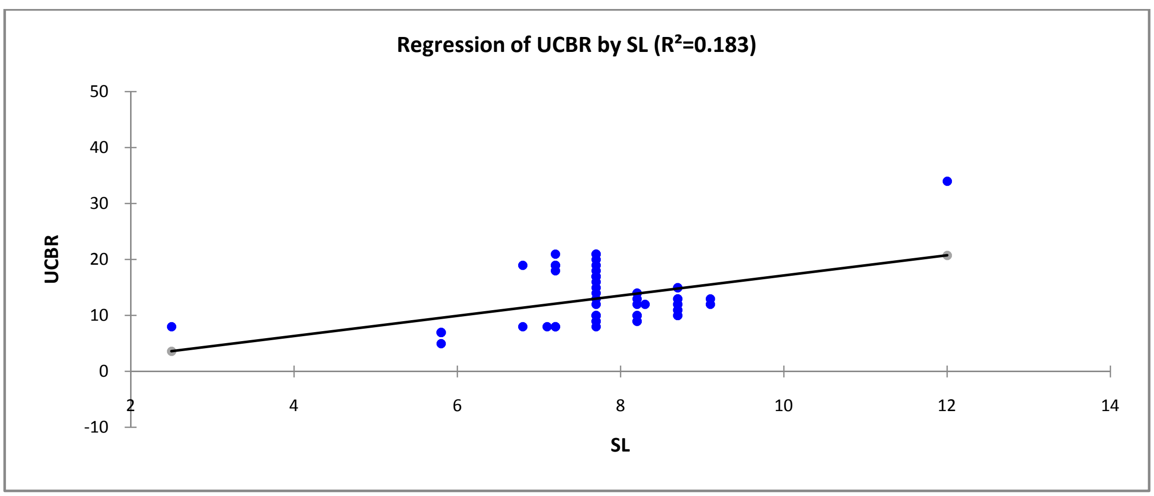


**Figure 1:** Scatter Plot and Regression Line for UCBR versusSL.

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

$$UCBR = -7.526 + 0.871PL \quad (2)$$

with $R^2 = 0.294$.

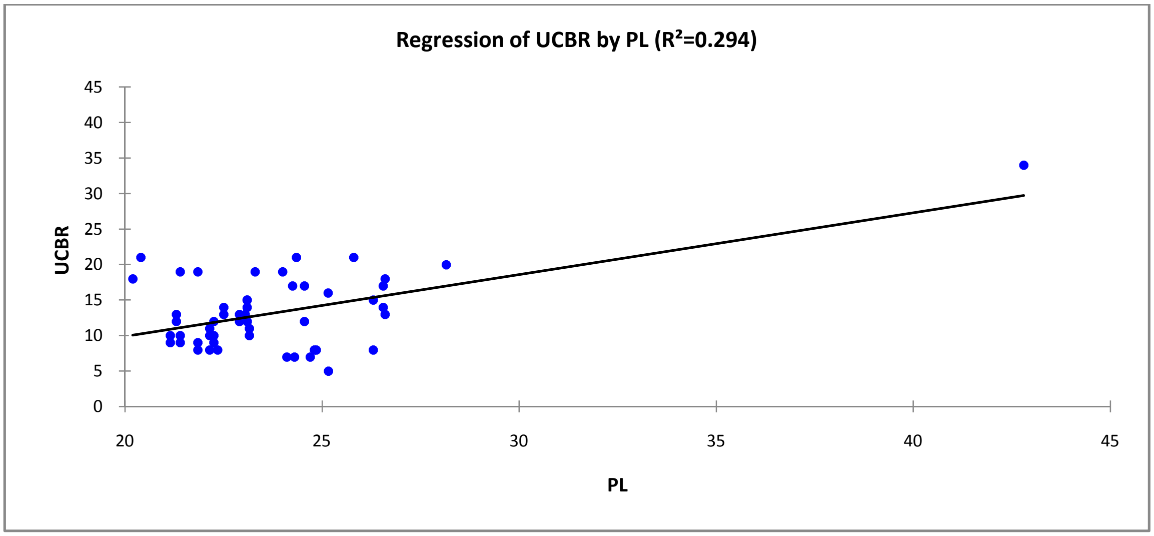


Figure 2: Scatter Plot and Regression Line forUCBRversus PL.

The variation between unsoaked CBR and Liquid limit is shown in Figure 3 and equation (3) presents their suitable relationship

$$UCBR = 44.012 - 0.533LL \quad (3)$$

with $R^2 = 0.304$.

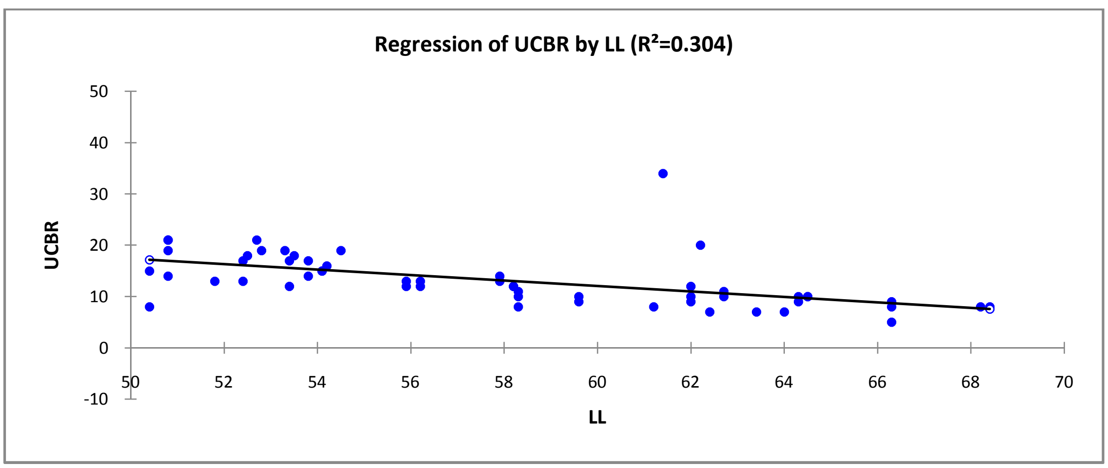


Figure 3: Scatter Plot and Regression Line forUCBRversus LL.

The variation between unsoaked CBR and Plasticity Index is shown in Figure 4 and the suitable trend line is presented in equation (4)

$$UCBR = 32.638 - 0.570PI \quad (4)$$

with $R^2 = 0.517$.

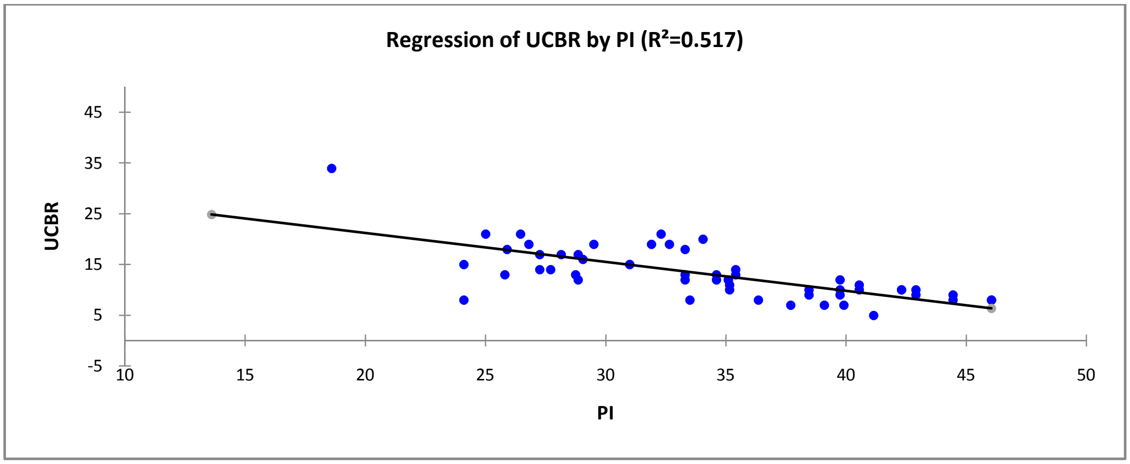


Figure 4: Scatter Plot and Regression Line forUCBRversus PI.

The variation between unsoaked CBR and Maximum Dry Density is shown in Figure 5 and the suitable trend line is presented in equation (5)

$$CBR = -39.906 + 0.036MDD \quad (5)$$

with $R^2 = 0.805$.

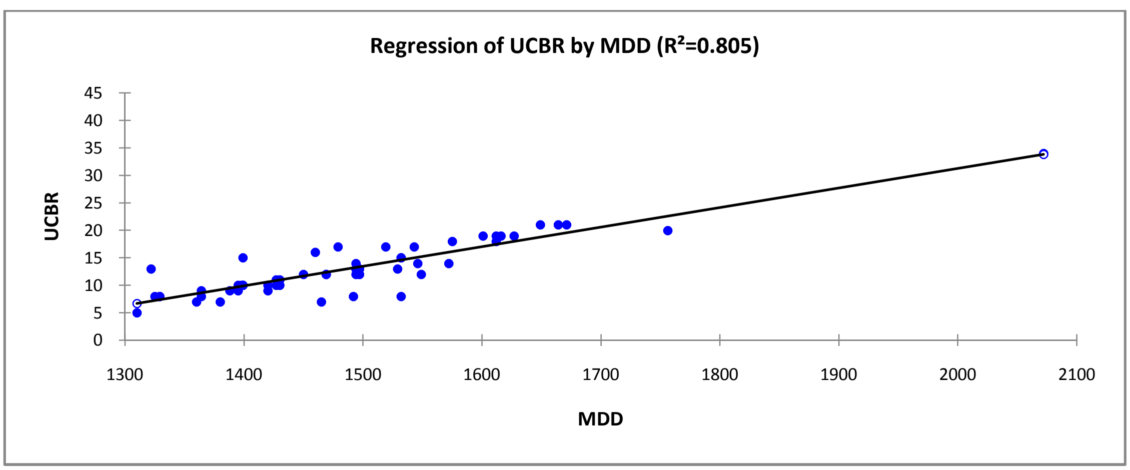


Figure 5: Scatter Plot and Regression Line forUCBRversus MDD.

The variation between unsoaked CBR and Optimum Moisture Content is shown in Figure 6 and the suitable trend line is presented in equation (6)

$$CBR = 46.396 - 1.214OMC \quad (6)$$

with $R^2 = 0.933$.

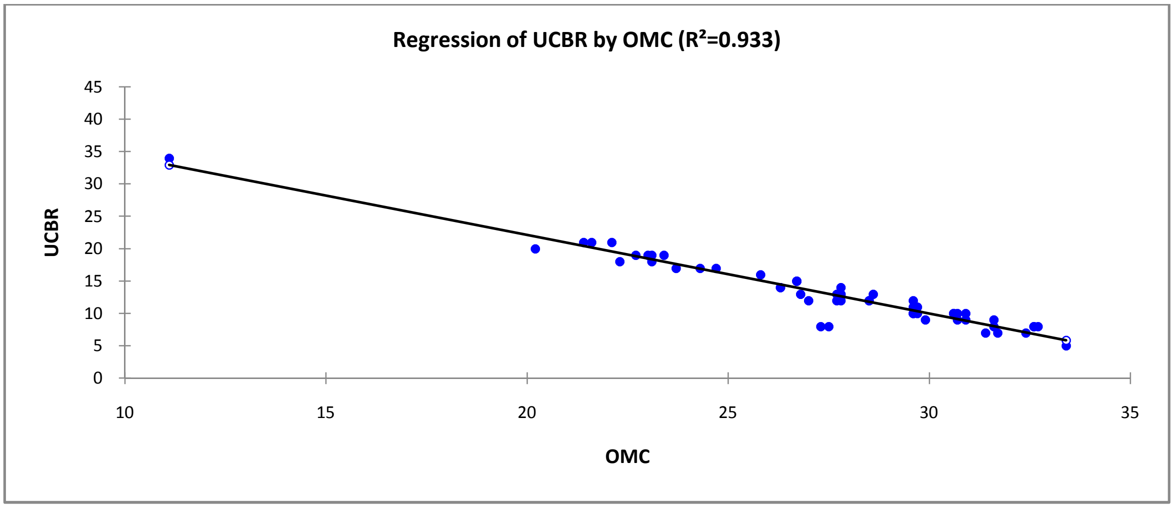


Figure 6: Scatter Plot and Regression Line forUCBRversus OMC.

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

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

| Regression Type | Correlation of UCBR with | R | $R^2$ |
|---|---|---|---|
| Single Linear Regression Analysis | SL | 0.428 | 0.183 |
| | PL | 0.542 | 0.294 |
| | LL | 0.304 | 0.304 |
| | PI | -0.719 | 0.517 |
| | MDD | 0.897 | 0.805 |
| | OMC | -0.966 | 0.932 |

### 3.2 Multiple Polynomial Regression Analysis

By correlating unsoaked CBR with SL and OMC, the mathematical equation generated isgiven as

$$UCBR = 48.726 - 0.465SL - 1.347OMC + 0.041SL^2 + 0.003OMC^2 \quad (7)$$

With $R^2 = 0.936$

Figure 7 is plotted with respect to laboratory UCBR value obtained for different CH soil samples used for validation and predicted UCBR value (obtained fromequation-1)

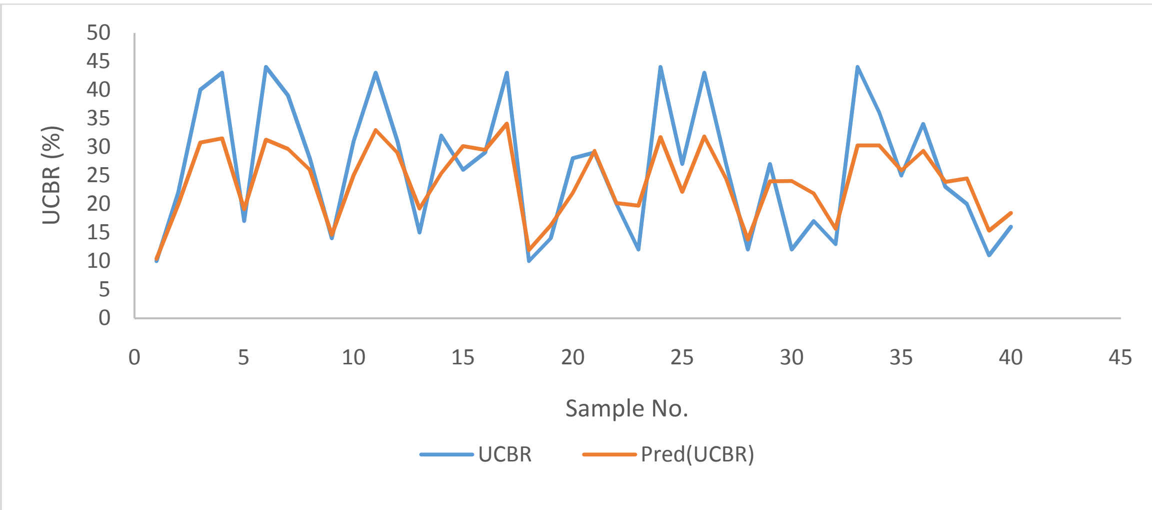


**Figure 7: Predicted UCBR of Equation 1 and Laboratory UCBR**

By correlating unsoaked CBR with PI and OMC, the mathematical equation generated isgiven as.

$$UCBR = 50.013 - 0.113PI - 1.357OMC + 0.003PI^2 + 0.001OMC^2 \quad (8)$$

With $R^2 = 0.938$.

Figure 8 is plotted with respect to laboratory UCBR value obtained for different CH soil samples used for validation and predicted UCBR value (obtained fromequation-2).

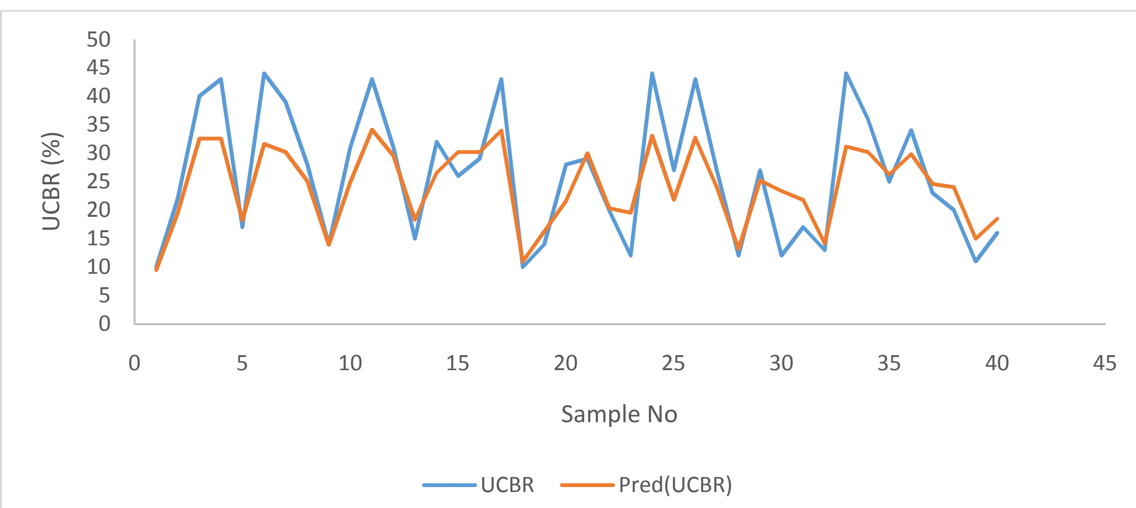


**Figure 8: Predicted UCBR of Equation 2 and Laboratory UCBR**

By correlating unsoaked CBR with MDD and OMC, the mathematical equation generated isgiven as.

$$UCBR = 63.575 + 0.018MDD - 2.7270MC - 9.113 \times 10^{-6}MDD^2 + 0.0240MC^2 \quad (9)$$

With $R^2 = 0.940$.

Figure 9 is plotted with respect to laboratory UCBR value obtained for different CH soil samples used for validation and predicted UCBR value (obtained fromequation-3).

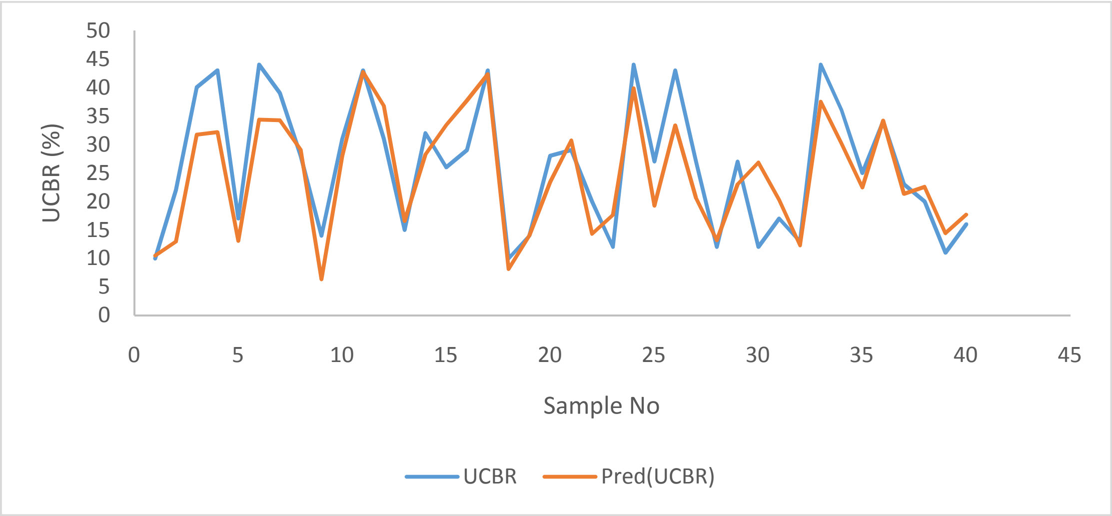


**Figure 9:** Predicted UCBR of Equation 3 and Laboratory UCBR

By correlating unsoaked CBR with PL and OMC, the mathematical equation generated isgiven as.

$$UCBR = 69.561 - 0.423PL - 2.3280MC + 0.003PL^2 + 0.0200MC^2 \quad (10)$$

With $R^2 = 0.944$.

Figure 10 is plotted with respect to laboratory UCBR value obtained for different CH soil samples used for validation and predicted UCBR value (obtained fromequation-4).

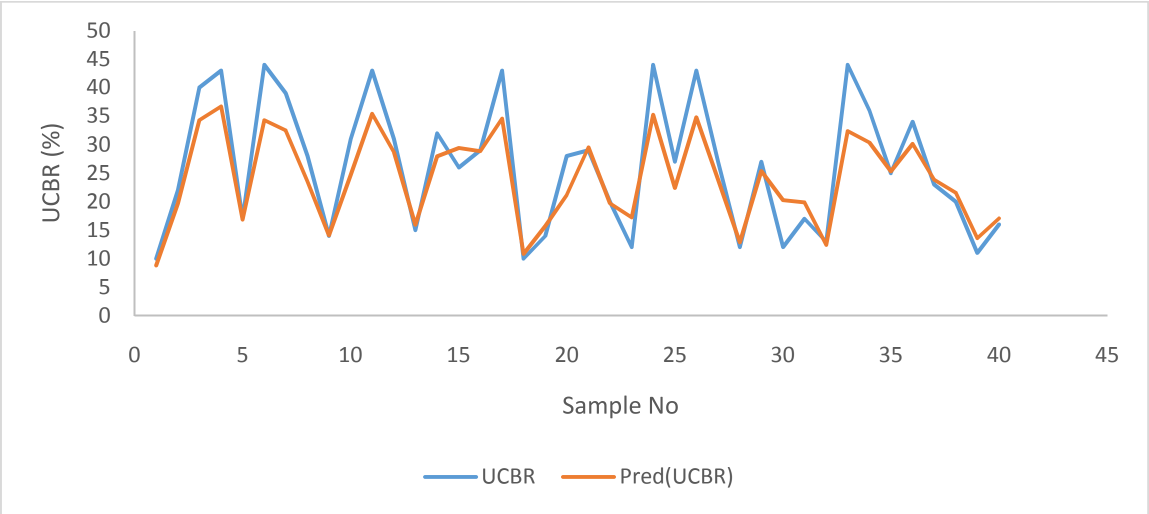


**Figure 10: Predicted UCBR of Equation 4 and Laboratory UCBR**

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

$$UCBR = 102.311 - 1.451SL + 2.181PL + 0.916LL - 0.064MDD - 4.069OMC + 0.128SL^2 - 0.038PL^2 - 0.015LL^2 + 0.011PI^2 + 1.722 \times 10^{-5} \times MDD^2 + 0.047OMC^2 \quad (11)$$

With $R^2 = 0.959$.

Figure 11 is plotted with respect to laboratory UCBR value obtained for different CH soil samples used for validation and predicted UCBR value (obtained fromequation-5).

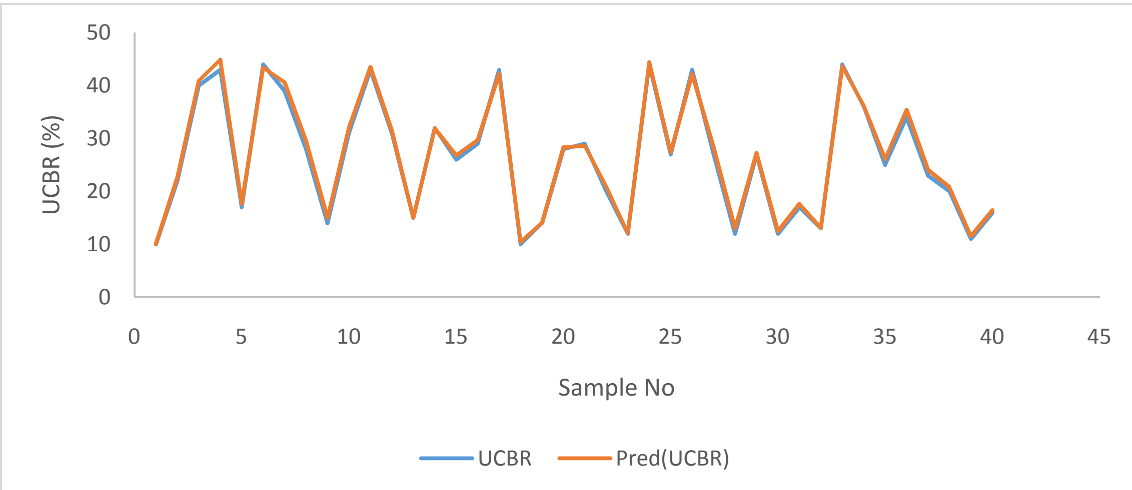


**Figure 11: Predicted UCBR of Model B5 and Laboratory UCBR**

## 4.0 Conclusion

Based on above test results and discussions, the following conclusions may be made:

1. among the single linear regression analyses, the UCBR can be predicted from OMC using the most fitted model as given in equation (6)
2. relatively an improved correlation than the single linear regression is obtained when multiple polynomial regression is used. 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 CH soils, as presented in equation (11).
3. in 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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