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Development of Empirical Models for The Estimation of CBR value of soil from their Index Properties. A case study of the Ogbia – Nembe Road in Niger Delta Region of Nigeria

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ABSTRACT

This paper developed linear, quadratic and multiple regression models to predict the soil index properties in Ogbia-Nembe road in the Niger Delta region of Nigeria. The soil index properties in Ogbia-Nembe road were modelled with the California Bearing ratio as the dependent variable. Thirteen models were developed to understand the relationship between these soil index properties: the independent variable and the California Bearing Ratio (CBR): the dependent variable; Six linear, Six quadratic and One multiple linear regression models were developed for this relationship. However, result from the Analysis of variance (ANOVA) showed that the Plastic Limit (PL), the Liquid Limit (LL), the Plasticity Index (PI) and the Moisture Content (MC) are not statistically significant predictor variable to evaluate the CBR value for Ogbia-Nembe Soil which is predominantly a mixture of inorganic clay of low plasticity and organic clay/inorganic soil of high compressibility based on unified soil classification system. Results of the ANOVA further showed that the Optimum Moisture Content (OMC) and the Maximum Dry Density (MDD) are better independent variables for the prediction of the CBR value of Ogbia-Nembe soil. Hence, the empirical models: **CBR = -69.89 + 54.944*MDD; CBR = 38.676 – 1.386 * OMC; CBR = -820.11 + 926.06MDD – 252.49MDD^2; CBR = 30.948 + 0.1570MC – 0.0718*OMC^2** and **CBR = 52.16 – 6.927*MDD-1.542*OMC**. These five acceptable regression model comprising of 2 linear model, 2 quadratic model and 1 multiple linear regression model having a coefficient of determination R^2 = 0.82, 0.93, 0.89, 0.96 and 0.94 respectively. These models can be used to predict the CBR of any given soil with relative similar soil index property.
The CBR values predicted by the model were further compared with those of the actual experimental test and found to relatively consistent with minimal variance.

Keywords: Linear model, Quadratic model, multiple regression model, soil index properties, Analysis of Variance, California Bearing Ratio, Coefficient of determination

Introduction

Every Engineering works, both horizontal and vertical construction requires the investigation of the soils carrying capacity which is aimed at determining the sustainability of such soil for the purpose of taking the resultant load resulting from such construction and the service load at use. This is important as the functionality of such structure has a direct relationship with the soil upon which it is situated. The weaker the soil, the more tendency for structures erected on it to become weak and collapse, while the stable the soil is, the stronger and less tendency for the structure erected on it not to get weak and collapse. More so, construction cost will also depend on the stability of the soil as more work may need to be done on improving the quality of a weak soil for sustainability for any meaningful Engineering works. Surrounded by these uncertainties and the fact that soil conditions vary from one location to another and from one point to another even within a given vast expanse becomes an issue of concern. To solve this concern, Investigation must be carried out on the condition of the soil on every site at intervals to determine the soil condition for proper engineering design and construction.

The Niger Delta Region is characterized with unstable soil conditions which vary in strength and other physical characteristics. Engineering works executed within this region must be properly planned and adequate information on the supporting soil done to avoid failures. One of the determinant investigative study required of every soil for the purpose of engineering works is the determination of the California Bearing Ratio (CBR). It is a measure of the strength of the soil material which is usually used as the foundation layer (subgrade) of every horizontal Engineering construction such as Road construction or the vertical Engineering construction such as sky scrapers. The determination of this CBR value of a soil requires an empirical method of design which involves the collection of the soil sample and subjecting it to pressure to achieve penetration using a pluger of standard area which is compared with an equal pressure required to achieve equal penetration on a standard crusted rock method. The value of the CBR of a soil determines various design parameters of the structure coming on the soil. For a road pavement, a lower CBR will inform the choice of an increased subgrade thickness while for structures like building, soil with low CBR will require increasing the foundation depth respectively to balance the loading on the soil.

CBR is a laborious and expensive test that requires collection of soil sample at locations along the site of investigation at pre-defined intervals. The collected sample will form a representation of the soil along the area or extent of the construction. The collected sample are remodeled at predetermined optimum moisture content and maximum dry density with standard proctor compaction for the purpose of the test. This test is usually conducted for both the soaked and unsoaked condition, making the determination of CBR of a soil a time dependent empirical analysis requiring time and resources. The expensive and time consuming constraints of CBR test that can be conducted within a given construction area with this constrain, the limited CBR test results may not accurately reflect the variation and distribution pattern of the soil strength over a large construction area. Trying to contend this will involve increasing the number of trial points which will result to cost overrun and increase project duration.

To overcome the cost overrun and project schedule constrain associated with increased trial point sampling and conduct of CBR test for all the trial point samples, a statistical model has been developed in this study to correlate the CBR value of a soil with other physical properties of soils that does not require laborious testing technique. Their physical properties will include Plasticity Limit (PL), Liquidity Limit (LL), Plasticity Index (PI), Maximum Dry Density (MDD) and Optimum Moisture Content (OMC) and the soil samples.

METHODOLOGY

The Ogbia – Nembe Road was delineated and disturbed Soil samples collected from twenty trial pits along the alignment at predetermined chainages using soil hand ulger at varying depth but not exceeding 1.3m depth. The collected soil samples from each of the twenty pits were subjected to Laboratory test for CBR value and other physical properties which included Plastic Limit, Liquid limit, Plasticity Index, Optimum Moisture Content, Maximum Dry Density, Particle size distribution in accordance to BS 1377 (1990) : Methods of Testing for soils for Civil Engineering Purposes. XLSTAT was used to perform basic calculations, data analysis, create tables and figures.

RESULTS

Results of the various physical properties of the soils collected from each of the twenty trial points is tabulated in Table 1. They include the Index properties: Plastic Limit, Liquid Limits, Plasticity Index and Specific Gravity; compaction characteristics – Maximum dry density, optimum moisture content, particle size distribution and California bearing ratio obtained at optimum moisture content.

The result from Table 1 showed that the plastic limit for the soil samples on East-West Road ranged from 12.37 to 37.00% with a mean plastic limit of 27.4%. The liquid limit for the soil samples ranged from 22.00 to 63.00% with a mean liquid limit of 49.80%. The plasticity index of the soil samples ranged from 9.00 to 30.00 with a mean plasticity index of 22.7%.

The very high liquid limit and moderately high plasticity index give indication that the soil is highly plastic. For the moisture content of the soil samples, the moisture content ranged from 13.20 to 52.20% with a mean moisture content of 21.40%. The specific gravity of the soil samples ranged from 2.53 to 2.63 with a mean specific gravity of 2.6 and the maximum dry density ranged from 1.60 to 1.84 g/cm^3 with a mean maximum dry density of 1.71 g/cm^3. The optimum moisture content of the soil samples ranged from 6.3 to 16.20% with a mean optimum moisture content of 10.42%.

Table 1: Results of the various physical properties of the soil collected on East-West Road

Geotechnical Investigation Result on Ogbia -Nembe Road									
Point	SEC. DIV.	Atterberg Limit			Moisture Content %	Specific Gravity.	Standard Compaction		California Bearing Ratio (CBR) (%)
									CBR Soaked
		Plastic Limit (%)	Liquidity Limit (%)	Plasticity Index			Maximum Dry Density (g/cm^3)	Optimum Moisture Content (OMC) %	CBR Value (%)
1	A	29	54	25	17.00	2.63	1.84	6.30	30.4
2		12	22	10	15.00	2.62	1.79	6.30	27.1
3		33	55	20	16.80	2.60	1.68	10.30	25.1
4		11	22	9	19.40	2.62	1.80	8.00	27.4
5	B	37	63	26	15.20	2.61	1.71	10.20	26.1
6		32	62	30	29.80	2.6	1.68	12.10	22.4
7		25	46	21	13.20	2.63	1.82	6.30	30.2
8		26	46	20	15.10	2.62	1.77	8.10	27.1
9	C	26	52	26	20.60	2.61	1.72	10.00	26.2
10		30	56	26	14.10	2.61	1.73	8.30	26.3
11		32	62	30	23.30	2.61	1.69	10.10	25.3
12		29	49	20	20.00	2.59	1.67	12.00	22.1
13	D	34	60	26	14.70	2.62	1.79	8.10	27.1
14		32	63	31	16.30	2.61	1.70	10.10	26
15		30	58	28	19.20	2.58	1.66	12.20	22.1
16		24	40	16	22.10	2.59	1.67	12.20	22.4
17	E	25	45	20	19.20	2.58	1.66	14.30	18.1
18		28	41	23	18.50	2.53	1.60	16.20	15.1
19		30	54	24	52.20	2.55	1.62	14.70	17.7
20		23	46	23	46.20	2.56	1.66	12.60	20.4

Table 2: Soil Index properties for sample soil collected on Ogbia-Nembe road

Statistics	P.L (%)	L.L (%)	PI (%)	M.C (%)	S.G	M.D.D (%)	O.M.C (%)
mean	27.40	49.80	22.70	21.40	2.60	1.71	10.42
median	29.00	53.00	23.50	18.85	2.61	1.70	10.15
std	6.52	11.94	5.98	10.30	0.03	0.07	2.86
min	11.00	22.00	9.00	13.20	2.53	1.60	6.30
max	37.00	63.00	31.00	52.20	2.63	1.84	16.20
skew	-1.37	-1.18	-0.91	2.29	-1.18	0.40	0.25
count	20.00	20.00	20.00	20.00	20.00	20.00	20.00

Classification based on the Unified Soil Classification System (USCS)

The result of the classification of soil samples collected from Ogbia-Nembe roads is shown in Figure 1. The result from Figure 1 showed that eleven soil samples had a liquid limit greater than or equal to 50%. It also showed that three soil samples were inorganic clay of high plasticity (fat clay), eight soil samples were inorganic clay of very low to medium plasticity (lean clay), eight soil samples were either organic clay of high plasticity or inorganic silt of high compressibility, and two soil samples were inorganic silt of very low to medium compressibility or organic silt of low compressibility. Figure 2 showed that 40% of the total soil samples were inorganic clays with very low to medium plasticity and 40% of the total soil samples collected on Ogbia-Nembe road were either inorganic silt with high compressibility or organic clay with high plasticity. The result from the classification of the soil on Ogbia-Nembe road revealed that the subgrade soil existing is predominately either organic clay or lean clay.

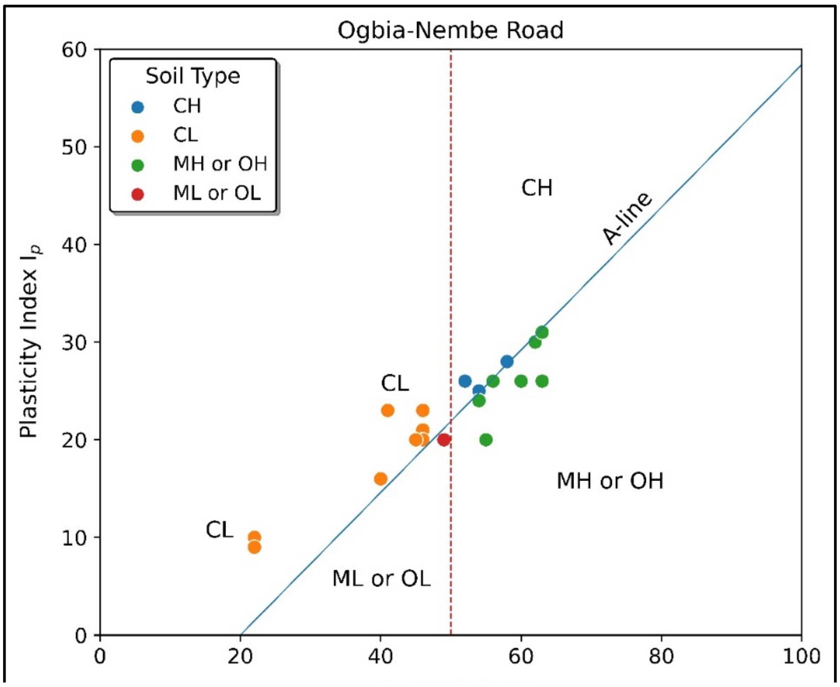

Figure 1: Soil classification of the flexible section of Ogbia-Nembe road

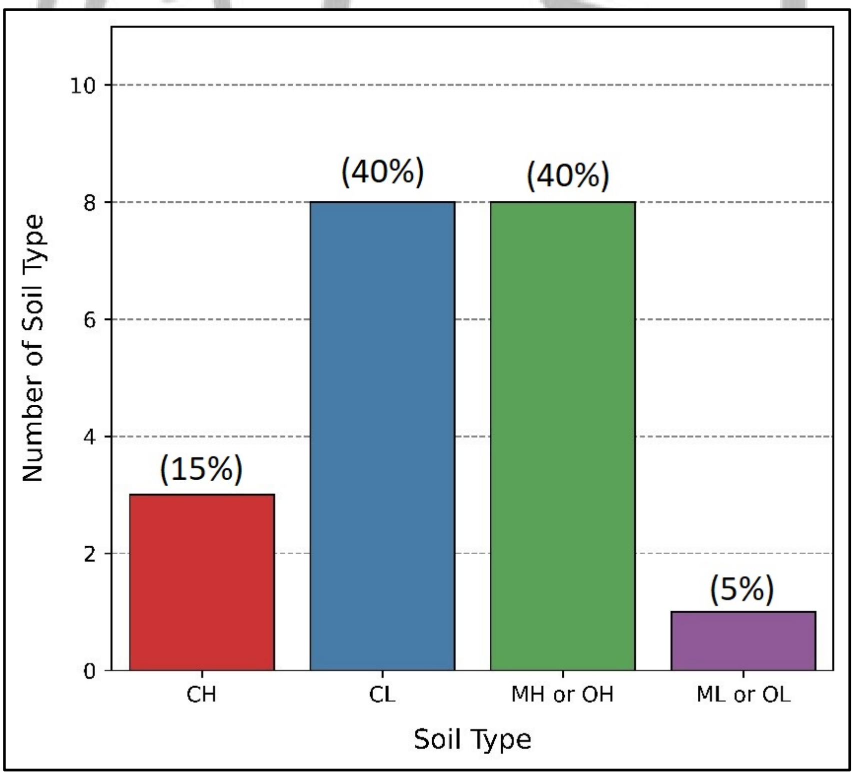

Figure 2: Number of soil types on Ogbia-Nembe Road

Classification based on American Association of State Highway and Transportation Officials AASHTO

Figure 3 present the classification of soil samples collected on the Ogbia-Nembe road based on AASHTO method. The result from Figure 3 showed that two soil samples fell into the A-4 or A-2-4 class, one soil sample fell into A-2-6 or A-6 class, six soil samples fell into A-2-7 or A-7-5 class, and eleven soil samples fell into A-7-6 class. The result further revealed that the soil samples collected on Ogbia-Nembe road were predominately A-7-6 class soil. Based on AASHTO soil classification, subgrade soil that falls into the soil class A-7-6 would generally have fair to poor strength, therefore it is expected that the subgrade strength for Ogbia-Nembe to be weak.

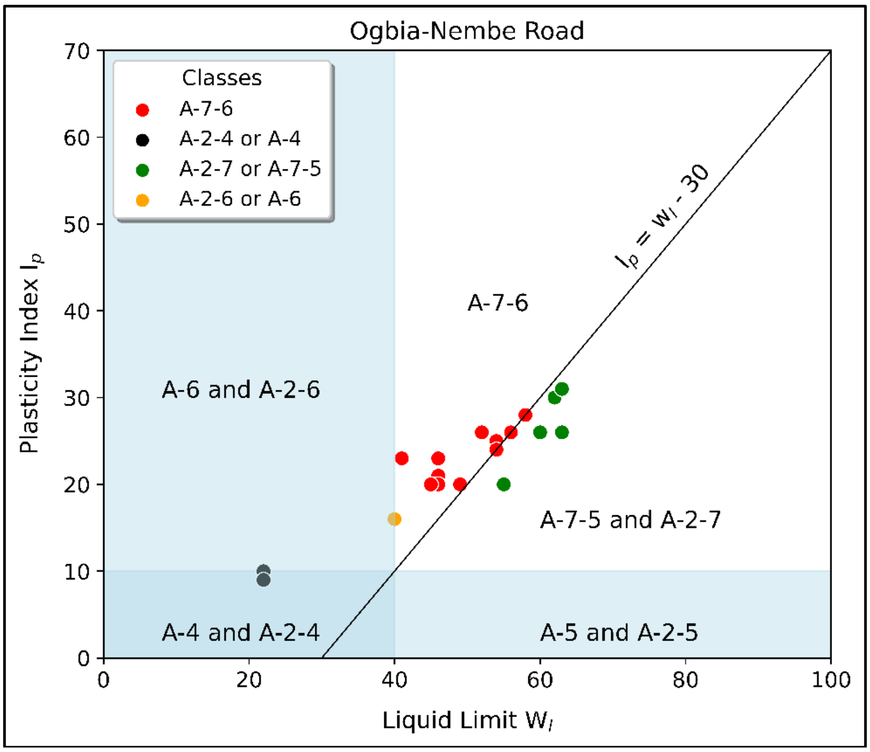

Figure 3: AASHTO Soil classification of the flexible section of Ogbia-Nembe Road

Table 3: Number of soil type based on AASHTO soil classification

Group Classification	Ogbia-Nembe Road	General Rating of Subgrade
A-4	2	Fair to poor
A-6	1	Fair to poor
A-7-5	6	Fair to poor
A-7-6	11	Fair to poor

No. of soil samples = 20

California Bearing Ratio of the Subgrade Soils

The result after testing of the California Bearing Ratio for the subgrade for Ogbia-Nembe roads in the Niger Delta region is presented in Table 4. The CBR for the 20 sample points tested on Ogbia-Nembe road ranged from 15.1 to 30.4%, with the mean CBR for the 20 sample points to be 24.23±4.10%.

Table 4: CBR statistics of the selected section of the East-West road

Statistics	Ogbia-Nembe
mean	24.23
median	25.65
std	4.10
min	15.1
max	30.4
skew	-0.66
count	20

Pearson R correlation between the California Bearing Ratio and soil index Properties

The result of the Pearson correlations between soil index properties and the California Bearing Ratio for the Ogbia-Nembe road is presented in Tables 5 and Figure 4. The result from Table 5 shows the Pearson correlations between soil index properties and CBR of the soil samples collected from Ogbia-Nembe road. Figure 4 showed that the plastic limit had a positive correlation with the liquid limit with Pearson correlation of 0.95, which implies that as the liquid limit of the soil increase positively linearly so does the plastic limit of the soil increase. The correlation between the plastic limit and liquid limit was significant at a level of significance of 5%. Also, both plastic and liquid limit were positively correlated with the plasticity index of the soil. The Pearson Correlation between the plastic limit and the plasticity index was 0.84 while the Pearson correlation between the liquid limit and plasticity index was 0.93, and the association between the three variables were significant ($p<0.05$). The moisture content of the soil was positively correlated with the optimum moisture content with Pearson correlation of 0.54, indicating that as the moisture content of the soil increases so does the optimum moisture content. Investigating the linear association of the soil index properties and the CBR, the results showed that the optimum moisture content was strongly negatively correlated with the CBR with Pearson correlation of -0.97, indicating very strong negative association between the two variables. The result implies that as the optimum moisture content of the soil increase it result to a corresponding decrease in the CBR and vice versa. The result also showed that the maximum dry density had a positive association with the CBR with Pearson correlation of 0.91, indicating that an increase in the maximum dry density would result to a increase in the CBR and vice versa. The result also showed that the moisture content of the soil was negatively correlated with the CBR with Pearson correlation of -0.55 indicating that an increase in the moisture content will decrease the CBR and vice versa.

Table 5: Pearson R relationship between California Bearing Ratio and soil index Properties in Ogbia-Nembe road

Variables	P.L (%)	L.L (%)	PI (%)	M.C (%)	S.G	M.D.D (%)	O.M.C (%)	CBR (%)
P.L (%)	**1.00**							
L.L (%)	**0.95**	**1.00**						
PI (%)	**0.84**	**0.93**	**1.00**					
M.C (%)	-0.01	0.07	0.12	**1.00**				
S.G	-0.10	0.02	-0.10	**-0.61**	**1.00**			
M.D.D (%)	-0.33	-0.24	-0.29	**-0.51**	**0.88**	**1.00**		
O.M.C (%)	0.25	0.15	0.22	**0.54**	**-0.92**	**-0.95**	**1.00**	
CBR (%)	-0.10	0.01	-0.08	**-0.55**	**0.96**	**0.91**	**-0.97**	**1.00**

Values in bold are different from 0 with a significance level alpha=0.05

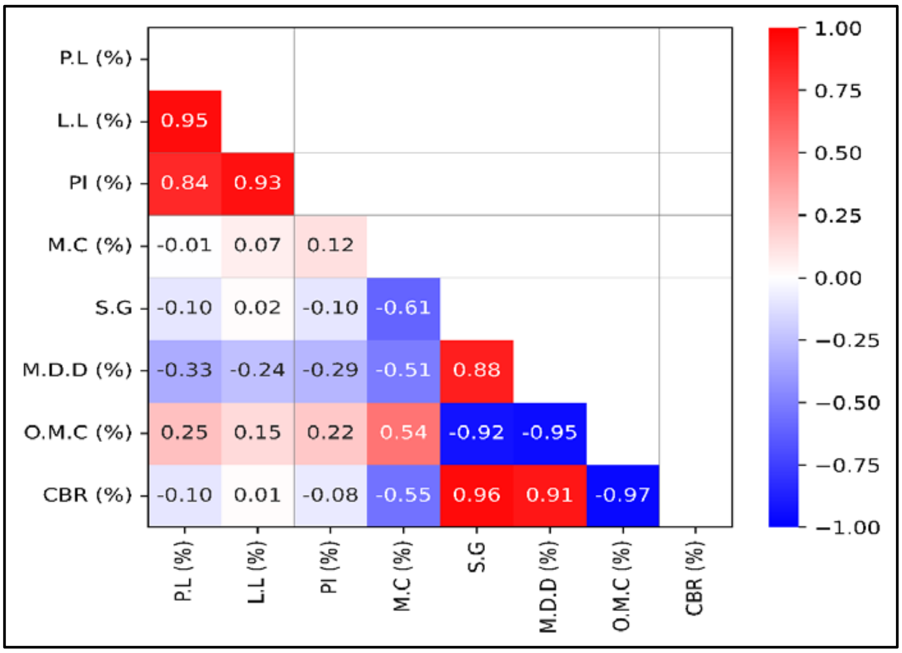

Figure 4: Heatmap showing the Pearson Correlation between soil index properties and CBR for Ogbia-Nembe soil samples

Modeling the Relationship between the California Bearing Ratio and the index properties of the soil

The modeling was done in other to reduce the cost of conducting CBR experiment which is expensive to carry out and requires at least 4days to conduct. The models developed will enable prediction of the CBR of any given soil with relatively similar soil index properties. Thirteen models were developed to understand the relationship between the soil index properties and CBR and also to investigate if the model would be a good predictor of the CBR value of the subgrade. Six linear models, six quadratic model and one multiple linear regression model were developed relating the variables.

Model 1: **Sample Linear Regression Model** **(y = a_o + a_1x)**

Model 1 is a simple linear regression model generating the linear model equations (Model No. 1- 6) in table 6. The relationship between the CBR and the Plastic Limit (PI) shows a linear relationship generating the linear Regression model: Model No 1. CBR =25.90 – 0.061PL and the coefficient of determination R^2 was 0.009 which indicates that only 0.009 variability in the CBR can be explained by the plastic limit of the soil. The result of the Analysis of Variance (ANOVA) show that the relationship between the CBR and plastic limit was not statistically significant. Same applies to the CBR relationship with the liquid limit Plasticity Index and the Moisture Content which have their coefficient of determinations R^2 as 0.00, 0.01 and 0.30 respectively in model Nos. 2 – 4 in table 6: indicating that the relationships are statistically insignificant. Model No. 5 & 6 relates the relationship between the CBR and the Maximum Dry Density (MDD) and Optimum Moisture Content (OMC) respectively and the corresponding linear model equations relating their relationship are : CBR = 69.89 + 54.944 * MDD with R^2 = 0.82 and CBR = 38.676 – 1.386OMC with R2 = 0.9374 respectively. The coefficient of differential is therefore statistically significant.

Model 2: **Quadratic Model** **(y = a_o + a_1x + a_1x^2)**

Model 2 represents the quadratic model which also have six (6) quadratic models: Model No. 7 – 12 in Table 6. With the various soil index properties as independent variables and the CBR as the dependent variable, six quadratic models were generated showing the relationships of the CBR with each of the six index properties. Model Nos. 7 –10 Table 6 shows the quadratic relationship of the CBR with the Plasticity Limit (PL), Liquidity Limit (LL), Plasticity Index (PI) and the Moisture Content (MC). The coefficient of determination (R^2) of the four quadratic models are 0.11, 0.13, 0.08 and 0.35 respectively which again shows the relationship between them and the CBR of the soils are not statistically significant for the prediction of CBR outcome. CBR = -0.820-11+ 926.06MDD – 252.49MDD^2 & CBR = 30.948 + 0.157OMC -0.071OMC^2 with coefficient of differentials R^2 being 0.0897 and 0.96 respectively which are statistically significant for the prediction of the CBR.

Model 3: Multiple Linear Regression Model

Model 3 is a combined multiple linear regression model of the various soil index properties that have significant relationship with the CBR in the modeling equations in Model 1 and 2. It considers the two soil index properties that are statistically significant for the modeling of the CBR of the soil using linear regression model, i.e., Maximum Dry Density (MDD) and the Optimum Moisture Content and this generated one single equation.

CBR = 52.16 -6.927*MDD – 1.5420*OMC

With a coefficient of determination (R^2) of 0.9387 which is very statistically significant having Mean Square Error (MSE) of 1.152 and Root Mean Square Error (RMSE) of 1.073. Result of the ANOVA provides sufficient evidence in stating that the Optimum Moisture Content (OMC) and the Maximum Dry Density are good predictors for evaluating the CBR of the subgrade soil of Ogbia – Nembe road.

Figure 7 shows a comparison of the actual CBR values obtained by laboratory investigation of the Obia - Nembe road and the predicted CBR values based on the regression models generated. Table 8 shows the variance in the CBR of Ogbia-Nembe soil when the actual and predicted are compared. Indicating a reasonable fit to the soil type in the study area.

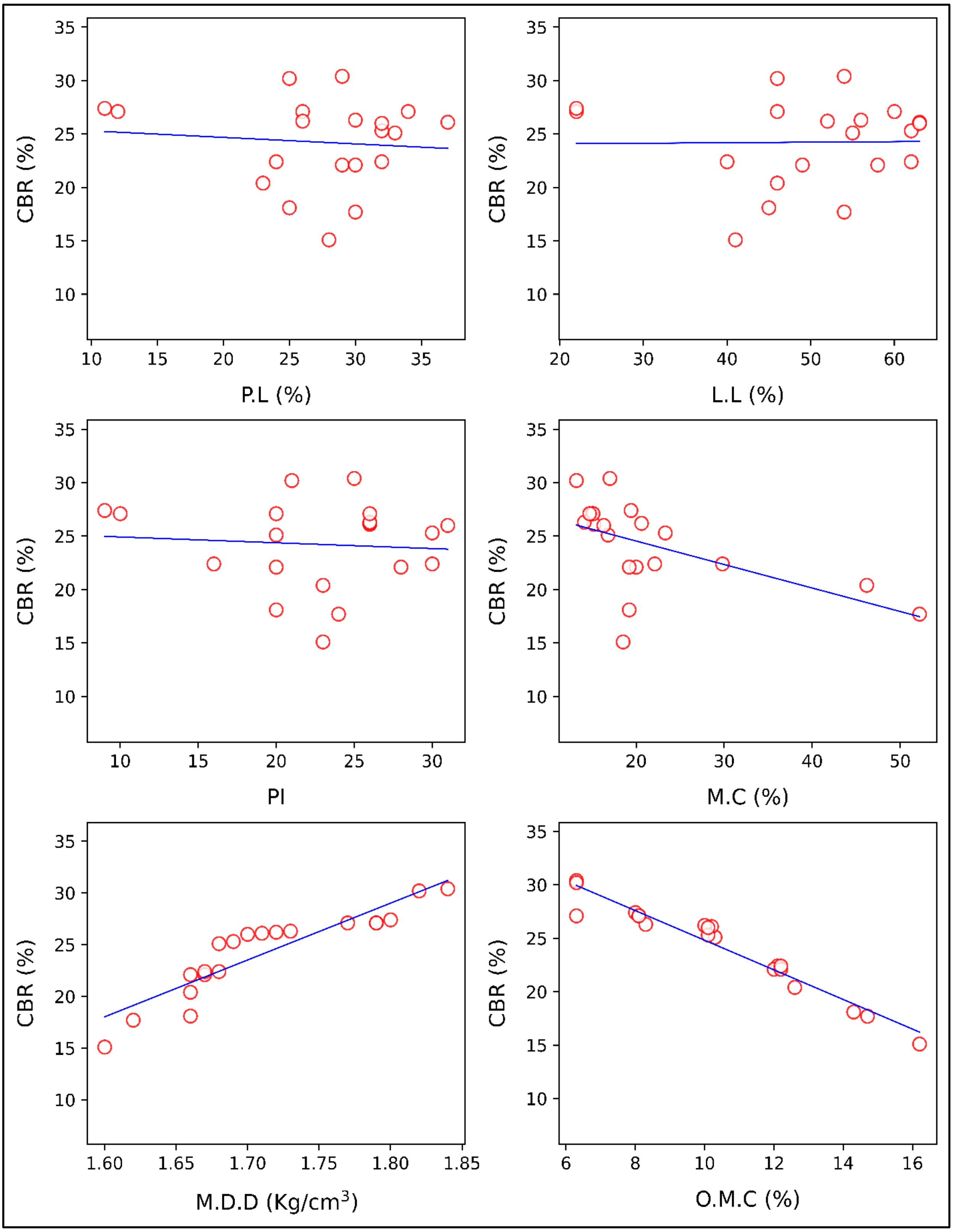

Figure 5: linear model showing the relationship between the soil index properties and California Bearing Ratio for Ogbia-Nembe

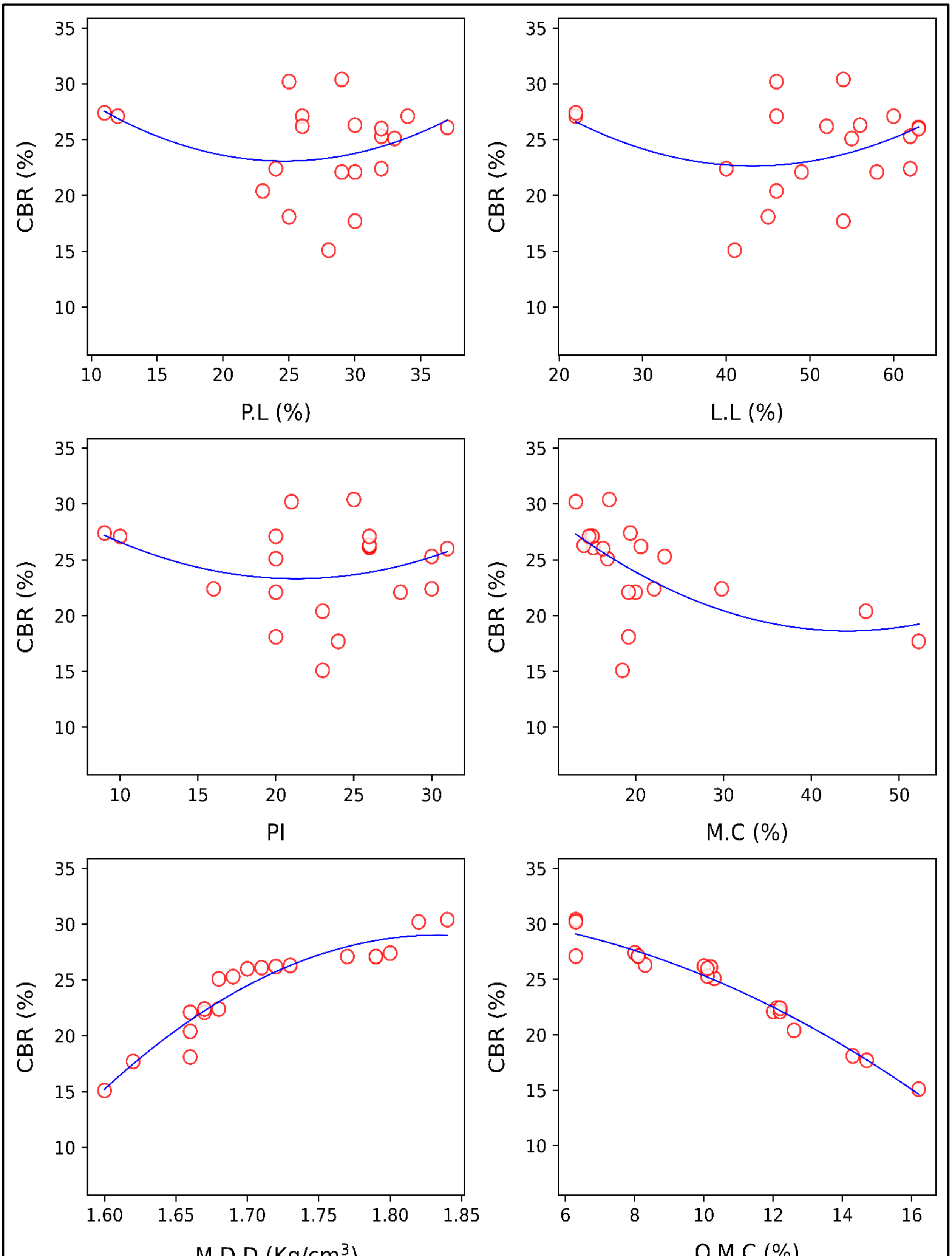

Figure 6: Quadratic model showing the relationship between the soil index properties and California Bearing Ratio for Ogbia-Nembe

Table 6: Regression Analysis result of Soil Index properties with the CBR (Ogbia-Nembe)

Type of Regression Model	Variables	Model No.	Model Equation	Goodness of Fit
Simple Linear Regression Model y = a_o + a_1x	CBR = f(PL)	1	CBR = 25.90-0.061*PL	R^2 = 0.009 MSE = 17.57 RMSE = 4.19
	CBR = f (LL)	2	CBR = 23.99+0.005*LL	R^2 = 0.00 MSE = 17.73 RMSE = 4.21
	CBR = f(PI)	3	CBR = 25.46-0.054*PI	R^2 = 0.01 MSE = 17.62 RMSE = 4.20
	CBR = f(MC)	4	CBR = 28.93-0.220*MC	R^2 = 0.30 MSE = 12.33 RMSE = 3.51
	CBR = f(MDD)	5	CBR = -69.89+54.944*MDD	R^2 = 0.82 MSE = 3.138 RMSE = 1.772
	CBR = f(OMC)	6	CBR = 38.676-1.386*OMC	R^2 = 0.9374 MSE = 1.111 RMSE = 1.054
Quadratic Model y = a_o + a_1x + a_1x^2	CBR = f(PL)	7	CBR = 37.61-1.179P.L+0.02*PL^2	R^2 = 0.11 MSE = 16.69 RMSE = 4.085
	CBR = f (LL)	8	CBR = 39.10-0.763LL+0.009*LL^2	R^2 = 0.13 MSE = 16.347 RMSE = 4.043
	CBR = f(PI)	9	CBR = 34.97-1.096PI+0.026*PI^2	R^2 = 0.08 MSE = 17.27 RMSE = 4.156
	CBR = f(MC)	10	CBR = 36.313-0.8023MC+0.009*MC^2	R^2 = 0.35 MSE = 12.130 RMSE = 3.483
	CBR = f(MDD)	11	CBR = -820.11+926.06MDD-252.49*MDD^2	R^2 = 0.897 MSE = 1.929 RMSE = 1.389
	CBR = f(OMC)	12	CBR = 30.948+0.157OMC-0.0718*OMC^2	R^2 = 0.96 MSE = 0.74 RMSE = 0.861
Multiple Linear Regression Model	CBR = f(OMC, MDD)	13	CBR = 52.16-6.927*MDD-1.542*OMC	R^2 = 0.9387 MSE = 1.152 RMSE = 1.073

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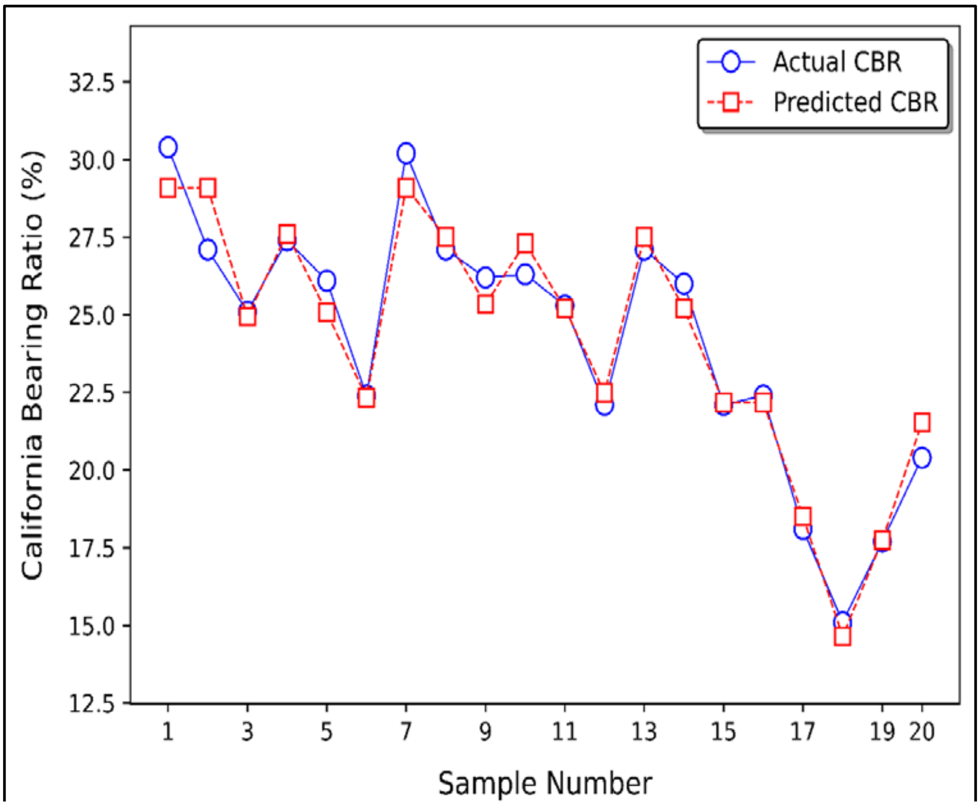

Figure 7: Comparison of the CBR between the predicted and actual value

Table 7: Percentage Variation in the predicted CBR

Sample No.	CBR (actual)	CBR (predicted)	Residual	% Variation
1	30.40	29.09	-1.31	-4.32
2	27.10	29.09	1.99	7.33
3	25.10	24.95	-0.15	-0.61
4	27.40	27.61	0.21	0.76
5	26.10	25.08	-1.02	-3.91
6	22.40	22.34	-0.06	-0.29
7	30.20	29.09	-1.11	-3.68
8	27.10	27.51	0.41	1.51
9	26.20	25.34	-0.86	-3.29
10	26.30	27.30	1.00	3.82
11	25.30	25.21	-0.09	-0.36
12	22.10	22.49	0.39	1.78
13	27.10	27.51	0.41	1.51
14	26.00	25.21	-0.79	-3.04
15	22.10	22.18	0.08	0.35
16	22.40	22.18	-0.22	-1.00
17	18.10	18.51	0.41	2.27
18	15.10	14.65	-0.45	-2.99
19	17.70	17.74	0.04	0.23
20	20.40	21.53	1.13	5.53

CONCLUSION

It was established that CBR value of a soils can be estimated from the value of some of the index properties of the soil which include the Optimum Moisture Content, Maximum Dry Density, Moisture Content and others. Linear, Quadratic and multiple regression models have been developed to predict the CBR value of the Ogbia-Nembe road in Niger Delta area of Nigeria from the Index properties of the soil. Thirteen models were developed to understand the relationship between these soil index properties: the independent variable and the California Bearing Ratio (CBR): the dependent variable; Six linear, Six quadratic and One multiple linear regression models were developed for this relationship.

However, result from the Analysis of variance (ANOVA) showed that the Plastic Limit (PL), the Liquid Limit (LL), the Plasticity Index (PI) and the Moisture Content (MC) are not statistically significant predictor variable to evaluate the CBR value for Ogbia-Nembe Soil which is predominantly a mixture of inorganic clay of low plasticity and organic clay/inorganic soil of high compressibility based on unified soil classification system. Results of the ANOVA further showed that the Optimum Moisture Content (OMC) and the Maximum Dry Density (MDD) are better independent variables for the prediction of the CBR value of Ogbia-Nembe soil. Hence, the empirical models;

CBR = -69.89 + 54.944*MDD; CBR = 38.676 – 1.386 * OMC; **CBR = -820.11 + 926.06MDD – 252.49MDD^2**; **CBR = 30.948 + 0.1570MC – 0.0718*OMC^2** and **CBR = 52.16 – 6.927*MDD-1.542*OMC**

These five acceptable regression model comprising of 2 linear model, 2 quadratic model and 1 multiple linear regression model having a coefficient of determination R^2 = 0.82, 0.93, 0.89, 0.96 and 0.94 respectively. These models can be used to predict the CBR of any given soil with relative similar soil index property.

The CBR values predicted by the model were further compared with those of the actual experimental test and found to relatively consistent with minimal variance.

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