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Regression Modelling of California Bearing Ratio (CBR) Predicted from Index

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Lateritic Soils were sourced from borrow pits in Edo State in Nigeria. Laboratory tests were conducted to determine the Atterberg limits, grading and CBR of soils obtained. Tests conducted include: sieve analysis, liquid limits, plastic limits, plasticity index (index properties), density, natural moisture content and CBR (soaked and unsoaked) tests. Using multivariate linear regression models, a mathematical model was developed to obtain a relationship between the CBR (soaked and unsoaked) of obtained soils with their index properties, which were obtained from the laboratory investigations conducted.

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Regression Modelling of California Bearing Ratio (CBR) Predicted from Index Properties for Lateritic Soils

Kayode_Ojo, N. [α] , Ehizokhale, M. E. [σ] & Ehiorobo, J. O. [ρ]

Abstract- Obtaining California Bearing Ratios (CBR) of soils for road construction projects could be a time-consuming and costly exercise. In order to reduce the time and cost of obtaining CBR values of soils, this paper presents a mathematical relationship between index properties of lateritic soils, which can easily be obtained from simple laboratory investigations, and their CBR (soaked and unsoaked) values.

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The statistical regression analyses showed a good correlation between experimental obtained and the predicted CBR values. The coefficient of determination (R2) differed for both the soaked and the unsoaked CBR values. The selected independent variables (index properties) had a better correlation with the unsoaked CBR than the soaked CBR. However, both CBR values did not satisfy the condition for road base and sub base as some of the materials can be qualified as subgrade material only after thorough compaction by several passes with vibratory roller or excavation and replacement with suitable fill materials has been carried out.

Keywords: california bearing ratio, index properties, multivariate regression model, plasticity index, subgrade.

I. Introduction

In highway design, bearing capacity of sub grade soil is of great importance in the determination of pavement thickness (Forkenbrock and Weisbrod, 2001). The sub-grade layer, which is the bottommost layer, is mostly affected as load comes upon it (Forkenbrock and Weisbrod, 2001). In Nigeria, California Bearing Capacity (CBR) test is one of the most common and comprehensive method currently used to determine the sub-grade strength. It is essentially a measure of the shear strength of a material at a known density and moisture content. The shear strength of soils can generally be considered in terms of Coulomb's Law, as discussed by Croney, (1977).Sub-grade plays an important role in imparting structural stability to the pavement structure as it receives loads imposed upon it by road traffic (Croney, 1977; Forkenbrock and Weisbrod, 2001). A range of factors influence the CBR of a particular material. Carter and Bentley (1991) mentioned the soil type, density, moisture content and method of sample preparation as playing important roles. Apart from the material properties themselves, moisture conditions are also pivotal. The moisture conditions at which the material is to be used vary according to climatic region, and as such the soaked CBR test is used to simulate the worst likely conditions in service and the un-soaked simulate the normal field condition (Kumar, 2014). For determining soaked value of the CBR, the sample is submerged in water for 96 hours prior to performing the penetration test.

In the tropics, lateritic soils are used as a road making material and they form the sub-grade of most tropical roads (Alayaki, 2012). Lateritic soil is generally believed to be a very good sub-grade material for road construction. Nigerian roads and highways are usually constructed on compacted lateritic soils foundation. Although some lateritic soils (especially gravelly aggregates) have been found to be quite good in pavement construction particularly those with appropriate geotechnical characteristics, the limited availability of these materials in the country is a challenge to constructing durable roads and highways (Alayaki ,2012).

A good highway or road is a gateway to national development as they create access to infrastructure (Okovido and Musa, 2004). In Nigeria, the failure of engineering facilities such as roads and embankments has attracted numerous opinions on the causes (Orie and Nweni, 2015). These failures have necessitated the need for research which revealed that the causes of the highway failure were traceable to indiscriminate dumping of waste, the use of substandard materials and incompetent contractors. Apart from these mentioned causes, insufficient knowledge of the sub-grade of the intended site before use is also a contributing factor of failure (Orie and Nweni, 2015). Huge amounts of money are spent on road maintenance on annual basis, yet the pavement does not last for a long period of time before its fails as a result of not knowing the condition of the sub-grade before design (Alayaki, 2012). CBR test is

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one of those parameters that serves as an indication of sub-grade soil strength and hence the service-life of a pavement depends on the sub-grade (Sathawara and Patel, 2013). Comparing soaked and un-soaked CBR will help to know the behavior of the soil before and after construction. Knowing this will help to minimize the high rate of pavement failure, and money spent on yearly maintenance will be used for other projects that will boost the economic and social development of the country (Orie and Nweni, 2015; Alayaki, 2012).

The aim of this study is to develop a relationship between the index properties of lateritic soils and their soaked and unsoaked CBRs of lateritic soils. This relationship will help in quick assessment of CBRs of soils during the design stages of engineering projects.

II. Materials and Method

a) Study Area

The study area covers Ebhohimi, and Ekpoma in Edo central senatorial zone of Edo state, Nigeria as shown in figure 1.

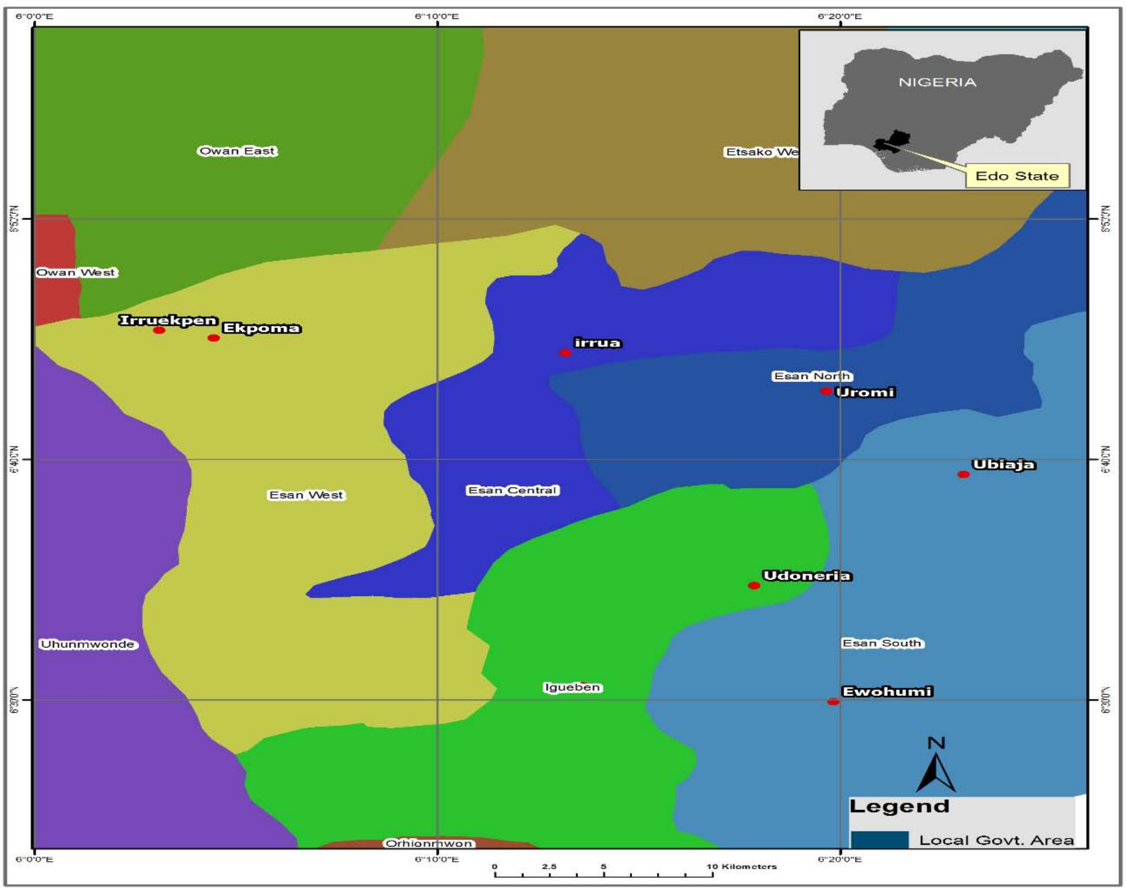


Figure 1: Location Map for the study area

b) Sample Collection

In order to have sufficient and reliable data for the targeted analysis, soil samples were collected from the study area. The samples were collected along the road, and borrow pits. A total of Twenty (20) disturbed samples were collected, using hand auger at a depth of 1 m to 2 m. Some were taken from both side of the road within a reasonable sampling interval of 2 to 3 km. The sample locations are shown in Table 1.

Table 1: Sample Locations

S/N	Location	Number of Samples Collected	Depth / Chainage
1	Ebohimi borrow pit	10	1 to 3m
2	Ekpoma road /BP	10	0.6-3m&43+230 – 65+100

c) Laboratory Tests

All laboratory tests were done in accordance with the British Standard Specifications B.S 1377: 1990 (BS, 1990). The tests included:

a. Atterberg limits,
b. Particle (grain) size analysis,
c. California bearing ratio and
d. Compaction test.

d) Analysis of Data using Multivariate Regression

To find the dependence of the measured geotechnical parameters on the soaked and un-soaked CBR, mathematical modeling using multivariate regression analysis was done (Bello, 2012). CBR values were taken as dependent variables and index properties (LL, PL, PI, OMC, MDD (compaction tests values), % passing of 0.075mm and 0.425mm) as independent variables.

Multivariate regression equation of the form as shown in Equation 1 was used.

$$\hat{y} = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + ---------- \beta_5 x_5 + \varepsilon \quad (1)$$

Where y is the dependent variables, $\beta_0, \beta_1, \beta_2, ---, \beta_5, \varepsilon$ are the coefficient to be determined (regression coefficients) and $x_1, x_2, ---, x_5$ are the independent variables.

The parameters of the equation were computed using E-view version 9.0 statistical software.

1. The first phase in the model development was the transformation of the independent variables (%passing 0.075mm and 0.425mm sieve, liquid limit, plastic limit, plastic index, maximum dry density (g/cm^3), optimum moisture content) into readable codes that can be used as input files for the analysis.
2. The second phase was to define the dependent variables (Soaked and un-soaked CBR) and the model analysis method. In this case, least square regression based on multivariate model was selected.
3. The third and final phase was to compute the coefficient statistics, and assess the model strength using coefficient of determination, thereafter generate the multivariate equations.

III. Results and Discussion

a) Laboratory Tests Results

The results of the laboratory tests for Ebhohimi borrow pits are shown in Table 2.

Table 2: Results for Ebhohimi borrow pits

S/N	Sample Location	%Passing 0.075mm (no200)	%Pasng 0.425 mm	Liquid Limit (%)	Plastc Limit (%)	Plasticity Index (%)	MDD (g/cm^3)	OMC (%)	CBR Soaked (%)	CBR Unsoaked (%)	ASSHTO Soil Classifica -tion
1	Ebhohimi borrowpit 1, Sample 1	44.1	66.2	57.49	18.57	38.92	1.81	16.92	0.63	0.71	A-7-5
2	Ebhohimi borrow pit 1, Sample 2	48.1	69.8	56.28	15.5	35.92	1.75	17.30	3.63	5.70	A-7-5
3	Ebhohimi borrow pit 1, Sample 3	42.1	64.1	54.75	16.4	38.5	1.72	14.30	8.18	9.72	A-7-5
4	Ebhohimi \borrow pit 1, Sample 4	38.2	61.08	46.31	16.97	29.34	1.74	14.30	2.38	2.89	A-7-5
5	Ebhohimi borrow pit 1, Sample 5	50.66	73.35	56.45	26.11	30.34	1.65	19.76	1.39	1.46	A-7-5
6	Ebhohimi borrow pit 2, Sample 1	46.4	66.8	54.49	23.71	30.78	1.65	15.20	3.71	4.09	A-7-5
7	Ebhohimi borrow pit 2, Sample 2	49.1	67.2	58.17	21.23	36.94	1.75	17.6	1.91	6.19	A-7-5

8	Ebhohimi borrow pit 2, Sample 3	49.9	68.5	53.04	19.46	33.58	1.75	17.34	1.23	1.30	A-7-5
9	Ebhohimi borrow pit 2, Sample 4	44.5	64.9	46.31	20.19	26.12	1.68	15.54	4.82	6.48	A-7-5
10	Ebhohimi borrow pit 2,	52.16	75.01	54.64	19.78	34.88	1.65	17.40	0.88	1.51	A-7-5

Based on the obtained test results from Ebhohimi borrow pit (Table 2), the soil is classified as A-7-5 (sandy soil). From the conventional Atterberg limit tests, liquid limit values are in the range of 46.31 to 58.17, plasticity limit values are of 15.5 to 26.45 and plasticity index value of 26.12 to 41.06 as shown in Table 2. Soils with liquid limit less than 30% are considered to be of low plasticity, those with liquid limit between 30% and 50% exhibit medium plasticity and those with liquid limit greater than 50% exhibit high plasticity (Arora, 2004). All samples exhibited high plasticity except sample 4 in pits 1 and 2 which exhibited medium plasticity. The particle size distribution passing through 0.075mm and 0.425mm ranged between 38.2 to 52.16 and 61.08 to 73.35, which indicate fine grained soils, the soil can be classified as sandy soil (Arora, 2004). The unsoaked CBR values ranged between 0.71 and 9.72, while its corresponding soaked samples range between 0.63 and 8.18%. The percentage decreases from soaked CBR to unsoaked CBR. This implies that as water is absorbed into the compacted specimen, the resistance to penetration becomes drastically reduced. It has been recommended by Federal Ministry of Works and Housing that the values of CBR for road base, sub base and subgrade should not be less than 80%, 30% and 10% respectively under soaked condition (FMWH, 1994). It can be seen that samples do not satisfy the condition for road subgrade, base and sub-base. Hence the CBR from that particular borrow pits are very low.

Table 3: Results for Ekpoma

S/N	Sample Location	%Passig 0.075mm (no 200)	%Passing 0.425 mm	Liquid Limit (%)	Plastic Limit (%)	Plasticity Index (%)	MDD (g/cm^3)	OMC (%)	CBR Soaked (%)	CBR Unsoaked (%)	ASSHTO Soil Classification
1	EkpomaUjioba RD,1.4m	36.06	68.35	53.32	19.00	34.32	1.59	18.60	17.6	33.2	A-7-5
2	EkpomaUjioba 0.65m	24.32	65.85	43.81	15.86	27.95	1.62	19.38	18.2	32.49	A-7-5
3	Ekpoma Borrow pit 1 0.75m	36.89	67.99	36.74	15.51	21.23	1.78	10.8	6.34	11.4	A-6
4	Ekpoma Borrow pit 2 0.75m	22.15	73.16	27.76	13.43	14.33	1.69	13.2	10.9	12.8	A-2-6
5	Ekpoma Borrow pit 2 1.5m	23.14	75.49	41.52	13.70	27.55	1.72	14.9	8.85	12.8	A-2-6
6	Ekpoma Borrow pit 3 1.5m	21.13	76.44	35.76	15.18	20.58	1.76	13.6	3.48	10.2	A-2-6
7	Ekpoma 50+500	40.44	74.7	45.80	25.2	14.29	1.59	16.0	8.29	10.1	A-7-5
8	Ekpoma 43+230	40.74	78.75	33.80	19.74	14.06	1.65	14.0	9.03	11.1	A-6
9	Ekpoma 47+500	36.23	77.43	29.38	17.45	11.92	1.71	13.6	4.99	5.09	A-6
10	Ekpoma 65+100	29.35	73.32	43.81	15.86	27.95	1.62	19.4	7.43	12.67	A-2-6

The laboratory tests results for soils from Ekpoma are presented in Table 3. Based on the obtained test results of plasticity, the soil classification was made in accordance to the AASHTO classification system, and it was classified as A-7-5, A-2-6, A-6. From the conventional Atterberg limit tests, liquid limit value ranging from 27.76 to 53.32, plastic limit value of 13.43 to 25.20 and plasticity index value of 11.92 to 34.32. Soils with liquid limit less than 30% are considered to be of low plasticity, those with liquid limit between 30% and 50% exhibit medium plasticity and those with liquid limit greater than 50% exhibit medium plasticity and those with liquid limit greater than 50% exhibit high plasticity. The values of California bearing ratio have been shown in Table 1. It has unsoaked CBR ranges between 10.1 and 33.2, which that of its corresponding soaked samples range between 3.48 and 17.6%. The percentage decreases from soaked CBR to unsoaked CBR. This implies that as water is absorbed into the compacted specimen, the resistance to penetration becomes drastically reduced. It has been recommended by Federal Ministry of Works that the values of CBR for road base, subbase and subgrade should not be less than 80%, 30% and 10% respectively under soaked condition. It can be seen that some of the samples satisfy the condition for road subgrade, but for it to be used for base and subbase materials, it is advisable to improve the soil by stabilization or excavation of the soil.

b) Regression Modelling

For this analysis, geotechnical properties including sieve analysis, liquid limit, plastic limit, plastic index, optimium moisture content and maximum moisture content were taken as independent variables as shown in tables 4 and 5while CBR soaked and unsoaked were taken as the dependent variables.To conduct the multivariate linear regression and solve the regression equation, multivariate statistical software E-view 9.0 was employed. The interphase of the statistical software containing both the dependent and independent variables is presented in tables 6 and 7 representing both the soaked and unsoaked CBR respectively. For ease of data transformation, the selected independent variables were coded as follows

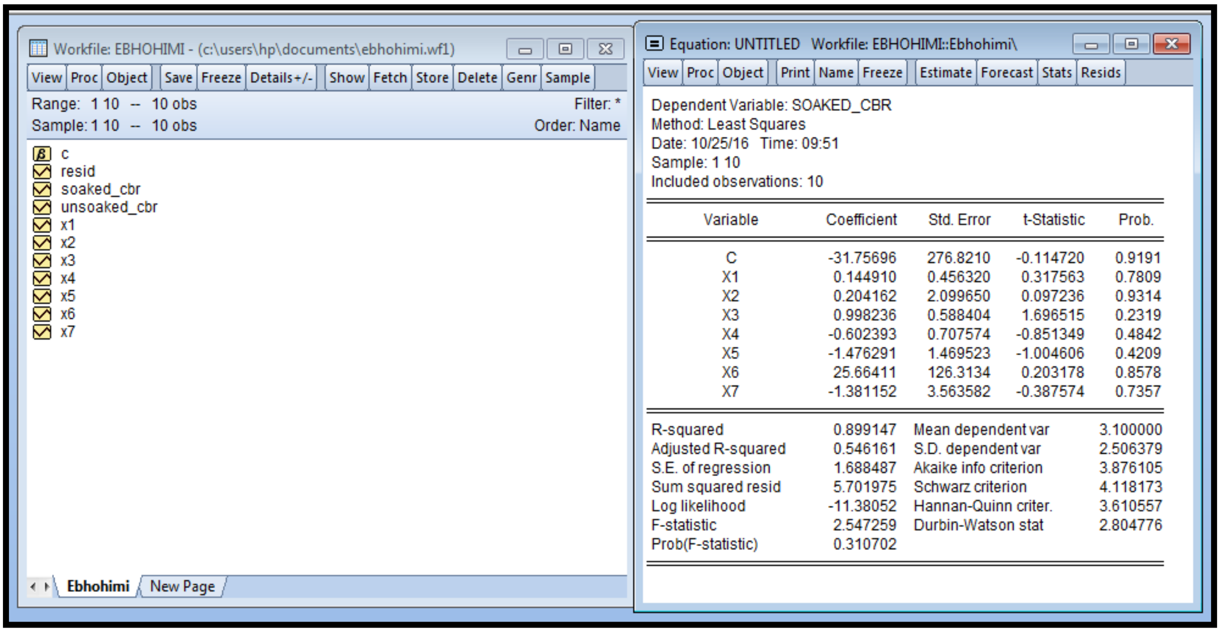
Table 4: Independent variable codes and their definition

S/No.	Variable Code	Variable Definition
1	X1	% Passing 0.075mm sieve
2	X2	% Passing 0.425mm sieve
3	X3	Liquid limit (%)
4	X4	Plastic limit (%)
5	X5	Plastic index (%)
6	X6	Maximum dry density (g/cm3)
7	X7	Optimum moisture content (%)

Table 5: Input data for analysis (Ebhohimi)

X1	X2	X3	X4	X5	X6	X7	SOAKED CBR	UNSOAKED CBR
44.1	66.2	57.49	18.57	38.92	1.81	16.92	0.63	0.71
48.1	69.8	56.28	15.5	35.92	1.75	17.30	3.63	5.70
42.1	64.1	54.75	16.4	38.5	1.72	14.30	8.18	9.72
38.2	61.08	46.31	16.97	29.34	1.74	14.30	2.38	2.89
50.66	73.35	56.45	26.11	30.78	1.65	19.76	1.39	1.46
46.4	66.8	54.49	23.71	30.78	1.65	15.20	3.71	4.09
49.1	67.2	58.17	21.23	36.94	1.75	16.81	1.91	6.19
49.9	68.5	53.04	19.46	33.58	1.75	17.34	1.23	1.30
44.5	64.9	46.31	20.19	26.12	1.68	15.54	4.82	6.48
52.16	75.01	54.64	19.78	34.88	1.65	17.40	0.88	1.51

Table 6: Software interphase showing the coefficient estimates of the dependent and independent variables

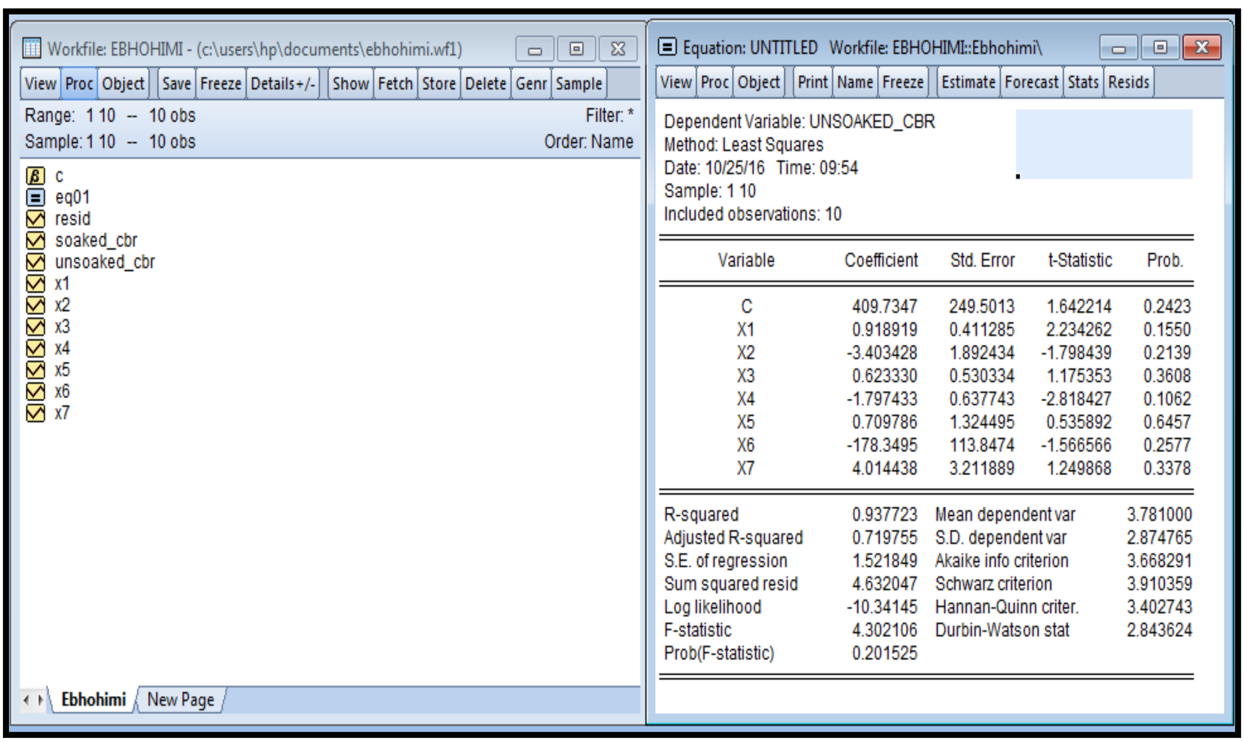


Dependent Variable: SOAKED_CBR
Method: Least Squares
Date: 10/25/16 Time: 09:51
Sample: 1 10
Included observations: 10

Variable	Coefficient	Std. Error	t-Statistic	Prob.
C	-31.75696	276.8210	-0.114720	0.9191
X1	0.144910	0.456320	0.317563	0.7809
X2	0.204162	2.099650	0.097236	0.9314
X3	0.998236	0.588404	1.696515	0.2319
X4	-0.602393	0.707574	-0.851349	0.4842
X5	-1.476291	1.469523	-1.004606	0.4209
X6	25.66411	126.3134	0.203178	0.8578
X7	-1.381152	3.563582	-0.387574	0.7357

R-squared	0.899147	Mean dependent var	3.100000
Adjusted R-squared	0.546161	S.D. dependent var	2.506379
S.E. of regression	1.688487	Akaike info criterion	3.876105
Sum squared resid	5.701975	Schwarz criterion	4.118173
Log likelihood	-11.38052	Hannan-Quinn criter.	3.610557
F-statistic	2.547259	Durbin-Watson stat	2.804776
Prob(F-statistic)	0.310702		

Table 7: Software interphase showing the coefficient estimates of the dependent and independent variables



Dependent Variable: UNSOAKED_CBR
Method: Least Squares
Date: 10/25/16 Time: 09:54
Sample: 1 10
Included observations: 10

Variable	Coefficient	Std. Error	t-Statistic	Prob.
C	409.7347	249.5013	1.642214	0.2423
X1	0.918919	0.411285	2.234262	0.1550
X2	-3.403428	1.892434	-1.798439	0.2139
X3	0.623330	0.530334	1.175353	0.3608
X4	-1.797433	0.637743	-2.818427	0.1062
X5	0.709786	1.324495	0.535892	0.6457
X6	-178.3495	113.8474	-1.566566	0.2577
X7	4.014438	3.211889	1.249868	0.3378

R-squared	0.937723	Mean dependent var	3.781000
Adjusted R-squared	0.719755	S.D. dependent var	2.874765
S.E. of regression	1.521849	Akaike info criterion	3.668291
Sum squared resid	4.632047	Schwarz criterion	3.910359
Log likelihood	-10.34145	Hannan-Quinn criter.	3.402743
F-statistic	4.302106	Durbin-Watson stat	2.843624
Prob(F-statistic)	0.201525		

i. *Analysis Test Results of soaked and un-soaked CBR for Ebhohimi samples*

From the result of Tables 6 and 7, it was observed that the coefficient of determination (R^2) differs for both the soaked and the unsoaked CBR analysis (0.899147 and 0.937723) respectively. The explanation is that the selected independent variables (percent passing 0.075mm sieve size, percent passing 0.425mm sieve size, liquid limit, plastic limit, plastic index, maximum dry density and optimum moisture content) had a better correlation with the unsoaked CBR than the soaked CBR. In addition, the high coefficient of determination as observed revealed the suitability of multivariate linear regression model in explaining the dependence of the independent variables on the regressor. Normally, this would imply a very good fit for the model. Thereafter, multivariate linear regression equation was developed as shown in Figure 2 and 3.

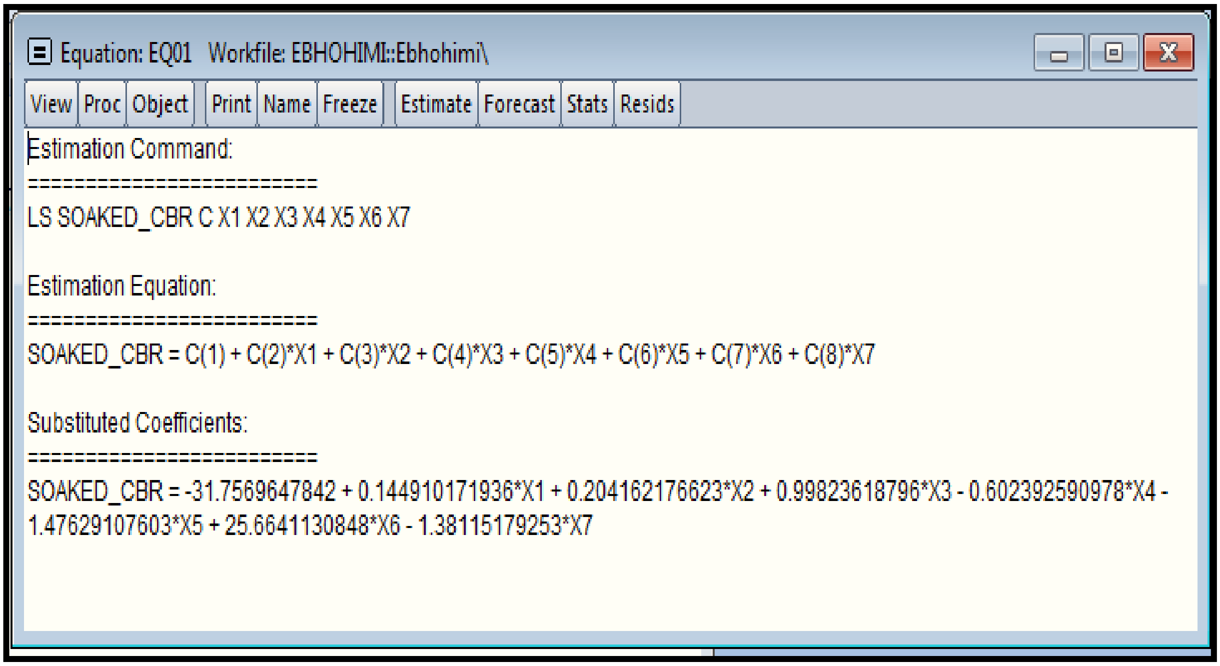


Figure 2: Multivariate linear regression equation showing the dependence of selected *Independent variables on the regressor*

Based on the observed (R^2) values, the multiple linear regression equation was thereafter developed using the estimated parameters and the substituted coefficients are as shown in Figures 2 and 3 which represent the soaked and unsoaked CBR. The "Cs"are the soaked CBR coefficient, while X1, X2…Xn are the independent variables. The values were substituted and equation (2) was derived.

$$CBRs = 31.7569647842 + 0.144910171936 * X1 + 0.204162176623 * X2 + 0.99823618796 * X3 - 0.602392590978 * X4 - 1.47629107603 * X5 + 25.6641130848 * X6 - 1.38115179253 * X7 \tag{2}$$

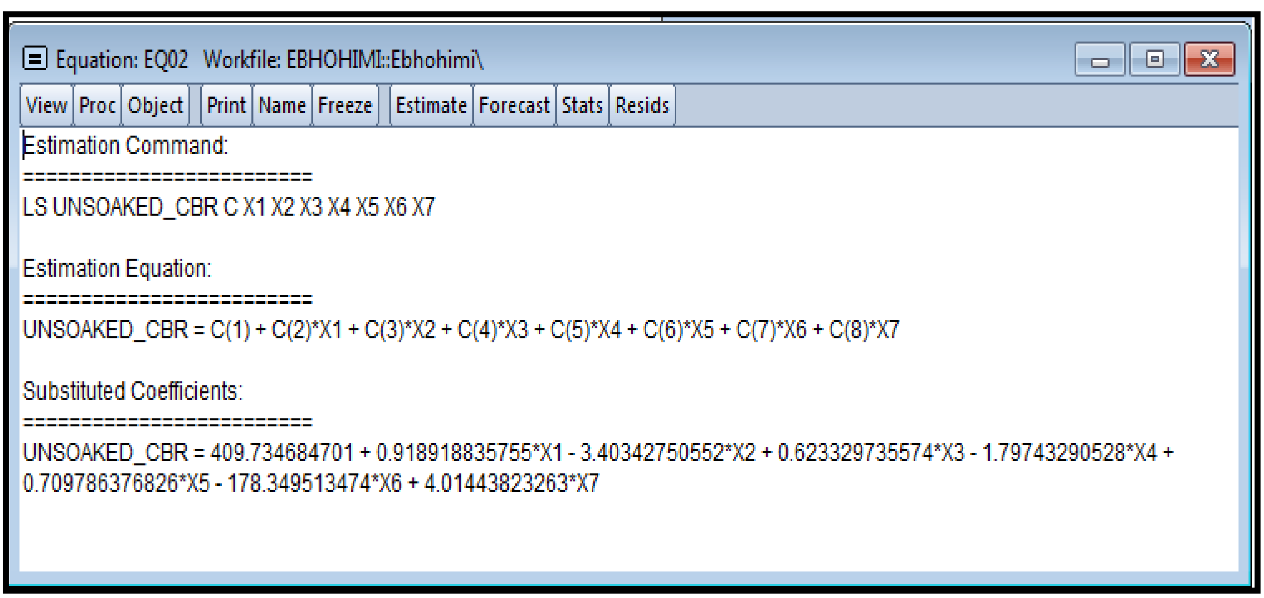


Figure 3: Multivariate linear regression equation showing the dependence of selected independent variables on the regressor

The same procedure in Figure 2 applies here. Multiple linear regression equation was developed using the estimated parameters and the substituted coefficients are as shown in Figure 3 which represent the unsoaked CBR. The "Cs"are the soaked CBR coefficient, while X1, X2…Xn are the independent variables (X1 = % 0.075mm sieve, X2 = % 0.425mm sieve, X3 = LL (%), X4 = PL (%), X5= PI (%), X6 = MDD (g/cm^3), X7= OMC (%)). The values were substituted and equation 3 was derived.

$$\begin{aligned} CBRu &= 409.734684701 + 0.918918835755 * X1 - 3.40342750552 \\ &* X2 + 0.623329735574 * X3 - 1.79743290528 * X4 \\ &+ 0.709786376826 * X5 - 178.349513474 * X6 + 4.01143823263 * X7 \end{aligned} \quad (3)$$

Thereafter, a graphical visualization was done, the graphical representation of soaked and unsoaked CBR for Ebhohimi sample, as shown in Figures 4 and 5.

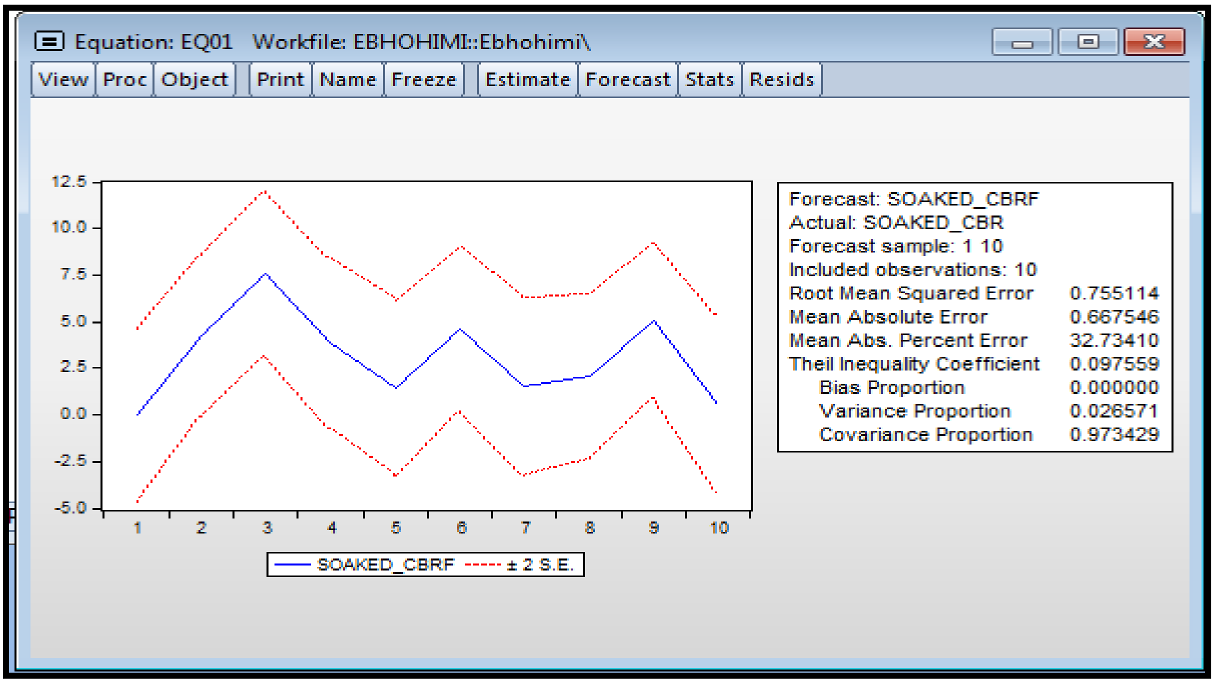


Figure 4: Statistics of fit based on 95% upper and lower bounds for soaked CBR

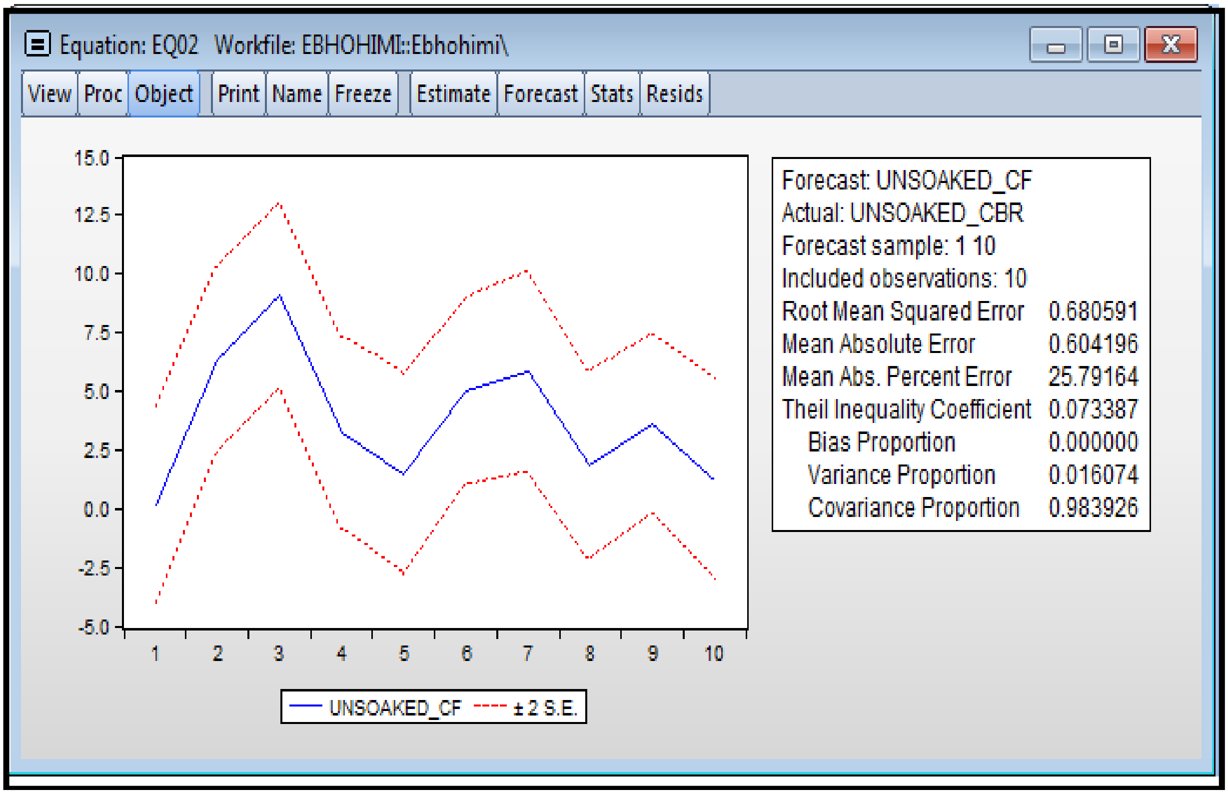
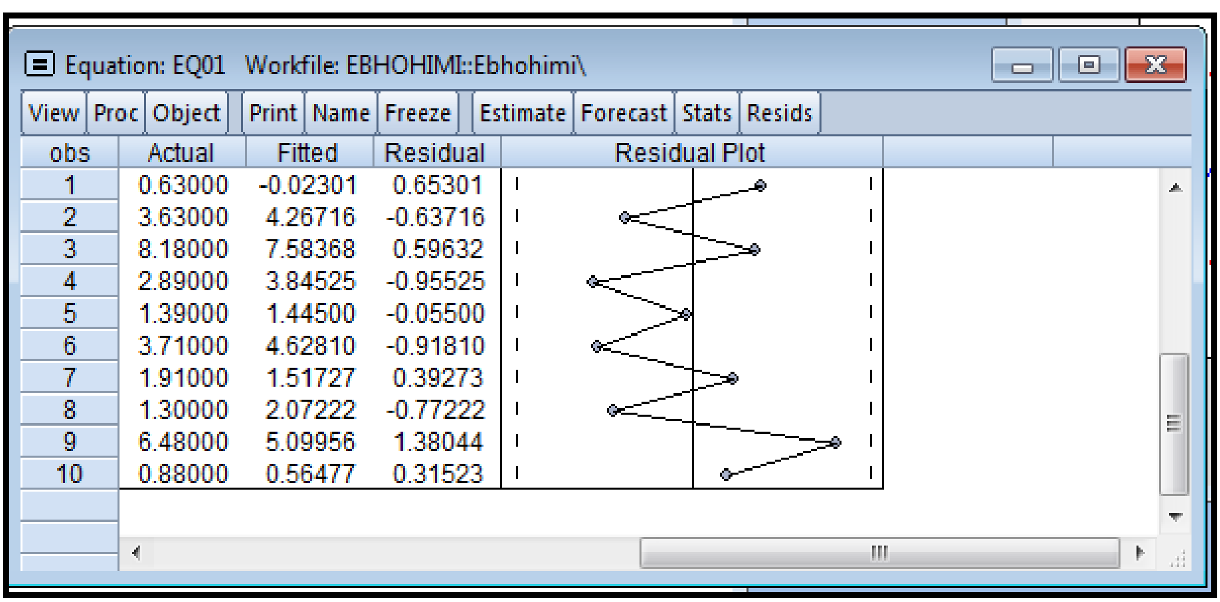


Figure 5: Statistics of fit based on 95% upper and lower bounds for unsoaked CBR

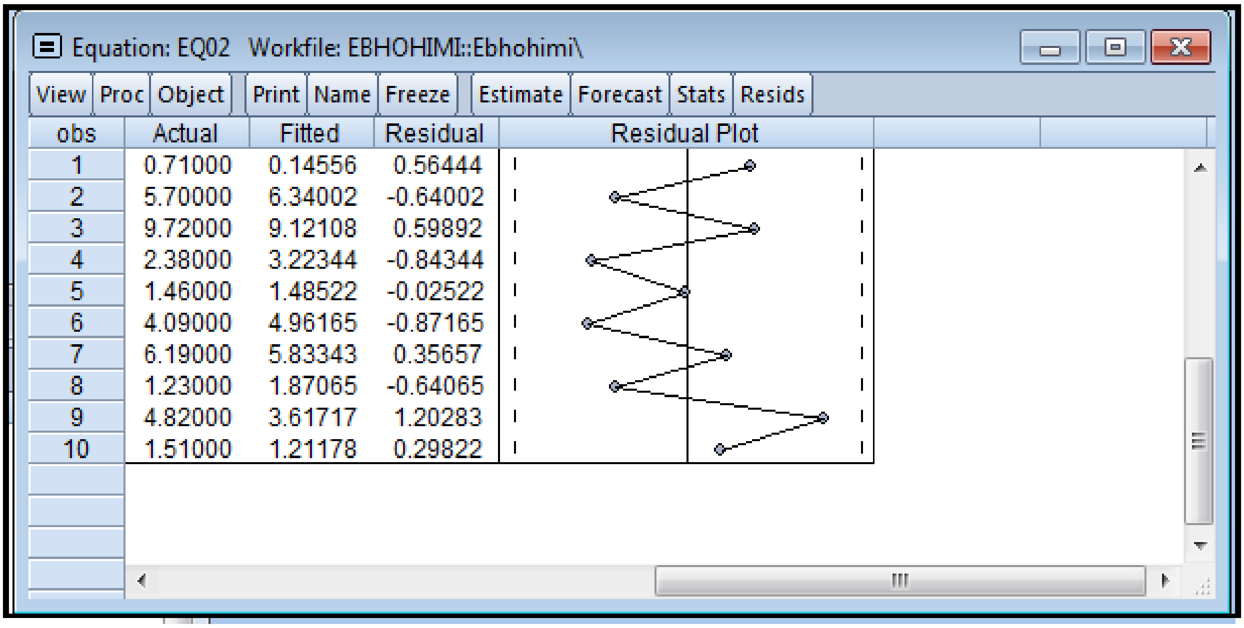
ii. *Statistics of fit based on 95% upper and lower bounds for soaked and unsoaked CBR*

The computed statistics of fit based on 95% lower and upper bounds was visualized graphically as presented in Figures 4 and 5 respectively representing the effect of selected independent variables on the soaked and unsoaked CBR for Ebhohimi borrow pit soils. The red dotted lines are the upper and lower bounds of the graph, while the blue line shows the variations in the CBR values. The selected independent variables have more effect on the unsoaked CBR than the soaked CBR.The statistical prediction Figure which shows the actual and predicted soaked and un-soaked CBR based on the multivariate regression approach is presented in Figures 6 and 7 respectively.


Equation: EQ01 Workfile: EBHOHIMI::Ebhohimi\

obs	Actual	Fitted	Residual
1	0.63000	-0.02301	0.65301
2	3.63000	4.26716	-0.63716
3	8.18000	7.58368	0.59632
4	2.89000	3.84525	-0.95525
5	1.39000	1.44500	-0.05500
6	3.71000	4.62810	-0.91810
7	1.91000	1.51727	0.39273
8	1.30000	2.07222	-0.77222
9	6.48000	5.09956	1.38044
10	0.88000	0.56477	0.31523

Figure 6: Actual and predicted soaked CBR



Equation: EQ02 Workfile: EBHOHIMI::Ebhohimi\

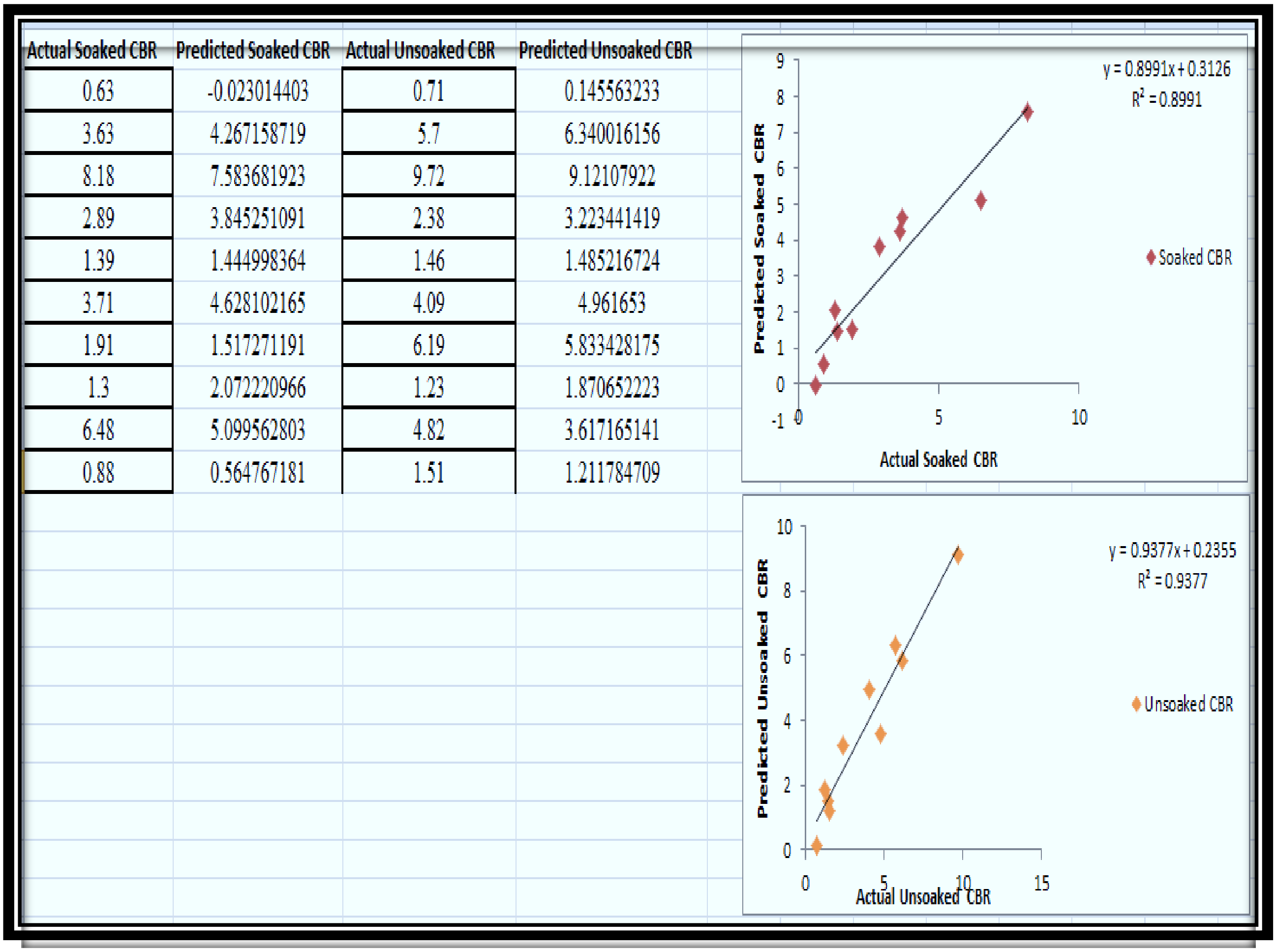
View | Proc | Object | Print | Name | Freeze | Estimate | Forecast | Stats | Resids

obs	Actual	Fitted	Residual	Residual Plot
1	0.71000	0.14556	0.56444	
2	5.70000	6.34002	-0.64002	
3	9.72000	9.12108	0.59892	
4	2.38000	3.22344	-0.84344	
5	1.46000	1.48522	-0.02522	
6	4.09000	4.96165	-0.87165	
7	6.19000	5.83343	0.35657	
8	1.23000	1.87065	-0.64065	
9	4.82000	3.61717	1.20283	
10	1.51000	1.21178	0.29822	

Figure 7: Actual and predicted unsoaked CBR

iii. *Comparison of Actual and Predicted CBR Values*

From the statistical prediction figures 6 and 7 which shows the actual and predicted soaked and unsoaked CBR based on the multivariate regression approach, it is observed that the actual CBR values and predicted CBR value for both soaked and unsoaked are relatively close, the highest variation is 1.38. To assess the strength of multivariate linear regression analysis in predicting the soaked and unsoaked CBR of the soil based on selected geotechnical parameters, a linear regression of output was done using the actual and predicted soaked and unsoaked CBR as the dependent and independent variables. Result obtained are presented in Figure 8.



Actual Soaked CBR	Predicted Soaked CBR	Actual Unsoaked CBR	Predicted Unsoaked CBR
0.63	-0.023014403	0.71	0.145563233
3.63	4.267158719	5.7	6.340016156
8.18	7.583681923	9.72	9.12107922
2.89	3.845251091	2.38	3.223441419
1.39	1.444998364	1.46	1.485216724
3.71	4.628102165	4.09	4.961653
1.91	1.517271191	6.19	5.833428175
1.3	2.072220966	1.23	1.870652223
6.48	5.099562803	4.82	3.617165141
0.88	0.564767181	1.51	1.211784709

Figure 8: Prediction accuracy of multivariate linear regression (Ebhohimi)

A plot was made between experimental and predicted values of CBR as shown in Figure 8

It is clear from this figure that most of the predicted CBR values are close to the reported experimental soaked CBR values. As the Actual CBR in soaked and the unsoaked increases, predicted CBR values also increases, indicating linear relationship exists between them. Considering the square of coefficient of correlation (R_2) for both is found to be 0.8991 (soaked) and 0.9377 unsoaked, there is evidence that a good correlations exist.

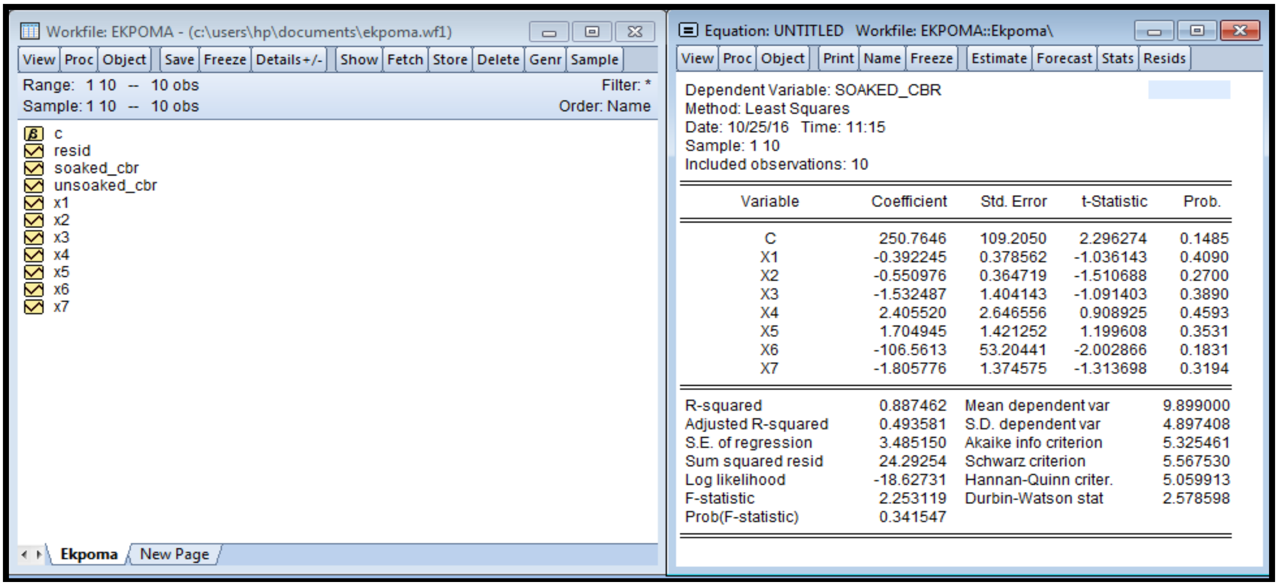
c) *Ekpoma sample*

The input data for Ekpoma analysis is shown in Table 9.

Table 8: Input data for analysis (Ekpoma)

X1	X2	X3	X4	X5	X6	X7	SOAKED CBR	UNSOAKED CBR
36.06	68.35	53.32	19	34.32	1.59	18.6	17.6	33.2
24.32	65.85	43.81	15.86	27.95	1.62	19.38	18.2	32.49
36.89	67.99	36.74	15.51	21.23	1.78	10.8	6.34	11.4
22.15	73.16	27.76	13.43	14.33	1.69	13.2	10.9	12.8
23.14	75.49	41.52	13.7	27.55	1.72	14.9	8.85	12.8
21.13	76.44	35.76	15.18	20.58	1.76	13.6	3.48	10.2
40.44	74.7	45.8	25.2	14.29	1.59	16	8.29	10.2
40.74	78.75	33.8	19.74	14.06	1.65	14	9.03	11.1
36.23	77.43	29.38	17.45	11.92	1.71	13.6	4.99	5.09
29.35	73.32	43.81	15.86	27.95	1.62	19.4	7.43	12.67

Table 9: Software interphase showing the coefficient estimates of the dependent and independent variables

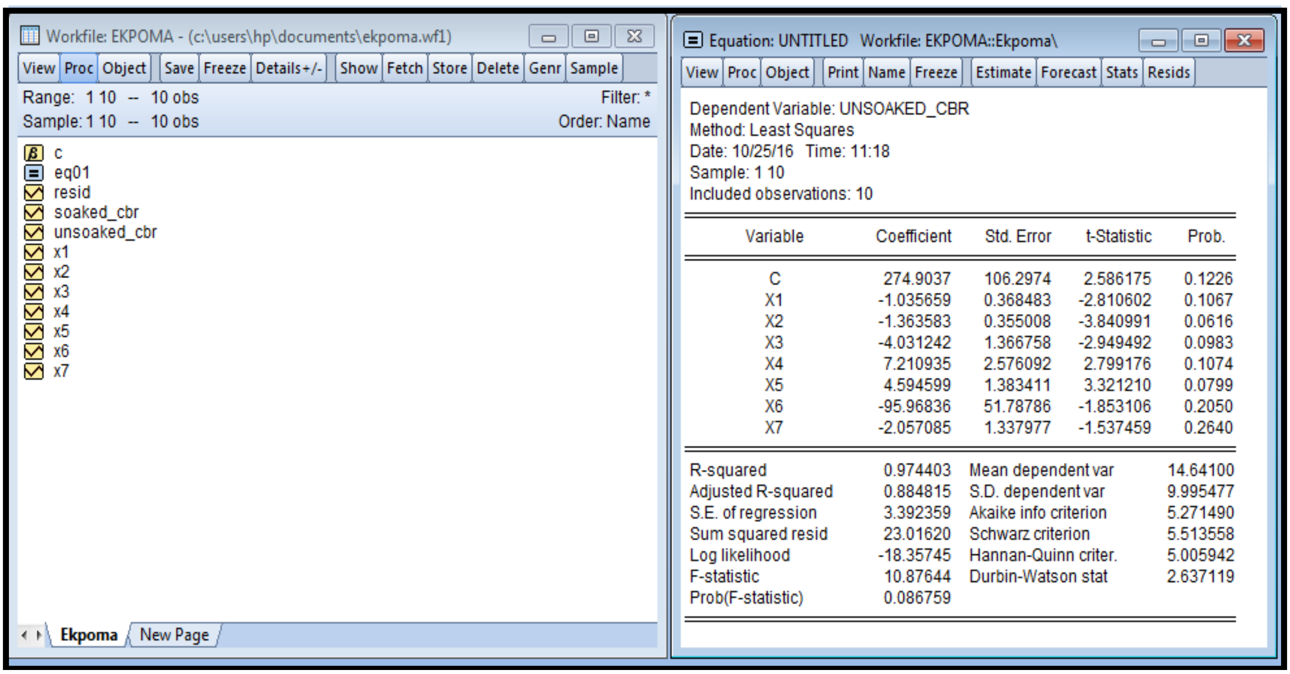


Dependent Variable: SOAKED_CBR
Method: Least Squares
Date: 10/25/16 Time: 11:15
Sample: 1 10
Included observations: 10

Variable	Coefficient	Std. Error	t-Statistic	Prob.
C	250.7646	109.2050	2.296274	0.1485
X1	-0.392245	0.378562	-1.036143	0.4090
X2	-0.550976	0.364719	-1.510688	0.2700
X3	-1.532487	1.404143	-1.091403	0.3890
X4	2.405520	2.646556	0.908925	0.4593
X5	1.704945	1.421252	1.199608	0.3531
X6	-106.5613	53.20441	-2.002866	0.1831
X7	-1.805776	1.374575	-1.313698	0.3194

R-squared	0.887462	Mean dependent var	9.899000
Adjusted R-squared	0.493581	S.D. dependent var	4.897408
S.E. of regression	3.485150	Akaike info criterion	5.325461
Sum squared resid	24.29254	Schwarz criterion	5.567530
Log likelihood	-18.62731	Hannan-Quinn criter.	5.059913
F-statistic	2.253119	Durbin-Watson stat	2.578598
Prob(F-statistic)	0.341547		

Table 10: Software interphase showing the coefficient estimates of the dependent and independent variables



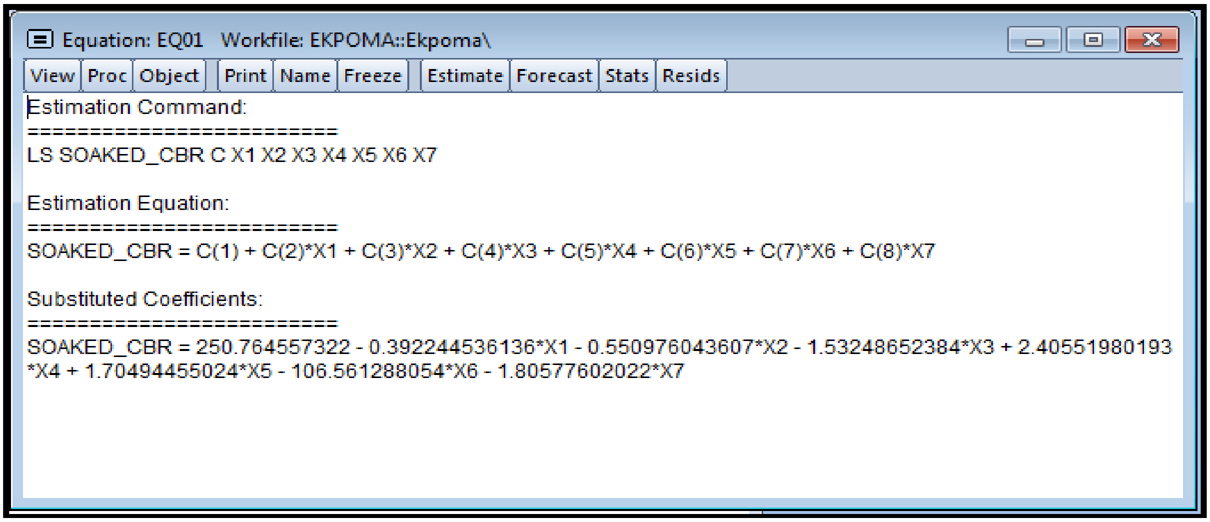
Dependent Variable: UNSOAKED_CBR
Method: Least Squares
Date: 10/25/16 Time: 11:18
Sample: 1 10
Included observations: 10

Variable	Coefficient	Std. Error	t-Statistic	Prob.
C	274.9037	106.2974	2.586175	0.1226
X1	-1.035659	0.368483	-2.810602	0.1067
X2	-1.363583	0.355008	-3.840991	0.0616
X3	-4.031242	1.366758	-2.949492	0.0983
X4	7.210935	2.576092	2.799176	0.1074
X5	4.594599	1.383411	3.321210	0.0799
X6	-95.96836	51.78786	-1.853106	0.2050
X7	-2.057085	1.337977	-1.537459	0.2640

R-squared	0.974403	Mean dependent var	14.64100
Adjusted R-squared	0.884815	S.D. dependent var	9.995477
S.E. of regression	3.392359	Akaike info criterion	5.271490
Sum squared resid	23.01620	Schwarz criterion	5.513558
Log likelihood	-18.35745	Hannan-Quinn criter.	5.005942
F-statistic	10.87644	Durbin-Watson stat	2.637119
Prob(F-statistic)	0.086759		

d) Analysis Test Results of soaked and un-soaked CBR for Ekpoma sample

From the result of Tables 9 and 10, it was observed that the coefficient of determination (R^2) differs for both the soaked and the unsoaked CBR analysis (0.887462 and 0.974403). The selected independent variables (percent passing 0.075mm sieve size, percent passing 0.425mm sieve size, liquid limit, plastic limit, plastic index, maximum dry density and optimum moisture content) had a better correlation with the unsoaked CBR than the soaked CBR. In addition, the high coefficient of determination as observed revealed the suitability of multivariate linear regression model in explaining the dependence of the independent variables on the regressor. From the results, it was observed that 88.7462% and 97.4403% of the variation in the soaked and unsoaked CBR can be explained by the selected independent variables. Thereafter, multivariate linear regression equation was developed as are shown in Figures 9 and 10 and


Equation: EQ01 Workfile: EKPOMA::Ekpoma\
View Proc Object Print Name Freeze Estimate Forecast Stats Resids

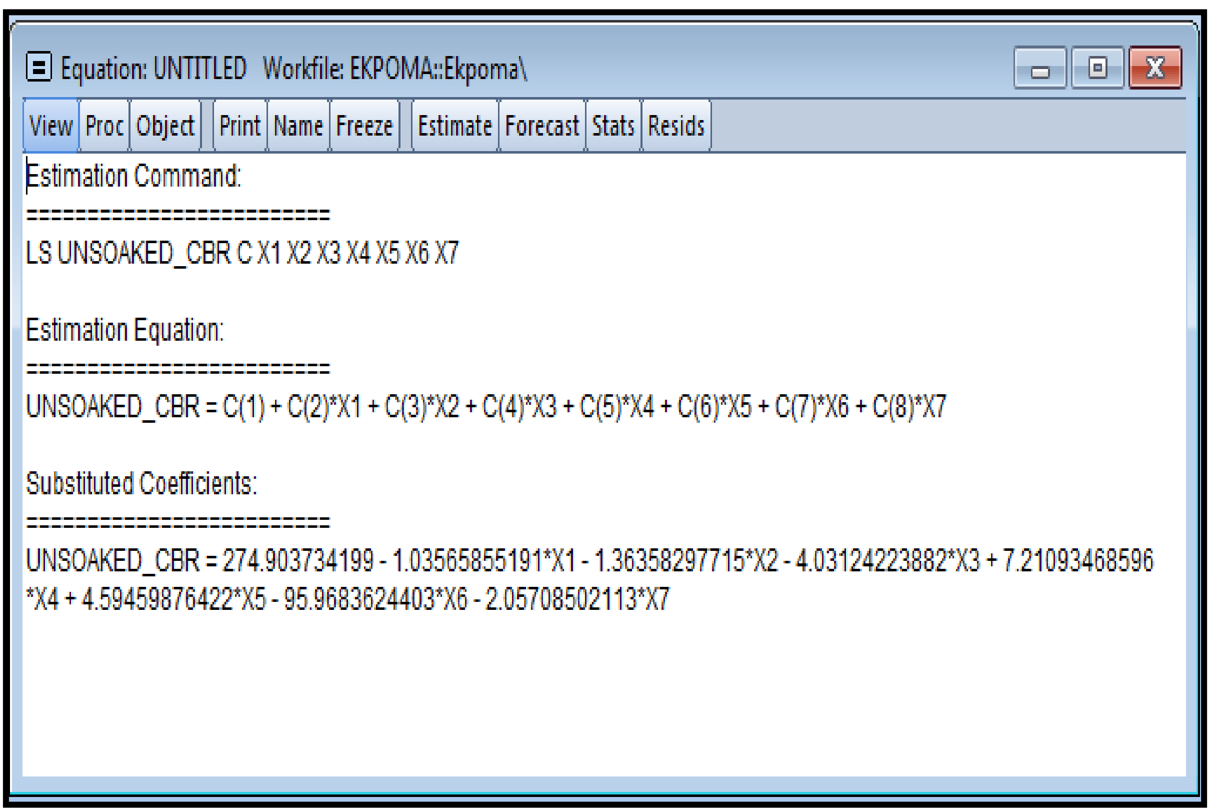
Estimation Command:
=========================
LS SOAKED_CBR C X1 X2 X3 X4 X5 X6 X7

Estimation Equation:
=========================
SOAKED_CBR = C(1) + C(2)*X1 + C(3)*X2 + C(4)*X3 + C(5)*X4 + C(6)*X5 + C(7)*X6 + C(8)*X7

Substituted Coefficients:
=========================
SOAKED_CBR = 250.764557322 - 0.392244536136*X1 - 0.550976043607*X2 - 1.53248652384*X3 + 2.40551980193 *X4 + 1.70494455024*X5 - 106.561288054*X6 - 1.80577602022*X7

Figure 9: Multivariate linear regression equation showing the dependence o f selected independent variables on the regressor

$$CBRs = 250.764557322 - 0.392244536136 * X1 - 0.550976043607 * X2$$
$$1.53248652384 * X3 + 2.40551980193 * X4 + 1.70494455024 * X5 \quad (4)$$
$$-106.561288054 * X6 - 1.80577602022 * X7$$


Equation: UNTITLED Workfile: EKPOMA::Ekpoma\
View Proc Object Print Name Freeze Estimate Forecast Stats Resids

Estimation Command:
=========================
LS UNSOAKED_CBR C X1 X2 X3 X4 X5 X6 X7

Estimation Equation:
=========================
UNSOAKED_CBR = C(1) + C(2)*X1 + C(3)*X2 + C(4)*X3 + C(5)*X4 + C(6)*X5 + C(7)*X6 + C(8)*X7

Substituted Coefficients:
=========================
UNSOAKED_CBR = 274.903734199 - 1.03565855191*X1 - 1.36358297715*X2 - 4.03124223882*X3 + 7.21093468596 *X4 + 4.59459876422*X5 - 95.9683624403*X6 - 2.05708502113*X7

Figure 10: Multivariate linear regression equation showing the dependence ofselected independent variables on the regressor

$$CBRu = 274.903734199 - 1.03565855191 * X1 - 1.36358297715 * X2 - 4.03124223882 * X3 + 7.21093468596 * X4 + 4.59459876422 * X5 - 95.9683624403 * X6 - 2.05708502113 * X7 \quad (5)$$

Based on the observed (R^2) values, the multiple linear regression equation was thereafter developed using the estimated parameters and the substituted coefficients as shown in Figures 9 and 10 which represent the soaked and unsoaked CBR models.

The graphical representation of the predicted values of soaked and unsoaked CBR for Ekpoma sample, are as shown in Figures 11 and 12.

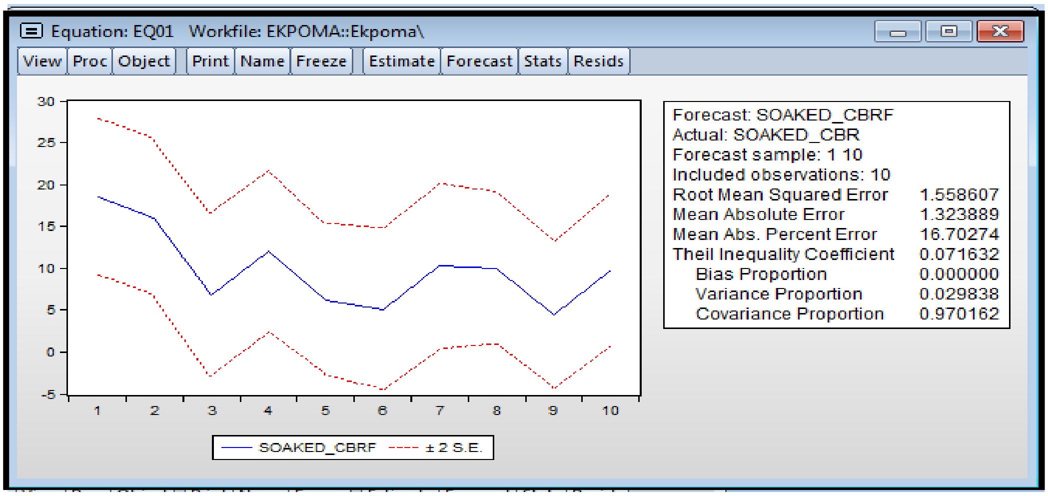


Figure 11: Statistics of fit based on 95% upper and lower bounds for soaked CBR

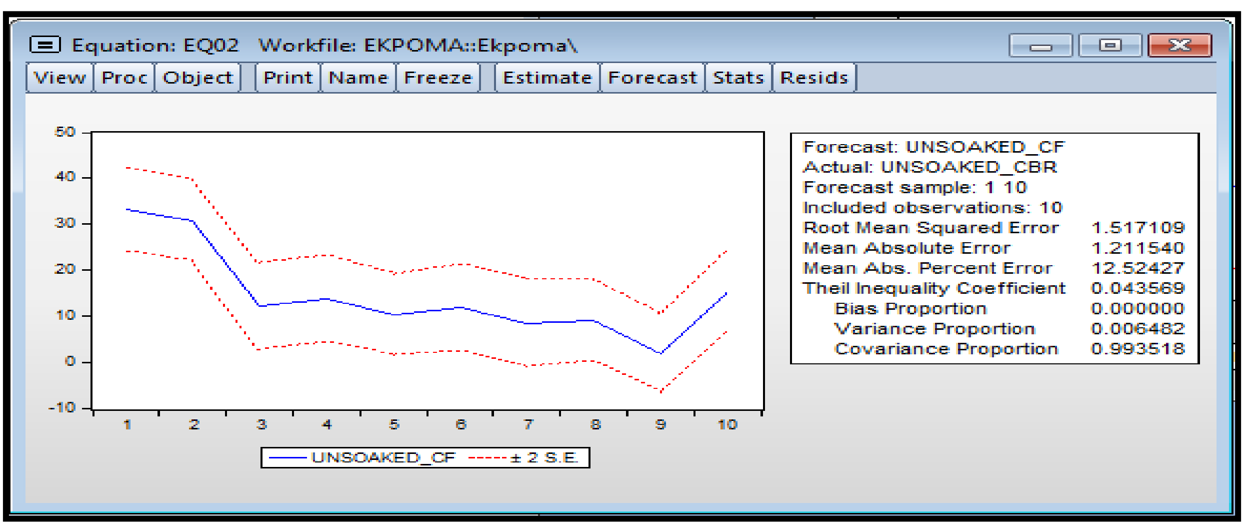
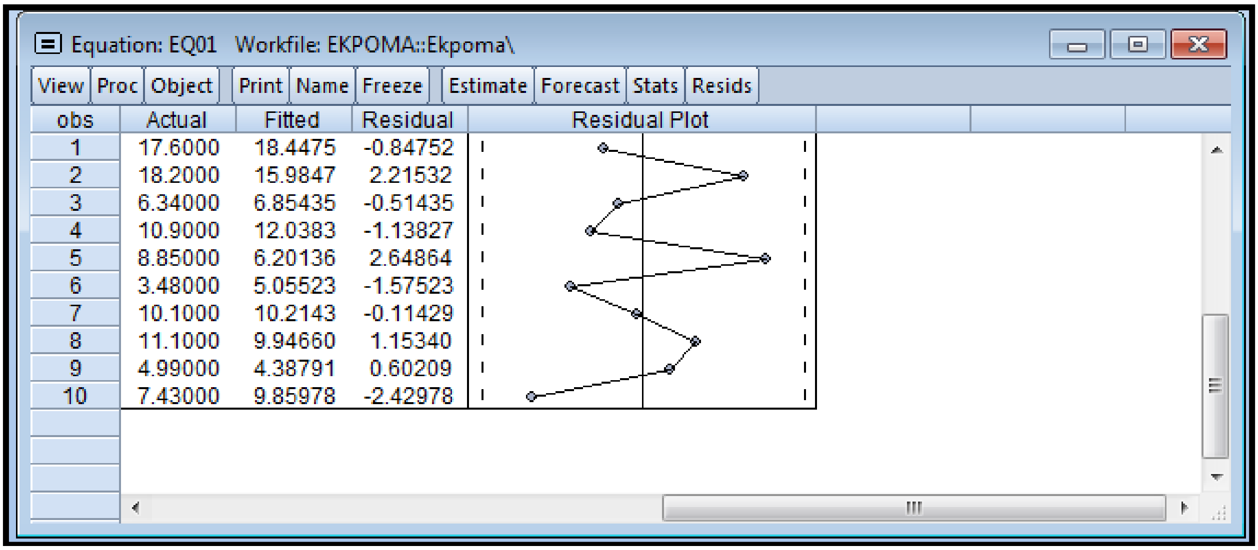


Figure 12: Statistics of fit based on 95% upper and lower bounds for unsoaked CBR

e) Statistics of fit based on 95% upper and lower bounds for soaked and unsoaked CBR

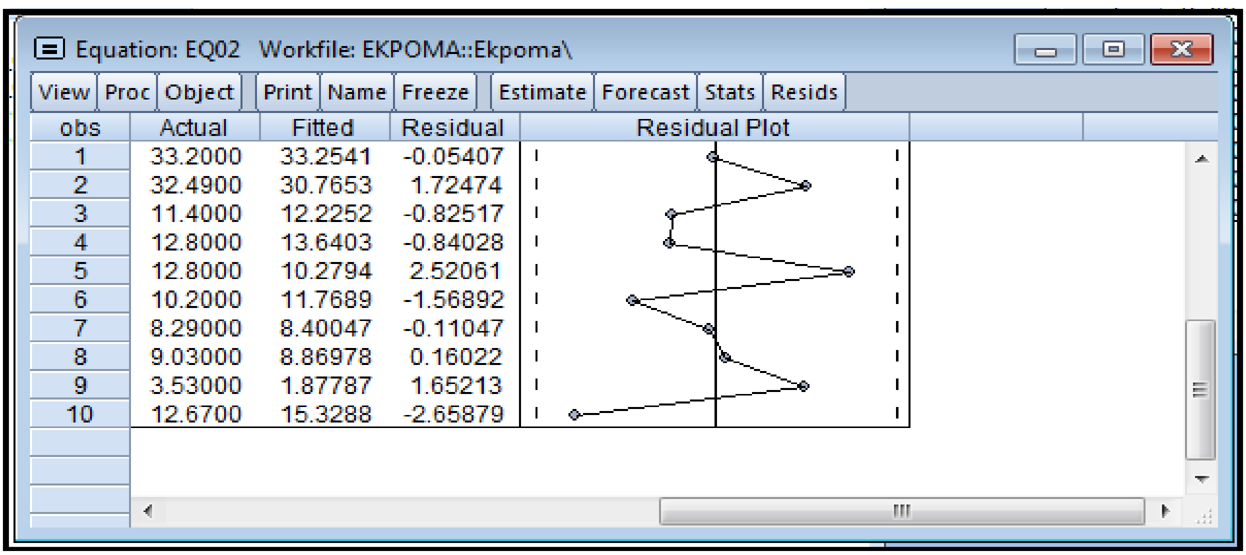
The computed statistics of fit based on 95% lower and upper bounds was visualized graphically as presented in figures 11 and 12 respectively representing the effect of selected independent variables on the soaked and unsoaked CBR for Ekpoma. The red dotted lines are the upper and lower bound of the graph, while the blue line is the CBR value. Viewing the soaked and the unsoaked CBR lines, the independent variables (LL, PL, PI, OMC, MDD, % passing of 0.075mm and 0.425mm sieve) have more effect on the soaked CBR than the unsoaked CBR values.

The statistical prediction table which shows the actual and predicted soaked and un-soaked CBR based on the multivariate regression approach is presented in figures 13 and 14 respectively.



obs	Actual	Fitted	Residual
1	17.6000	18.4475	-0.84752
2	18.2000	15.9847	2.21532
3	6.34000	6.85435	-0.51435
4	10.9000	12.0383	-1.13827
5	8.85000	6.20136	2.64864
6	3.48000	5.05523	-1.57523
7	10.1000	10.2143	-0.11429
8	11.1000	9.94660	1.15340
9	4.99000	4.38791	0.60209
10	7.43000	9.85978	-2.42978

Figure 13: Actual and predicted soaked CBR

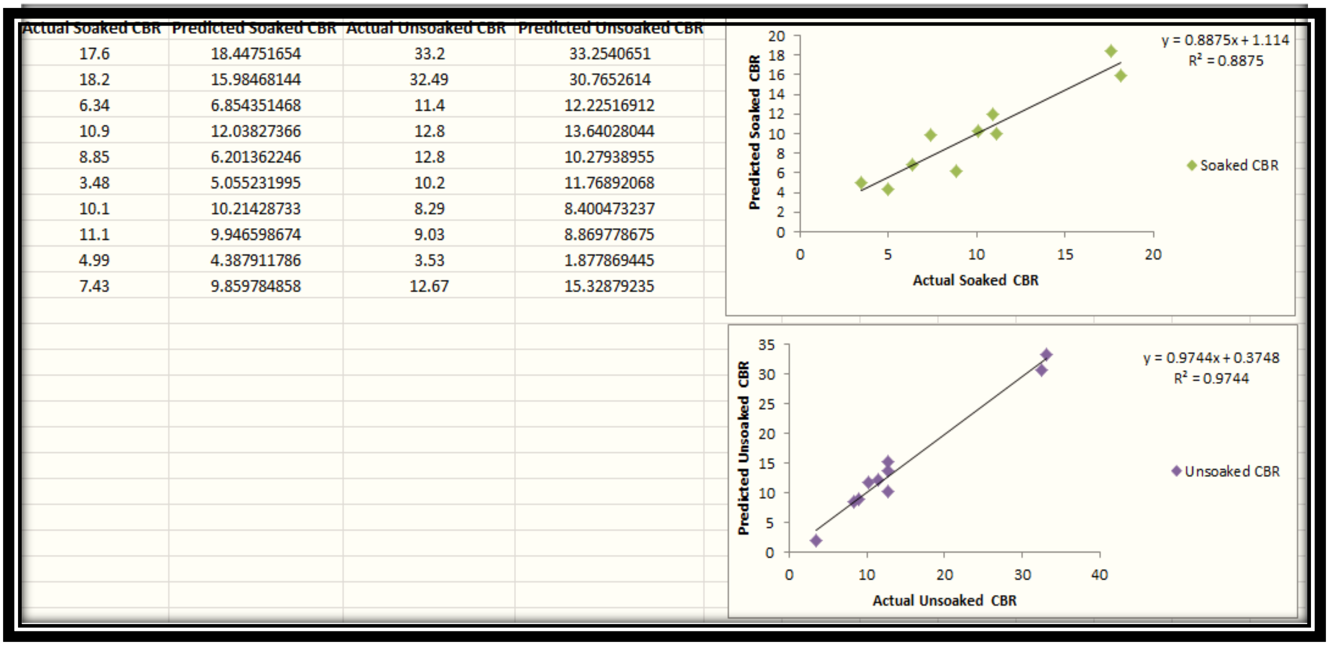


obs	Actual	Fitted	Residual
1	33.2000	33.2541	-0.05407
2	32.4900	30.7653	1.72474
3	11.4000	12.2252	-0.82517
4	12.8000	13.6403	-0.84028
5	12.8000	10.2794	2.52061
6	10.2000	11.7689	-1.56892
7	8.29000	8.40047	-0.11047
8	9.03000	8.86978	0.16022
9	3.53000	1.87787	1.65213
10	12.6700	15.3288	-2.65879

Figure 14: Actual and predicted un-soaked CBR

f) Statistical Prediction of Actual and Predicted CBR soaked and unsoaked

The statistical prediction table which shows the actual and predicted soaked and un-soaked CBR based on the multivariate regression approach is presented in Figures 13 and 14 respectively. To assess the strength of multivariate linear regression analysis in predicting the soaked and unsoaked CBR of the soil based on selected geotechnical parameters, a linear regression of output was done using the actual and predicted soaked and unsoaked CBR as the dependent and independent variables. Result obtained is presented in Figure 15



Actual Soaked CBR	Predicted Soaked CBR	Actual Unsoaked CBR	Predicted Unsoaked CBR
17.6	18.44751654	33.2	33.2540651
18.2	15.98468144	32.49	30.7652614
6.34	6.854351468	11.4	12.22516912
10.9	12.03827366	12.8	13.64028044
8.85	6.201362246	12.8	10.27938955
3.48	5.055231995	10.2	11.76892068
10.1	10.21428733	8.29	8.400473237
11.1	9.946598674	9.03	8.869778675
4.99	4.387911786	3.53	1.877869445
7.43	9.859784858	12.67	15.32879235

Figure 15: Prediction accuracy of multivariate linear regression for both soaked and un-soaked CBR (Ekpoma) sample

A plot was made between experimental and predicted values of CBR as shown in Figure 15 It is clear from this figure that most of the predicted CBR values are close to the reported experimental soaked CBR values and hence considering the limitations of developed correlation and the test related errors, the proposed equations can be regarded as well validated.

It is observed from figure 15 that the experimental soaked CBR values are close to predicted values. The model developed for soaked CBR value has correlation coefficient (R^2) =0.8875 and R^2= 0.9744 for the unsoaked indicating a reasonable fit.

Table 11: Statistical parameters of cross validation output data

Location	Model (Y)	R^2	Adjusted R^2	Standard Deviation (σ)	Standard Error (SE)	Mean (μ)
Ebhohimi CBRs	0.8991 X + 0.3126	0.8991	0.5461	2.5063	1.6884	3.1000
Ebhohimi CBRu	0.9377 X + 0.2355	0.9377	0.7197	2.8747	1.5218	3.7810
Ekpoma CBRs	0.8875 X + 1.114	0.8874	0.4935	4.8974	3.4851	9.8990
Ekpoma CBRu	0.9744 X + 0.3748	0.9744	0.8848	9.9954	3.3923	14.641

Statistical parameters such as coefficient of multiple determinations (R^2), standard deviation (σ), standard error (SE), Adjusted R^2, and mean (μ) of estimated and measured values obtained after multivariate analysis were determined for both soaked and unsoaked CBR for Ebhohimi and, Ekpoma. Comparing the soaked and unsoaked CBR values of these two locations, it was observed in Table 11, that Ekpoma sample has a higher determination coefficient (R^2) of 0.9744 for unsoaked CBR as a function of independent variables (LL, PI, MDD, OMC, 0.075mm and 0.425mm sieve) and Ebhohimi sample has a higher determination coefficient (R^2) of 0.8991 for soaked CBR, which is also as a function of the independent variables. This means that the model has a higher coefficient of determination compared with un-soaked CBR.

Table 12: Summary of the experimental and predicted CBR soaked and unsoaked

	Sample No.	BP1	BP2	BP3	BP4	BP5	BP6	BP7	BP8	BP9	BP10
Ebhohimi	Experimental Value of CBRs	0.63	3.63	8.18	2.38	1.39	3.71	1.91	1.30	4.82	0.88
	Predicted value of CBRs	0.02	4.26	7.58	3.84	1.44	4.62	1.51	2.07	5.09	0.56
	Experimental Value of CBRu	0.71	5.70	9.72	2.89	1.46	4.09	6.19	1.23	6.48	1.51

	Predicted value of CBRu	0.14	6.34	9.12	3.22	1.48	4.96	5.83	1.87	3.61	1.21
Ekpoma	Sample No.	RD1	RD2	BP3	BP4	BP5	BP6	RD7	RD8	RD9	RD10
	Experimental Value of CBRs	17.6	18.2	6.34	10.9	8.85	3.48	8.29	9.03	4.99	7.43
	Predicted value of CBRs	18.4	15.9	6.85	12.0	6.20	5.05	10.2	9.94	4.38	9.85
	Experimental Value of CBRu	33.2	32.4	11.4	12.8	12.8	10.2	10.1	11.1	5.09	12.6
	Predicted value of CBRu	33.2	30.7	12.2	13.6	10.2	11.7	8.40	8.86	1.87	15.3

IV. Conclusion

From this study, it was observed that the regression model was able to capture the relation between index properties of soils and the soaked and unsoaked CBRs. At Ebhohimi site, the coefficient of regression with values predicted from the developed regression model and experimentally obtained values were found to be high (Soaked was observed to be 0.89 and the unsoaked is 0.93). Ekpoma (R^2) was observed to be 0.88 for the soaked and 0.97 for the unsoaked.

The results of the analysis indicate that there is a close relationship between experimental CBR values and the predicted CBR values.

However, the results show that more than half of the sample materials do not satisfy the requirement for both road base and subbase. Some of the materials can only be used as subgrade materials only after thorough compaction by several passes with vibratory roller or excavation and replacement with suitable fill material has been carried out.

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