ОЦЕНЯВАНЕ НА ЯКОСТНИТЕ СВОЙСТВА НА СРЯЗВАНЕ НА ГЛИНЕСТИ ПОЧВИ В ГР. ЛАГОС С ИЗПОЛЗВАНЕ НА КОЕФИЦИЕНТА НА КОНСИСТЕНЦИЯ

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EVALUATION OF THE SHEAR STRENGTH PROPERTIES OF CLAY SOILS IN LAGOS STATE USING THEIR LIQUIDITY INDEX

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Abstract:
This paper correlates the shear strength (Cu) of clay soils and their liquidity index (LI) in Ikeja, Kosofe, Oshodi-Isolo and Ikorodu Local Government Areas (LGA.) of Lagos state. Atterberg limits and Triaixal tests were carried out on soil samples and results were correlated using statistical tools for simple and multiple regressions equations.
Results of linear regression for Ikeja, Kosofe, Oshodi-Isolo and Ikorodu soils gave; Cu = 278.5 + 0.698LI, 472 + 9.163LI, 472 + 9.163LI and 298.3 + 72.5LI respectively. Linear multiple regression for Ikeja, Kosofe, Oshodi-Isolo and Ikorodu gave; CU = 232.8 +80.74 LI - 28.67ϕ, 251 + 42.27 IL - 27.92ϕ, 899.2 + 5.464 LI - 27.92ϕ and 698.371+(42.271)LI - 5.585 ϕ respectively while exponential multiple regression gave; CU = $(4.90402)(0.16500)^{LI} + (0.05266)^{\phi}$, $(6.64407)(0.09110)^{LI} - (0.01206)^{\phi}$, $(12.7621)(2.6198)^{LI} - (0.1175)^{\phi}$ and $(6.64407)(0.09110)^{LI} – (0.01206)^{\phi}$ respectively. Ikeja soil gave minimum correlation coefficient of 0.849 indicating perfect correlation of the data.

Keywords:
Liquidity index, Shear Strength, Atterberg Limit, Triaxial Test, Cassagrande, Regression, Correlation, Clay Soil.

1. INTRODUCTION

This study considered the possibility of expressing the relationship between the undrained shear strength (Cu) and liquidity index (IL) of clays by an empirical equation, such that it would be possible to estimate the shear strength of a clay by using its liquidity index. It is considered that Atterberg limit tests are not only convenient but may also provide a cheaper method of assessing the quick undrained shear strength of clays.

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Atterberg Limits and Index properties have been in wide use for preliminary soil classification. It is well known fact that natural structure of a clayey soil has a marked influence on its engineering behaviour. The Liquid limit and plastic limit indicate the plasticity of soil and both are dependent on amount and type of clay in the soil, while the plasticity index is seen to be dependent mainly on the amount of clay present in the soil. Plasticity index in combination with the liquid limit forms the basis for identifying both the type and nature of clay.

The Atterberg limits are a basic measure of the critical water contents of a fine-grained soil, its shrinkage limit, plastic limit, and liquid limit. It is well known that over-consolidated clays have higher shear strength than unconsolidated deposits and this is also reflected in the liquidity index by the difference in moisture content. As a dry, clayey soil takes on increasing amounts of water, it undergoes distinct changes in behaviour and consistency).

This study was undertaken to determine the natural water content, liquid limit, plastic limit, plasticity index, liquidity index (using Atterberg limit) and shear strength (using liquidity index) of a soil that are to have engineering structures built on it, so as to control the effect of shrinkage and expansion and also avoid failure of any structure build on it. Thus, these test are used widely in the preliminary stage of designing any structure to ensure that the soil have the correct amount of shear strength and not too much change in volume as it expand and shrink with different moisture content. It is considered that this work provides a rough indication of the shear strength of clayey soils by using their liquidity index value

2. LITERATURE REVIEW

Proper determination of the soil shear resistance parameters (cohesion and angle of internal friction) is a major factor in the design of different geotechnical constructions. These parameters can be found either on the site or in the laboratory. The most common tests which are used for determining the cohesion and angle of shearing resistance values in the laboratory are triaxial compression and direct shear tests. However, experiment conducted on laboratory to determine the shear strength parameters is extensive, cumbersome and costly. In order to avoid these problems, numerical solutions have been developed to determine the shear strength parameters.

When the quality of the soil-strength data is poor, geotechnical engineers may wish to evaluate the shear strength as a lower bound value in making important design decisions (Wood, 1990; Kayabali and Tufenkci, 2010; O'Kelly, 2013).

Undrained shear strength and compression index are very useful parameter in order to take engineering decision. The bearing capacity of soil estimate mainly the unrdained shear strength of the soil. Laboratory test for obtaining these values are expensive and time consuming process, while the soil parameter like natural moisture content, Atterberg limits and field density can be estimated faster and cheaper. Therefore, the relationship of shear strength from water content, Atterberg limits and field density are useful for restraint of testing number and costs (Kiran and Hari, 2016, Slamet widodo *et al* ., 2014).

The measured values for the liquid and plastic limits of soils are widely used as index parameters. They are used to compute the plasticity index, which can be empirically correlated against many soil properties in geotechnical design (Vardanega and Haigh, 2014).

Sample disturbance is one of the most important factors influencing the undrained shear strength of fine-grained soils measured by laboratory techniques. The unconfined compression test (UCT) is one of the most common tools used to determine the undrained shear strength of soils. The undrained shear strength determined in this way is highly sensitive to disturbance caused by the sampling process, compared to other means such as consolidation or triaxial tests (Kamil *et al*., 2015)

(Nagaraj *et al*., 2012) further stated that published data from various literature sources clearly show that the variation of the undrained shear strength at the liquid limit is observed to be nearly 60 times (from as low as 0.2 kPa to as high as 12 kPa) and that at the plastic limit is more than 17 times (from 35 kPa to 600 kPa), hence no unique value of undrained shear strength can be assigned either at the liquid limit or plastic limit of soils.

According to (Tuncer and Craig, 2009), the undrained strength of clays has been widely related to the liquidity index *IL*

It should be noted that regression equation between soil parameter and the Atterberg limits had been developed more than 50 years ago. Several authors have proposed relationships between strength and liquidity index and a lot of researches have been carried out in modern times due to sophistication of laboratory equipment and their relative accuracy. Determining of undrained shear strength and compressibility parameters in laboratory are however really tedious and time consuming. Therefore, a correlation between undrained shear strength and Atterberg limits is useful for restraint of testing number and costs (Slamet Widodo *et al*., 2014).Following this, several correlation equations have been proposed from the relationship between the shear strength of clay soils and their liquidity index as well as other Atterberg limits parameters.

Clay is predominant in most of the subgrade soils of Nigeria. Due to the relative abundance of these soils and ease of acquisition they have found wide application in engineering construction works. (Oyediran and Durojaiye 2011).

Obasi (2012) conducted an independent laboratory tests on some clay samples sourced from several actual project locations in Eastern Nigeria, and made relationship between undrained shear strength(Cu) and plasticity index(PI.).

Liquidity index (IL) is calculated as a ratio of the difference between the natural moisture content and plastic limit to the plasticity index (Adebisi, 2012)

The study evaluated the undrained shear strengths and the liquidity index using both linear and multiple regressional analysis.

3. METHODOLOGY

The study locations were four land areas in Lagos metropolis namely Ikeja, Ketu, Oshodi and Ikorodu. Soil samples were collected from six sampling points (designated as BH 1 – 6) in each of the locations. Disturbed samples were collected at varying depths of 0.2m to 0.3m for grain size distribution for Atterberg limits test while the undisturbed samples were collected for the Triaxial test to determine the shear strength at the depth of 0.5m. Diameter hand hanger was deployed for the sample collection for Atterberg limit test and tubes were utilized for the collection of soil sample for the triaxial shear strength test. The sample collected in the field were moved to the laboratory wrapped in polythene bags. This was to prevent moisture alteration.

The following laboratory tests carried out included the Atterberg Limit and undrained triaxial tests. The Atterberg limit tests were used to the determine the liquid and plastic limits respectively while the undrained triaxial was used to determine the shear strength of the soils.

3.1. Atterberg Limit

The liquid limit is the moisture content at which the groove, formed by a standard tool into the sample of soil taken in the standard cup, closes for 10mm on being given 25 blows in a standard manner. That is, the limiting moisture content at which the cohesive soil passes from liquid state to plastic, while the plastic limit of a soil is the statement of water or moisture content as a percentage of its dried weight.

The following procedures were observed:

i. Weight of the moisture cans were taken and named A, B, C for easy identification and recorded the weights with respective to their names on a sheet.
ii. Water was added from wash bottle little by little to the soil sample that passed the no.40 sieve pan while mixing the sample with spatula, until the ball formed is non sticky to the palm or finger.

iii. A uniform thread was formed from the soil ball was rolled into glass plate using the fingers in forward and backward movement thereby providing enough pressure of 90 strokes per minute.
iv. The thread was rolled until it was 3 mm in diameter and broken into pieces. This process was repeated for two steps until the rolling thread crumbled.
v. The weight of the crumbled soil were collected in the moisture cans (A, B, C).
vi. The moisture cans were then kept in oven for sixteen hours to dry well.
vii. The dried weights of all the soil samples were taken
viii. The water content of the soil were expressed as a percentage of the oven dried mass for each of the trials calculated. The flow curve on the semi-logarithmic graph provided the relationship between the water content and the corresponding number of drops of the cup. The flow curve is a best fit straight line drawn as nearly as possible to the plotted points.
ix. The liquid limit, LL, of the soil is the water content which corresponds to the intersection of the flow curve with the 25 drops ordinate reported to the nearest integer. This can also be done in Excel using a scatter plot, fitting a trend line using a logarithmic model to find the equation ($w = a + b[log(N)]$), then substituting a value of N = 25 into this equation and manipulating to solve for w, the Liquid Limit.
x. The portions of the crumbled roll together and place in a moisture can. 25(*N LL = w 0.12N*). The container and the moist soil were weighed and dried in the oven while the other half was repeated.
xi. The plasticity index was calculated from(PI = LL – PL)

3.2. Undrained Triaxial Test

The standard undrained triaxial test is a compression test, in which the soil specimen is first consolidated under all round pressure in the triaxial cell before failure is brought about by increasing the major principal stress.

It may be perform with or without measurement of pore pressure although for most applications the measurement of pore pressure is desirable.

i. The sample was placed in the compression machine and a pressure plate was placed on the top carefully to prevent any part of the machine or cell from jogging the sample while it was being setup. The probable strength of the sample was estimated and a suitable proving ring selected and fitted to the machine.
ii. The cell was properly set up and uniformly clamped down to prevent leakage of pressure during the test, making sure that the sample was properly sealed with its end caps and rings (rubber) in position and that the sealing rings for the cell were correctly placed.
iii. After the sample was setup, water was admitted and the cell was fitted under water, escapes from the valve, at the top which was closed, but water was not required when the sample was to be tested at zero lateral pressure.
iv. The air pressure in the reservoir was increased to raise the hydrostatic pressure to the required amount. The pressure gauge was set during the test and all the necessary adjustments was made to keep the pressure constant.
v. The handle wheel of the screw jack was rotated until the underside of the hemispherical seating of the proving ring, through which the loading was applied, touched the cell piston.
vi. The piston was then lowered down by the handle until it touched the pressure plate on the top of the sample, and the proving ring was again brought in contact for another test.

4. RESULTS, ANALYSIS AND DISCUSSION

4.1. Atterberg Limit Tests

Five (5) tests were carried out on soil samples from each of the location as shown in the figures below

Table 4.1. Liquid limit results

LGA.	Type of test	LL	LL	LL	LL	LL		PL	PL
Ikeja	Container No								
	No of blows	42	35	27	19	12			
	wt. of wet soil + container (g)	28.5	33.8	38.8	45.1	43.7		24.3	26.1
	wt. of dry soil + container (g)	25.1	27.6	30.5	35.5	31.4		23.1	24.7
	wt. of container (g)	16.9	15.7	17.1	21.4	16.7		15.9	18.0
	wt. of dry soil (wd) (g)	8.2	11.9	13.4	14.1	14.7		7.2	6.7
	wt. of moisture (wm) (g)	3.4	6.2	8.3	9.6	12.3		1.2	1.4
	Moisture content (Wm.Wd)%	41.5	52.1	61.9	68.1	83.7		16.67	20.89
Oshodi	Container No								
	No of blows	40	33	27	17	13			
	wt. of wet soil + container (g)	28.8	32.7	40.5	33.3	40.2		22.5	21.4
	wt. of dry soil + container (g)	24.6	26.8	31.8	25.5	29.8		21.5	20.5
	wt. of container (g)	15.3	15.9	18.0	14.6	16.7		16.3	15.6
	wt. of dry soil (wd) (g)	9.3	10.9	13.8	10.9	13.1		5.2	4.9
	wt. of moisture (wm) (g)	4.2	5.9	8.7	7.8	10.4		1.0	0.9
	Moisture content (Wm.Wd)%	45.2	54.1	63.0	70.3	80.9		19.2	18.4
Ikorodu	Container No								
	No of blows	43	37	29	21	15			
	wt. of wet soil + container (g)	28.4	35.7	39.8	36.9	40.7		23.6	22.1
	wt. of dry soil + container (g)	24.8	29.3	30.9	28.4	30.5		22.1	20.9
	wt. of container (g)	16.5	16.7	15.6	15.6	17.4		16.7	16.4
	wt. of dry soil (Wd) (g)	8.3	12.6	15.3	12.8	13.1		5.4	4.5
	wt. of moisture (Wm) (g)	3.6	6.4	8.9	8.5	10.2		1.5	1.2
	Moisture content (Wm.Wd)%	43.4	50.8	58.2	65.6	77.9		27.8	26.7
Kosofe	Container No								
	No of blows	32	29	27	12	10			
	wt. of wet soil + container (g)	32.0	46.7	46.8	54.2	42.5		51.1	52.8
	wt. of dry soil + container (g)	30.3	42.7	39.1	44.8	35.6		47.8	49.3
	wt. of container (g)	16.3	16.8	15.6	19.0	16.1		42.5	45.3
	wt. of dry soil (Wd) (g)	14.0	25.9	23.5	25.8	19.5		5.3	4.0
	wt. of moisture (Wm) (g)	1.7	4.0	7.7	9.4	6.9		3.3	3.5
	Moisture content (Wm/Wd)%	12.4	15.4	32.8	36.4	35.4		62.3	87.5

Table 4.2. Water content

LGA.	Weight of wet sample + lid (grams)	Weight of dry sample + lid (grams)	Weight of dry sample (grams)	Weight of wet sample (grams)	Weight of wet sample (grams)	Weight of water (grams)
Ikeja	24.3	23.1	15.9	7.2	8.4	1.2
	25.1	24.7	18.0	56.7	8.1	1.4
Oshodi	22.5	21.5	16.3	5.2	6.2	1.0
	21.4	20.5	15.6	4.9	5.8	0.9
Ikorodu	23.6	22.1	16.7	5.4	6.9	1.5
	22.1	2.9	16.4	4.5	5.7	1.2
Kosofe	51.1	47.8	42.5	5.3	8.6	3.3
	52.8	49.3	45.3	4.0	7.5	3.5

Table 4.3. Computed moisture content (mc)

LGA.	Weight of Wet Sample Ww (g)	Weight of Dry Sample Ws (g)	Moisture Content M	Percentage Moisture content % M	Average Percentage Moisture Content % M
Ikeja	1.2	7.2	0.167	16.67	18.78
	1.4	6.7	0.208	20.89	
Oshodi	1.0	5.2	0.192	19.23	18.80
	0.9	4.9	0.184	18.37	
Ikorodu	1.5	5.4	0.278	27.77	27.22
	1.2	4.5	0.257	26.67	
Kosofe	3.3	5.3	0.622	62.26	74.88
	3.5	4.0	0.875	87.5	

Table 4.4. Maximum principal stress

LGA.	Cell pressure (kN/m^2)	Principal stress difference (deviator stress) (kN/m^2)	Maximum principal stress (cell pressure + deviator stress) (kN/m^2)
Ikeja	100	399.47	499.47
	200	573.16	773.16
	300	613.68	913.68
Oshodi	100	422.63	522.63
	200	639.74	839.74
	300	674.47	974.47
Ikorodu	100	451.58	551.58
	200	660.00	860.00
	300	677.39	977.39
Kosofe	100	416.8	516.8
	200	741.1	941.1
	300	810.5	1110.5

Table 4.5. Table of shear strength and liquidity index

points	Shear Strength	Liquidity index
A	528.87	1.93
B	578.95	2.02
C	596.32	2.16

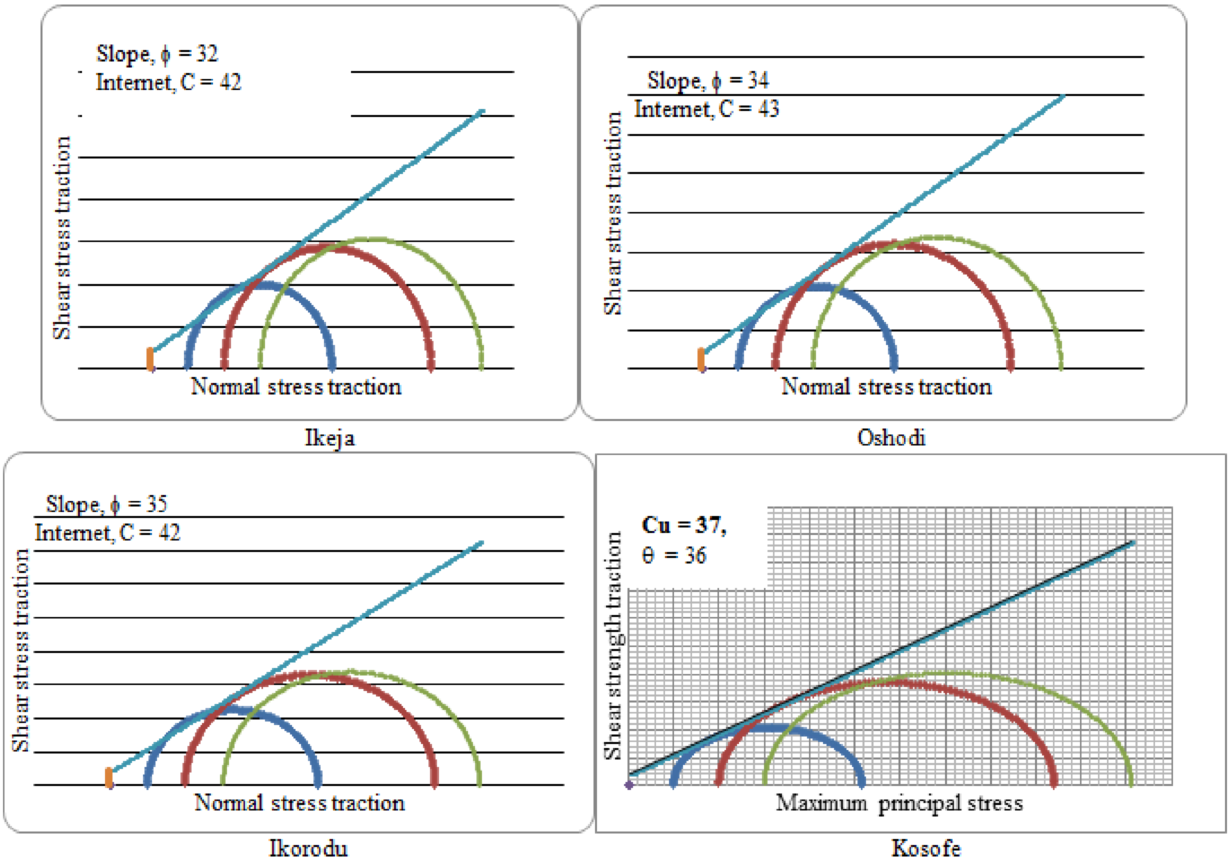

Figure 4.1. Mohr Circle graph

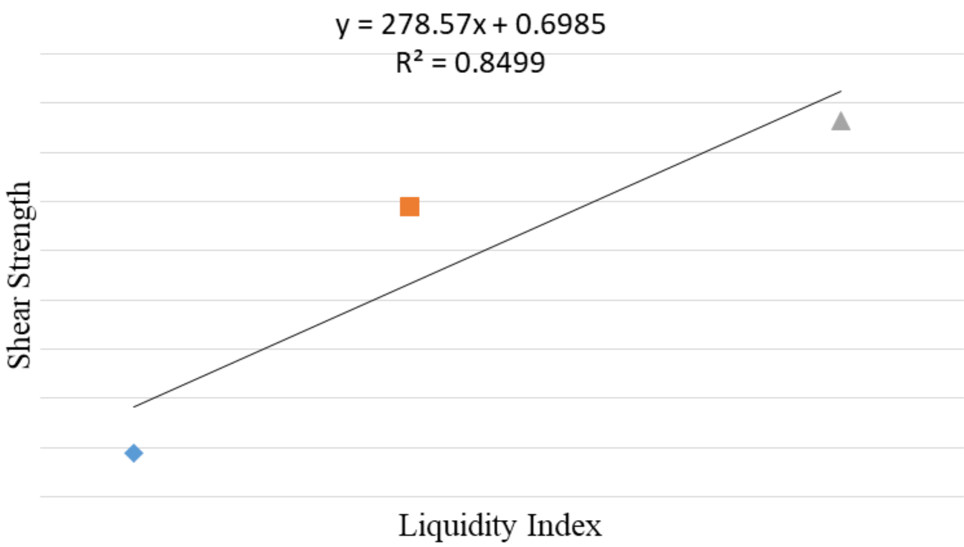

Figure 4.2. Linear regression graph for shear strength and liquidity index

4.2. Simple Regression Models

From the linear graph above

Cu= 278.5LI + 0.698

$R^2 = 0.849$

From the exponential graph

$Cu=270.0e^{0.494IL}$

$R^2 = 0.841$

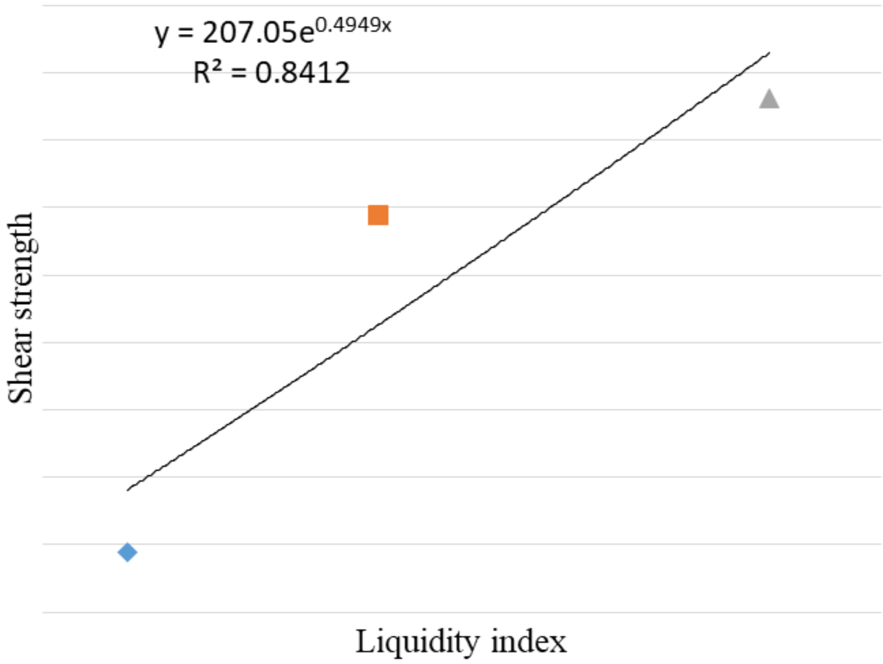

Figure 4.3. Exponential regression graph for shear strength and liquidity index

Table 4.6. Table of shear strength, liquidity index and phai (ϕ)

points	Shear Strength (Cu)	Liquidity index (LI)	Phai (ϕ)
A	528.87	1.93	32
B	578.95	2.02	34
C	596.32	2.16	35

4.3. Multiple Exponential Regression Models

Coefficients:

(Intercept)	L.I	ϕ
4.90402	-0.16500	0.05266

Equation $CU = (4.90402) - (0.16500)^{LI} (0.05266)^{\phi}$

The results shown above gives us estimate for Regressed-values and these values indicate contribution of predictors to the model. The Exponential regression model is

$CU = (4.90402) - (0.16500)^{LI} + (0.05266)^{\phi}$.This implies that *L.I* has a positive significant effect on *CU* while ϕ has a negative non-significant effect on *CU*. Hence, the best predictor of *CU* was *L.I* whereas ϕ has no effect.

4.4. Multiple Linear Regression Models

Coefficients:

(Intercept)	L.I	ϕ
-232.8	-80.74	28.67

Equation $CU = -232.8 - 80.74LI + 28.67\phi$

The Multiple Linear estimate for Regressed-values and these values indicate contribution of predictors to the model. The Multiple regression model is $CU = -232.8 - 80.74LI + 28.67\phi$. This implies that *L.I* has a positive significant effect on *CU* while ϕ has a negative non-significant effect on *CU*. Hence, the best predictor of *CU* was *L.I* whereas ϕ has no effect.

5. CONCLUSION

The relationship of shear strength and the liquidity index of soil samples collected from four locations in Lagos Metropolis, Nigeria were investigated. An exponential regression models were conducted in order to obtain the most suitable relationships between the shear strength *(C_U)* and the liquidity index *(I_L)*.

i. The regression equation demonstrates that a direct linear relationship exist between shear strength value and the soil liquidity index. It was shown that the undrained shear strength is related to the liquidity index via the linear regression equations $Cu= 278.5LI + 0.698$ $(R^2 = 0.849)$
ii. The regression equation demonstrates that a direct exponential relationship exist between shear strength value and the soil liquidity index. It has been shown that the undrained shear strength is related to the liquidity index via the exponential regression $Cu = 270.0e^{0.494IL}$ $(R^2 = 0.841)$.
iii. A good agreement was observed between the actual and predicted values of shear strength, which is the main characteristic of a good fitting model.
iv. Multiple regression equations between the shear strength, liquidity index and the angle of internal friction from the mohr circle were also derived for both linear and exponential equations
v. C $CU = (4.90402) – (0.16500)^{LI} + (0.05266)^{\phi}$ for the exponential and $Cu = -232.8 - 80.74\ LI + 28.67\ \phi$ for the linear equation.
vi. Liquidity index (IL) values for the soil samples are more than zero. This shows moisture content is higher than the plastic limit, and it is indicative of semi-liquid soil.
vii. In the regression equations, the value of R2 increases with increase in independent variable, which indicate that the value of shear strength influence the value of liquidity index of the soil.

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