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Laboratory Analysis of Some Index Properties of Lateritic Soil Partially Replaced with Quarry Dust

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Abstract

The index properties of soils are properties which facilitate the identification and classification of soils for engineering purposes. These properties indicate the type and conditions of the soil. Over the years, it has been observed that failure of infrastructure occurs when poor earth materials are used in construction and lateritic soil is one of these earth materials. They lack the capacity to perform satisfactorily in the landfill areas because of their high hydraulic conductivity despite the fact that they are firm soils. The materials used for this research are lateritic soil and quarry dust. The lateritic soil sample used was collected beside the Civil Engineering laboratory, University of Benin at (06° 24' 01.326"N, 05° 37' 02.988"E) while the quarry dust samples used was collected from the Structural Laboratory Unit of the Civil Engineering laboratory, University of Benin at (06° 24' 11.310"N, 05° 37' 01.026"E). The disturbed lateritic soil sample was collected at a depth of 1.5m and transported to the Civil Engineering Laboratory. The lateritic soil was air dried for five days to allow for partial elimination of natural water and then sieved with sieve no. 4 (4.75mm opening) to obtain the final soil samples for the tests. This lateritic soil sample and the quarry dust was mixed at 5%, 10%, 15%, 20% and 25% by weight and the following test were performed; particle size test, specific gravity, Atterberg limit and compaction. From the laboratory test carried out, it was observed that the soil is of the clayey sand soil type of medium plasticity with a specific gravity of 2.13, a liquid limit of 29.5%, and a plastic limit of 19.37%, an OMC of 14.6% and an MDD of 1.68mg/m3. When compared with the specifications of the Federal Ministry of Works and Housing (FMWH), the soils with these values are not suitable for use as construction materials as they usually have low shear strength and are more susceptible to the shrink-swell behavior. However, at 25% replacement quarry dust replacement, the specifications were satisfactory with a liquid limit of 23.8%, a plastic limit of 10.28%, an OMC of 11.90% and a MDD of 1.73 mg/m^3, which conform to (FMWH) standard. However, regarding ANOVA analysis carried out, the null hypothesis was rejected at 5% level of significance showing that there is a significant difference in the percentage replacement of the lateritic soil sample with quarry dust.

1.0 Introduction

The index properties of soils are properties which facilitate the identification and classification of soils for engineering purposes. These properties indicate the type and conditions of the soil, provide a relationship to structural properties and are used extensively by engineers to

discriminate between the different kinds of soil within a broad category [1]. Since the index property of a soil provides a good knowledge about the soil conditions, it is important that these properties are investigated before construction is done on such soil in order to have a safe and economic work. The index properties of soils have therefore been considered an essential preliminary to the construction of any civil engineering work such as road, buildings, dams, bridges, foundations, among others [2]. Over the years, it has been observed that failure of infrastructure occurs when poor earth materials are used in construction and lateritic soil is one of these earth materials. Lateritic soils which contribute to the general economy of the tropical and sub-tropical regions, where they are in abundance have been found to lack the capacity to perform satisfactorily in the landfill area because of their high hydraulic conductivity despite the fact that they are firm soils [3]. Hence, modification of these soils to improve their performance as construction materials becomes necessary. This is known as soil stabilization.
Soil stabilization achieves a number of objectives that are important in obtaining a long-lasting structure from earth materials, including better mechanical characteristics, better cohesion between particles which reduces the porosity and changes in volume due to moisture fluctuations, and improved resistance to rain, wind and erosion. However, lime and cement are most commonly used stabilizing agents for soils are becoming increasingly expensive. Therefore, the use of waste materials, either from industries or from agricultural produce has been initiated owing to its good engineering properties as well as its economy [4]. The present study however seeks to investigate the effects of various percentages of quarry dust on the index properties of lateritic soil.
Studies carried out by [5]; [6]; [7]; [8]; [9] has proven quarry dust to be a well-accepted and cost effective ground improvement technique for weak soil deposits and these, being largely a waste product, will reduce environmental impact, if consumed by construction industries in large quantities.

2. Methodology

2.1. Sample location

The main materials used for this research are lateritic soil and quarry dust. The lateritic soil sample used was collected beside the Civil Engineering Laboratory, University of Benin at (06° 24' 01.326"N, 05° 37' 02.988"E) while the quarry dust sample used was collected from the Structural Laboratory Unit of the Civil Engineering Laboratory, University of Benin at (06° 24' 11.310"N, 05° 37' 01.026"E).

2.2. Collection and preparation of samples

The disturbed lateritic soil sample was collected from beside the Civil Engineering Laboratory, University of Benin at a depth of 1.5m and transported to the Civil Engineering Laboratory. The lateritic soil was air dried for five days to allow for partial elimination of natural water and then sieved with sieve no. 4 (4.75mm opening) to obtain the final soil samples for the tests.

2.3. Mix proportions

Quarry dust were added to the lateritic soil sample at a 5% increment and this percentage replacement was done by weight of the soil. The mix proportions are shown in Table 1.

Table 1: Mix Proportions of Quarry Dust

S/N	Lateritic soil %	Quarry Dust %	% of lateritic soil + Quarry Dust
1	100	0	100
2	95	5	100
3	90	10	100
4	85	15	100
5	80	20	100
6	75	25	100

2.4. Laboratory test

The following index property tests were carried out on the above samples according to the American Society for Testing and Materials (ASTM) Standards: Particle size distribution using the Sieve Analysis Method, Specific gravity test, Atterberg limits tests (plastic limit and liquid limit) and Compaction test. The Atterberg limits test and compaction test was carried out on the lateritic soil sample at 0%, 5%, 10%, 15%, 20% and 25% replacement with quarry dust.

2.4. Particle size distribution test

The particle size distribution is the relative number of particles in a soil sample that is distributed over specified size ranges. This test is performed to determine the percentage of different grain sizes contained within a soil sample. The particle size distribution test was carried out in accordance to the American Society for Testing and Materials [10]. From this, the percentage mass retained on each sieve as well as the uniformity coefficient is estimated using Equation (1) and (2).

$$\text{Percentage retained} = \frac{weight\ of\ soil\ retained}{total\ weight\ of\ soil} \times 100 \quad (1)$$

$$\text{Uniformity Coefficient, } C_u = \frac{D_{60}}{D_{10}} \quad (2)$$

Where,

D_{60} = grain diameter at which 60% of soil particles are finer and 40% are coarser,

D_{10} = grain diameter at which 10% of soil particles are finer and 90% are coarser.

2.5. Specific gravity test

This refers to the mass of solids present in a soil compared to the mass of water in that same soil at the same volume. Determining the specific gravity of soils helps engineers understand how porous the soil is or how many voids it contains. Specific gravity test is therefore required in calculating phase relationships of soils. The test was carried out in accordance with the method described by the American Society for Testing and Materials [11]. From this, the specific gravity of the soil is estimated using Equation (3).

$$\text{Specific gravity, } \rho_s = \frac{(W_3 - W_1)}{(W_2 - W_1) - (W_3 - W_4)} \quad (3)$$

Where,

W_1 = Weight of density bottle,

W_2 = Weight of density bottle + soil sample,

W_3 = Weight of density bottle + Soil sample + water

W_4 = Weight of density bottle + water

2.6. Atterberg limits test

The Atterberg limits tests are widely used procedure for establishing and describing the consistency of cohesive soils and in soil classification. The two commonly determined Atterberg limits are the liquid and plastic limit of a soil. The liquid limit is the moisture content at which soil changes from a plastic to a liquid state. Here, the casagrande method was used to determine the liquid limit of the soil sample. The liquid limit for a soil is usually obtained from a plot of moisture content against number of blows. The plastic limit is the moisture content at which the soil will start to crumble. From this, the plasticity index for the soil is estimated using Equation (4).

$$\text{Plasticity Index, } PI = LL - PL \quad (4)$$

Where,

PI = Plastic Index
LL = Liquid Limit
PL = Plastic Limit

2.7. Compaction test

Compaction of soil is done to determine the optimal moisture content at which a given soil experiences its maximum compression and achieves its maximum dry density. This is achieved by the application of stress on the soil resulting in the removal of air voids leading to its densification. The test was carried out in accordance with the method described by the American Society for Testing and Materials [12] Standard. From this, the maximum dry density for the soil is estimated using Equation (5)

$$\text{Dry Density, } \gamma_d = \frac{W_2 - W_1}{(1+w).V} \quad (5)$$

Where,

W_1 = weight of mold + base plate (kg),
W_2 = weight of mold + base plate + compacted soil (kg),
W = moisture content of the soil (%),
V = volume of the mold ($1000cm^3$)

3.0. Results and Discussion

The results obtained from the laboratory tests carried out on the lateritic soil and quarry dust samples at appropriate percentage replacements are presented and discussed in the following subsection.

3.1. Sieve Analysis Test

The results of the sieve analysis test carried out on the lateritic soil sample is presented in Table 2.

Table 2: Results of sieve analysis on lateritic soil

Sieve no (mm)	Mass Retained (g)	Mass Passing (g)	Percentage Passing (%)
2.36	0	100	100
2	0	100	100
1.18	1.2	98.8	98.8
0.6	12.2	86.6	86.6
0.425	8.3	78.3	78.3
0.3	12	66.3	66.3
0.212	16.3	50	50
0.15	4.9	45.1	45.1
0.075	4.7	40.4	40.4

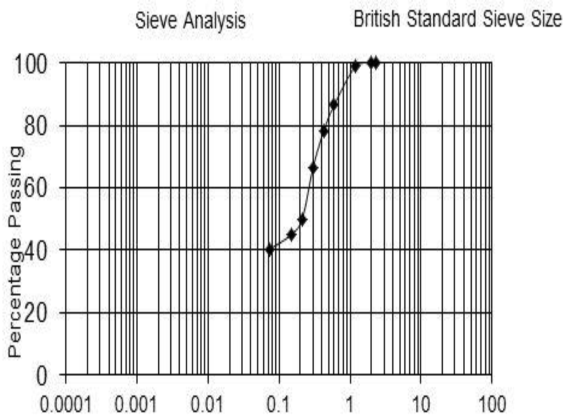

Fig 1: Particle Size Distribution Graph of the Lateritic soil sample

Table 2 shows the results of sieve analysis carried out on the lateritic soil sample. The percentage fine of the soil was found to be 40.4% being the percentage of lateritic soil particles passing through the sieve 0.075mm. Classification based on [13] indicated that the curve observed in Fig. 1 is clayey-sand soil. According to the [14] specification, the clay content for both sub-grade and sub-base material must not exceed 35%. Since the soil sample has more clay content, it is not suitable for use as a construction material as this could be responsible for instability in structures.

3.2. Specific gravity test

The results of the specific gravity test carried out on the lateritic soil sample is shown in Table 3

Table 3: Results of specific gravity on lateritic soil

Bottle Number	B	B + S	B + S + W	B + W	WS	GS	AGS
DI	22.7	53.7	92.9	75.4	31	2.3	
JO4	20.4	45.3	83.2	69.1	24.9	1.95	2.13

As seen in Table 3, the specific gravity of the lateritic soil was calculated as 2.13. According to [15], the lower the specific gravity, the larger the clay fraction of the soil is. The AASTHO system of classification has established that standard range for specific gravity of lateritic soil is 2.0-3.0. Since the specific gravity value is on the lower side, the lateritic soil sample tested contains large clay fraction. Soils with high clay fraction are known to have low strength, high compressibility and high level of volumetric changes and are most susceptible to shrinking and swelling. The soil being fairly plastic is therefore, plastic, has low strength, high compressibility and is susceptible to the shrink-swell behavior.

3.3. Atterberg Limits (Liquid and Plastic Limit)

The results for the Atterberg limit test carried out on the lateritic soil sample at 0%, 5%, 10%, 15%, 20% and 25% replacement with quarry dust is shown in Table 4.

Table 4: Results of the Atterberg limits test

% of quarry dust	Liquid Limit (%)	Plastic Limit (%)	Plasticity Index %
0	29.5	19.37	10.13
5	28.5	18.64	9.86
10	27.5	15.81	11.69
15	25.5	14.83	10.67
20	24.5	14.29	10.21
25	23.8	10.28	13.52

As outlined in [13], liquid limits less than 30% are considered to be of low plasticity and compressibility. Soils with this liquid limit are least susceptible to the shrink-swell condition. The results for liquid limit obtained in Table 4 satisfies this condition with the lateritic soil sample at 25% quarry dust replacement having the lowest potential to exhibit the shrink-swell behavior. The Federal Ministry of Works and Housing [14] specifies that liquid and plastic limits of 35% maximum, and plasticity index of 12% minimum are suitable for use as sub-base and base course materials for construction works. While the soil sample at 0-20% did not satisfy this condition, it did at 25% quarry dust replacement satisfies this condition thus making the soil suitable for use as a sub-base and base material.

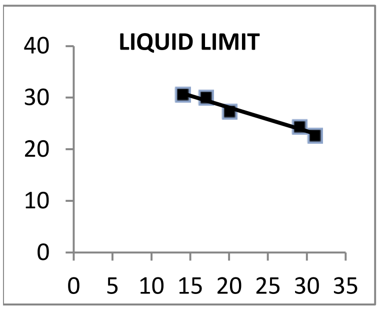

Fig 2: Graph of Atterberg limits at 0% replacement

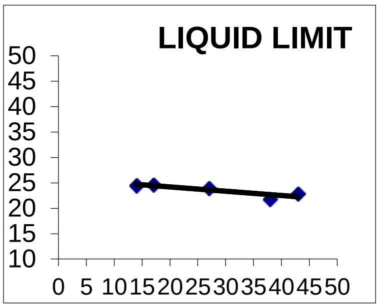

Fig 3: Graph of Atterberg limits at 5% replacement

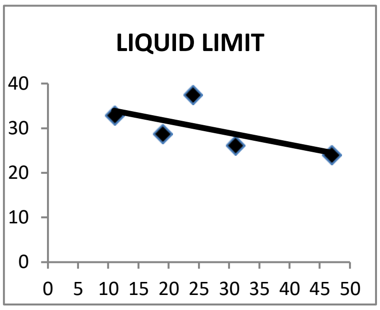

Fig 4: Graph of Atterberg limits at 10% replacement

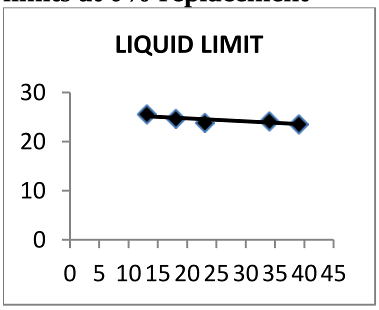

Fig 5: Graph of Atterberg at 15% replacement

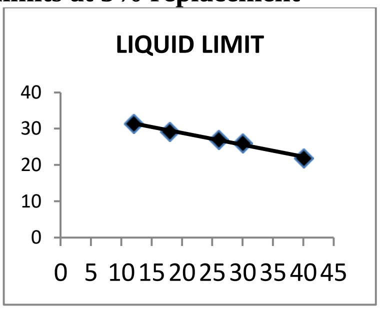

Fig 6: Graph of Atterberg limits at 20% replacement

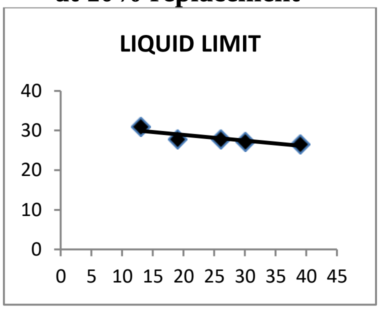

Fig. 7: Graph of Atterberg limits limits at 25% replacement

3.3. Compaction Test

The results for the compaction test carried out on the lateritic soil sample at 0%, 5%, 10%, 15%, 20%, 25% replacement with quarry dust buttressed as optimum moisture content and maximum dry density is presented in Table 5.

Table 5: Results of the compaction test

% of quarry dust	Optimum moisture content	Maximum Dry Density
0	14.60	1.68
5	13.87	1.69
10	15.00	1.70
15	12.02	1.71
20	12.00	1.72
25	11.90	1.73

Table 5 shows that the optimum moisture content reduces while the maximum dry density increases with increase in the percentage of quarry dust present in the lateritic soil sample. According to [16], samples characterized with high value of maximum dry density and low optimum moisture content is best suitable for use as sub-base and sub-grade materials. Also, the Federal Ministry of Works and Housing specified OMC less than 18% for both sub-base and sub-grade materials. Based on these specifications, the soil with 25% quarry dust replacement best satisfies both conditions and is hence, more suitable for use as a sub-base and sub-grade material.

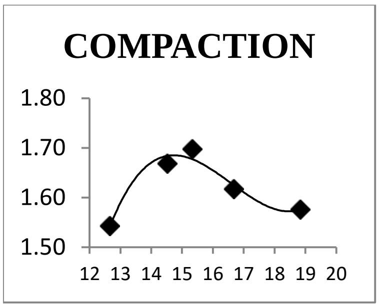

Fig 8: Graph of Compaction at 0% replacement

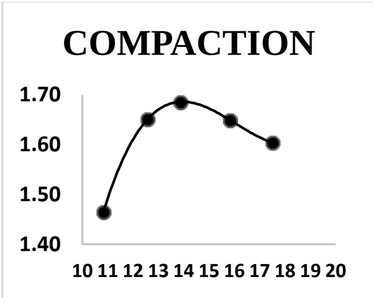

Fig 9: Graph of Compaction at 5% replacement

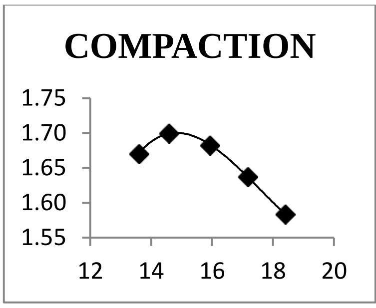

Fig 10: Graph of Compaction at 10% replacement

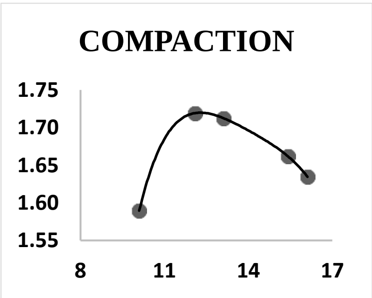

Fig 11: Graph of Compaction at 15% replacement

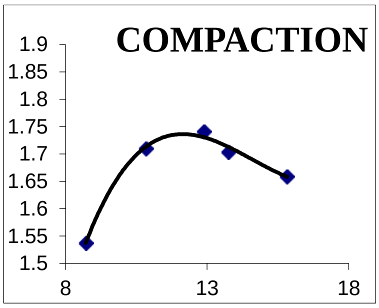

Fig 12: Graph of Compaction at 20% replacement

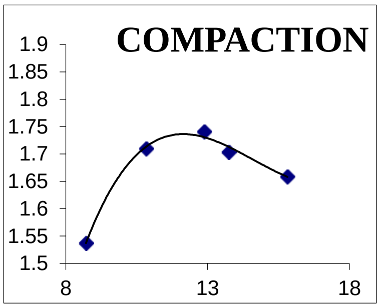

Fig 13: Graph of Compaction at 25% replacement

3.4 ANOVA Analysis

The analysis of variance (ANOVA) is a powerful tool for the tests of significance. It is the separation of variance ascribable to one group of causes from the variance ascribable to the other group. For the validity of the F-test in ANOVA, the following assumptions are made:

a) The observations are independent
b) Parent populations from which observation are taken are normal
c) Various treatment and environmental effects are additive in nature.

However, our analysis is that of a two-way classification since we are dealing with percentage replacement of the soil sample in categories associated with difference in the properties of the soil. The Table 6 is a presentation of the analysis of two-way classification divided into A and B categories.

Table 6: ANOVA Computation

Sources of Variation	Sum of Squares (SS)	Degree of Freedom (d.f.)	Mean Sum of Squares (MSS)	Variance Ration (F)
Factor A (Rows)	Sum of Squares for A (SSA)	(k – 1)	$\frac{SSA}{k-1}$	$F_A = \frac{MSSA}{MSSB} \sim F[(k-1), (k-1)(h-1)]$
Factor B (Columns)	Sum of Squares for B (SSB)	(h – 1)	$\frac{SSB}{h-1}$	$F_B = \frac{MSSA}{MSSB} \sim F[(h-1), (h-1)(k-1)]$
Error	Sum of Squares due to error (SSE)	(k – 1) (h – 1)	$\frac{SSE}{(k-1)(h-1)}$	
Total	Total Sum of Square (TSS)	hk – 1		

Analysis of variance of the two-way classification is computed as follows:

Null Hypothesis:

The percentage replacement and the soil result are homogeneous

H_{OPR}: = μ_1, = μ_2, = μ_3,…… = μ_6, i.e., there is significant difference in the percentage replacement.

H_{OPR}: = μ_1, = μ_2, = μ_3,…… = μ_9, i.e., there is significant difference in the soil Properties.

Alternative Hypothsis

H_{1PR}: = μ_1, = μ_2, = μ_3,…… = μ_6, i.e., there is no significant difference in the percentage replacement.

H_{1PR}: = μ_1, = μ_2, = μ_3,…… = μ_9, i.e., there is no significant difference in the soil Properties.

%	LL (%)	PL (%)	PI (%)	OMC (%)	MDD (g/cm³)	Row Total (R)	R^2
.05	28.50	18.64	9.86	13.87	1.69	72.56	5264.9536
.10	27.5	15.81	11.69	15.00	1.70	71.7	5140.89
.15	25.5	14.83	10.67	12.02	1.71	64.73	4189.9729
.20	24.5	14.29	10.21	12.00	1.72	62.72	3933.7984
.25	23.8	10.28	13.52	11.90	1.73	61.23	3749.1129
CT	129.8	73.85	55.95	64.79	8.55	**332.94**	**22278.7278**
C^2	16848.0	5453.8225	3130.4025	4197.7441	73.1025	**29703.1116**	

Row = Percentage Replacement

Column = Soil Result

Row Sum of Squares (RSS) = ($28.5^2 + 18.64^2 + 9.86^2 + 13.87^2 + \ldots + 10.28^2 + 13.52^2 + 11.90^2$ +

1.73^2) = **6009.505**

$\sum Row = \sum Column$ = 332.94

n = Total number of observation = hk = 5 x 5 = **25**

Correction Factor CF = $\frac{G^2}{n} = \frac{332.94^2}{25}$ = **4433.962**

Total Sum of Squares TSS = Row Sum of Squares RSS – Correction Factor CF

= 6009.505 – 4433.962 = **1575.543**

Sum of Squares along the Row RSS = $\frac{\sum Row^2}{h}$ – CF = $\frac{22278.728}{5}$ – 4433.962 = **21.784**

Sum of Squares down the Column CSS = $\frac{\sum Column^2}{k}$ – CF = $\frac{29703.112}{5}$ – 4433.962

= **1506.660**

Sum of Squares due to Error = TSS – RSS – CSS = 1575.543 – 21.784 – 1506.660

= **47.099**

Computation of Degree of Freedom d.f. for various Sum of Squares:

d.f. for TSS = n – 1= hk – 1 = 5 x 5 – 1 = **24**

d.f. for RSS = k – 1 = 5 – 1 = **4**

d.f. for CSS = h – 1 = 5 – 1 = **4**

d.f. for SSE = (5 – 1)(5 – 1) = 4 x 4 = **16**

Computation of Mean Sum of Squares MSS:

Mean Row Sum of Squares MRSS = $\frac{RSS}{k-1} = \frac{21.784}{4}$ = **5.446**

Mean Column Sum of Squares MRSS = $\frac{CSS}{h-1} = \frac{1506.660}{4}$ = **376.665**

Mean Error Sum of Squares MESS = $\frac{SSE}{(k-1)(h-1)} = \frac{47.099}{4 X 4}$ = **2.944**

Test Statistic: Under the null hypothesis H_{OR} and H_{OC}, we get respectively:

$F_R = \frac{MRSS}{MESS} = \frac{5.446}{2.944}$ = **1.850 ~ F (4, 16)**

$F_C = \frac{MCSS}{MESS} = \frac{376.665}{2.944}$ = **127.943 ~ F (4, 16)**

Table 7: ANOVA Table

Sources of Variation	Sum of Squares (SS)	Degree of Freedom (d.f.)	Mean Sum of Squares (MSS)	Variance Ration(F)
Percentage Replacement	21.784	4	5.44	F_R = 1.850 ~ F (4, 16)
Soil Result	1506.660	4	376.665	F_C = 127.943 ~ F (4, 16)
Error	47.099	16	2.944	
Total	1575.543	53		

Critical Values: From the F-distribution Table, the critical (tabulated) value of F for (4, 16) d.f. at 5% level of significance is **3.01**

Since the calculated value of the test statistic **F_R = 1.850** is less than the critical value (**3.01**), it is not significant. This means that there is no sufficient evidence against the null hypothesis, therefore, we fail to reject the null hypothesis. Hence, we conclude that there is no significance difference in the improvement as contributed by individual percentage. However, the calculated value of the test statistic **F_C = 127.943** is very much greater than the critical value (**3.01**), it is highly significant. Hence, we reject the null hypothesis at 5% level significance and conclude with 95% confidence that there is significance difference in the soil result obtained as related to individual soil test performed on the sample.

4.0 Conclusion

Laboratory analysis carried out on the lateritic soil samples collected beside the Civil Engineering Laboratory, University of Benin at (06° 24' 01.326"N, 05° 37' 02.988"E) showed that increase in percentage replacement of lateritic soil samples with quarry dust brought about a significant improvement in the index properties of the soil samples. It was also observed that the index properties of the lateritic soil varied and depended on the percentage of quarry dust used. The results indicated that the soil is of the clayey sand soil type of medium plasticity with a specific gravity of 2.13, a liquid limit of 29.5%, and a plastic limit of 19.37%, an OMC of 14.6% and an MDD of 1.68mg/m3. When compared with the specifications of the Federal Ministry of Works and Housing (F.M.W & H), soils with these values are not suitable for use as construction materials as they usually have low shear strength and are more susceptible to the shrink-swell behavior. However, at 25% replacement quarry dust replacement, the specifications were satisfied with a liquid limit of 23.8%, a plastic limit of 10.28%, an OMC of 11.90% and a MDD of 1.73 $mg/m^{3.}$ From the ANOVA analysis we rejected the null hypothesis at 5% level significance and conclude with 95% confidence that there is significance difference in the soil result obtained as related to individual soil test performed on the sample. We can therefore infer that the stabilization carried out on the soil at different percentage replacement has an improvement on the properties of the soil.

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