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# Effect of Sample Re-use on the Compaction Characteristics of Concretionary Lateritic Soil as Subgrade Material

Yohanna, P., Nwaiwu, C.M. C. and Oluremi, J. R.

**Abstract** — Laboratory compaction tests were conducted to investigate the effect of reusing samples of lateritic gravel soils in the determination of soil compaction characteristics. Twelve soil samples obtained from a large borrow pit located along Damagun-Potiskum road in Yobe state were subjected to compaction process using British standard light (BSL) compaction, West African standard (WAS) compaction and British standard heavy (BSH) compaction. Initial identification and classification tests revealed that fifty percent of the soils are A-4 soils, twenty five percent of the soils are A-2-4 soils based on AASHTO classification system. Others are either A-5(two) or A-1-b (one) soils. In general, maximum dry densities (MDDs) from reused sample compaction were higher than those obtained from the fresh sample compaction. No general trend was established for differences in optimum moisture content (OMC) values when either re-used sample or fresh sample compaction was employed. In general, MDD increased with gravel content while OMC decreases. Statistical analysis using t-test on MDD values shows higher values of mean and variance for sample re-use compaction than fresh sample compaction, The two – way analysis of variance (ANOVA) of MDDs, OMCs and compactive effort results for sample re-use and fresh sample compactions l were statistically significant with the effect of compactive effort being more pronounced than the MDDs and OMCs. Regression analysis carried out shows that gravel content; specific gravity and compactive effort have significant effect on the maximum dry densities of the soil samples.

Based on the results obtained, although all the soil samples could be used as subgrade material, Sample 4 with up to 70% gravely materials was considered the best as subgrade material for road construction purposes.

**Index Terms** — Lateritic soil, re-use sample compaction, fresh sample compaction, gravel content, maximum dry density, optimum moisture content, statistical analysis

## 1. INTRODUCTION

Laterite soil consisting of gravelly and sandy materials for pavement use occurs widely in many African sub-regions. The main groups of these road making gravels and sands include the concretionary gravels, residual gravels and sands as well as transported gravels and sands [1]. Lateritic gravely paving materials constitute the major materials belonging to the concretionary gravel group. Concretionary laterite gravels are formed by insitu tropical weathering which involves partial and complete alteration of the original mineralogy, geochemistry, texture and structure of fabric of the parent rock [1]. Nearly all kinds of rocks can be deeply decomposed by the action of high rainfall and elevated temperatures. The peculating rain water causes dissolution of primary rock minerals and decrease of easily soluble elements of sodium, potassium, calcium, magnesium and silicon. This process, known as laterization gives rise to a residual concentration of more insoluble elements, predominantly iron and aluminium [2].

1. *Yohanna, P., M. Sc. Holder, Department of Civil Engineering, Ahmadu Bello University Zaria, Kaduna State. paulyohanna@yahoo.co.uk*
2. *Nwaiwu, C.M. C , Professor, Department of Civil Engineering, Nnamdi Azikiwe Universtity Awka, Anambra State,*
3. *Oluremi, J. R., Researcher, Department of Civil Engineering, Ladoke Akintola University of Technology, Ogbomoso, Oyo State, Correspondence Email: jroluremi@lautech.edu.ng; paulyohanna45@yahoo.co.uk*

Laterite therefore consists mainly of the minerals kaolinite, goethite, hematite and gibbsite which form in the course of this weathering processes [1]. Lateritization is economically the most important factor in the formation of laterite ores deposits.

Gravelly soils consisting of sound gravel-size particles in a matrix of finer materials have proved to be a satisfactory construction material for several large earth dams. The gravel fraction of these soils impacts a relatively high shear strength, high compacted density and low compressibility, while the permeability of the soil is governed by the properties of the matrix material [3]. Series of research by Ola [4] on the mechanical properties of concretionary laterite soils from rain forest and savannah zones of Nigeria shows that, concretionary laterites have superior properties to the crushed granite gravel. Excellent properties of concretionary laterite soils were used to explain the longitivity of the earlier road constructed in southern Nigeria.

Thagesen, [5] defined laterite as a group of highly weathered soils formed by the concentration of hydrated oxides of iron and aluminium commonly found in the leached soils of the humid tropics where they were first studied. They are formed under weathering system through the process of laterization, where the decomposition of ferro-alumnino silicate minerals and permanent deposition of sesquioxides ($Al_2O_3$ and $Fe_2O_3$) takes place. Laterites and lateritic soils form a group comprising a wide variety of red, brown, and yellow, fine-grained residual soils of light texture as well as nodular gravels and cemented soils [6]. They are identified by the presence of iron and aluminium oxides or hydroxides, particularly those of iron, which give the colours to the soils [7]. Fookes [8] named laterites based on hardening, such as "ferric" for iron-rich cemented crusts, "alcrete" or bauxite for aluminium-rich cemented crusts, "calcrete" for calcium carbonate-rich crusts, and "silcrete" for silica rich cemented crusts.

The behaviour of laterite in pavement structure has been found to depend mainly on their particle size characteristics, the nature and strength of the gravel particles, the degree to which the soils have been compacted as well as the traffic and environmental conditions [2].The field performance of laterite soil are determined by the mode of formation morphological characteristics, degree of weathering and the chemical and mineralogical composition, which in turn rely on weathering system determined by the joint effects of the parent materials, climate, vegetation, etc as reported by [2], [9]. These factors are affected by the topography and drainage conditions so that soils having similar mineralogical and geotechnical characteristics can often be associated with particular topographical areas [10].

Series of research by Gidigasu [2] revealed that sample re-use compaction test gives rise to higher dry unit weights than with fresh sample. This is attributed to the fact that the soil particles break down progressively under the impact of the rammer. It was also explained in terms of different degree of workability in some cohesive soils. Research showed that the amount of breakdown of coarse particles improves the nature of the grading curve; this gives rise to higher dry unit weight and low optimum moisture content. Soils that become poorer on re-compaction may give rise to lower dry unit weight and higher optimum moisture content. The nature of the grading curve as well as the strength of the concretionary coarse fraction are crucial factors in determining the influence of fresh and re-use samples on the compaction characteristics of gravely laterite soils.

The aim of the study was to apply different ways of compaction to the compaction of iron stone gravely lateritic soils. The specific objectives were to investigate the peculiar characteristics of concretionary lateritic soils at twelve (12) different locations in a large borrow pit and to examine the influence of sample-use on the compaction characteristics of concretionary lateritic soils in comparison with fresh sample compaction.

## 2. MATERIALS AND METHODS

### 2.1 Materials

Soil Sample Location: The soil samples used for the study were obtained alone Damagun-Potiskum road in Yobe state. The disturbed samples were collected at twelve (12) different points in a large borrow pit. According to [11], [12], [13], it belongs to quaternary deposits of northern eastern part of Nigeria.

### 2.2 Methods

*Index Properties*

Laboratory test were conducted to determine index properties of twelve samples of lateritic gravel aggregates which are relevant to their use as road construction materials in accordance with British Standards [14]. Measured values of index properties were shown in table 2. Based on the index properties and the grading characteristics, the soils are classified according to AASHTO [15].

*Compaction Test*

Compaction tests were conducted in accordance with [14] as well as Nigerian General Specification [16] in order to establish the compaction characteristics of the concretionary laterite soil. Specimens were compacted with three compaction energy: British Standard Light (BSL) energy level consisting of a 2.5 kg rammer falling 300 mm into three layers in a British Standard mould, each receiving twenty seven (27) blows. In the West African Standard Compaction (WASC) test. It is the same procedure but a 4.5 kg rammer was used instead of 2.5 kg for the standard method and the number of layers were increased to five instead of three for the earlier method, 10 blows per layer at hammer height of fall of 450mm was used. In the modified method, the procedure is of almost the same as the West African method five layers at 27 blows per layer. After determining the moisture content for every water increment, the results were plotted. Smooth curves were drawn through the resulting points and the positions of optimum moisture content and the maximum dry density were determined on the graphs.

*Fresh Sample compaction Test*

In fresh sample compaction the same procedure was used as in sample re-use method with little deviations. Soils samples were compacted at three energy levels with the same no of blows, height of fall, weight of rammer and the mould size. Each sample was compacted once without re-use of the sample for the next compaction. A total of 15000g was used for one complete compaction instead of 3000g used earlier. The Maximum dry density and bulk density was determined as before. The same procedure was followed for the remaining samples, their dry densities and optimum moisture contents were determined.

## 3. RESULTS AND DISCUSSIONS

Soil identification: Preliminary tests carried out on the twelve soil samples include Physico-chemical; physico-mechanical and grading characteristics summarized in Table 1 and 2 respectively.

### 3.1 Physico-chemical and physico-mechanical properties

Physico-chemical properties of the laterite soils investigated include pH and free swell of the soils expressed in percentage (see table 1). Soil pH showed the degree of acidity or alkalinity of the soil under consideration. The pH values varied from 4.65 to 5.26.This showed that all the samples tested were weakly acidic. Acidity may be attributed to the various mineralogical composition of the laterite soils basically Iron and Aluminium. Also acidity of the soils may be attributed by considerable drainage (leaching) in the soils due to low rainfall with high rate of evaporation).The free swell values ranges from 7.5 % to 27.5 %.The low values of free swell indicate the absence of montmorillonite and other swelling materials in the soils.

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| Sample ID | pH | Free Swell (%) | Water absorption (%) | Specific Gravity |
|---|---|---|---|---|
| 1 | 5.12 | 20.0 | 3.88 | 2.46 |
| 2 | 4.68 | 17.5 | 3.67 | 2.60 |
| 3 | 5.12 | 20.0 | 4.10 | 2.60 |
| 4 | 4.98 | 15.0 | 5.34 | 2.63 |
| 5 | 4.83 | 7.5 | 5.27 | 2.65 |
| 6 | 4.77 | 17.5 | 3.84 | 2.66 |
| 7 | 4.76 | 10.0 | 4.90 | 2.58 |
| 8 | 4.78 | 21.0 | 4.42 | 2.68 |
| 9 | 4.78 | 17.5 | 4.98 | 2.63 |
| 10 | 4.65 | 27.5 | 5.44 | 2.53 |
| 11 | 4.73 | 27.5 | 5.00 | 2.55 |
| 12 | 5.26 | 19.5 | 5.39 | 2.50 |

**Table 1 Physico-chemical and physico-mechanical properties of the soils.**



| Sample ID | Consistency indices | | Hydrometer analysis | | | Sieve analysis | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | LL (%) | PI (%) | Clay (%) | Silt (%) | Sand (%) | Gravel (%) | Sand (%) | ‹4.75mm (%) | <425μm (%) | ‹75μm (%) |
| 1 | 35.75 | 6.19 | 34.60 | 9.45 | 55.95 | 7.00 | 28.00 | 93.00 | 75.50 | 65.00 |
| 2 | 34.20 | 3.55 | 34.60 | 16.95 | 48.45 | 7.00 | 25.00 | 93.00 | 69.60 | 68.00 |
| 3 | 35.25 | 4.07 | 24.60 | 11.95 | 63.45 | 26.00 | 24.50 | 74.00 | 50.30 | 49.50 |
| 4 | 24.40 | 2.36 | 22.10 | 9.45 | 68.45 | 70.00 | 16.50 | 30.00 | 14.00 | 13.50 |
| 5 | 30.20 | 1.08 | 32.10 | 11.95 | 55.95 | 56.00 | 18.00 | 44.00 | 26.20 | 26.00 |
| 6 | 38.50 | 0.81 | 32.10 | 11.95 | 55.95 | 30.10 | 22.90 | 69.90 | 48.00 | 47.00 |
| 7 | 41.03 | 8.85 | 32.10 | 9.45 | 58.45 | 23.00 | 24.50 | 77.00 | 52.50 | 52.50 |
| 8 | 36.60 | 3.90 | 34.60 | 11.95 | 55.95 | 25.00 | 22.00 | 75.00 | 54.50 | 53.00 |
| 9 | 38.70 | 5.93 | 32.10 | 6.95 | 60.95 | 29.00 | 29.00 | 71.00 | 42.30 | 42.00 |
| 10 | 41.00 | 1.76 | 32.10 | 9.45 | 58.45 | 27.00 | 19.00 | 73.00 | 54.40 | 54.00 |
| 11 | 38.60 | 7.04 | 34.60 | 14.45 | 50.95 | 31.00 | 50.00 | 69.00 | 28.00 | 19.00 |
| 12 | 30.80 | 7.43 | 19.60 | 11.95 | 68.45 | 41.50 | 30.25 | 58.50 | 29.50 | 28.25 |

**Table 2 Consistency and Grading characteristics of the soil samples**

| Sample No | BSL | | WAS | | BSH | |
|---|---|---|---|---|---|---|
| | OMC (%) | MDD ($kN/m^3$) | OMC (%) | MDD ($kN/m^3$) | OMC (%) | MDD ($kN/m^3$) |
| 1 | 13.50 | 18.20 | 12.50 | 18.35 | 11.00 | 19.08 |
| 2 | 13.00 | 18.52 | 12.50 | 18.35 | 13.00 | 19.37 |
| 3 | 13.20 | 19.48 | 11.55 | 19.22 | 10.54 | 19.89 |
| 4 | 10.90 | 19.42 | 10.10 | 19.80 | 9.24 | 19.88 |
| 5 | 12.2 | 19.15 | 10.00 | 19.38 | 9.75 | 20.45 |
| 6 | 13.55 | 19.50 | 11.50 | 19.19 | 9.00 | 19.94 |

ISSN 2229-5518

| | | | | | | |
|---|---|---|---|---|---|---|
| 7 | 10.55 | 19.18 | 11.50 | 19.30 | 11.50 | 19.70 |
| 8 | 14.40 | 17.59 | 12.25 | 19.20 | 11.58 | 19.84 |
| 9 | 12.25 | 18.84 | 11.50 | 19.30 | 11.75 | 19.34 |
| 10 | 11.50 | 18.55 | 13.25 | 18.33 | 11.75 | 19.69 |
| 11 | 11.75 | 18.55 | 10.80 | 18.64 | 11.75 | 19.69 |
| 12 | 12.50 | 18.95 | 9.25 | 20.22 | 10.00 | 19.90 |

**Table 3a Sample Re-Use compaction characteristics**

| Sample ID | BSL | | WAS | | BSH | |
|---|---|---|---|---|---|---|
| | OMC (%) | MDD (kN/m³) | OMC (%) | MDD (kN/m³) | OMC (%) | MDD (kN/m³) |
| 1 | 13.40 | 17.65 | 13.2 | 18.27 | 14 | 18.50 |
| 2 | 13.4 | 18.21 | 13.40 | 18.30 | 10.30 | 18.94 |
| 3 | 13.75 | 18.65 | 9.00 | 19.10 | 10.50 | 19.70 |
| 4 | 13.30 | 18.55 | 13.30 | 18.64 | 10.00 | 19.19 |
| 5 | 10.50 | 18.65 | 12.00 | 18.88 | 12.00 | 19.96 |
| 6 | 12.30 | 18.10 | 10.80 | 19.29 | 11.60 | 19.32 |
| 7 | 13.70 | 18.10 | 11.50 | 19.18 | 10.60 | 19.30 |
| 8 | 12.50 | 17.60 | 13.40 | 18.36 | 12.00 | 19.27 |
| 9 | 11.30 | 18.72 | 11.80 | 18.90 | 7.50 | 20.10 |
| 10 | 15.00 | 17.65 | 12.28 | 18.26 | 12.00 | 18.82 |
| 11 | 15.00 | 17.65 | 12.70 | 18.20 | 12.00 | 18.82 |
| 12 | 11.50 | 18.60 | 8.50 | 19.08 | 8.88 | 19.54 |

**Table 3b Fresh sample compaction characteristics**

Physico-mechanical properties of the soils are also shown in Table 1. The parameters investigated and presented in the table are; water absorption, and specific gravity. Water absorption of the laterite soils varied between 3.67 and 5.44 %. Low values of water absorption suggest the absence of swelling materials in the soils. The specific gravity varied between 2.46 and 2.68. Low values of specific gravity suggest the presence of organic matters in the soils. High organic matter content in the soil affects the shear strength and the soil stiffness.

### 3.2 Grading characteristics

Particle size distribution curves for the soils samples are shown in fig 1. Sieve analysis(wet sieving) carried out on the soils showed that samples 4, 5,10 and 11 contains more than 50% gravely materials. Other samples have less than 50 % gravely materials. The gravel size particles varied between 7 % and 70 %, sand content varied between 16.5 % and 50 % while the fine content ranges from 13.5 % to 68 % (see fig 1). Sample 4 with the highest gravely materials is considered the best as sub grade material for road construction [17], [18]. The hydrometer analysis of all the samples showed that they have an average of 20 % clay, 10 % silt and 50 % sand. Samples 4 and 12 have the highest with up to 68.45 % sand. This favours their suitability as construction materials for road sub grade.

**Fig. 1 Particle size distribution curves of the soil samples**

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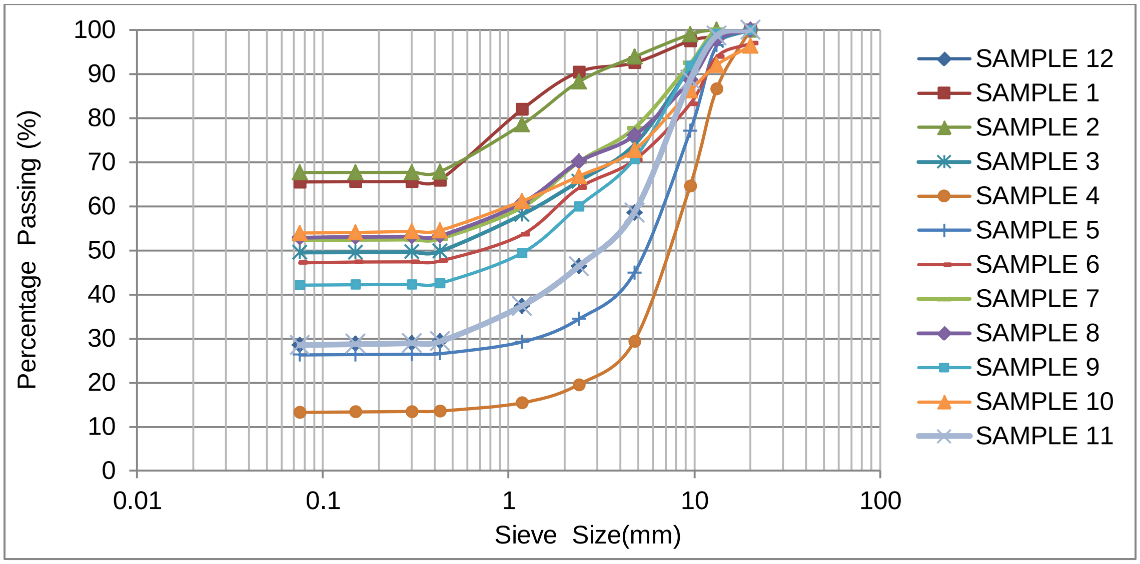


### 3.3 Compaction Characteristics

Results of sample re-use and fresh sample compactions are shown in table 3a and 3b. It can be noticed that with sample re-use method of compaction, higher values of dry densities were obtained than with fresh sample compaction method. These results suggest that the increase could be attributed to the fact that the soil particles break down progressively under the impact of the compaction rammer during the compaction process. The amount of breakdown of the re-used sample causes the breaking down of the coarse particles. Results obtained are in agreement with previous statements of [2], [19]. Higher values of dry unit weights obtained with sample re-use over fresh sample compaction may also suggest that in sample re-use, the volume of voids is reduced to a minimum than in fresh sample compaction which lead to the aggregation of gravely and sandy materials in the soils giving it its higher density.

Optimum moisture content decreased with increase in the compactive effort but no general trend was established for differences in optimum moisture content (OMC) values when either re-used sample or fresh sample compaction was employed. The optimum moisture content varied between 9.00% and 14.40% for sample re-use compaction test, varied between 8.88% and 15% for fresh sample compaction test. Lower values of optimum moisture content with increase compactive effort suggest the aggregation of gravely and sandy materials in the soils. Also results obtained suggest that the lateritic clay gravels have good workability as engineering construction materials and can be rated as fair to good as road construction materials. The results show that the optimum moisture content decreases with an increase in the compactive effort and agreed with previous investigations of [20]. The maximum dry density and the optimum moisture content obtained from the laboratory results are independent of the soil sample but on the compaction method used [21].

#### 3.3.1 Influence of sample re-use on the maximum dry unit weight of concretionary laterite soils

Fig 2-4 shows the influence of gravel content on the maximum dry unit weight for different compactive effort using a second order polynomial relationship. The maximum dry density generally increased with increase in gravel content (for both re-use sample and fresh sample compaction) when compacted with all the compactive effort. These increase, resulted from increasing gravel to gravel contact, which interferes with transmission of compaction energy to the finer materials on the voids. Results obtained agreed with previous investigations of [3], [22]. Figure 3 indicated that at a gravel content of approximately 10-36%, maximum dry density increases with increase in the gravel content. Above 36% gravel content, lower values of maximum dry density are obtained when compacted with an intermediate compactive effort.

Fig 5 shows the influence of gravel content on the percentage difference in maximum dry density. Results obtained showed that with light compactive effort, the percentage difference in maximum dry density is independent on the gravel content. With intermediate compactive effort, the percentage difference in maximum dry density increases with increase in the gravel content. With heavy compactive effort, the percentage difference in maximum dry density decreases with increase in the gravel content. Results obtained suggest that the variations in the gravel content do not have a significant influence on the maximum dry density when soil samples are compacted with light compactive effort, irrespective of the compaction method used. Results obtained, revealed that with intermediate compactive effort, an increase in the gravel content increase the maximum dry density with sample re-use over fresh sample compaction. With BSH compactive effort, increase in the gravel content decreases the maximum dry density with sample re-use than with fresh sample.

**Fig. 2 Variation of Maximum Dry density with Gravel Content for BSL Compaction**

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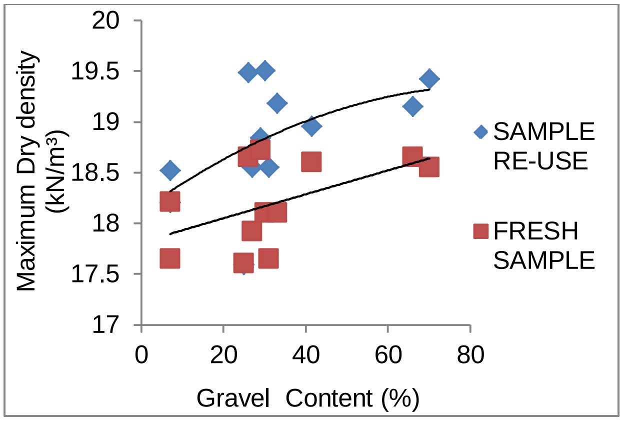



**Fig. 3 Variation of Maximum Dry density with Gravel Content for WAS Compaction**

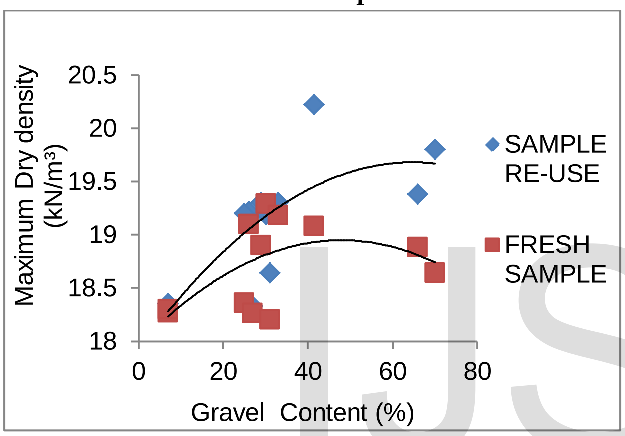



**Fig. 4 Variation of Maximum Dry density with Gravel Content for BSH Compaction**

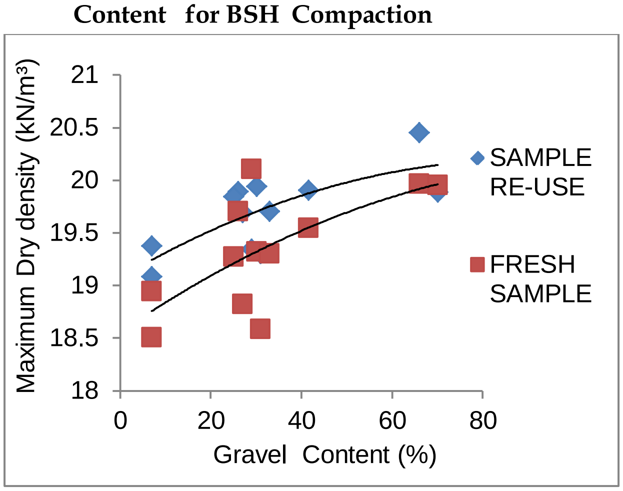
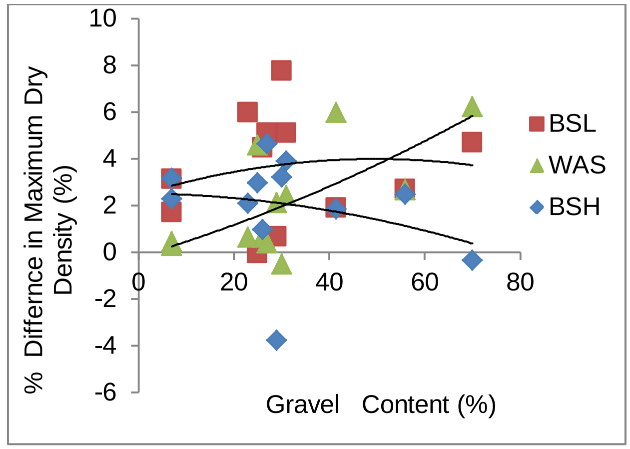



**Fig. 5 Variation of Percentage Differnce in Maximum Dry**

**Fig. 6 Variation of Optimum Moisture Content with Gravel**

**Density with Gravel Content**




### 3.3.2 Influence of sample Re-use on the optimum moisture content of concretionary laterite soils

Results on the influence of sample re-use on the optimum moisture content showed that no general trend could be established for differences in optimum moisture content (OMC) values when either re-used sample or fresh sample compaction was employed (see table 3a and 3b). It also showed that the optimum moisture content is independent of compactive effort. Results obtained is not in agreement with the findings of Gidigasu [2] which state that sample re-use compaction method gives lower values of optimum moisture content than with fresh sample compaction.

Fig 6-8 shows results on the influence of gravel content on the optimum moisture content for different compactive effort using a second order polynomial relationship. Results obtained showed that with sample re-use compaction method, the optimum moisture content decreases with increase in gravel content independent on the compactive effort. While with fresh sample compactive effort the optimum moisture content decreases with increase in gravel content for light compactive effort only. For intermediate and heavy compactive effort, the optimum moisture content decreases at gravel content from 0-20%, and increases at greater than 40% gravel content. The optimum moisture content is not influenced at gravel content of 20-40%

Fig 9 shows the influence of gravel content on the percentage difference in optimum moisture content. Results obtained showed that with all compactive effort, the percentage difference in optimum moisture content is independent on the gravel content. There is no direct correlation between the percentage difference in optimum moisture and the gravel content.

**Fig. 8 Variation of Optimum Moisture Content with Gravel content for BSH Compaction**

**content for BSL Compaction**

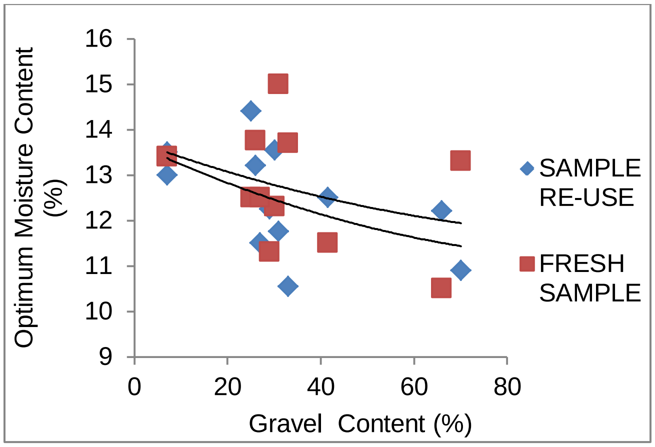
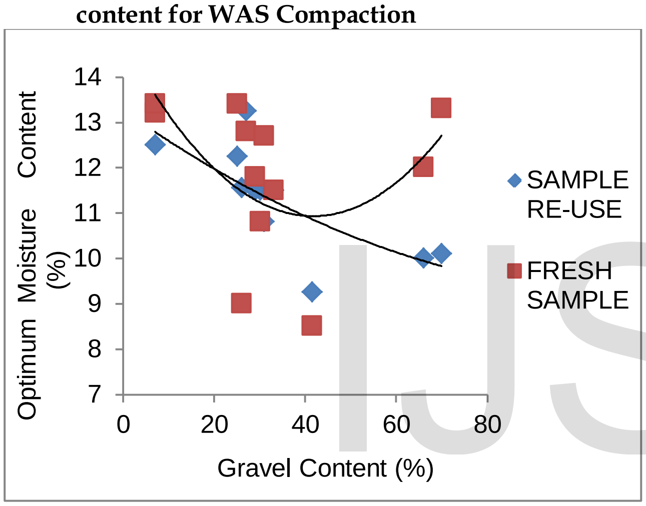



**Fig. 7 Variation of Optimum Moisture Content with Gravel content for WAS Compaction**



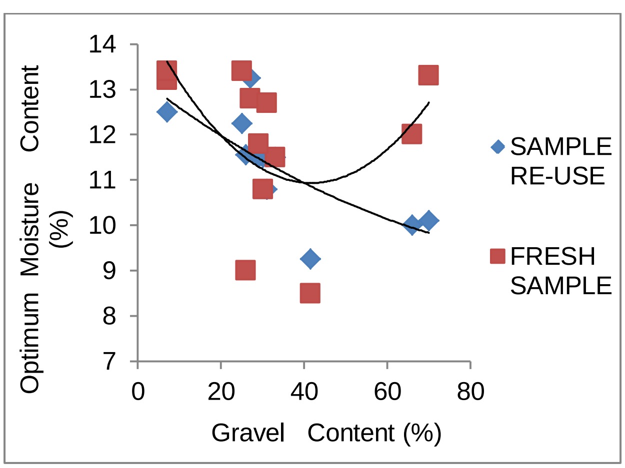
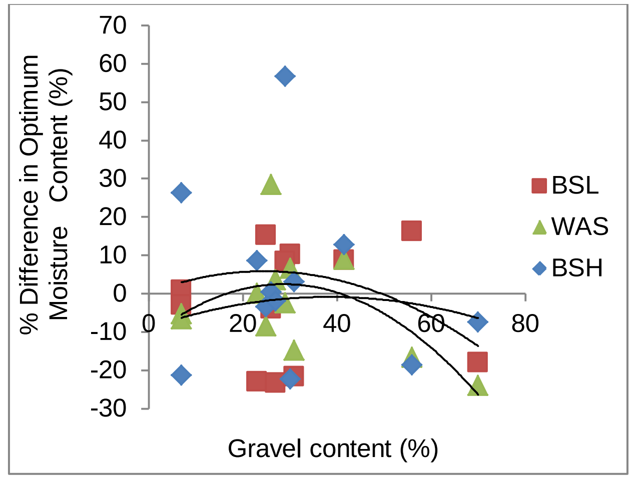




**Fig. 9 Variation in Percentage Difference in Optimum Moisture Content with Gravel Content**




### 3.4 Statistical Analysis

#### 3.4.1 T-test

Table 4a-c shows a t-test for two-samples assuming unequal variances. Statistical analysis using t-test on MDD values for sample re-use and fresh sample compaction shows higher values of mean and variance for sample re-use compaction than fresh sample compaction, except in one case for BSH compaction(see table 4a-c).As the compactive effort increases , the mean and variance also increases. In the case of OMCs, reverse is the case were fresh sample compaction have higher values of mean and variance compared to sample re-use compaction.

#### 3.4.2 Hypothesis

Null Hypothesis: if P (T<=t) one-tail > t Critical one-tail and P (T<=t) two-tail > t Critical tail accept the hypothesis (significant effect).

Alternative Hypothesis: if P (T<=t) one-tail < t Critical one-tail and P (T<=t) two-tail < t Critical two-tail reject the hypothesis (no significant effect).

| | *MDD sample re-use compaction* | *MDD fresh sample compaction* | *OMC sample re-use compaction* | *OMC fresh sample compaction* |
|---|---|---|---|---|
| Mean | 18.8275 | 18.1775 | 12.44166667 | 12.9708333 |
| Variance | 0.331475 | 0.203584091 | 1.31719697 | 1.96202652 |
| Observations | 12 | 12 | 12 | 12 |
| Hypothesized Mean Difference | 0 | | 0 | |
| df | 21 | | 21 | |
| t Stat | 3.078244456 | | -1.01227286 | |
| P(T<=t) one-tail | 0.002850758 | | 0.161464782 | |
| t Critical one-tail | 1.720742871 | | 1.720742871 | |
| P(T<=t) two-tail | 0.005701515 | | 0.322929564 | |
| t Critical two-tail | 2.079613837 | | 2.079613837 | |

**Table 4a: T-Test for Two-Sample Assuming Unequal Variances: BSL compaction energy.**



| | *MDD sample re-use compaction* | *MDD fresh sample compaction* | *OMC sample re-use compaction* | *OMC fresh sample compaction* |
|---|---|---|---|---|
| Mean | 19.10666667 | 18.705 | 11.39166667 | 11.82333333 |
| Variance | 0.35129697 | 0.169336364 | 1.386287879 | 2.747624242 |
| Observations | 12 | 12 | 12 | 12 |
| Hypothesized Mean Difference | 0 | | 0 | |
| df | 20 | | 20 | |
| t Stat | 1.928370283 | | -0.735459084 | |
| P(T<=t) one-tail | 0.034063261 | | 0.23529877 | |
| t Critical one-tail | 1.724718218 | | 1.724718218 | |
| P(T<=t) two-tail | 0.068126521 | | 0.470597541 | |
| t Critical two-tail | 2.085963441 | | 2.085963441 | |

**Table 4b: T-Test for Two-Sample Assuming Unequal Variances: WAS compaction energy**

| | *MDD sample re-use compaction* | *MDD fresh sample compaction* | *OMC sample re-use compaction* | *OMC fresh sample compaction* |
|---|---|---|---|---|
| Mean | 19.73083333 | 19.2883333 | 10.905 | 10.948333 |
| Variance | 0.123626515 | 0.23048788 | 1.457936364 | 2.9065788 |
| Observations | 12 | 12 | 12 | 12 |
| Hypothesized Mean Difference | 0 | | 0 | |
| df | 20 | | 20 | |
| t Stat | 2.575918439 | | -0.07185297 | |
| P(T<=t) one-tail | 0.009020642 | | 0.471716305 | |
| t Critical one-tail | 1.724718218 | | 1.724718218 | |
| P(T<=t) two-tail | 0.018041284 | | 0.94343261 | |
| t Critical two-tail | 2.085963441 | | 2.085963441 | |

**Table 4c: T-Test for Two-Sample Assuming Unequal Variances: BSH compaction energy**

Results obtained shows that both P (T<=t) one-tail and P (T<=t) two-tail for sample re-use and fresh sample compaction are lower than their corresponding critical values (no significant effect). Therefore result obtained agrees with the alternative hypothesis. The Null Hypothesis should be rejected and alternative hypothesis accepted. The same trend was observed for all the compactive effort considered.

### 3.4.3 Two-way analysis of variance

The two – way analysis of variance (ANOVA) of MDD and compactive effort result for sample re-use compaction (see Table 5a) shows that the effects of MDD for sample re-use compaction (FCAL = 3.893739> FCRIT - 2.258518 and compactive effort (FCAL = 17.32161> FCRIT = 3.443357) on the compaction characteristics of laterite soil were statistically significant with the effect of compactive effort being more pronounced than that of sample re-use MDD.

In the case of fresh sample compaction (see Table 5a) shows that the effects of MDD on fresh sample compaction (FCAL = 8.596732> FCRIT = 2.258518 and compactive effort (FCAL = 63.74609> FCRIT = 3.443357) on the compaction characteristics of laterite soil were statistically significant with the effect of compactive effort being more pronounced than the MDD of fresh sample compaction.

| | Source of Variation | df | F | P-value | F crit | remark |
|---|---|---|---|---|---|---|
| Sample re-use compaction | MDD | 11 | 3.893739 | 0.003229 | 2.258518 | FCAL>FCRIT, Significant effect |
| | Compactive effort | 2 | 17.32161 | 3.03E-05 | 3.443357 | FCAL>FCRIT, Significant effect |
| Fresh Sample compaction | MDD | 11 | 8.596732 | 1.15E-05 | 2.258518 | FCAL>FCRIT, Significant effect |
| | Compactive effort | 2 | 63.74609 | 7.01E-10 | 3.443357 | FCAL>FCRIT, Significant effect |

**Table 5a:Two-way analysis of variance for MDD sample re-use and fresh Sample compaction**



The two – way analysis of variance (ANOVA) of OMCs and compactive effort result for sample re-use compaction (see Table 5b) shows that the effects of OMCs for sample re-use compaction (FCAL = 2.36902> FCRIT = 2.258518 and compactive effort (FCAL = 7.770607> FCRIT = 3.443357) on the compaction characteristics of laterite soil were statistically significant with the effect of compactive effort being more pronounced than that of sample re-use OMCs.

In the case of fresh sample compaction (see Table 5b) shows that the effects of OMCs on fresh sample compaction (FCAL = 2.571984> FCRIT = 2.258518 and compactive effort (FCAL = 7.411107> FCRIT = 3.443357) on the compaction characteristics of laterite soil were statistically significant with the effect of compactive effort being more pronounced than the OMCs of fresh sample compaction.

| | Source of Variation | df | F | P-value | F crit | remark |
|---|---|---|---|---|---|---|
| Sample re-use compaction | OMC | 11 | 2.36902 | 0.040956 | 2.258518 | FCAL>FCRIT, Significant effect |
| | Compactive effort | 2 | 7.770607 | 0.002799 | 3.443357 | FCAL>FCRIT, Significant effect |
| Fresh Sample compaction | OMC | 11 | 2.571984 | 0.028522 | 2.258518 | FCAL>FCRIT, Significant effect |
| | Compactive effort | 2 | 7.411107 | 0.003463 | 3.443357 | FCAL>FCRIT, Significant effect |

**Table5b:Two-way analysis of variance for OMC sample re-use and fresh Sample compaction**

### 3.4.4 Regression Analysis

A regression analysis was performed using data in Table 1-3. Results of regression analysis showed that the maximum dry density for both sample re-use and fresh sample compaction was influenced by the grading properties, specific gravity and compactive effort applied for the respective soils in agreement with Gidigasu [2]. The geotechnical properties considered for these analyses include the percentages of gravels, sand, silt and clay alongside their respective specific gravities. The coefficient of each parameter in regression equations (see equation 1 and 2) revealed the extent to which each of these parameters influence the maximum dry densities of each of the twelve samples considered. The gravel content, specific gravity and compactive effort has the most significant effect on the maximum dry density having a positive coefficient with others having negative coefficient for sample re-use compaction. The positive coefficient of gravel content for sample re-use compaction could be due reduction in the voids within the soil matrix leading to the increase in the maximum dry density. However, for fresh sample compaction only specific gravity and compacitive effort have a positive influence on the maximum dry densities.

The correlation coefficient values (R2) shows a strong relationship between maximum dry density and the parameters with R2 values of 63.7 % and 80.8 % for sample re-use and fresh sample compaction respectively.

The regression equations are

$$\mathrm{MDD_{(SR)}} = 29.4 - 0.217\mathrm{Cl} - 0.176\mathrm{Si} - 0.168\mathrm{Sa} + 0.0045\mathrm{Gr} + 3.12\mathrm{G_s} + 0.44\mathrm{CE} \quad 1$$
$$\mathrm{R^2} = 63.7\%$$

$$\mathrm{MDD_{(FS)}} = 32.6 - 0.301\mathrm{Cl} - 0.287\mathrm{Si} - 0.245\mathrm{Sa} - 0.00559\mathrm{Gr} + 5.06\ \mathrm{G_S} + 0.577\mathrm{CE} \quad 2$$
$$\mathrm{R^2} = 80.8\%$$

Where MDD (SR) =Maximum dry density of sample re-use compaction, MDD (FS) = Maximum dry density of fresh sample compaction, Cl = Clay, Si = Silt, Sa = Sand, Gr = Gravel content, $\mathrm{G_S}$ = Specific Gravity, CE = Compactive Effort

## 4. Conclusion

Result of preliminary investigation showed that fifty percent of the soils are A-4 soils, twenty five percent of the soils are A-2-4 soils based on AASHTO classification system. Others are either A-5 (two) or A-1-b (one) soils. Initial identification and classification tests revealed that the soils consist of 7-70% gravel fraction, 16.5-50.0 % sand fraction and 13.50-68 % fines. Liquid limit values ranged between 24.40 and 41.03 % while plasticity index values varied from 0.81 to 8.85%, maximum dry density for reused sample compaction were higher than those obtained from the fresh sample compaction. No general trend was established for differences in optimum moisture content (OMC) values for both re-used sample and fresh sample compaction.

The maximum dry density increases with increase in gravel content for all the compactive effort when plotted using a second order polynomial relationship. No general trend could be established for the relationship between gravel content and optimum moisture content (OMC) when plotted using a second order polynomial relationship. In general, maximum dry density increased with gravel content while OMC decreases with some exceptions. Statistical analysis using t-test on MDD values for sample re-use and fresh sample compaction shows higher values of mean and variance for sample re-use compaction than fresh sample compaction, except in one case for BSH compaction.

The two – way analysis of variance (ANOVA) of MDDs, OMCs and compactive effort result for sample re-use and fresh sample compaction shows that the effects of MDDs, OMCs and compactive effort on the compaction characteristics were statistically significant with the effect of compactive effort being more pronounced than the MDDs and OMCs Regression analysis revealed that specific gravity, gravel content and compactive effort significantly influence the maximum dry densities of the soils. Sample 4 with up to 70% gravely materials was considered the best as sub grade material for road construction purposes.

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