



# Effect of Compaction and Moisture on the California Bearing Ratio of Residual Lateritic Soils in Kontagora, Niger State

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**ABSTRACT:** The research explores impact of compaction and moisture on the California Bearing Ratio (CBR) of residual lateritic soils collected from Kontagora and its surrounding areas in Niger State, Nigeria. 20 disturbed soil samples were used in laboratory testing to examine the effects of the variables on CBR values. The tests conducted include: Sieve analysis, Atterberg limit, Compaction test and CBR using both British Standard Light (BSL) and British Standard Heavy (BSH) compaction efforts. The results show that soils compacted using heavy compaction effort achieved higher compaction, with an average MDD values of 1.95 g/cc when compared to 1.84 g/cc for BSL. Samples compacted with light compaction effort generally showed higher OMC, averaging 13.91%, even though both compaction efforts exhibited good consistency in MDD values. When the samples were soaked, there was a significant reduction on CBR values for both compactive efforts. Under the heavy compaction, the mean CBR decreased from 89.83% (unsoaked) to 69.22% (soaked) with a total reduction of 20.61%. Samples under BSL experienced a more pronounced decline, with the mean CBR dropping from 74.96% to 52.09%, projecting a 22.87% reduction. The statistical analysis indicated that these reductions were significant, reinforcing the critical role of moisture in diminishing soil strength. Although the heavy compacted soil samples consistently showed higher CBR values than BSL compacted samples in both soaked and unsoaked conditions. The high loss in CBR value of the soil samples when soaked in water stresses the importance of adequate moisture control. Based on these findings, the study recommends the adoption of heavy compaction combined with effective moisture control and drainage measures to enhance pavement durability and ensure reliable road performance in the study area.

**Keywords:** Lateritic soil, CBR, Compaction, Unsoaked, Soaked



## 1. INTRODUCTION

Residual lateritic soils are rank among the most widely distributed type of soils in Nigeria, especially in tropical and sub-tropical regions where much chemical weathering of the underlying rocks takes place. These soils, rich in iron and aluminum oxides, showcases distinct reddish coloration and display geotechnical properties that are highly variable depending on their mineral composition, degree of weathering, and environmental conditions [1-4]. The widely use of these materials in civil engineering, particularly in the construction of roads, stresses the necessity of understanding their mechanical properties under compaction and environmental condition [5].

The California Bearing Ratio (CBR) test in road construction is a very important test used to assess the ability of soils in sustaining impose road traffic load. It is used in examining subgrade and base materials strength in flexible pavement structures. This test can be used to assess the strength of soils in both soaked and unsoaked states and is particularly useful for determining how soils respond to variations in moisture and compaction [6-8]. Even though the CBR values of lateritic soils are not fixed, because they vary widely due to some factors. Some of these factors which the CBR of soils depend on includes moisture content, soil plasticity, particle gradation, and most critically, the level of compactive effort applied during construction.

The relationship between compaction effort, moisture content, and California Bearing Ratio (CBR) performance is critically important for residual lateritic soils to be assessed for used as subgrade and base materials in road construction. These parameters directly control density, stiffness and load-bearing capacity under traffic [9,10]. As such inadequate control of these factors can lead to premature pavement failure, excessive deformation and increased maintenance costs, especially under increasing traffic loads [11-13].

Several studies conducted in time past have established that increased compaction effort generally leads to higher maximum dry densities and improved CBR values, while excessive moisture content can significantly reduce bearing strength, particularly in fine-grained or highly plastic lateritic soils. The CBR of lateritic soils has also been reported to respond differently depending on their origin, degree of weathering, mineralogy and iron/aluminium oxide content, which influence their structure, suction and cementation characteristics [14,15]. Previous research in Nigeria and other tropical regions has predominantly concentrated on lateritic soils from the southern, south-western and humid central zones, examining their compaction–CBR relationships, moisture sensitivity and variability under different energy levels and conditioning (soaked/unsaturated). These works collectively highlight the need for location-specific characterization, as laterites from different geological and climatic settings often exhibit markedly different strength–moisture–compaction behaviour even over short distances [16].

Kontagora is situated in the Basement Complex geological zone and the region has lateritic soils deposits that have developed from the weathering of igneous and metamorphic rocks in their original position. Despite the ongoing infrastructure development in the area, which include road expansion initiatives, there is still a significant deficiency in empirical data and research regarding the performance of local residual soils. The CBR of these residual soils assessed for moisture and compaction conditions in sub-urban area like Kontagora is yet under study. This limited information presents a challenge for engineers aiming to provide cost-effective and resilient pavements that are adapted to the behavior of local soils.

This research examines the California Bearing Ratio of 20 disturbed residual lateritic soil samples gathered from specific sites in Kontagora. The objective of the research evaluates the impact of compaction energy (BSL and BSH) and moisture conditions (soaked and unsaturated) on the load-bearing capacity of these lateritic soils. The findings will provide crucial data to inform pavement design and moisture management strategies. Potential soil stabilization initiatives in the area on some of the soil samples were also suggested. In addition, the results will enhance the existing knowledge about the behavior of lateritic soils in northern Nigeria, aiding both academic and practical engineering decision-making.

## 2. MATERIALS AND METHODS

### 2.1 STUDY AREA AND SOIL SAMPLING

The research was carried out in Kontagora and its surrounding areas, situated in the northwestern region of Niger State, Nigeria (refer to Figure 1). This area is categorized as a tropical hinterland, characterized by seasonal rainfalls, rolling terrain, and lateritic soil profiles formed primarily from weathered Basement Complex rocks. Disturbed method of sample collected was administered with a total of twenty (20) samples collected from six (6) different locations from borrow pits spread within the region. Sampling was done in such a manner that the samples collected present variability and reflects typical sources of construction materials in the location. Hand augers and diggers were used to collect the soil samples at depths ranging between 0.5 m to 1.5 m, and the samples were taken to the soil mechanics laboratory in the Department of Civil Engineering at the Federal University of Technology Minna for examination.

### 2.2 LABORATORY TESTING

The laboratory tests were carried out in accordance to specification outline in [17]. The test conducted includes:

#### A. Sieve analysis

The method used was consistent with [17]. Each of the soil sample used for the sieve analysis was weighed and was soaked for 24 hours. Thereafter the samples were washed using the sieve size of 0.075 mm and the samples that remained were carefully collected and placed in a pan. The pan was subsequently put into an oven maintained at a temperature ranging from 80°C to 100°C for 24 hours. A standardized collection of sieves was cleared and organized in decreasing size, placing the largest sieve at the top and the smallest at the bottom. The set of sieve sizes used were 5.0 mm, 3.35 mm, 2.0 mm, 1.18 mm, 0.85 mm, 0.60 mm, 0.425 mm, 0.300 mm, 0.150 mm, and 0.075 mm, with the pan positioned at the end. The sieves were ensured to be close and aligned so as to prevent the escape soil samples. The soil samples that were dried in the oven were then placed into the top sieve with the 5.00 mm aperture. The set of sieves were set in motion and vibrated for 10 minutes using a mechanical sieve shaker. The soil held on each sieve was measured with a weighing balance, and the percentage retained was calculated as shown in Equation 1.

$$\text{Percentage Retained} = \frac{\text{mass of the soil sample on each sieve}}{\text{total mass of soil sample}} \times 100 \quad (1)$$

**B. Atterberg limit**

The cone penetrometer method was used to determine the liquid limit. To find the LL, a small amount of dry soil sample was ground into fine particles with a mortar, and then the sample was sifted through a 0.425 mm sieve. A portion of the sieve pulverized soil sample, weighing about 200 g was placed on a uniform glass plate. Water was added to create a thick paste of uniform texture through the aid of a spatula. The penetrometer mould was then fill with a considerable portion of the paste right to the brim. The upper portion of the mould filled with the soil sample was cut to align with the cup's top. The cone was placed and lowered to make contact with the upper surface of the soil sample within the mould. The cone was dropped, and the dial gauge showed the penetration in millimeters. To ensure accuracy and precision, two penetration measurements were recorded for each sample, and the average of these two values was considered. The soil inside the mould was emptied and cleaned and a small portion was taken for moisture content determination. The whole process was carried out again until a penetration above the recommended 200mm was obtained. A graph of penetration (mm) against moisture content was plotted and the moisture content at 200 mm was determined which gave the liquid limit for the soil sample.

For the determination of the plastic limit, an approximate mass of 20 grams of pulverized soil sample, which had been previously sieved through a 0.425 mm mesh, was used in the experimental procedure. The crushed sieve soil sample was combined with water on a flat glass plate using a spatula. The combined soil sample was rolled between the palms to a diameter of approximately 3 mm, at which point the soil sample broke apart. The loosened soil was subsequently moved into moisture cans and baked in the oven for 24 hours. The dried samples were subsequently taken out of the oven, weighed, and the moisture content was determined.

The Plasticity Index (PI) measures the range over which the soil remain plastic, that is, the range in which the soil can be moulded without cracking or crumbling. The difference between the liquid limit and the plastic limit was established as indicated in Equation (2).

$$PI = LL - PL \tag{2}$$

**C. Compaction test:**

The compaction test was conducted according to the procedure outlined in [17], employing both British Standard Heavy (BSH) and British Standard Light (BSL) energy levels. For this test, 3000g of dry soil was weighed and blended with a small quantity of water. After which the soil sample was transferred inside a standard mould of 1000 cm<sup>3</sup> diameter and compacted using a two energy rammers falling at an height of 45 cm. 4.5 kg rammer utilized for heavy compaction (BSH) in five layers and 2.5 kg rammer for standard compaction (BSL) in three layers. At both ends of compaction, the mold collar was removed, and the surface of the compacted soil was smoothed to match the upper edge of the mold. After this, the mould with the compressed soil was weighed to the closest 1.0g using a weighing scale. Two samples were taken from the compacted soil, one from the upper layer and one from the lower layer, to evaluate the moisture level. The entire soil sample was subsequently taken out of the mold and placed into a sizeable mixing tray for re-pulverization. The complete procedure was carried out again for the two energy levels until the weight of the mould and the compacted soil sample decreased.

For each of the compacted soil samples, the bulk density was determined using Equation 3 and the dry density was further evaluated from the bulk density in Equation 4 using the moisture content and volume of the compacted mould. The graph of the dry density against moisture content was plotted and the point at the peak of the curve representing the OMC and MDD were obtained.

$$\rho_{bulk} = \frac{W_s}{V} \tag{3}$$

Where:  $\rho_{bulk}$  = compacted soil bulk density (g/cm<sup>3</sup>)

$W_s$  = weight of the compacted soil (g)

$V_s$  = Volume of the mould (cm<sup>3</sup>)

$$\rho_d = \frac{100\rho_b}{(100+W)} \tag{4}$$

Where:  $\rho_d$  = Dry density of the compacted soil (g/cm<sup>3</sup>)

$\rho_b$  = Bulk density of the compacted soil (g/cm<sup>3</sup>)

$w$  = Moisture content (%).

**D. California Bearing Ratio (CBR) test**

The CBR test adhered to the procedures detailed in [17]. The soils samples were compacted using their respective optimum moisture content determined for both heavy and standard compaction efforts. To evaluate the load carrying capacity of the soil materials and their sensitivity to moisture, tests were performed in both soaked and unsoaked states. In saturated condition, the soil samples were immersed in water for 96 hours before testing to simulate a worst-case moisture situation. During the testing process, 6000 g of dry soil samples were used. The soil samples were blended at its ideal moisture level obtained from the compaction test evaluation. The soil samples were compacted in five layers for heavy compaction and in three layers for standard compaction in the CBR mould. Every layer of compaction was struck 62 times with a 2.5 kg rammer for BSL and a 4.5 kg rammer for BSH. The soil surface of the samples after compaction was leveled to match the upper edge of the mould, thereafter the mould containing the compacted soil was positioned in the CBR machine and loaded appropriately. The plunger of the CBR machine was then lowered onto the soil specimen, and testing was done to penetration in intervals of 0.25 mm, starting from 0.25 mm to 7.50 mm. Loading was exerted on the top and bottom of the specimen and the values of penetration and force readings were recorded. The force values from the proving ring were plotted against the plunger penetration measured by the dial gauge.

The California Bearing Ratio (CBR) value was then calculated from Equation 5a and 5b as shown below and the lesser of the two values obtained at 2.5mm and 5.0mm was chosen as the CBR value.

$$\text{CBR value at 2.5mm} = \frac{\text{Applied load} \times 100}{13.24} \tag{5a}$$

$$\text{CBR value at 5.0mm} = \frac{\text{Applied load} \times 100}{19.96} \tag{5b}$$

**2.3 STATISTICAL AND VARIANCE ANALYSIS**

Statistical analysis was carried out on the compaction characteristics result, which comprised of the maximum dry density (MDD) and optimum moisture content (OMC), and the California Bearing Ratio (CBR) results of the 20 soil samples. This analysis included the mean, standard deviation, and the minimum and maximum values of MDD, OMC, and CBR, as well as the coefficient of variation.

The mean ( $\bar{x}$ ) in Equation 6 provides the average value.

$$\bar{x} = \frac{\sum_{i=1}^n x_i}{n} \tag{6}$$

Where  $x_i$  = individual data points and n = the total number of samples (n = 20)

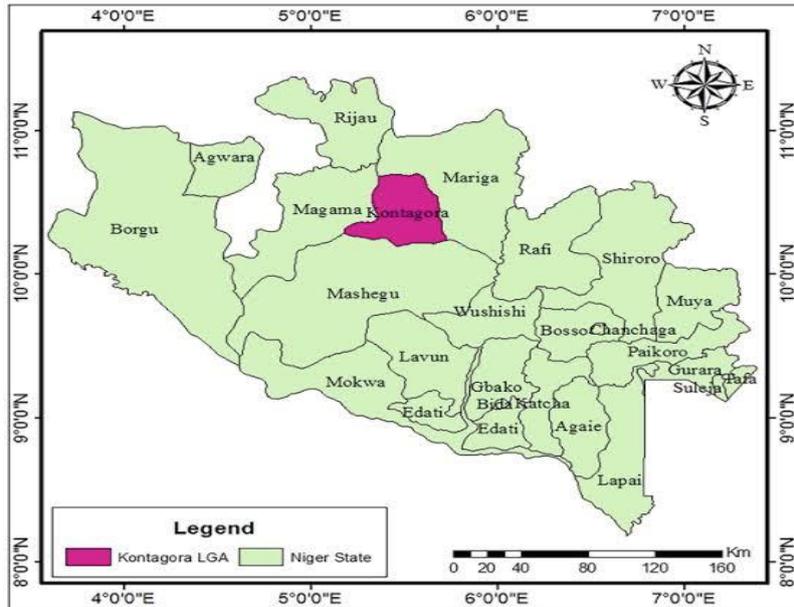
The standard deviation (s) measures the dispersion of the data from the mean (Equation 7)

$$s = \sqrt{\frac{\sum_{i=1}^n (x_i - \bar{x})^2}{n-1}} \tag{7}$$

The coefficient of variation (CV) in Equation 8 represents the standard deviation expressed as a percentage of the mean.

$$CV = \frac{s}{\bar{x}} \times 100\% \tag{8}$$

A one-way analysis of variance (ANOVA) was conducted using Microsoft Excel to statistically assess the difference between the soaked and unsoaked CBR. The F – value was compared with the critical  $F_{\alpha}$  at 95% confidence level ( $\alpha = 0.05$ ). Since  $F > F_{\alpha}$ , the null hypothesis ( $H_0$ ) is rejected. Also, since  $p \leq 0.05$ ,  $H_0$  is rejected, connoting significant difference between soaked and unsoaked CBR.

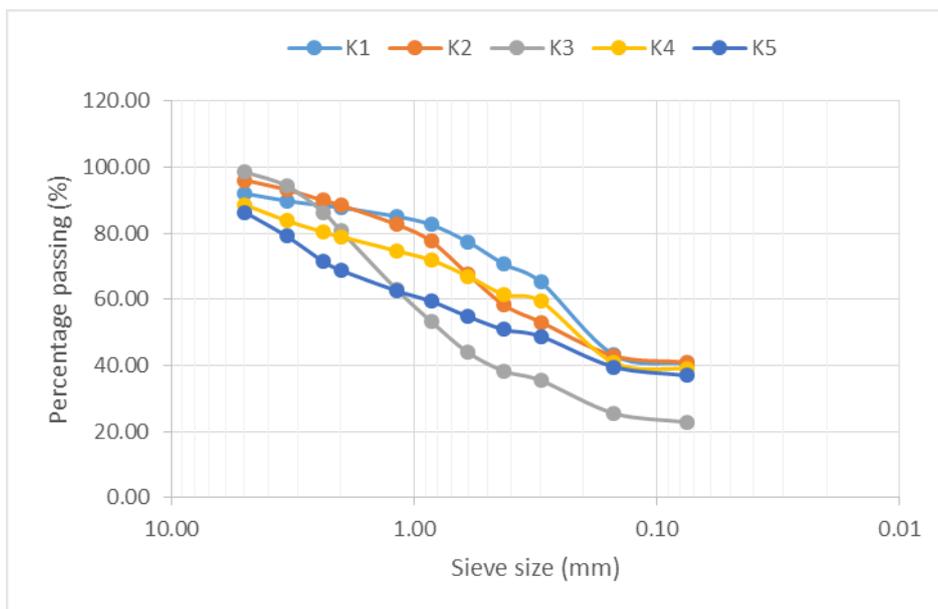


**FIGURE 1** Map of Niger State with reference to Kontagora [18]

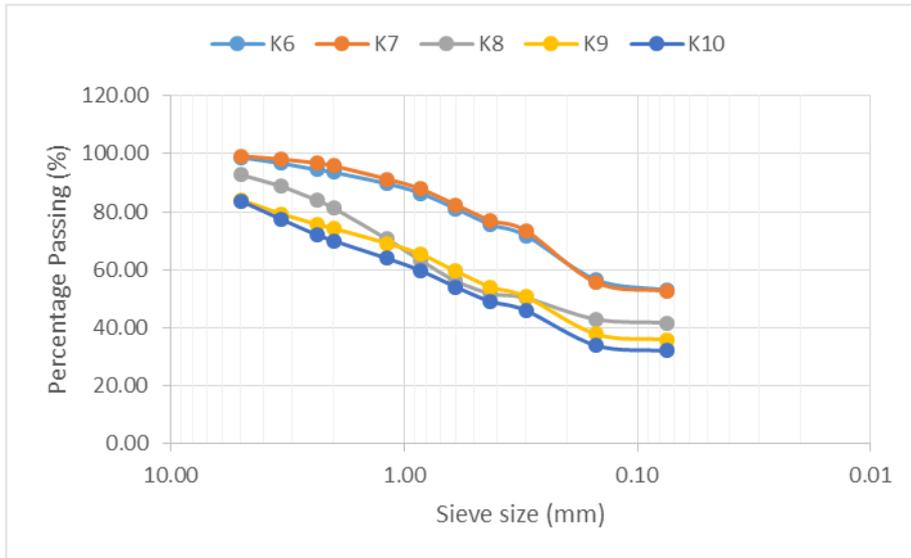
### 3. RESULTS AND DISCUSSIONS

#### 3.1 PARTICLE SIZE DISTRIBUTION

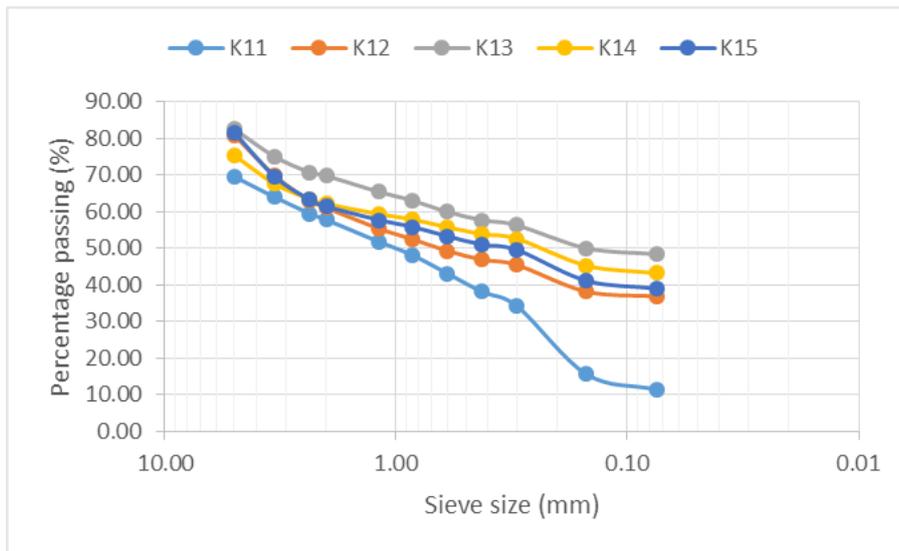
The particle size distribution of the residual lateritic soil samples were evaluated against the [19] general specification, which stipulates that material used as subgrade and subbase in road construction should generally have  $\leq 35\%$  fines to ensure adequate drainage and strength. From Figure 2 to 5, about 80% of the soil samples have fines exceeding the threshold, indicating potential susceptibility to poor drainage and strength. However, 20% of the samples fall within the acceptable range. The variation in fine content among the residual lateritic soils indicates that the particle size distribution is not uniform throughout the study area. Therefore, it is essential and crucial to conduct proper care and evaluation for material testing prior to choosing soils for pavement construction, guaranteeing that only those with appropriate gradation profiles are utilized.



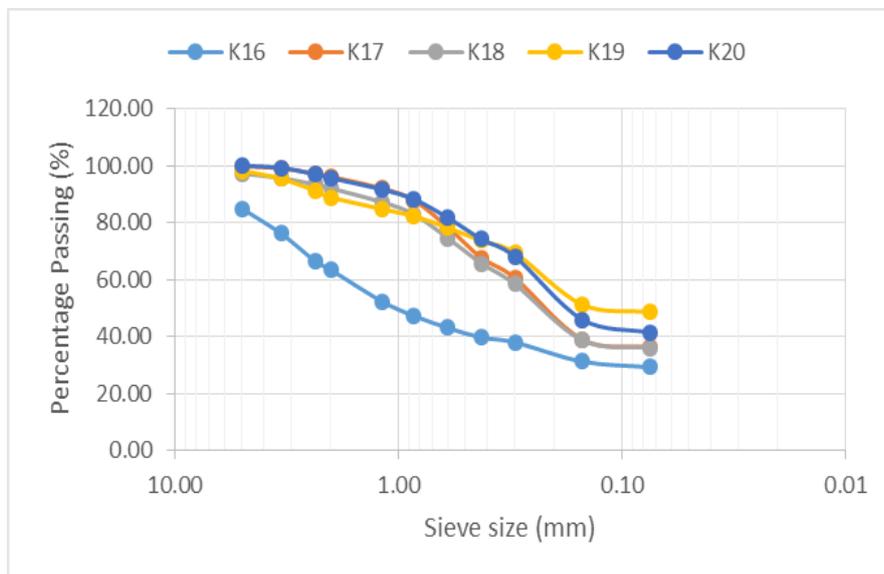
**FIGURE 2** Particle size distribution graph for soil samples K1 to K5



**FIGURE 3** Particle size distribution graph for soil samples K6 to K10



**FIGURE 4** Particle size distribution graph for soil samples K11 to K15



**FIGURE 5** Particle size distribution graph for soil samples K16 to K20

### 3.2 ATTERBERG LIMITS

The Atterberg limits are important for evaluating how workable soils are and their shrink-swell properties used in road pavement. As noted in [19], soil samples typically used for road construction, either as a subgrade and sub-base layers must possess a liquid limit (LL) of less than or equal to 50%, on the other hand the plasticity index (PI) should be between 10% and 30% so as to reduce the level of deformation and provide sufficient strength when subjected to impose load. According to Figures 6 and 7, most soil samples meet the LL requirement, which suggests a higher clay content, along with the ability to retain moisture and swell. For the plasticity index, some of the soil samples recorded PI values above the threshold limit. This is an indicative of high plasticity and potential for undesirable deformations when the soil is under traffic loads [20,21]. Generally, the PI values of the soil samples ranged from 15.41% to 35.90% .

Majority of the soil samples showed moderate plasticity. This suggest that the soil samples are generally appropriate for use as road material, though some variations exist among them. While some of the soil samples in comparison reveal low plasticity indices, indicating low clay content and increased stability. Hence, the differences in plasticity stresses the need for thorough selection and perhaps stabilization using lime or cement, to improve their performance in road construction as elaborated on in subsequent sections [22,23].

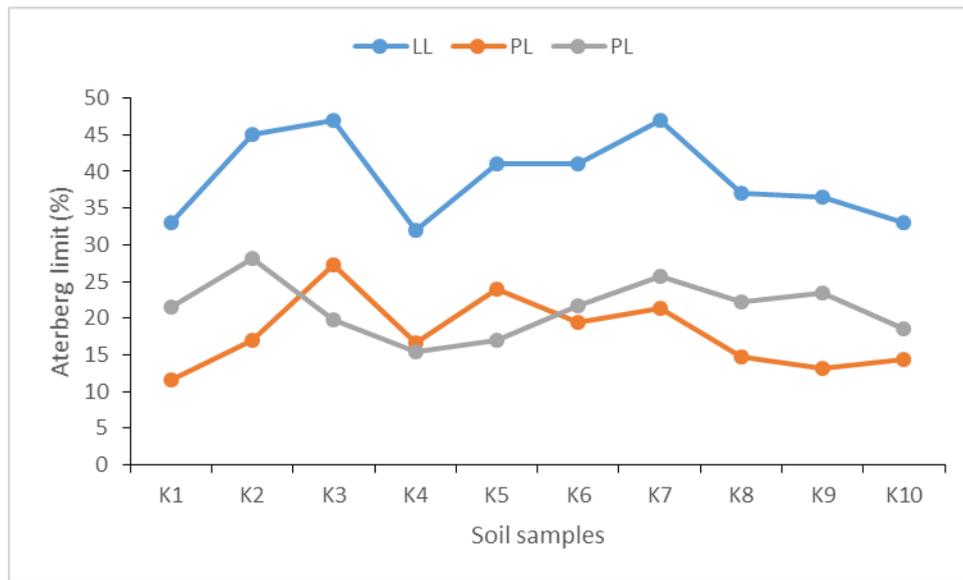


FIGURE 6 Differences in the consistency limit for soil samples K1 to K10

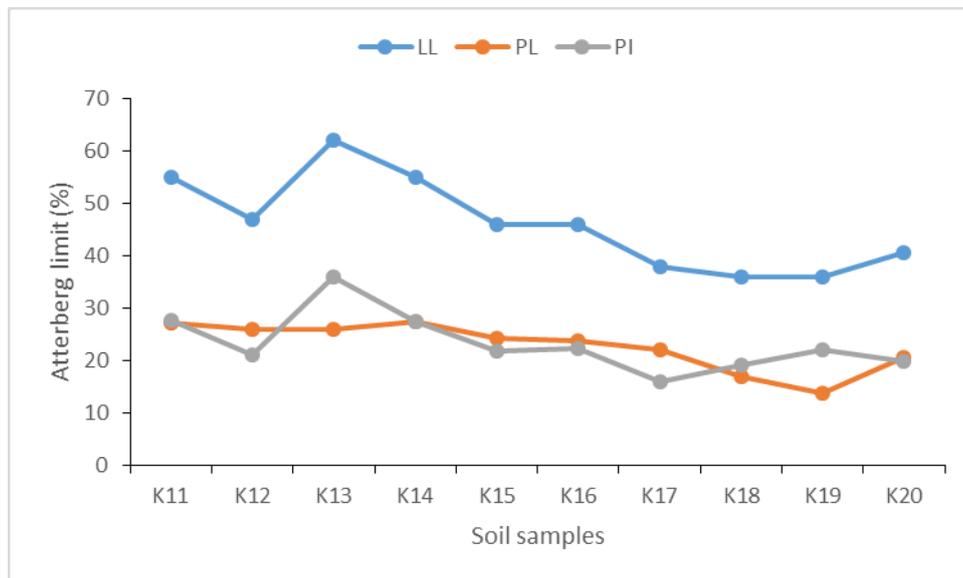


FIGURE 7 Differences in the consistency limit for soil samples K11 to K20

### 3.3 COMPACTION CHARACTERISTICS

The compaction characteristics results of the soil samples under both the Heavy (BSH) and Standard (BSL) compaction showed variability in the Maximum Dry Density (MDD) (see Figures 8a and 8b) and Optimum Moisture Content (OMC) (refer to Figures 9a and 9b). From the result, the values of MDD for the heavy compaction were higher than those with standard compaction (BSL). This is expected due to the difference in the compaction energy which may have caused the increase in density under BSH. This trajectory suggest the influence of compaction energy variation on maximum dry density of soil. The MDD under BSH was achieved at 2.13 g/cm<sup>3</sup> while under BSL, the peak was recorded at 2.05 g/cm<sup>3</sup>.

Moreover, OMC values tend to be higher for BSL compared to BSH, suggesting that a reduced compaction effort necessitates a higher water content to reach maximum density. As can be seen from the figures provided, under the heavy compaction, the highest optimum moisture content was recorded at 17% while the lowest was at 9%. On other hand for standard compaction, the OMC ranged from 9.50% to 17%. Hence, juxtaposing these result with the provision and regulation stipulated by the Federal Ministry of Works and Housing (FMWH) for subgrade, subbase, and base materials, there is notable different levels of suitability. Lateritic soils considered for road construction should have an MDD of no less than 1.80 g/cm<sup>3</sup> and an OMC ranging from 8% and 18%. Most of the soil samples tested meet this criteria under both compaction methods. In addition, the OMC values for all tested samples were within the acceptable limits, confirming that the soils can achieve adequate moisture levels for effective compaction.

The statistical analysis of the compaction characteristics results are presented in Table 1. Under the BSH compaction, the average MDD approximately 1.95 g/cc with a relatively low standard deviation of 0.08 g/cc was evaluated. This result indicates that the MDD of the soil samples are consistent across the sampled locations. The Optimum Moisture Content under BSH averaged around 12.55%, with a standard deviation of 2.11%. For the BSL compaction effort, there was a slight decrease in the average MDD of about 1.84 g/cc. Similar to BSH, its standard deviation of 0.09 g/cc points to comparable consistency in density, however at a slightly lower with range of 0.39 g/cc. With respect to moisture, BSL compacted samples generally required a higher OMC, averaging approximately 13.91%. The standard deviation for BSL's OMC was 2.40%, indicating a slightly wider spread in optimum moisture content compared to BSH, with values ranging from 9.5% to 17%.

The higher MDD values obtained under BSH suggest that these soils can gain higher load-bearing capacity when adequately compacted in base or subbase layers in road construction. The BSL results show lower MDD values and higher OMC. This suggests that the material may be suitable for subgrade layers where less compaction is usually used. The findings highlight the need for proper compaction selection methods to meet FMWH specifications for road pavement applications.

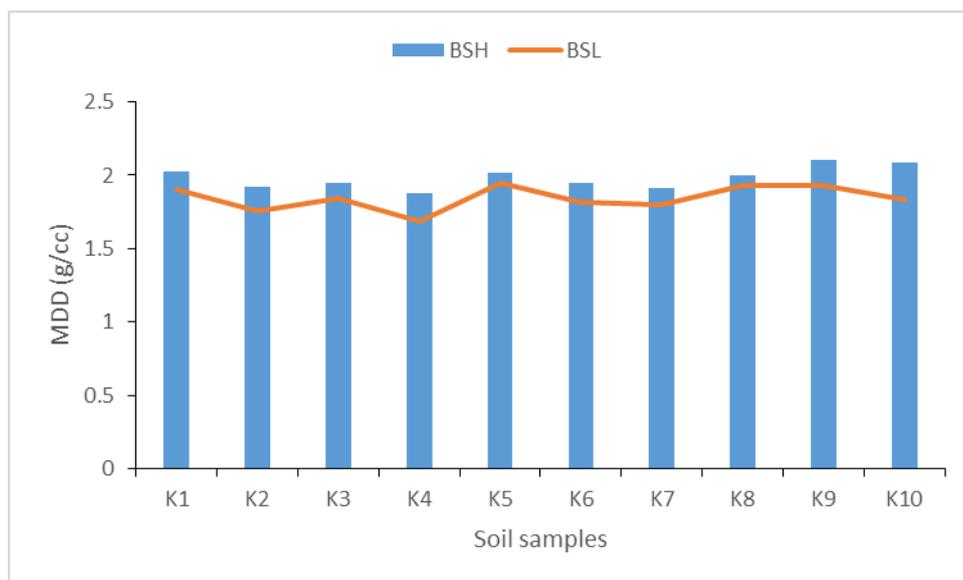
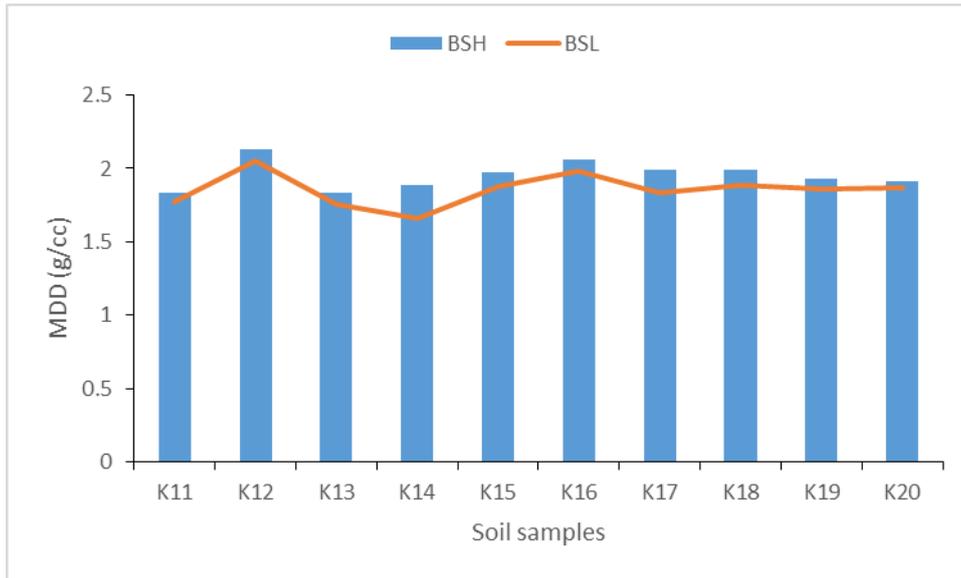
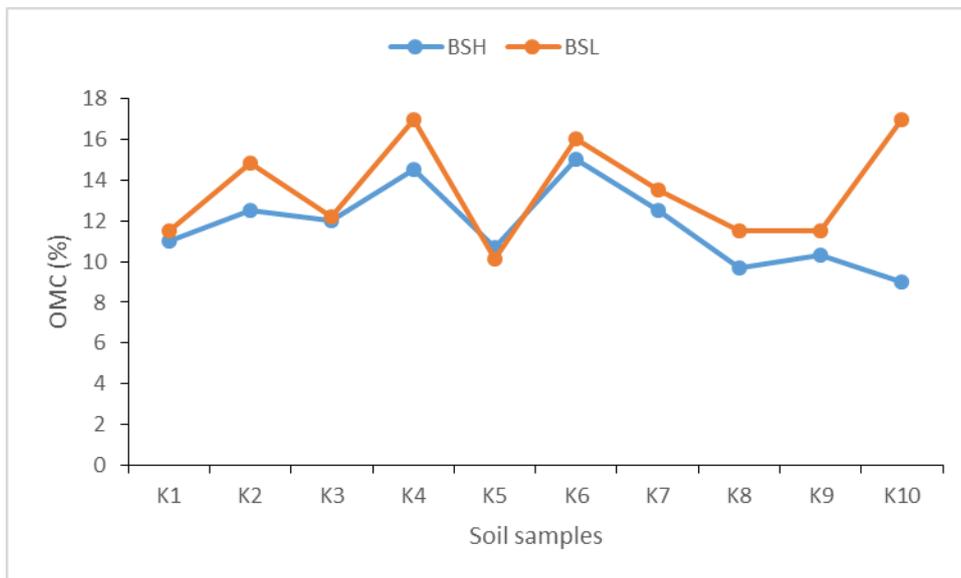


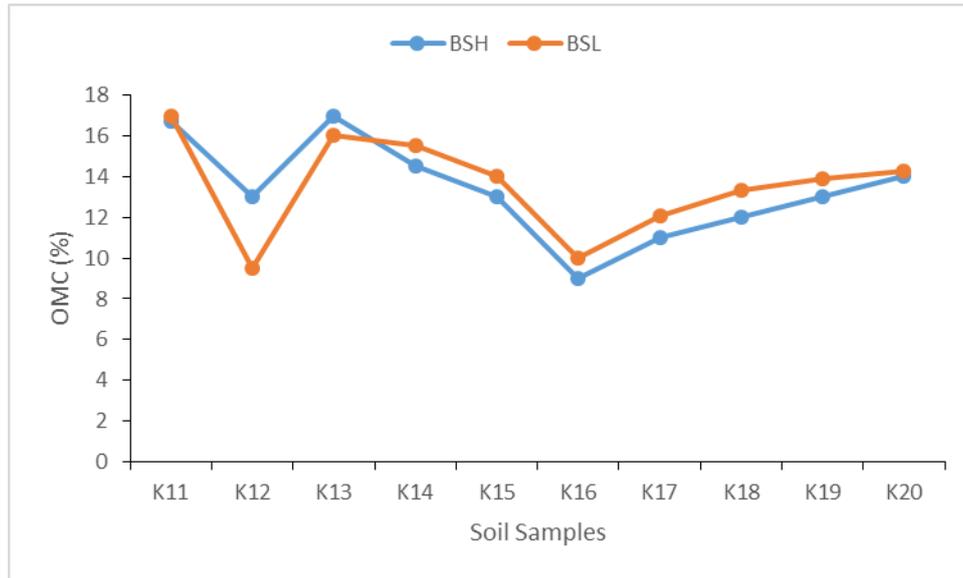
FIGURE 8a. Maximum dry density for soil samples K1 to K10



**FIGURE 8b.** Maximum dry density for soil samples K11 to K20



**FIGURE 9a.** Optimum Moisture Content for soil samples K1 to K10



**FIGURE 9b.** Optimum Moisture Content for soil samples K11 to K20

**Table 1** Statistical information of the soil samples compaction characteristics

Statistic	BSH		BSL	
	MDD (g/cc)	OMC (%)	MDD (g/cc)	OMC (%)
Mean	1.95	12.55	1.84	13.91
Median	1.94	12.75	1.84	13.70
Standard Dev.	0.08	2.11	0.09	2.40
Minimum	1.83	9.00	1.66	9.50
Maximum	2.09	17.00	2.05	17.00
Range	0.26	8.00	0.39	7.50

### 3.4 CALIFORNIA BEARING RATIO (CBR) OF THE SOIL SAMPLES

The California Bearing Ratio (CBR) results of the soil samples demonstrated significant variances (refer to Table 4.4). The findings demonstrate that CBR values observed under BSH (see Figures 10a and 10b) tend to be consistently higher compared to those recorded under BSL (refer to Figures 11a and 11b). The increased in CBR with higher energy level stresses the importance of compaction effort in enhancing soil strength. It therefore implies that heavy compaction can be suitable for road construction where heavy traffic is imminent. There was also a significant difference in the unsoaked CBR and soaked CBR of the soils samples. The highest CBR under unsoaked condition was recorded at 115.16% and the lowest at 46.31% under the heavy compaction effort. While under the standard compaction the highest CBR peaked at 91.47%.

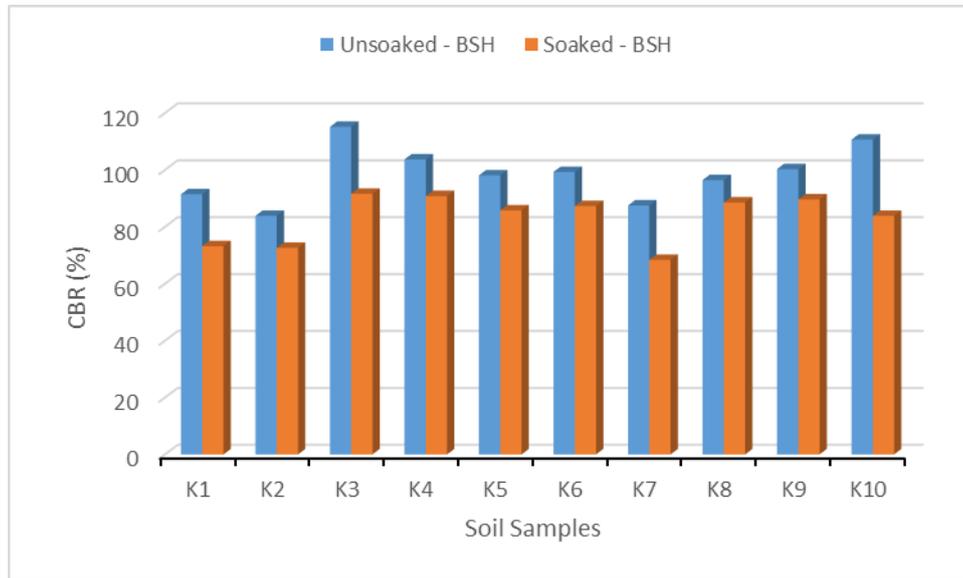
Under soaked condition, the CBR values were lower than those obtained in the unsoaked condition. This suggest that some of the soil samples are vulnerable to moisture influences. For instance under the heavy compaction the highest value of soaked CBR stands at 91.80% and the minimum was recorded at 9.39%. On the other hand under the standard compaction the highest soaked value was at 82.89%, about 9.7% reduction when compared to the highest value recorded under heavy compaction. The level of decrease in CBR in soaked condition for some of the soil samples was high, suggesting that these soil samples may perform poorly under wet condition. Use of admixture such as cement or lime can enhance the characteristics of these soil samples for efficient use as road material. These additives have been shown to be effective for stabilizing soil [24].

The result of these findings when compared with the specifications stipulated by the Federal Ministry of Works and Housing, which set a minimum CBR of 30% for subgrade and 80% for subbase materials, indicates that most of the unsoaked CBR of the soil samples fulfill the requirement for use as subbase material in road construction under heavy compaction. Even though under the standard compaction effort few of the samples met this criteria. This results reveals the impact of compaction effort on improving the strength of lateritic soil.

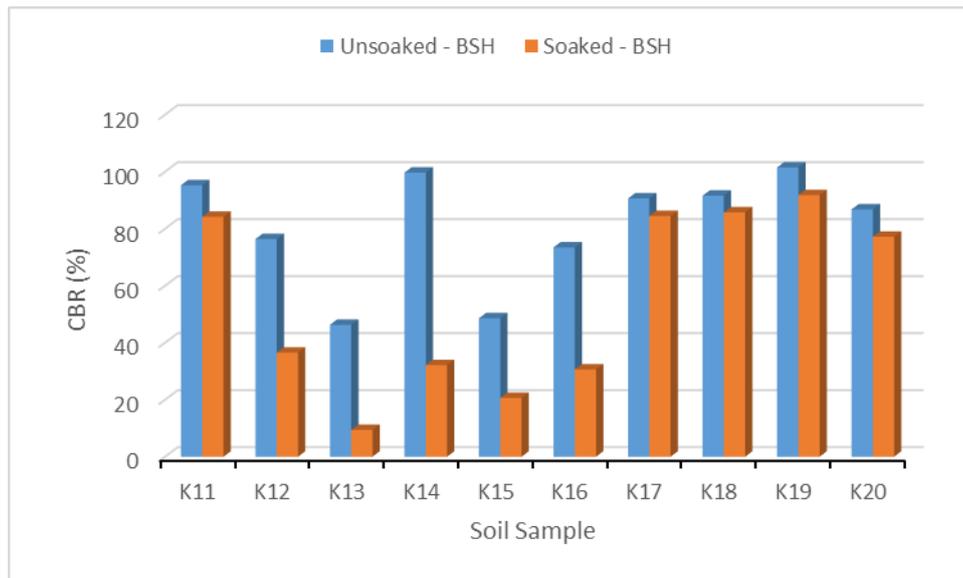
The statistical analysis of the soil samples reveals a mean Unsoaked CBR of 89.83% under BSH, but the values decreased substantially when soaked to a mean Soaked CBR of 69.22%. This 20.61% reduction in CBR from unsoaked

condition highlights a considerable loss of bearing capacity when in soaked condition. Furthermore, the standard deviation under heavy compaction increases sharply from 17.68 (unsoaked) to 26.93 (soaked), indicating a significant differences in strength lose. Some BSH compacted samples exhibited much sensitivity with moisture, with their CBR values plummeting from as high as 46.31% (unsoaked) to as low as 9.39% (soaked). Similar trend also occurred under BSL compaction, there is a marked decrease in CBR upon soaking. The mean Unsoaked CBR of 74.96% falls to a mean Soaked CBR of 52.09%, representing a 22.87% absolute drop. The standard deviation under BSL also increases from 18.63 (unsoaked) to 23.17 (soaked), though the increase in variation is slightly less when compared to BSH compacted soil samples.

In general, the notable drop in CBR for specific samples after soaking shows that these soils properties need adequate modification (like lime or cement treatment) to improve capacity to withstand strength loss due to moisture effects before being used in road construction.



**FIGURE 10a.** CBR of soil samples K1 to K10 BSH



**FIGURE 10b.** CBR of soil samples K11 to K20 BSH

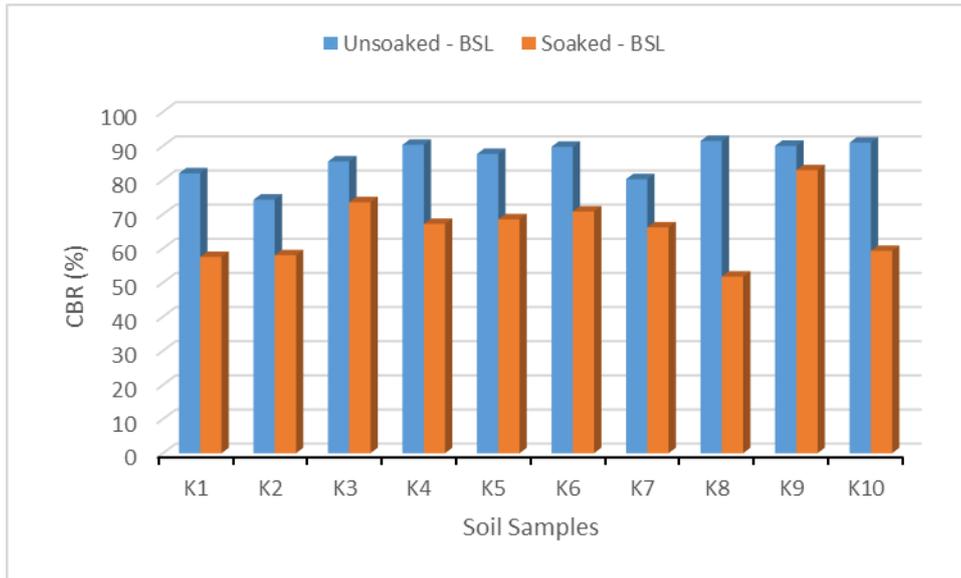


FIGURE 11a. CBR of soil samples K1 to K10 BSL

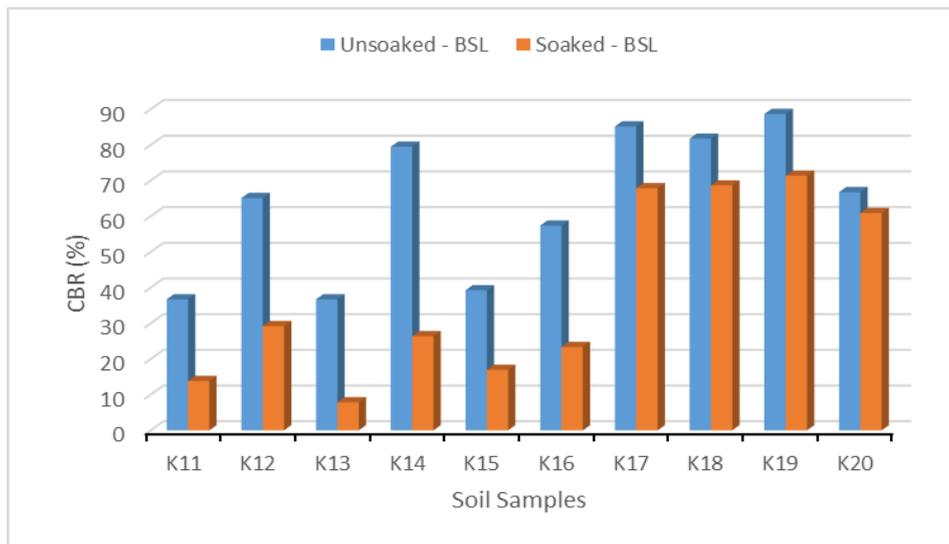


FIGURE 11b. CBR of soil samples K11 to K20 BSL

Table 2 CBR Statistical information of the soil samples

Metric	BSH Unsoaked (%)	BSH Soaked (%)	BSL Unsoaked (%)	BSL Soaked (%)
Mean	89.83	69.22	74.96	52.09
Median	93.44	84.03	81.87	60.09
Standard Deviation	17.68	26.93	18.63	23.17
Minimum Value	46.31	9.39	36.72	7.85
Maximum Value	115.16	91.8	91.47	82.89

### 3.5 STATISTICAL VARIANCE OF CALIFORNIA BEARING RATIO (CBR) FOR SOIL SAMPLES

The analysis of variance (ANOVA) comparing unsoaked and soaked CBR values for each compaction effort (BSH and BSL) was conducted to determine whether moisture conditioning significantly affects the strength performance of the lateritic residual soils.

For BSH-compacted samples, the ANOVA between unsoaked and soaked CBR values yielded an F-statistic of 8.19 which is less than the F - critical (4.098) and a p-value of  $0.0068 < 0.05$  (Table 3). The ANOVA analysis result suggest that there is a significant difference between the unsoaked CBR values and the soaked CBR of the soil samples. The reduction in CBR after soaking implies that even under high compaction effort, moisture has a pronounced weakening effect on the soil structure and strength of the soil samples. Similarly, for BSL compacted samples, the ANOVA analysis showed an F-statistic of 11.83 higher than F-critical (4.098) and a p-value of  $0.0014 < 0.05$ , validating the rejection of the null hypothesis and suggesting that a notable difference exists between the unsoaked CBR and soaked CBR values (Table 4). The effect of soaking is even more pronounced under the BSL compacted samples due to low CBR values obtained. The additional loss from moisture exposure further reduces their load-bearing capability.

In general, the ANOVA analysis results presents strong conclusion that soil samples under soaked condition experience a significantly reduction in CBR regardless of compaction effort. However, the reduction in CBR values of the soil samples is more in lightly compacted (BSL) soils, underscoring the importance of proper compaction and moisture control for long-term pavement performance.

**Table 3 ANOVA Single factor for Unsoaked and Soaked CBR Values under BSH compaction**

<b>SUMMARY</b>						
Groups	Count	Sum	Average	Variance		
Unsoaked (%)	20	1796.66	89.833	312.6106		
Soaked (%)	20	1384.45	69.2225	725.1698		

<b>ANOVA</b>						
Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	4247.927103	1	4247.927	8.186562	0.006825	4.098172
Within Groups	19717.8282	38	518.8902			
Total	23965.7553	39				

**Table 4 ANOVA Single factor for Unsoaked and Soaked CBR Values under BSL compaction**

<b>SUMMARY</b>						
Groups	Count	Sum	Average	Variance		
Unsoaked (%)	20	1499.29	74.9645	347.0057		
Soaked (%)	20	1041.89	52.0945	536.9961		

<b>ANOVA</b>						
Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	5230.369	1	5230.369	11.83339	0.001427	4.098172
Within Groups	16796.03	38	442.0009			
Total	22026.4	39				

## 4. CONCLUSIONS

Based on the results of the study on the residual lateritic soils in Kontagora, Niger State, it can be concluded that:

- i. More than 80% of the residual lateritic soil samples contained fines exceeding FMWH (2016) limits.
- ii. Most samples satisfied the liquid limit requirement, but plasticity index values showed that some soils were excessively plastic.
- iii. British Standard Heavy (BSH) compaction achieved higher MDD and lower OMC than BSL compaction.
- iv. British Standard Light (BSL) compaction produced lower MDD and higher OMC.

- v. Many of the soil samples satisfied compaction requirements under both energy levels, supporting their potential use in roadworks.
- vi. Unsoaked CBR values were significantly higher than soaked values for all samples.
- vii. Under BSH compaction, mean CBR reduced from 89.83% (unsoaked) to 69.22% (soaked) while under BSL compaction, mean CBR reduced from 74.96% to 52.09% after soaking.
- viii. Several BSH-compacted samples met the  $\geq 80\%$  CBR requirement for subbase materials. However only a few BSL-compacted samples satisfied subbase CBR requirements.
- ix. ANOVA confirmed that soaking significantly reduced CBR values ( $p < 0.01$ ) for both compaction energies.
- x. BSH compaction consistently yielded higher CBR values than BSL under both soaked and unsoaked conditions.
- xi. The wide variability in soaked CBR highlights the need for adequate compaction and effective moisture control.

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## CONFLICTS OF INTEREST

The authors declare no conflict of interest

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