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REVIEW ARTICLE

CORRELATION ANALYSIS OF COMPACTION PROPERTIES OF SOIL WITH VARIOUS SOIL PARAMETERS OVER GBARAMATU NIGER DELTA, NIGERIA

Amarachukwu A. Ibe[a*]., Chukwunenye M. Ogbodo[b]

[a] Department of Physics, Nigeria Maritime University, Okerenkoko
[b] Department of Civil Engineering, Nigeria Maritime University, Okerenkoko
[*]Corresponding Author Email: draaibe17@gmail.com

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ABSTRACT

This study presents the analysis of soil compaction properties relationship over Gbaramatu subsurface of Niger Delta region. It is employed to determine the soil suitability for a wide range of Engineering needs, such as the development of foundations, roadways, and other facilities. The study aims to investigate the relationship between compaction properties on soil samples from Gbaramatu different locations. Ten (10) boreholes disturbed soil samples were collected for this investigation. Laboratory tests were conducted to obtain moisture contents, Particles Size Distribution, Specific Gravity and Consolidated Drained Shear results. Geotechnical analysis was equally conducted on the obtained laboratory parameters, to further obtain the Coefficient of curvature (Cc) and uniformity coefficient (Cu). Standardize statistical correlation tests were presented. Our findings indicate a positive relationship between the optimum moisture content and the coefficient of uniformity corresponding to higher optimum moisture concentrations. This discovery has far-reaching consequences for soil management and irrigation techniques. The results support the assumption that, the physical geology of the location is attributed to swamp reclamation and landfills. This research finally provides useful information about the engineering properties of Gbaramatu soils, and the correlation equations generated will be helpful in predicting values or modeling the correlated properties for soils within the Niger Delta region of Nigeria.

KEYWORDS

Gbaramatu, Niger Delta, soil, Compaction

1. INTRODUCTION

The need to provide basic structural shelters especially in Island settings has led to land reclamation processes from swamp to creeks environment. The sedimentation and land fill can contribute to local datum of swamp belts and river channels, these areas are flood prone due to clay layer presence and partially decayed organic materials. Sediments are attributed to high gradient thickness over a short period of time, other parameters like subsidence and faults can affect the thickness disparity of the physical geology of the environment. The adaptation of this type of environment in constructing an Engineering structural feature, contributes to an adequate precaution adaptation due to the location mechanical instability experience (Akintorinwa and Adesoji, 2009; Ayolabi et al., 2013).

“Unfortunately, there have always been inadequate precautionary measures alongside the presence of mechanically unstable soil materials in most structures erected on such piece of land, which has led to avoidable and devastating collapse of building structures, with its consequence been death” (Ayolabi et al., 2013). For us to design a formidable foundational architecture for structures around this type of riverine environment, robust Geophysical and Geotechnical parameters of the subsurface are paramount (Ayolabi et al., 2013). Although, every architectural framework is assisted by geological formations, it is fundamental to initiate a pre-construction study of the proposed sites subsurface (soil) to measure the stability and acceptability of the host soil particles, along with comprehensive post construction measures, to ensure structural integrity (Oyedele and Okoh, 2011).

In foundation studies, Geophysical and Geotechnical techniques are utilized (Akintoriniwa et al., 2010; Fatoba et al., 2010; Akintorinwa and Abiola, 2011; Oyedele et al., 2012; Coker et al., 2013; Ofomola et al., 2018). A group researchers evaluated the foundation integrity of a crystalline basement complex using an integrated approach of Geophysical and Geotechnical techniques (Olayanju et al., 2017). This would be dependent on the physical characteristics of the several strata that constitute the earths subsurface, having a significant and measurable disparity (Ofomola et al., 2018). These features, which include velocity, electrical resistivity, density and acoustic qualities, reveal the type and composition of earth materials. Clay minerals are influential in predicting the rigidity and compressibility of soils according to Geotechnical studies (Mehmet and Gurkan, 2007; Rozalina and Yanful, 2012; Ofomola et al., 2018).

Since the clay texture percentage of the soil influences cohension, friction angle, and plasticity index of soil, the clay content has a considerable impact on soil capability (Ofomola et al., 2018). Some researchers emphasized the necessity of categorizing soil properties dependent on clay composition as well as the need to integrate approaches, in order to achieve accurate projections of bearing capacity (Thomas et al., 2000). Other workers generated assessment methods that focused on two or more indices, with discrete threshold used to divide soil properties into swelling potential (Thomas et al., 2000; Igwe and Umbugadu, 2020). As a result, pre-foundation studies are now considered to prevent the destruction of irreplaceable lives and property that is invariably associated with such failures (Oyedele and Okoh, 2011).

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So, the ground investigations are essential preliminary to the construction of high-rise buildings or structures in a swampy/flood prone areas. The objectives of a ground investigation are to obtain reliable information in order to generate an economic and appropriate design, to equally evaluate all conditions associated with the ground and the groundwater as well as to meet the requirement for the tendering construction time and the cost schedule. The results and interpretation of the investigation are crucial factors for the stability and serviceability of the structure (Meissner et al., 2012). "Empirical correlations are widely used in Geotechnical Engineering practice, as a tool to estimate the Engineering properties of soils" (Sorensen and Okkels, 2013).

The bearing capacity of rock/soil is the determinant factor for any reliable Engineering structure and its attainment depends on the foundation material that can carry the structural and the expected load (Terzaghi et al., 1996; Osinowo and Falufosi, 2018). Soil properties such as cohension, angle of internal friction, capillarity, permeability, elasticity and compressibility affect the bearing strength of soil and subsequently defines the allowable loads that can be applied on the soil. The attention to construct a properly designed Engineering structures was attributed to frequent structural failures and associated loss of lives (Ede, 2010; Osinowo and Falufosi, 2018).

Settlement for structural construction are evaluated regularly and as well as over consolidated soils using compression and swelling index coefficients, that was obtained through consolidation test techniques (Alptekin and Tagh, 2019). These compressibility parameters are the determinant factor in the evaluation of soil layers that are finely grained. For the sustainable and cost effective layouts of structural applications, compaction properties and other soil parameters must be determined. The compressibility parameters are obtained through laboratory tests (Kurnazet al., 2016). However, correlation of compaction properties of soil with other various soil parameters can be adopted in Geotechnical Engineering. This helps in establishing rapid and low cost techniques in Geotechnical parameter predictions (Onyejekwe et al., 2014).

"The correlation between two or more soil properties has been found to be dependent in varying degrees on soil type, the testing method used to obtain the numerical value of the parameter itself and the homogeneity of the soil" (Uzielli et al., 2007; Onyejekwe et al., 2014). Many researchers investigated the presence of correlations between compressibility features and other soil parameters from inception (Kurnaz et al., 2016). They equally presented techniques for evaluating the compression index that is based on multiple linear regression analysis (Bae and Heo, 2011; Akayuli and Ofosu, 2013; Lee et al., 2015; Kurnaz et al., 2016). Their investigations are mainly concerned with the known soil parameter properties and compressional index correlations (Isik, 2009; Kurnaz et al., 2016).

Prior studies have equally examined the link between coefficient of uniformity, Cu and other soil properties as soil strength, permeability, and erosion resistance (Dong et al., 2011; Hossain et al., 2016). However, studies on the relationship between coefficient of uniformity Cu and other soil parameters in soil samples are sparse. Some researchers conducted research on the correlation between coefficient of uniformity, Cu and dry density, in soil samples collected from a building project in Turkish territory (Kavzoglu et al., 2017). The findings revealed a positive association between the coefficient of uniformity Cu and dry density, with an increase in the coefficient of uniformity leading to an increase in dry density. The researchers suggested that the association between coefficient of uniformity, Cu and dry density could well be characterized by greater soil particle distribution with an enhancement in coefficient of uniformity, resulting in an increase in dry density.

In a study of soil samples from three separate locations in India, discovered a robust link between coefficient of uniformity and dry density, with greater coefficient of uniformity concentration equating to higher dry density values (Pappu and Kode, 2010). Similar to this study by that examined soil samples from two Malaysian settings, a considerable positive relationship between uniformity coefficient and dry density was noted (Baker and Ramli, 2014). Numerous researchers have looked into the correlation between soil parameters. However, not all investigations have discovered a substantial relationship or correlation between soil parameters. A group researchers studied the association between coefficient of uniformity and dry density in soil samples collected from a Chinese agricultural area (Zhang et al., 2019). The findings revealed a substantial positive association between coefficient of uniformity and dry density, with an increase in coefficient of uniformity causing an increase in dry density. The authors proposed that the association between coefficient of uniformity and dry density could be explained by greater soil mechanical properties with an increase in coefficient of uniformity, resulting in an increase in dry density.

A studied the compressibility of soil using regression analysis. Park and his co-worker established a new compression index equation evaluated the empirical correlations of compression index for marine clay using regression analysis (Lav and Ansal, 2001; Park and Koumoto, 2004; Yoon et al., 2004). The governing relationship of compression index and other soil property indices of an established low plasticity probable clay soil was studied by (Gunduz and Arman, 2006). An Empirical model that establishes compression index from weathered phyllites was equally studied (Akayuli and Ofosu, 2013). Furthermore, several studies have also been conducted to investigate the relationship between the optimum moisture content and the soil uniformity coefficient (Bjerrum et al., 2005; Kim et al., 2012; Choudhary et al., 2018). However, the results of these investigations have been divergent, and no conclusion has been reached on the mechanism of this correlation. Some researchers established a connection between higher coefficients of uniformity and higher optimum moisture contents in soils (Bjerrum et al., 2005; Kim et al., 2012).

A group researchers identified a high variability relationship between optimum moisture content and coefficient of uniformity, with certain soils demonstrating a positive correlation and others exhibiting negative values (Choudhary et al., 2018). These divergent views imply that the correlation between optimum moisture content and coefficient of uniformity is complex and may be affected by a variety of factors including soil type, climate, and management strategies. Mechanical instability of physical Geology of an environment is mostly attributed to reclamation of swap, flood zones, river channels and these contribute to distressed building or structural foundation failure. The study was necessitated due to the structural foundation failures observed within the study location. Resolving these situations particularly over Gbaramatu environment is challenging, establishing a comprehensive Geotechnical scenario for the location that will enhance forth guide structural foundation's decision should be encouraged in order to avert future structural failures. The study aim is to investigate the correlation of soil compaction properties with other various soil properties over Gbaramatu, Niger Delta.

2. Geological Setting

The study area is within latitude 4o,7o N and longitude 3o,9o E sited on Gbaramatu community, Niger Delta basin. The location is within the humid tropics with two distinct seasons, namely (1) rainy season (April to October) and the dry season (November to March). Most precipitation is received during the rainy season (Aizebeokhai et al., 2010). It is a well vegetated, waterlogged area with active water flooding. During the dry season, the soil is waterlogged, but it drains leaving behind a highly fractured surface, while some areas are inaccessible due to swampy conditions (Ayolabi et al., 2013). The Geology of the area is derived from the regional geology of Niger Delta basin that is made up of three stratigraphic formations, namely, Benin, Agbada and Akata Formations.

The Cretaceous fracture zones of the setting manifested as trenches and ridges in the deep Atlantic control tectonic architecture of the plate boundary across the western coast of equatorial Africa. The fault zone ridges separate the margin into individual basins and constitute the boundary faults of the Cretacous Benue-Abakaliki trough, which cuts deep into the West African shield in Nigeria (Lehner and De-Ruiter, 1977; Tuttle et al.,1999). "The shallowest is the Benin Formation and is made up of freshwater bearing continental sands and gravels. Agbada Formation is the next in sequence, underlying the Benin Formation. It consists of sand and shale intercalation with a thickness of about 3,700km, these forms a better representation reservoir unit of the sequence (Nwankwo et al., 2014). The final on the sequence is the Akata Formation with 7,000 m thickness range. It is made up of shales, clays and silts. This Formation is of turbidite origin." (Short and Stauble, 1967; Nwankwo et al., 2014).

Figure 1: Map of Niger Delta (Gbaramatu inserted) (Olakunle, 2016).

Table 1: Geological units of the Niger Delta (Short and Stauble, 1967; Akpokodje, 1989)		
Geologic unit	Lithology	Age
Alluvian (General)	Gravel, sand, clay silt	
Freshwater backswamp and meander belt	Sand, Clay, some silt and gravel	
Saltwater mangrove swamps and backswamps	Medium fine sand, clay and some silt	Quaternary
Active/abandored beach ridges	Sand, clay and some silt	
Sombreiro Warri deltaic ridges	Sand, clay, and some silt	
Benin Formation	Coarse to medium sand, subordinate silt and clay layers	Miocene to Recent
Agbada Formation	Mixture of sand, clay and silt	Eocene to Recent
Akata Formation	Clay	Paleocene

3. Methods

Materials used for this study are stack of sieves with a cover, mortar and pestle, balance that is sensitive to 0.1g, oven, mechanical sieve shaker and bush. The research methodology was conducted in three stages (i) sample collection (ii) laboratory experiments and test (iii) Data analysis and results discussion.

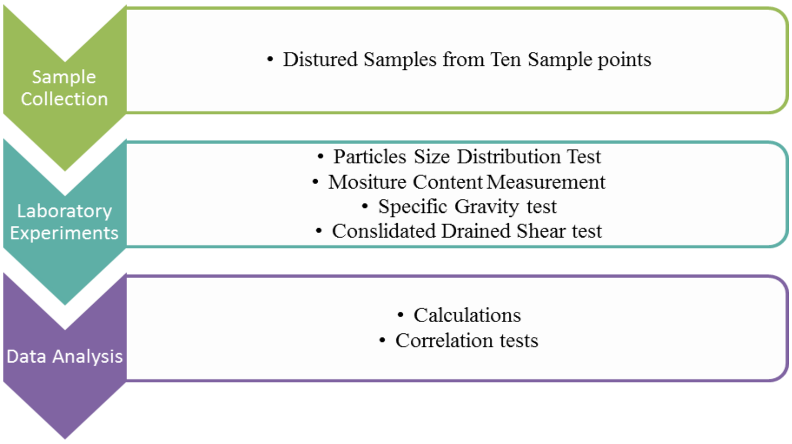


Figure 2: Workflow pattern

In the initial stage or phase, disturbed samples from ten sample borehole points were collected at the depth of 1m using an augering technique from the study location. These samples were obtained in accordance to BS5930, and were properly prepared for laboratory investigations. In the laboratory, particle size distribution, the moisture content, specific gravity and dry density were conducted in accordance with procedures as stated in BS1377. The information obtained was subjected to various laboratory test according to the American Society for Testing and Materials (ASTM, 1979), and the British standards Institute (BS, 1377) (Akpokodge, 1989).

Table 2: Boreholes and Their Location Coordinates.		
BOREHOLE	NORTHERN	EASTERN
BH 1	05º 34.769’	005º 19.830’
BH 2	05º 34.912’	005º 20.612’
BH 3	05º 34.880’	005º 19.808’
BH 4	05º 34.825’	005º 20.910’
BH 5	05º 34.998’	005º 19.810’
BH 6	05º 34.783’	005º 20.702’
BH 7	05º 34.013’	005º 19.812’
BH 8	05º 34.665’	005º 20.381’
BH 9	05º 35.053’	005º 19.826’
BH10	05º 34.707’	005º 20.270’

To obtain the particle size distribution of the grain, sieve analysis technique were adopted using the established step by step procedure. The sieve distinguishes particles of high magnitude with that of small orientation. This can be obtained through sieves placement with little size sieve configuration that is on top of stacked sieve hierarchy, thus the grain size distribution of the soil sample was obtained by plotting the finer sand percentage with its corresponding sieve.

In addition, moisture content measurement was carried out using gravimetric method. The technique procedure was through weighing of collected disturbed soil sample, and equally oven dried for a specific time under approved temperature conditions before weigh repeat. The moisture content is computed using specimen’s original and final weight measurements, with the condition assumption that all weight loss is related to moisture removal (Bonner, 1981; Wrolstad et al., 2005; Zambrano et al., 2019). “The preparation and drying conditions (e.g., time, temperature, type of oven, humidity, and pressure) influence the efficiency of moisture removal and the resulting drying time required to complete a test can vary from hours to days” (Bradley, 2010; Zambrano et al., 2019).

Table 3: Particle Size Soil Classification (Adopted from: USCS)	
Soil Type	Particle
Clay	< 0.002
Silt	0.02 – 0.075
Sand Fine	0.075 – 0.42
Medium	0.42 – 2.0
Coarse	2.0 – 4.75
Gravel	4.75 – 7.5

Furthermore, specific gravity test and dry density were equally conducted in accordance with the laboratory procedures as stated in BS 1377. Coefficient of curvature (Cc) and coefficient of uniformity (Cu) were calculated from particle size distribution results using the equations (1) and (2) respectively.

$$C_u = \frac{D_{60}}{D_{10}} \quad (1)$$

$$C_c = \frac{{D_{30}}^2}{D_{60} \times D_{10}} \quad (2)$$

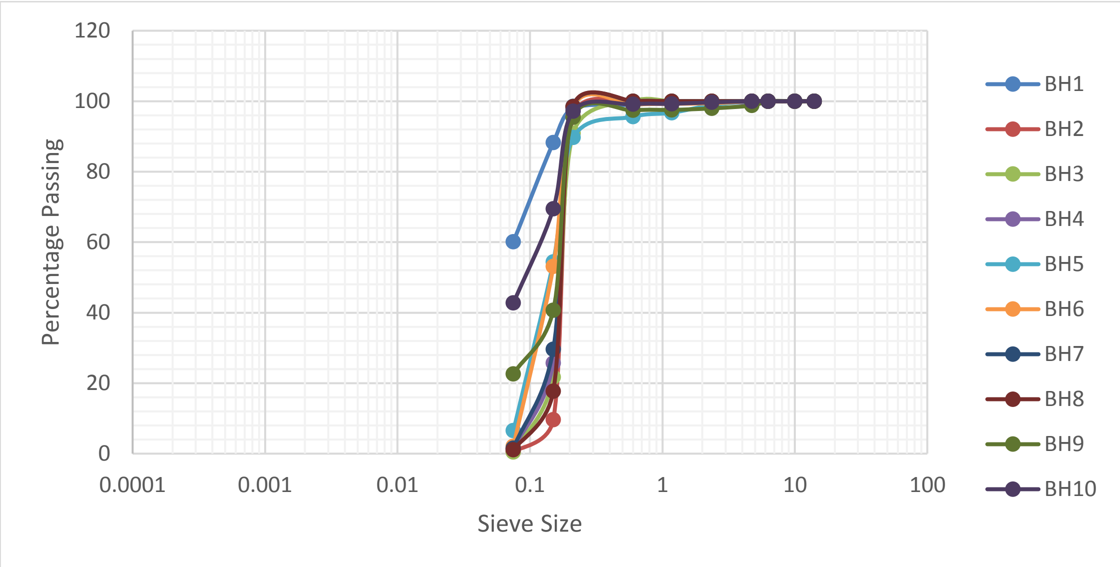
The values of D_{10}, D_{30}, and D_{60} which corresponds to the diameter of finer percentage of 10, 30, and 60 respectively were obtained from the distribution curve.

4. Results and Discussion

Dataset from ten (10) boreholes (BH) in Gbaramatu Niger Delta region disturbed soils was collected for this investigation. The established results of the parameters obtained from several tests were evaluated using statistical regression analysis. The values and results obtained from the location area are shown in table 4.

Table 4: Soil Properties Values Obtained.						
Borehole No	Moisture Content (%)	Specific Gravity	Bulk Unity Weight (kN/m³)	Dry Unit Weight (kN/m³)	Cu	Cc
BH 1	24.4	2.48	17.3	13.9		
BH 2	11.8	2.47	20.1	18	1.19	1.07
BH 3	15.8	2.5	20.1	17.3	1.58	1.42
BH 4	24.4	2.48	17.3	13.9	1.78	1.38
BH 5	21	2.53	17.7	14.6	2.25	0.84
BH 6	30.8	2.56	17.7	13.5	2.13	1.06
BH 7	19.8	2.6	17.6	15.2	2.11	1.32
BH 8	25.5	2.59	17.6	14	1.46	1.17
BH 9	22.8	2.64	19.2	15.6	1.73	1.38
BH 10	28.4	2.66	18.8	14.6	2.25	1.17

The table 4, shows that BH 1 does not have values for Cu and Cc as the D10 had no values in the particle size distribution curve. With the particle size distribution results, as shown in figure 3, it is observed that the samples are all sandy as they range between 0.075 – 4.75 and they are not well graded. This shows that the physical geology of the location is attributed to probably swamp reclamation.



CLAY	SILT			SAND			GRAVEL		
	FINE	MEDIUM	COARSE	FINE	MEDIUM	COARSE	FINE	MEDIUM	COARSE

Figure 3: Particle size distribution curves for sampled borehole points

The ten (10) samples dry densities were correlated to coefficient of uniformity and coefficient of curvature respectively. The correlation coefficients were equally obtained respectively. The correlation between dry density and coefficient of uniformity for the sampled soils is shown in figure 4. The Coefficient of Uniformity (CU) quantifies the size distribution of soil particles in a material. It is computed by dividing the diameter of the 60% finer particle by the diameter of the 10% finer particle. The coefficient of uniformity is frequently employed to determine soil's appropriateness for structural applications, as a more uniform particle size pattern can contribute to an enhanced strength and stability (Kavazanjian et al., 1998).

However, soil dry density parameter is determined as its mass per unit volume and is generally measured in grams per cubic centimeter. It is equally an important quantity in geotechnical engineering because of its influence on strength and compressibility of the soil. The coefficient uniformity and dry density of soil have often demonstrated a correlation, with an increased coefficient of uniformity rates typically leading to higher dry densities (Kavazanjian et al., 1998). The improved compaction and loading of soil particles with a more consistent size distribution is attributed to this relationship. Across all soil components, the findings of the investigations revealed a significant favorable connection between coefficient of uniformity and dry density. These findings support the theory that a more consistent particle size distribution contributes to improved soil compaction and greater dry densities (Hassan et al., 2009). Because it allows for the prediction of soil behavior based on particle size distribution, this evidence can be crucial in the design of basements and other geotechnical projects.

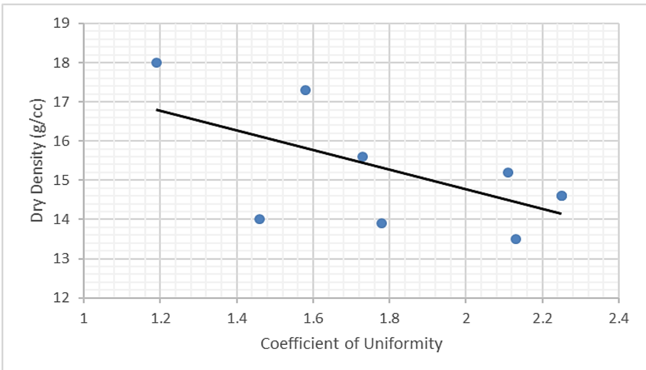


Figure 4: Coefficient of Uniformity and dry density relation

A linear function was used to fit the points and equation 3 shows the mathematical relationship, with a correlation coefficient of $R = 0.612$.

$$dD = -2.5045Cu + 19.775 \tag{3}$$

Where dD = Dry Density,

Cu = Coefficient of Uniformity

R = Correlation Coefficient

Figure 5 shows the correlation between the dry density and coefficient of curvature for the sampled soils. A polynomial of 4th degree was used to fit the points. The mathematical relations are as shown in equation 4 with a correlation factor of R = 0.5.

$$dD = 258.88Cc^4 - 1014.3Cc^3 + 1441.6Cc^2 - 875.79Cc + 205.37 \quad (4)$$

Where dD = Dry Density,

Cc = Coefficient of Curvature

R = Correlation Coefficient

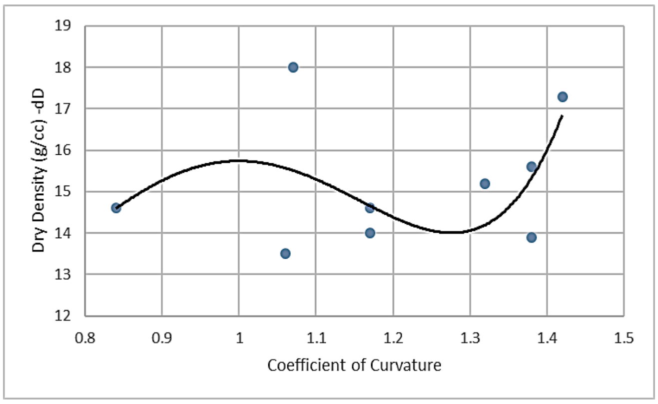


Figure 5: Coefficient of curvature and dry density relation

The ten (10) samples' moisture contents were correlated to coefficient of uniformity and coefficient of curvature respectively. Correlation coefficients were obtained. The coefficient of uniformity increases as the optimum moisture content increased for the sampled soil as shown in figure 6. The correlation equation and the coefficient of regression were obtained as shown in equation 5.

$$OMC = 0.0382Cu + 0.9814 \quad (5)$$

$R = 0.603$

Where OMC = Optimum Moisture Content

Cu = Coefficient of Uniformity

R = Correlation Coefficient

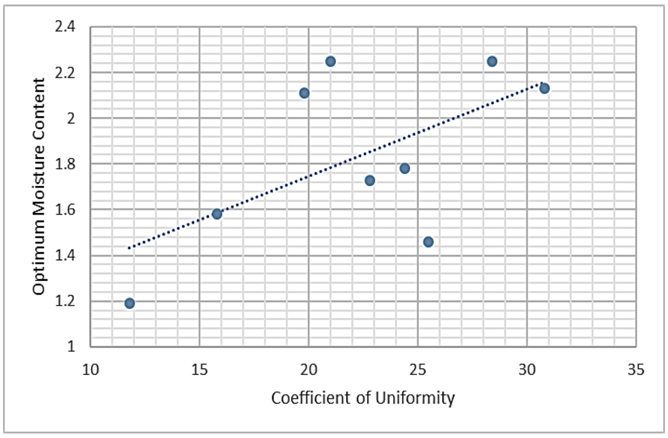


Figure 6: Optimum moisture content with coefficient of uniformity relation

Figure 7 shows the correlation between the moisture content and the coefficient of curvature, equation 6 shows the linear correlation fitness with R = 0.955.

$$OMC = 0.0505Cc \quad (6)$$

$R = 0.955$

Where OMC = Optimum Moisture Content

Cc = Coefficient of Curvature

R = Correlation Coefficient

The Soil moisture content is a key component in assessing its physical and chemical qualities. We analyze the relationship between the optimum moisture content and the coefficient of uniformity, which is a measure of soil particle size distribution, in this investigation. We examined the moisture content of soil samples with distinct distributions of particle sizes at various water concentrations. Our findings indicate a positive relationship between the optimum moisture content and the coefficient of uniformity, with greater coefficients of uniformity corresponding to higher optimum moisture concentrations. The study has far-reaching consequences for soil management and irrigation techniques.

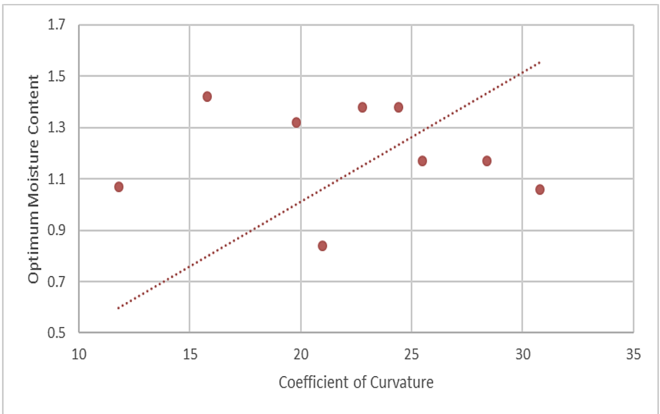


Figure 7: Optimum Moisture content and Coefficient of Curvature relation

Table 5: Scale of Correlation Coefficient

Scale of Correlation coefficient	Value
$0 < R \leq 0.19$	Very Low Correlation
$0.2 < R \leq 0.39$	Low Correlation
$0.4 < R \leq 0.59$	Moderate Correlation
$0.6 < R \leq 0.79$	High Correlation
$0.8 < R \leq 1.0$	Very High Correlation

Considering all the correlation coefficients in relation to standard scale of correlation shown in table 5, The correlation between dry density and coefficient of uniformity with a correlation coefficient of $R = 0.612$, is considered to be of high correlation. The correlation between the dry density and coefficient of curvature with a correlation factor of R = 0.5, is considered to be moderately correlated. The correlation between the optimum moisture and coefficient of uniformity with a correlation factor of R=0.603, is considered to be of high correlation. The correlation between the optimum moisture content and the coefficient of curvature, had a fine linear correlation fitness with R = 0.955, which shows a very high correlation. The implication of the correlation coefficient values obtained in the research is considered scientifically reasonable to be used for Engineering works and studies within the study location.

5. Conclusions

The investigation has provided useful information about the Engineering properties of Gbaramatu soils. The relationship among both coefficient of uniformity, and dry density, with respect to other soil parameters are essential characteristics of soil compaction and structural stability, and it is affected by a variety of factors such as soil type and characteristics, compaction method and equipment employed, and soil moisture content at the moment of compaction. Acknowledging this relationship is critical for effective assessment and interpretation of soil compaction and stability data, as well as for applicability. The correlation equations generated will be helpful in predicting values of the correlated properties for soils within the Niger Delta region of Nigeria. The parameters contributed in generation of subsurface report for the location, which will serve as a bench mark for Civil Engineering construction and soil strength evaluation over Gbaramatu, Niger Delta. However, more research is needed to investigate the relationship between soil parameters in various soil categories and compactive efforts.

Declarations of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Availability of Data and Material

Not Applicable.

Competing Interests

The authors declare that they have no competing interests.

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Author Contributions

All authors contributed to the study conception and design. Material preparation, data collection and analysis were performed by Chukwunenye M. Ogbodo. The first draft of the manuscript was written by Amarachukwu A. Ibe. All authors read and approved the final manuscript.

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