Classification and Evaluation of Soil Compaction at Shallow Depth in Ogobiri and its Environs, Bayelsa State, South-South Nigeria

Didei, Innocent S. & Oborie, Ebiegberi
Department of Geology,
Niger Delta University,
Bayelsa State, Nigeria
dideiinnocent@gmail.com

Abstract
Soil compaction is one of the most important aspects of any earthwork construction. Determining the level of compaction of soil in Ogobiri, Sagbama Local Government Area of Bayelsa State, Nigeria, is to ascertain the compatibility or the rate of compaction of the underlying earth materials (soils). Six (6) samples were collected at regular intervals of one (1) and two (2) meters from three boreholes drilled at three different locations which were used for the laboratory analysis. The samples collected were subjected to different laboratory test to determine the geotechnical index properties and the level of compaction of the soil. Sieve analysis result from the samples shows that the percentage of fines and sands ranges from 9.30%-23.56% and 0.12%-20.24% respectively. Atterberg limits result also shows that the soil liquid limit (LL) ranges from 33.07%-56.16%, Plastic limit (PL) ranges from 16.58%-20.52%, plasticity index (PI) ranges from 12.55%-36.79%. The values of maximum dry density (MDD) and optimum moisture content (OMC) are 1.67g/cm^3 and 12.4%. The analysis done for this work reveals that the soil in Ogobiri can be classified as medium to high plastic soils (Unified Soil Classification System) and that the soil is moderately compacted. Comparing the CBR test results with the Nigeria standard, the soils in Ogobiri can be used as a sub-grade material for construction.

Keywords: *Compaction, Classification, Plasticity, Particle Size Distribution, Ogobiri, Moisture Content.*

Introduction

The behaviour of every foundation, roads, airfields, etc. depends primarily on the engineering characteristics of the underling deposits of soil or rock (earth materials). The proper compaction of soil is intended to ensure that the compacted soil will reliably and safely withstand loads of various kinds. Soil compaction on construction sites occurs either deliberately when foundations and sub grades are prepared or as an unintended result of vehicular traffic (Randrup and Dralle 1997). To determine whether a treatment is necessary for the alleviation of soil compaction, the degree of compaction needs to be quantified.

It has been said that the top three factors in road construction are ''compaction, compaction, and compaction''. Compaction is the process by which the volume of air in a mixture is reduced by using external forces to reorient the constituent aggregate particles into a more closely spaced arrangement. This reduction of air volume in a mixture produces a corresponding increase in unit weight or density (Roberts et al 1996). Numerous researchers have stated that soil compaction is the greatest determining factor of soil performance (Scherocman, and Martenson, 1984, Scherocman1984, Geller 1984, Bell et al., 1984, Hughes 1984, Hughes 1989). Among the major causes for failure of roads in Nigeria is the inadequate soil compaction during construction. There is, therefore, the need to strictly control the

compaction of soils if the design life of any structure is to be attained.
Four (4) Types of compaction of the soil which include; Vibratory compaction tests in which the soil the soil is vibrated as it is compacted, which is particularly effective in compacting cohensionless soil such as sand and gravel.

Kneading compaction tests in which a small ‘’foot’’ is loaded, then unloaded, at various locations on the surface of the sample being compacted; the sol is effectively kneaded with this procedure. Impact compaction tests in which a standard weight is repeatedly dropped on the soil sample for a prescribed number of blows. The weight is adjusted to achieve the desired compaction effort. Pressure compaction tests in which a uniform pressure is applied to the soil and maintained long enough for the soil to compact under the pressure.

Soil compaction changes pores pace, particle size, particle distribution and soil strength. One way to quantify the change is by measuring the bulk density. As the pore space is decreased within a soil, the bulk density is increased (Compaction Handbook, 2008).
Geologically the study area Ogobiri, in Sagbama Local Government Area of Bayelsa State is the same as the of the Niger Delta sedimentary basin.

Short and stable (1979), have stated that, the Niger delta is made up of three stratigraphic units (formations) the Benin formation, the Akata formation, and Agbada formations. Alabo et al (1983), Worked on the geotechnical index of red soils in eastern Niger Delta in order to determine the stability and compatibility of soils for use of fill. Also Akpokodje and Arumele (1989), have worked on the geotechnical index properties to ascertain the soil properties for pavement of in Niger Delta, investigated the effect of various roads in Niger Delta. The indication of their result is that soil due to high percentage of fine particles (clay and slit) is not suitable for road construction. The present of clay and silt promote early failure of road due to their ability to expand and contract as they absorb water and give out water respectively.

If compaction is performed improperly, settlement of the soil could occur and result in unnecessary maintenance costs or structure failure. Almost all types of earth work projects and other construction compaction technique. The purpose of soil compaction is to;

- Improve the load bearing capacity.
- Prevent soil settlement and frost damage.
- To provide stability.
- To reduce water seepage, swelling and contraction
- To reduce settling of soil.

  The study therefore aims to provide an integrated assessment of compaction rate of soils and at different depth in Ogobiri, Sagbama Local Government Area in Bayelsa State, South-South Nigeria.

Geomorphological Unit of the Study Area
Geomorphology deals with all the elements of landscape. It acts as the useful link between geology and the geotechnical engineer. The physiography of the study area conforms to the geomorphic features of the Niger delta, governed by several factors which influence the transportation, deposition of sediment, shape and growth of the delta. It consists mainly of fresh water swamp, mangrove swamp, beaches, bars, estuaries, (etu-efeotor and odigi 1983). Which stretches from Benin river estuary and terminates at the mouth of Imo River? It receives its sediment from suspended and traction load of river Niger and Benue.

The Niger Delta progress and changes its shape by the process of channels switching which occurs simultaneously at the different part of the delta and having various part of depositional and morphological units. According to Akpokodje (1989) and Abam (2015), the surface distributions of the various morphological units are listed below;
Dry flat lands and plains
Sombreiro-warri deltaic plain with abundant fresh water swamps.
Fresh water swamps.
Meander belts and alluvial swamps.
Salt water or mango swamps.
Bayelsa state covers an area over 12,000km square with over 185km square of coast line of the Niger delta. According to Allen, (1965) and Ibe, (1988), four (4) morphological units in the sub aerial Niger delta were recognised these are:
The outer barrier island complex
The vegetated tidal floods,

The lower flood plains formed by the number of distributaries of Niger and Benue rivers /the narrow upper flood plain. Therefore, the study area which is located in Bayelsa is a corner flood plain formed by the number of the distributaries of the Ann River Benue (river null).
The relief of the study area according to (Otamata, 1975 and Abam, 2015), is generally low-land plain 0-20m above the sea level. Generally the study area is a low land characterised by tidal flat and coastal beaches, beach ridge, barriers and flood plains. The study area lies between the upper and lower delta of the Niger delta which suggest a low-lying relief. The study area is sedimentary terrain. It is a flood plain which is usually flooded in periods of peak rain fall. The drainage system of the study area is derivate patterns which are characteristics of the Niger Delta river system comprising of dense network of distributaries, rivers creeks, and interaction of predominant river system amongst which are the Niger, Forcados, Nun, Ase, Warri, Sombreibo rivers. The dense river networks create a condition of hydrological continuity. Hence development in one part of the delta, such as pollution by oil spills can readily be felt in other parts. As the depot of all the flood waters of the Niger Delta and its tributaries, the delta experiences severe water flooding during the wet season.

Location and Accessibility

The boreholes were drilled to the depths of two meters with the hand auger and samples were taken at each depth (1m, and 2m) within the study areas located at Ogobiri, Bayelsa state, Nigeria. Geographically, the latitude and longitudes of borehole 1 are 4^{0}58'' N and 6^{o}6'17'' E respectively, the latitude and longitude of borehole 2 are 4^{o} 58' 15'' N and 6^{o}17''E respectively and the latitude and longitude of borehole 3 are 4^{o} 58' 31''N and 6^{o}6' 14'' E respectively. The study areas are all accessible by main road, footpath, and water ways. see fig 1 and 2.

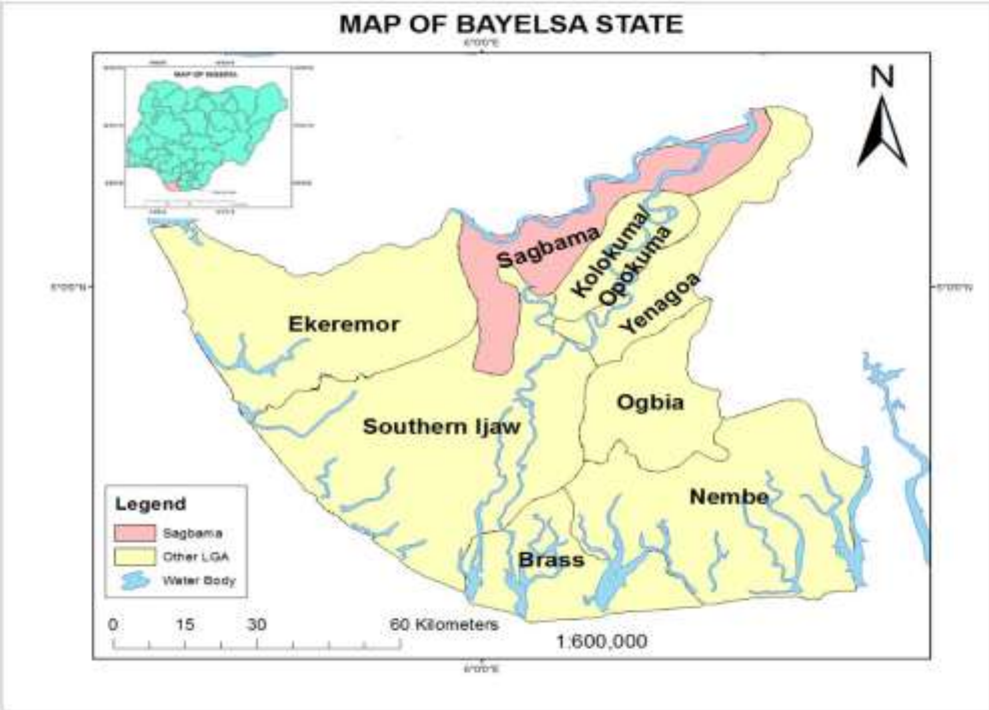

Fig 1 Showing map of Bayelsa State and the study area

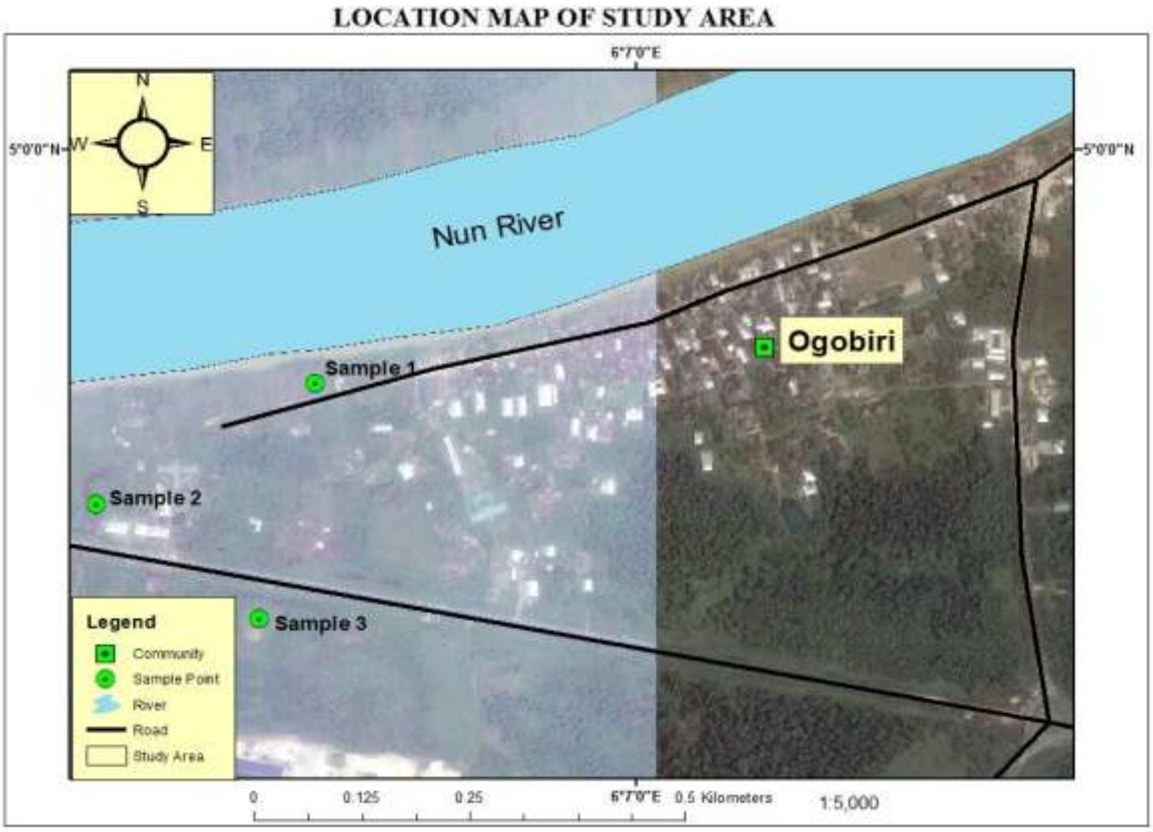

Fig 2 Showing locations of samples

Geology of the Area

The Niger Delta is situated in the gulf of guinea and extends throughout the Niger Delta province as defined by Klett et al (1997), from the Eocene to the present, the Delta has prograded south westward, forming depobelts that represents the most active portion of the Delta at each stage of its development (Doust and omatsola, 1990), a sediment volume of 500,000km cube (Hospars, 1965), and a sediment thickness of over 10km in the basin depocenter (Kaplan et al 1994). The geology of the tertiary section of the Niger Delta is divided into three formations Benin, and Akata, representing prograding depositional facie distinguished mainly on the basis of sand-shale ratio and further divided into depobelts as progradation proceeds into deeper waters. Starcher (1995), documented the formation of the Akata formation initiated in the paleocene and through the recent. A paralic sequence of alternating lower Eocene-to-pliestocene sandstone sand bodies with shale intercalations, which is known as the Agbada formation overlies the under compacted Akata shales. An extensively massive, porous and unconsolidated freshwater bearing continental sands known as the Benin formation caps the Niger Delta lithological cross section. The study area is part of the Niger Delta. The area is situated in the central Niger Delta sedimentary basin of southern Nigeria. Location accessibility to the area is by road. Nigeria lies in coastal Niger Delta sedimentary basin. The detailed geology of the area has been described by Allen, (1965), Reyment, (1965), Short and stable, (1967). Litho-strategically, the rocks are divided into the oldest Akata Formation (Paleocene), the Agbada Formation (Eocene) and the youngest Benin Formation (Miocene- Resent). The wells and borehole tap water are from the overlying Benin Formation (coastal plain sand). This formation comprises of lacustrine and Fluvial deposits whose thickness are variable but exceeds 1970metres (Asseez 1989).The Benin Formation has lithology's consisting of sands, silts, gravels and clayey intercalation.

Geology and Hydrogeology of the Area

The study area lies between latitude and longitude. The area is situated in the central Delta sedimentary basin of southern Nigeria. Access to the place is the Yenagoa-Amassoma road.. Yenagoa, the capital city of bayelsa state, Nigeria lies in the coastal Niger Delta sedimentary basin. It is endowed with sedimentary rocks characteristic of the Niger Delta. The detailed geology of the area has been described by Allen (1965), Short and Stubble, (1967). Litho stratigraphically, the rocks are divided into the oldest Akata formation (paleocene), the Agbada formation (Eocene) and the youngest Benin formation (Miocene to recent). The wells and boreholes tap water from the overlaying Benin formation (coastal plain sands). This formation comprises lacustrine and fluvial deposits whose thicknesses are variable but basically exceeds 1970meters (Asseez, 1989). The Benin formation has lithology's consisting of sands, silts, gravel, and clayey intercalations. The hydrogeology of the study area has been described by several researchers such as Etu-Efeotor, (1981). Amadi et al (1989), Etu-Efeotor and Akpokodje (1990), Edet, (1993), Udom et al (1999).

The Benin formation is the water bearing zoneof the area. It is overlain by Quatenary deposits (40-150m) thick, and generally consists of rapidly alternating sequences of sands and salty clay which later becomes increasingly prominent seawards (Akpokodje, 1987). Generally multi-aquifer systems have been identified in the Delta based on strata logs (Etu-Efeotor, 1987). The first aquifer is mostly unconfined, while the rest are confined. The average depths of boreholes in ogobiri are between 20 and 50meters (Udom and Amah, 2006). Deep boreholes in the area tap water depths up to 200m 0r more. In terms of water quality, (Udom et al, 2013) have noted that ground water in most parts of ogobiri is high in iron content. The static water level in the area ranges from 0-1m during the rainy season. Rainfall is the major source of recharge for aquifers in the area.

Table 1: Geologic Units of the Niger Delta (After Akpokodje 1989)

GEOLOGIC UNITS	LITHOLOGY	AGE
Alluvium (general)	Gravel, sand, clay and silt	
Freshwater, Back swamps meander belt	Sand, clay, some silt, and gravel.	
Saltwater, mangrove swamps and Back swamps	Medium-fine sand, clay and some silt	Quaternary
Active/Abandoned beach ridges	Sand, clay and silt	
Sambrerio-Warri deltaic plain	Sand, clay and silt	
Benin formation (coastal plain sand)	Coarse-medium sand, subordinate silt and clay	Miocene-Recent
Agbada formation	Mixtures of clay, sand and silt.	Eocene-Recent
Akata formation	Clay	Paleocene

Method and Materials

The investigation comprised three (3) geotechnical boreholes with soil sampling executed with hand auger. The procedure adopted for boring was opening of the ground with the auger by rotating in clockwise direction the T-handle of the auger extension. Additional extension is attached to the auger after advancing 1m down-hole until the required depths are achieved.

Representative disturbed samples were taken at regular intervals of 1.0m depth. The samples obtained were stored in bags and transported to the laboratory for detailed and systematic description of the soil in each stratum.

A total of six (6) samples were collected within Ogobiri and its environs. Samples were collected at every 1m depth interval during the drilling process with the use of hand auger to a depth of 2m.

During sampling, visual inspection of the soil was done to disenable the soil in the field with respect to texture, grain size, composition and colour. The samples were bagged in polythene bags and stored for laboratory analysis. Moisture content was carried out in the laboratory immediately after samples was collected in order to prevent moisture loss.

Results and Discussion

Specific Gravity Test

The specific gravity test is used to calculate the specific gravity of soil sample by determining the ratio of the weight of a given volume of aggregates to the weight of an equal volume of water. Attached in the index are the data sheets for each soil sample calculated specific density. Table 2 presents a summary of this test.

Table 2: Specific Gravity Test Result

BOREHOLE NUMBER	SAMPLE NUMBER	AVERAGE SPECIFIC GRAVITY
1	1	2.54
	2	2.11
2	3	2.20
	4	2.12
3	5	1.89
	6	1.69

TABLE 3: Showing moisture content values of the samples

Borehole number	Sample number	Average moisture content %
1	1	29.00
	2	21.51
2	3	30.49
	4	25.06
3	5	29.55
	6	33.13

The moisture content of samples from location one ranges from 21.51% to 29.00%, samples from location two ranges from 21.51% to 30.49% and location three ranges from 29.55% to 33.13%.

Atterberg Limits

The Atterberg limits are a basic measure of the critical water contents of a fine grained soil, such as the liquid limit, plastic limits, and plasticity limit. These limits were determined in this test. Table 4.3 shows this consistency limits.

TABLE 4: Consistency Values

Borehole number	**Sample number**	**Properties**		
		Liquid limit	**Plastic limit**	**Plasticity index**
		%	%	%
1	1	44.56	16.86	27.70
	2	38.98	16.72	22.26
2	3	33.07	20.52	12.55
	4	37.73	16.58	21.17
3	5	56.16	19.37	36.79
	6	33.09	18.48	14.60

From the experimental results, liquid limits and plastic limits ranges between 33.07%-56.16% and 16.58%-20.52% respectively. The plasticity indices range between 12.55%-36.79%. From the plasticity indices, we can say that the Ogobiri soils are moderate to highly plastic soils because the plastic indices fall between 12-36% (as shown in table 2), plastic index classification (Akins, 1979)

Sieve Analysis

The sieve analysis test helps to determine the size of particle distribution of coarse and fine aggregates. Table 4.4 shows the sizes of the sample for this research work.

Table 5: Values of sieve analysis test distribution

Borehole number	Depth (m)	Sample number	properties			
				Gravel	Sand	Silt
1	1.00	1		0	0.56	13.61
	2.00	2		0	20.24	13.07
2	1.00	3		0	2.64	23.56
	2.00	4		0	12.56	9.30
3	1.00	5		0	0.33	20.76
	2.00	6		0	0.12	13.60

The percentage of fines and sands ranges between 9.30%-23.56% and 0.12%-20.24% respectively. Using the MIT classification, most of the soils are retained and passes through sieve 200 (0.075mm), the soils can be classified as fine sands and coarse to medium silt.

Compaction

The study objective for carrying out the compaction test was to determine the relationship between water and dry density of the soil type and also the optimum water content and corresponding maximum dry density of the soil. Table 6 shows the value for these parameters.

Table 6: Shows compaction test values
Borehole Number BH-1

Sample number	Units	SP-1
Depth	(m)	
Optimum moisture content (OMC)	(%)	12.4
Maximum dry density (MDD)	(mg/m^3)	1.67

The values of the maximum dry density (MDD) and optimum moisture content (OMC) are 1.67g/cm^{3}and 12.4% respectively. This experimental result shows that the Ogobiri soil is of medium compaction

California Bearing Ratio (CBR)
Using the moisture content and corresponding dry density, the amount of soil used for CBR was calculated. The sample was tested using the CBR machine. The moisture content at different points (that is at different height and at its different moisture content locations (borehole) was determined. Table 7 shows the CBR values.
The values of the unsoaked and soaked CBR are 5 and 4 respectively. These values compared to the Nigerian Standard (FMW, 1997) shows that the soil can be used as a sub grade material.

Table 7: Shows CBR values

Borehole number	1
Depth (m)	0.5
Sample number	1
Optimum moisture content (%)	12.4
Maximum dry density (g/cm^3)	1.67
Soaked CBR value	4

Assessment of Soil Compaction
The optimum moisture content (OMC) and the maximum dry density (MDD) are 12.4% and 1.67g/cm^3 respectively. The range of values that maybe anticipated when using the standard proctor compaction test method are for clay, MDD may fall between 1.44g/cm^3 and 1.67g/cm^3 and OMC may fall between 20-30%. For salty clay, MDD is usually between 1.60-1.845g/cm^3 and OMC between 8 and 15%. Hence the Ogobiri soil is salty clay.
The geotechnical properties of Ogobiri soil has been carried out in compliance with BS 1377 methods of soil testing for geotechnical engineers. The result showed that the studied soil samples are classified as salty clay and moderately compacted.
The Ogobiri soil is moderately compacted because of the higher percentage of sands over fines (salty and clay). The compaction of the soil is determined by the percentage of fines.

Classification Characteristics

Table 8: Shows USCS Classification of Ogobiri Soil

sample location	1 (AMGBARI-PELE)		2 (AYAGBO 1)		3 (AYAGBO 2)	
Samples	1	2	3	4	5	6
% fines	13.61	13.07	23.56	9.30	20.76	13.60
% sand	0.56	20.24	2.64	12.56	0.33	0.12
Plastic limit	16.86	16.72	20.52	16.58	19.37	18.48
Liquid limit	44.56	38.98	33.07	37.73	56.16	33.09
Plasticity index	27.70	22.26	12.55	21.17	36.79	14.60
USCS Classification AASHTO	MH A-7-5	ML A-7-5	MH A-7-5	MH A-7-6	ML A-7-6	ML A-7-6

Classification tests results on Ogobiri soil as presented in table 8 Sieve analysis (PSD) shows that the soils consist of 9.30%-23.50% fines and 0.12-20.24% sands. The dominance of fines over sand indicates a non-uniform distribution of grain sizes which implies poor grading. Consistency tests shows liquid limits and plasticity indices ranges from 33.07%-56.16% and 12.55%-36.79% respectively, this indicates that the soils are medium to high plastic soils. This is corroborated by the unified soil classification (USCS) plasticity chart which further classifies the soil as low plastic and high plastic soils. Analysis of these results (PSD and Atterberg limits) using the American Association of State Highway and Transport Official (AASHTO) Classification scheme, categorised the soils as clayed soils of A-7 (A-7-5 and A-7-6) type.

Compaction Characteristics

The compaction characteristics of soils in the Niger Delta have been found to be dependent on their percentage content of fines (Akpokodje, 1986, 1987), Ugbe, 2011).,Abam, (2005). In comparison with AASHTO classification, the soil is generally rated as poor to fair sub-grade earth material.

From Atterberg limits, the liquid limits value ranges from 33.07%-56.16% while the plastic limits ranges from 16.58%-20.52%. Federal Ministry of works and Housing (1972), for road works recommend liquid limits of 50% maximum for sub-base and base materials. Samples 1, 2, 3, 4 and 6 falls within this specification, thus making it suitable for sub-base and base material, only sample 5 cannot be used as a sub base and base materials.

From the proctor compaction test, the OMC and MDD values are 12.4% and 1.67g/cm^3 respectively. According to Flatherty, (1988) the range of values that may be anticipated when using the standard proctor test methods are: for clay, maximum dry density is (MDD) may fall between 1.44- 1.68g/cm^3 and optimum moisture content (OMC) may fall between 20-30%. For salty clay, MDD is usually between 1.6-1.845g/cm^3 and OMC ranges between 12-25%. For sandy clay, MDD usually ranges from 1.76 -2.16g/cm^3 and OMC between 8-15%. Thus, looking at the results of Ogobiri soils, the soil is salty clay. The unsoaked and soaked CBR values are 5 and 4 respectively. A comparison of these CBR values with Nigeria standard (FMW, 1997) confirms that the soil could be used as a sub-grade material but unsuitable for use as a sub-based and base material in road construction since the CBR values are lesser than 30% and 80% respectively. This suggests that the soils would fail with time under heavy load, if used in this capacity.

Conclusion

Major laboratory analysis was carried out from the six soil samples obtained, these includes: moisture content, specific gravity, sieve analysis, Atterberg limits, proctor compaction, and California bearing ratio.

Sieve analysis and Atterberg limits were carried out to decipher particle size distribution of samples and plasticity of the samples respectively.

The ability to investigate and evaluate the density of any construction or project site leads one to determine the state of relative soil compaction which ultimately specifies compaction standards. The study has dealt with the evaluation of soil compaction under different construction projects, which has immense potentiality to judge the condition of the structure. Based on field tests and laboratory tests results, the relative compaction of soils was calculated.

Soaked and unsoaked CBR values ranges from 4%-5%and under the same condition for optimum moisture content (OMC) and maximum dry density (MDD) of 12.4% and 1.67 respectively. This shows that the soil can be used as a sub-grade material. From all the tests carried out and the results gotten, It can be concluded that the predominant soil type is mainly fine to medium sand, silt and clay. The soil is said to moderately compact.

The laboratory results for the liquid limits (LL), plastic limits (PL) and the plasticity index (PL) ranges from (33.07%-56.16%), (16.58%-20.52%) and (12.55%-36.79%) respectively. This indicates that the soils are medium to high plastic soils.

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