



## **GEOTECHNICAL ATTRIBUTES OF NIGER DELTA SOILS, WARRI ENVIRONS, NIGERIA**

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### **ABSTRACT**

The study of geotechnical index properties of soils in Warri, Delta state was carried out to determine the index properties of soil. The laboratory test carried out included, moisture content, grain size analysis, Atterberg limits and compaction test. These results indicate that the soil is poorly graded, well drained, it is of intermediate plasticity, medium swelling potential. The results of particle grain size distribution test show that the soil sample is mainly sand. This means that they will tend to increase in compressibility and decrease in shear strength. Also, as a result of their poorly graded nature, they will have negative effects such as high effective porosity, large mean pore size, low density and high permeability. The compaction results show that the maximum dry density (MDD) and the optimum moisture content (OMC).

## INTRODUCTION

Geotechnical investigations are performed by geotechnical engineers or engineering geologists to obtain information on the physical properties of soil and rock around a site to design earthworks and foundations for proposed structures and for repair of distress to earthworks and structures caused by subsurface conditions. This type of investigation is called a site investigation. Additionally, geotechnical investigations are also used to measure the thermal resistivity of soils or backfill materials required for underground transmission lines, oil and gas pipelines, radioactive waste disposal, and solar thermal storage facilities. A geotechnical investigation will include surface exploration and subsurface exploration of a site. Sometimes, geophysical methods are used to obtain data about sites. Subsurface exploration usually involves soil sampling and laboratory tests of the soil samples retrieved, Some soil test measure direct properties of the soil, while other measure “index properties which provide useful information about the soil without directly measuring the property desired. Some of the more commonly performed laboratory test included: Moisture content determination, Atterberg limits, grain size analysis test and compaction test.

There tests are very useful in determining the geotechnical behaviour of soil in Warri of Delta State.

## OBJECTIVE AND SCOPE OF STUDY

This study aims at establishing the sub-soil types and profile to ascertain the geotechnical characteristics of the underlying soils for geological and civil engineering purposes

## LOCATION AND ACCESSIBILITY OF THE STUDY AREA

The study area is located in Warri South Local Government Area of Delta State (Figure 1). The study area, Warri is on latitude 5<sup>o</sup>.33’31N and longitude 5<sup>o</sup>.32’35E land which lies between 23 and 40ft above sea level. It is part of the Niger Delta province which occurs at the southern part of Nigeria bordering the Atlantic Ocean.

The Niger Delta extends from longitude 3.5E to 8.45E and latitude 4.5N to 5.65N and covers an area of approximately 36, 260km<sup>2</sup> (i.e. about 4% of Nigeria) and is third largest Delta in the world (Kogbe 1989). The region is of great socio-economic importance to Nigeria because of enormous reserves of petroleum of various types of civil engineering infrastructure. The area of study is accessible by road and water.

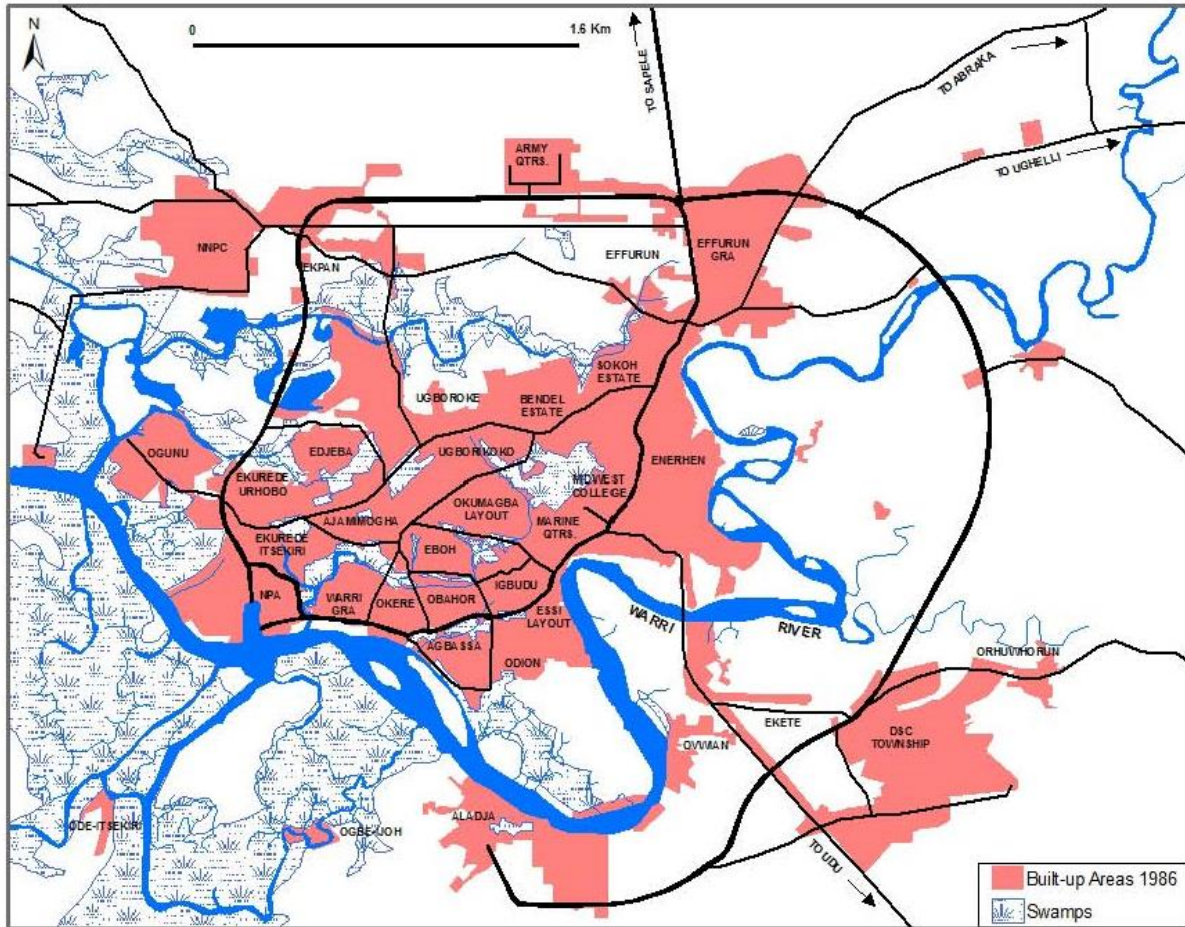


Figure 1: Location map of the Study Area

## GEOLOGY OF NIGER DELTA

A Delta is a discrete shoreline protuberance formed at a point where a river enters an ocean or other body of water (Elliott, 1986a; Bhattacharya and walker; 1992).Coaler sediments (Sands) tends to be deposited near the mouth of the river; finer sediments are carried seaward and deposited deeper water. The form and character of the sediment is determined by the predominant sedimentary processes of fluvial, wave and tidal actions.

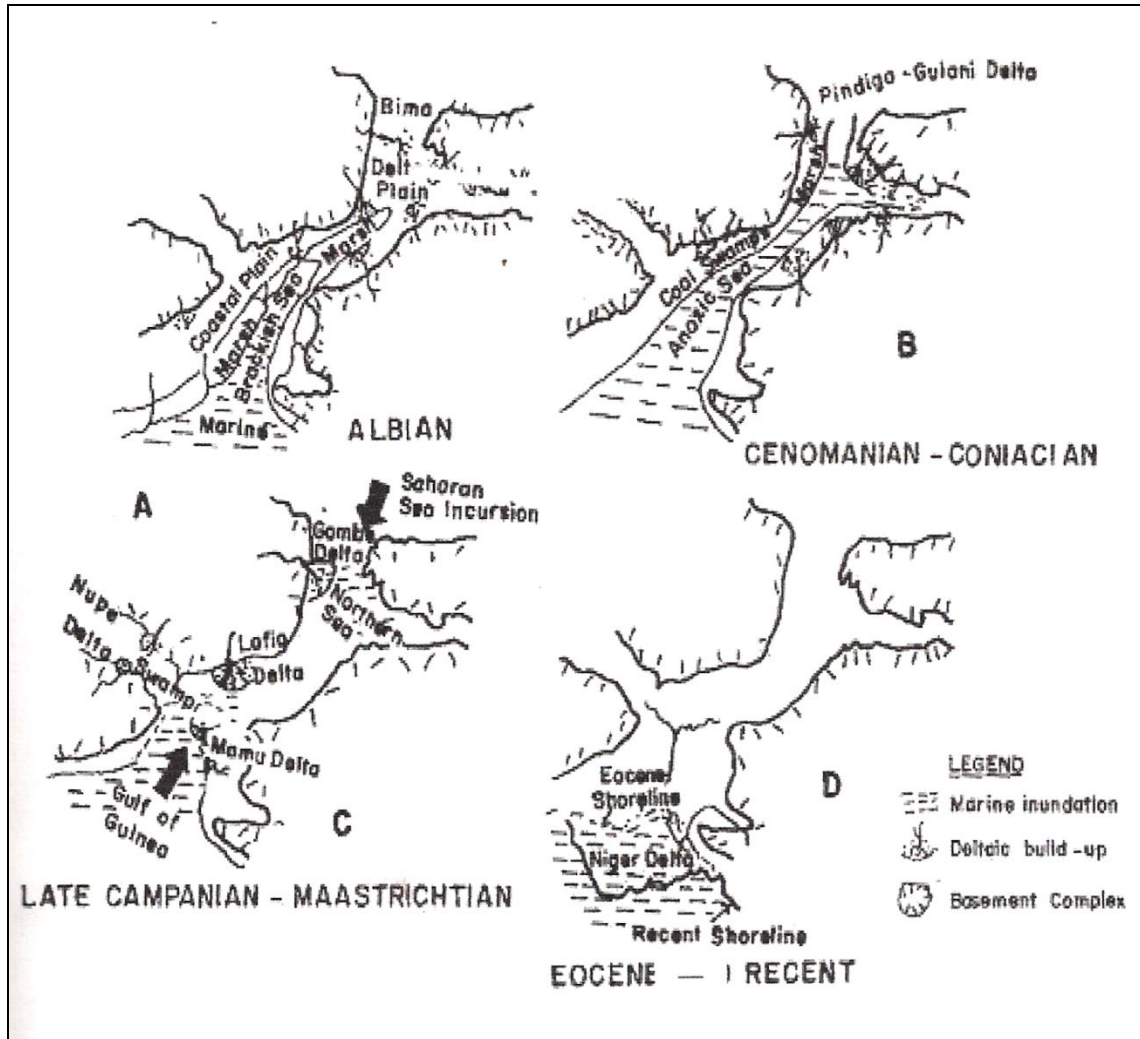
The Niger Delta Basin is situated on the continental margin of the Gulf of Guinea in Equatorial West Africa, covering about 75,000km<sup>2</sup>(28958mi<sup>2</sup>)with average thickness of about 12km(7mi) (Knox and omatsola,1988).It is one of the world’s most petroliferous Tertiary Delta that together account for about 5% of the world’s oil and gas reserves. The onshore portion of the Niger Delta province is delineated by the geology of southern Nigeria and southwestern Cameroon, the northern boundary of Niger Delta is the Benin flank and east northwest trending hinge line south of the West Africa basement massif. The northeastern

boundary is defined by outcrop of the cetaceans on the Abakaliki High and further east south east by the Calabar flank, a hinge line bordering the adjacent Precambrian. The offshore boundary of the province is defined by the Cameroon Volcanic line to the east, the eastern boundary of the Dahomey basin (The eastern-most West African transform-fault passive margin) to the west

The Niger Delta Basin has built out into the central Atlantic at the north of the Niger-Benue and Cross River Drainage systems. The Delta stretches for about 300km from apex to mouth and covers an area of at least 75,000km (Doust, 1989).It is considered to have been built out covering a crustal tract on the trailing edge of the Africa continent, and has been classified as a marginal sag basin by Kingston *et al.* (1983).Various articles have been published on the origin, geology, hydrocarbon generation, plays and potentials of this important prolific Delta. The stratigraphy of Niger Delta Basin, which include those of Stanley (1966), short and stumble (1967), Allen (1970),Weber(1971),Murky (1972),Hospers,(1975),Weber and Daukoru (1975), Petters (1978), Ekweozor and Okoye (1980), Ejedawe (1981), Ejedawe et al (1984), Busting (1988), Knox and Omatsola (1989), Akinosho (1993) and Oti *et al* (1995) are well documented. Data acquired during exploration and exploitation and researches by oil developing companies and the academia (Department of geology and related disciplines in Nigerian universities) have contributed whole lots of information to the understanding of the petroleum geology of Niger Delta basin.

**Paleogeography and tectonics:** The tectonic framework of the continental margin along the West coast of Equatorial Africa is controlled by Cretaceous fracture zones expressed as trenches and ridges in the deep Atlantic developed during the continental rifting and separation of Africa from South America. The fracture zone ridges subdivide the margin into individual basins, and in Nigeria, from the boundary fault of the Cretaceous Benin-Abakaliki Trough, which cuts far into the West African Shield. The trough represents a failed arm of a rift triple junction system (Aulacogen).

The two arms that followed the southwestern and southeastern coast of Nigeria and Cameroon developed into the passive continental margin of West Africa, whereas the third failed arm formed the Benue trough sediment accumulation continual from cretaceous to



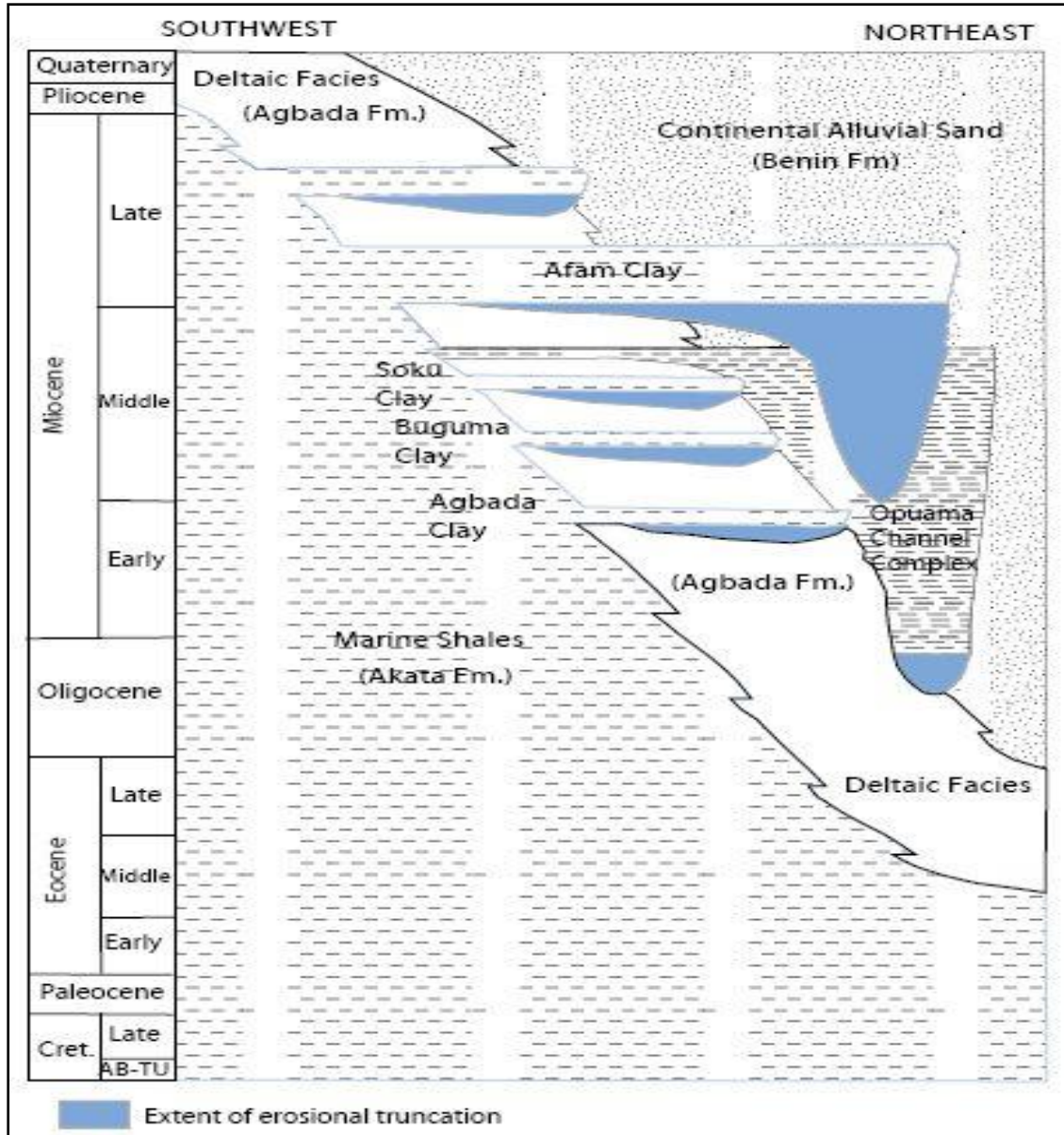
**Figure 2:** Cretaceous to Recent paleogeographic evolution of Nigerian rift and continental margin deltas (from Petters, 1978)

Thick successions of synrift marine and marginal marine clastics and carbonates were deposited in a series of transgressive and regressive phase (Doust and Omatsola,1989)during this period across the Benue trough and during the santonian (late cretaceous) the synrift phase ended while a basin inversion set in with the development of Abakaliki anticlinoria and Afikpo syncline. Renewed subsidence occurred as the continents separated further and the sea transgressed the Benue trough producing the proto-delta in the Anambra basin.

The proto-delta continued to prograde during middle cretaceous times into the collapsed continental margin at the site of triple junction sediment supply was mainly along drainage systems that followed the two failed rift arm, the Benue and Bida Basins. Sediment procreation was interrupted by episodic transgressions during late cretaceous time by early Tertiary time a regional transgression (base level rise)deposited the oldest litho logic unit of the Niger Delta; Akata formation.

**Lithostratigraphy:** Since inception in early cretaceous time, the southern basin of Nigeria has been the scene of at least three major depositional cycles (Short and Stauble, 1967). The first possibly a double cycle commenced in Albian time to Coniacian times and involved mainly marine deposition within the whole basin; between Albian to Lower Cenomanian and Turonian to Coniacian time. It was terminated by a brief phase of folding in Santomanian formation, which consists of continental and fluvial sands, gravel, and back swamp deposits (2500m [8250ft] thick).

Outcrop sediments in the northern reaches of the Niger Delta Basin, range in age from Eocene to recent. The Eocene outcrops occur in south of the Benin Flank and the basin areas in the northern fringe of the delta. The recent outcrops are the present coastlines. Surface evidences of Oligocene and Miocene deposits are limited and much of the age determination is uncertain. The approximate surface boundaries of the Eocene-recent sediments have been indicated Hosper, (1977). The three major lithostratigraphic units defined in the subsurface of the Niger Delta (Akaka, Agbada and Benin formations) decrease in age basin ward reflecting the overall regression of depositional environments within the Niger Delta clastic wedge. Stratigraphic equivalent units to these three formations are exposed in southern Nigeria (Short and Stauble, 1967). The formations reflect a gross coarsening-upward progradational clastic wedge (short and stauble, 1967), deposited in marine, deltaic, and fluvial environments (Weber and Daukoru, 1975; Weber 1986).



**Figure 3:** Stratigraphic column showing the three formations of the Niger Delta (Tuttle et al.1999). Modified from Doust and Omatsola (1990)

### METHODOLOGY

The samples used for this work are disturbed samples obtained from seven boreholes in basic sites in Delta State, drilled to a depth of 6m (borehole 5), 2.5m (borehole 6) and 1.5m (borehole 7). During sampling, visual examination of each sample was made as well as insitu description based on texture and

colour. Sample were put into poythene bags to prevent loss of the natural water content any other alteration that may arise due to exposure to the air.

**LABORATORY TECHNIQUES:**

The even disturbed samples were analyzed in the laboratory for water content, Atterberg limits, grain size distribution and compaction test.

**Moisture content determination (oven drying method):**

1. Accurate weight of dry and clean container ( $M_1$ ) was measured.
2. 30g of the soil sample was then placed in the container and
3. The weight of the container and the soil ( $M_2$ ) were weighed together.
4. Oven – drying of this oil to a recommend duration of 12-18 hours depending on the amount of materials in the oven at a temperature of 105<sup>o</sup> C to 110<sup>o</sup>C
5. After state 4, the container was removed from the oven and weighed to obtain the masses of the container and dry soil in  $M_3$ .
6. Calculation of the water content (MC) was done as followed.

$$\begin{aligned}
 MC &= \frac{\text{Mass of water}}{\text{Mass of solid soil}} \times 100 \\
 &= \frac{M_2 - M_3}{M_3 - M_3} \times 100\%
 \end{aligned}$$

7. Finally, step 1-6 were repeated for all the samples whose water contents is to be determined

**Determiation of Atterberg limits:**

This test enables us to know the moisture content at which a soil sample passes from one stage to the next and is known as consistency limit. The liquid and plastic limits are two of five limits proposed by Atterberg.

**Liquid limit determination:**

This is the minimum moisture content at which the soil will flow under its own weight. In order words, it is a soil – water mixture with no measureable shear strength.

**Procedure:**

Method using the Casagrande Apparatus

- 1) The soil was sieved and air dried through ASTM Sieve No. 40 (0.425mm opening)
- 2) To about 200gram of the dry soil, water was added and mixed thoroughly to form a uniform paste.
- 3) A portion of the paste was placed in the cup of the liquid limit device, and the surface was leveled off parallel to the base to a maximum depth of 1cm. then the grooving tool was drawn through the samples along the symmetrical axis of the cup (i.e. from the center of the hinge).
- 4) The crank (handle) was turned at a rate of about two revolutions per second until the two parts of the soil came into contact at the bottom of the groove along the distance of 13mm. The number of



blows at which this occurred was recorded.

- 5) Approximately 10g of soil was taken near the closed groove for moisture content determination.
- 6) The soil was removed and mixed. By changing the water content of the soil step 3-5 four water determinations ranging from 10-50 blows were obtained.
- 7) A plate of moisture content (on a linear scale as ordinate) against the numbers of blows (on a log scale abscissa). Such a plot, gave a flow curve that was approximately linear through the point that gave a line of best fit. The water content which corresponds to 25 blows on the flow curve was the liquid limit of the soil.

**Plastic limit determination:**

Plastic limit is the maximum water content as which the soil can be rolled into a thread of 3mm an diameter without breaking.

**Procedure:**

- 1) 20g of dry soil used in the liquid limit was mixed with distilled water to a uniform soil paste.
- 2) A portion of soil moulded into a thread.
- 3) A thread was rolled on a glass plate unit it is 3m in diameter and showed no sign of crumbling, then the specimen was wetter than the plastic limit.
- 4) The 3mm crumbled thread was used to determine the moisture content.
- 5) Step 1-4 were repeated to obtain three determinations, and average value of the moisture content, which gave the plastic limit of the soil.

Test No.	1	2	3	4
Can No.	AB	E	G	H
Mass of wet soil + can(g)M2	12.2	16.3	17.1	18.5
Mass of dry soil + can (g) M3	5.2	5.5	5.8	6.3
Mass of can(g) M1	10.0	10.8	11.2	12.2
Mass of wet soil (g)	7.2	8.9	9.7	10.7

**Table 1:** Plastic Limit Determination

**Compaction test:**

Compaction of densification is the process whereby soil particles are mechanically forced to pack more closely together by expelling air from the voids. The test involves the determination of mass of the dry soil per unit volume when the soil is compacted in a specific manner over a range of moisture content.

The strength of any earth material is related to its density, and the objectives of densification is simply to improve the engineering properties of the soil mass.

The laboratory compaction test also reveals optimum moisture content at which the compaction should be carried out to achieve the maximum dry density possible for the earth material (soil). In this work,

the modified proctor test method was used. Some advantages of compaction include the reduction of subsidence, reduction in shrinkage (decrease in volume) and increase in soil strength (shear strength).

### Grain size analysis:

The particles size distribution (texture) of a soil refers to the sizes and the relative proportions of various size groups of the solid particles that mek up a given soil materials.

The various particle size groups and their limits that are commonly used in Engineering Geology were adapted from MIT (Massachusetts's Institute of Technology) textural classification.

NAMES OF SOIL	QUALIFICATION TERM	PARTICLE SIZE RANGE (MM)
Boulders		>200
Cobbles		200 – 60
Gravel	Coarse	60 – 20
	Medium	20 – 6
	Fine	6-2
	Coarse	2-0.6
Sand	Medium	0.6 – 0.2
	Fine	0.2 – 0.06
	Coarse	0.06 – 0.02
Slit	Medium	0.02 – 0.006
	Fine	0.0006 – 0.002
Clay		<0.002

**Table 2:** Particles size limit of soil

The laboratory determination of the particle size distribution of soils is usually accomplished by sieving and sedimentation analysis. The former method is used for the coarse fraction (i.e. sizes (0.075mm) while the later is for fine fraction (<0.7mm). The full description of the laboratory procedure of these methods are given in the American Society for Testing of Material (ASTM 479) and the British Standard (BS 1377).

## RESULT AND DISCUSOIN

### MOISTURE CONTENT DETERMINATION:

The moisture contents of the soil samples varied from 8.1% at Cinema site to 26,9% at Okumagba Avenue off Total filling station. The high value of water content contained in the sample is as a result of the type of clay mineral preset. The large range of water content in the soil sample that the soil will be prone to expansion, and shrinkage when water is expelled from its pore spaces.

Sample no R2		Sample no R1	
Mass of cup + wet soil, M2	41.4	Mass of cup + wet soil, M2	21.3
Mass of cup + dry soil, M3	36.6	Mass of cup + dry soil, M3	21.1
Mass of cup, M1	18.5	Mass of cup, M1	5.2
Mass of dry soil, Ms	18.5	Mass of dry soil, Ms	16.9
Mass of water, Mw	4.0	Mass of water, Mw	2.2
Water content W%	26.9	Water content W%	13.0

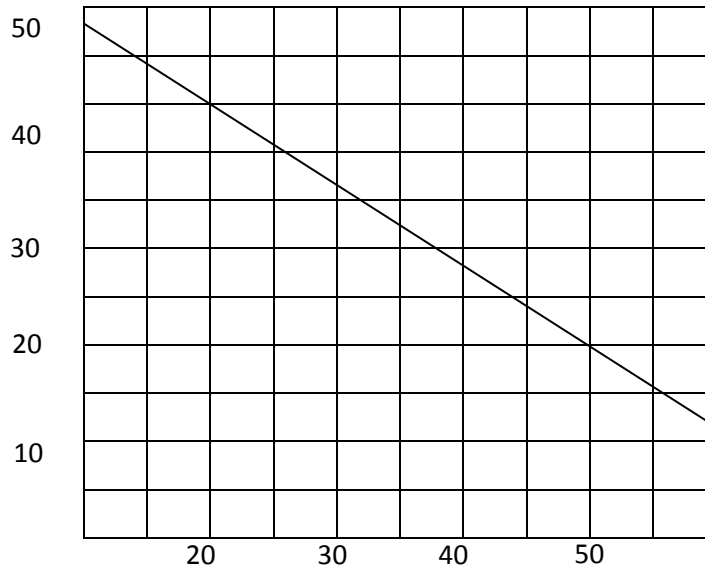
**Table 3: Moisture Content Determination**

**ATTERBERGE LIMITS:**

It is observed that the highest value of liquid limit (38.0%) was recorded in Giwamu road and the lowest values (22.05) in Ighorue street. On the other hand, the highest value of plastic limit (22.4%) was recorded in Giwamu Road while the lowest value (19.5%) was recorded in Okumagba Avenue off Total filling station. Further more, the highest plasticity index value (17.9%) was recorded in Akemu street while the lowest value (2.1%) in Ighorue street. These values indicate that the soils are of intermediate plasticity as well as of low to medium swelling potential and they denote increase in compressibility and decrease in shear strength. It will easily promote early failure of roads due to their ability to expand when they absorb water and contract when they lose it. This could account for failures that show as cracks on our roads in Delta State.

Test No.	1	2	3	4
Can No.	X	Y	Z	W
Mass of wet soil + can(g)M2	19.4	23.0	29.9	25.1
Mass of dry soil + can (g) M3	15.8	17.8	18.7	19.1
Mass of can(g) M1	5.4	5.7	5.8	5.9
Mass of wet soil (g)	14.0	17.3	18.1	19.2
Mass of dry soil (g)	10.4	12.1	12.9	13.2
Mass of moisture	3.6	5.2	15.2	6.0
Water content, W%	34.6	43	40	4.5
No of blows	34	26	22	18

**Table 4: Liquid limit Determination**



**Figure: 4:** Flow index = 0.7, Liquid limit = 40%, Plastic limit = 22.4%, Plasticity index = 17.6%

**COMPACTION:**

It can be seen that the results of the maximum dry densities and optimum moisture content range from (1763.2 – 1891.3) kg/m<sup>3</sup> and (7.1 – 10.4)% respectively. These soil will be mechanically forced to pack more closed together during compaction. This will lead to expulsion of air from the voids, thereby leading to increase in soil density, shear strength and reduction in compressibility, permeability, subsidence as well as deterioration.

**GRAIN SIZE ANALYSIS:** The result of the particles size distribution test show that the soil sample is mainly sand that is having an average value of coarse sand fracture as 36.3%, medium sand fraction as 37.3% and fine sand fraction as 13.6%

The coefficient of Uniformly (CU) of the sample have an average value of 4.2 which is less than 5 of British Standard (BS:1377). And that shows that the soil is poorly graded. Hence the soil is not suitable for base course materials. Moreover, as a result of their poorly graded nature, they will have negative effective such a high effective porosity large mean pore sizes and low density.

**CONCLUSION**

The sample analysis results from various location in Warri Delta State show very high percentage of fine soil (i.e. silts clays and fine sand) without gravel sized particles. This is usually classified under the unified soil classification scheme (USC) as poorly graded since it does not contain particles of all sizes. This high percentage of fine and shows high porosity, low permeability with decreasing stability.

The moisture content (MC) values range from 8.1 – 26%. This shows that some areas are well drained while others are not. The significance of the moisture content is that, the greater the amount of water a soil contains, the less interaction there will be between adjacent particles and the more the more the soil will behave like a liquid, i.e. decreasing shear strength. The liquid limit values range between 19.5 – 22.4%. This shows that the soil is of intermediate plasticity, and is an indication of low strength. The plasticity index values range from 2.1 – 17.9%. This indicates that the soil is of low medium swelling potential. The larger the plasticity index, the greater is the engineering problem associated with using the soil as an engineering material.

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