IOSR Journal of Applied Geology and Geophysics (IOSR-JAGG)
e-ISSN: 2321–0990, p-ISSN: 2321–0982.Volume 11, Issue 1 Ser. I (Jan. – Feb. 2023), PP 35-49
www.iosrjournals.org

Investigation of Grading Characteristics and Soil Classification Using Grain-Size Analysis: A Case Study of Yenagoa and Its Environs, Bayelsa State.

Akpoku, Bello .M.[1] and George, Godwin .C.[2]
[1]*Bayelsa Oil Company Limited*
[2]*Department of Physics (Geophysics unit), Niger Delta University, Bayelsa State*
Corresponding mail: chimuemela@gmail.com

Abstract
Soil classification systems are used to help predict soil behaviour and provide information to geologists, engineers, builders, agricultural extension agents, community planners, and government agencies. Geoscientists and engineers use soil classification systems to characterize soils, determine potential behaviour, and understand limitations of the soils encountered in construction projects. Grain size analysis was used to investigate soil gradation and classification of the study area. The particle size distribution curves show that the soil samples were predominantly composed of fine-medium sands, with a lesser proportion of coarse sand and gravel fractions. The sands were generally poorly graded with coefficient of uniformity ranging between 2.8 to 4.3 while the minimum and maximum values for the coefficient of curvature is 0.77 and 2.1 respectively. Effective size, uniformity coefficient, coefficient of sorting and coefficient of gradation were derived. From the results, classification of the thirty soil samples was such that, 6 samples each were of Fat Clay (CH) or Elastic Silt (MH) and Lean Clay categories respectively, 10 samples were classified as Clayey Sand (SC) or Silty Sand (SM), while 4 samples each were Poorly Graded Sand with Silt (SP-SM) and Poorly Graded Sand (SP) respectively. Generally, the upper sections (< 10m depth) were dominated by fine (clay and silt) sediments, while the proportion of coarse (sand and gravel) increased with depth.

Keywords; ***Grain size analysis, soil grading, coarse grain soil, Soil classification.***

Date of Submission: 27-01-2023 Date of Acceptance: 09-02-2023

I. Introduction

Coarse grained soil can be ranked based on diverse particle sizes contained in the soil, the classification of the coarse-grained soil is called Soil gradation (1). Soil gradation is a vital aspect of geotechnical engineering and soil mechanics. It also indicates the presence of engineering parameters such as hydraulic conductivity, shear strength and compressibility. Site design and ground water drainage of sites are controlled by the gradation of the on-site or in situ spoils. A well graded soil will have less effective drainage than a poorly graded soil, though the quality of clay must be put in the consideration. Soil gradation is gotten by studying the results of hydrometer analysis or sieve analysis. Soils can be graded through the use of AASHTO soil classification system of the United soil classification system. Grain size distribution curve is used to determine soil gradation, this distribution curve produced from the results of various laboratory tests. Several studies concerning soil mechanics, hydrogeophysics and hydrology have been carried out in the area (2, 3, 4, 5, 6, 7, 8). Nevertheless, little is known in the area of the gradation and characterization of the soil within the study area. This research investigates the determination of soil gradation and characterization using granulometric method. The technique used in this research is reliable and cost-effective.

II. Geology And Description Of Study Area

The study area covers selected locations within Yenagoa Local Government Area of Bayelsa state. It is part of the Niger Delta situated in the continental margin of the Gulf of Guinea in the West Africa Coast and lies within longitudes 6015' and 6020'E of the Meridian and latitude 40 55' and 50 05'N of the equator. The study area is accessible through major and minor roads.

Major access to the area is Mbiama – Yenagoa road with other minor network of roads linking the different communities and their environs. Figure 1 shows the map of the study area.

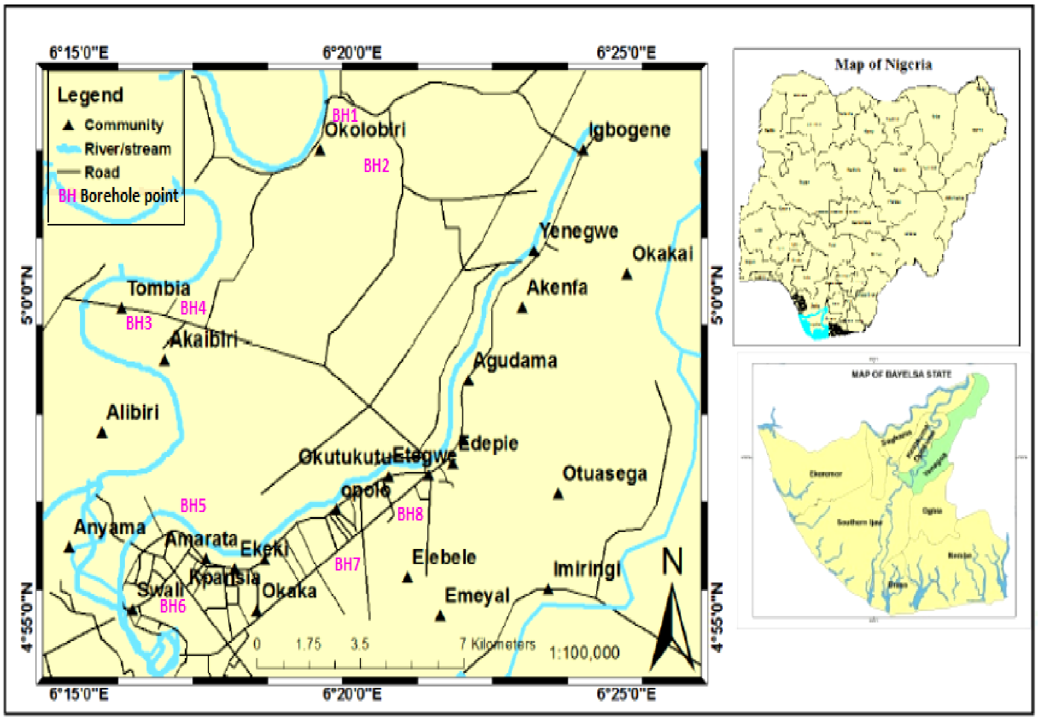

Fig. 1: Map of the study area

The Geology of the area is within the Niger Delta Sedimentary belt of Nigeria has been geologically described by Reyment (2018). This basin evolved through several depositional cycles. The Late Createaceous (Maastrichtian) to Early Tertiary (Paleocene) Transgression terminated the southern advance of the upper Cretaceous proto-Niger Delta and heralded the Tertiary to Recent Niger Delta as it waned (Rayment, 2018). The Niger Delta is situated on the continental margin of the Gulf of Guinea in Equatorial West Africa between Latitude 3^o and 6^o and Longitude 5^o and 8^oE. It covers all areas of about 75,000Km^2 (Short and Stauble, 1967). It extends from the Calabar flank and the Abakiliki trough in Eastern Nigeria to the Atlantic Ocean. Short and Stauble, 1967 recognized three subsurface stratigraphic units in the modern Niger Delta which are, Akata,Agbada and Benin Formations in order of decreasing age.

2.1 Akata Formation

The Akata Formation is the basal lithostratigraphic unit found in the Niger Delta Region, ranging from Paleocene to Holocene age (Reyment, 2018; Etu–Efeotor, 1997). Its marine pro-delta mega facies are composed of thick shales, turbidite sands, and small amounts of silt and clay. The Akata formation is made up of high pressure, low density, and deep marine deposits consisting of plant relics near the contact with overlying Agbada formation. Petroleum geologist in the area believes the formation is the main source rock in the Niger Delta and the lateral equivalent of the Imo Shale.

2.2 Agbada Formation

The Agbada Formation is essentially a cyclic paralic sequence of sandstones and shales representing deposits of the delta front megafacies. The interbedded shales are thought of as fields in the area (Reijers, 2011). About 99% of the Sandstone reservoirs in the Niger Delta occur within this succession. The outcrop equivalent is the Ameki formation. This Eocene to Recent siliciclastic sequence grades upwards into the Benin Formation.

2.3 Benin Formation

It is an extensive stratigraphic unit in the southern Nigeria sedimentary basin it outcrops in Benin, Onitsha, and Owerri provinces and also in the Niger Delta areas. It consists of poorly cemented sands, medium to coarse in size has an average thickness of about 18,000m and it ranges from Miocene to Recent in age. Among the minor components, Limonite coating, lignite streaks, haematite, and feldspar are common. The environment of deposition is probably transitional to continental. It is the main source of potable groundwater in the Niger Delta area.

2.4 Hydrogeology

The Benin Formation is the aquifer layer and all boreholes are drilled in this Formation. With minor intercalations of clay layers, it gives rise to a multi-aquifer system out of which have been identified (Etu-Efeotor, 1981). The first aquifer is (Holocene age) and more prolific and extents to about 60-90m (unconfirmed) while the second (Oligocene) is less prolific and underlines the first multi-aquifer system and leave also been identified from lithologic logs of boreholes from other pores of the Niger Delta by (Offodile 1992; Edet, 1993; Udom*et al.*, 1998).

III. Materials And Methodology

1. Casangrande's liquid limit device
2. Grooving tools of both standard and ASTM type
3. Oven
4. Evaporating dish
5. Sieve
6. Weighing balance
7. Wash bottle
8. Mortar and pestle
9. Distilled water

3.1 Soil boring and sample collection

Overburden and soil boring were performed at several locations: a total of twenty-four soil boring points were occupied in the study area. Samplings were executed using an auger hand rig which was conducted across six stations. During the boring operations, disturbed samples were collected at 2m interval up to a depth of 20m. Undisturbed samples were also retrieved from the boreholes with conventional open-tube sampler. All samples recovered from the boreholes were examined, identified and roughly classified in the field before taken to the laboratory for analysis.

IV. Result And Discussion

Based on the determined geolectric layering, thirty disturbed soil samples were selected from the corresponding depths of the eight boreholes drilled within the study area. Boring was performed using hand auger to a depth 6 m in 4 borehole sites and manualpercussion rig to a depth of 30 m in 4 locations. The soil samples were secured in waterproof bags and brought to the laboratory for sample preparation and testing. Visual inspection of the recovered samples shows that the relatively near surface samples were predominantly finer in texture, while samples obtained at lower subsurface depths tend to be coarser as per their grain sizes.

Table 1 showing Borehole locations

S/No.	BH/VES Location	BH No.	Drill method	Samples
1	Okolobiri, Teaching Hospital	BH1	Hand Auger	1 - 4
2	Okolobiri, Primary School	BH2	Hand Auger	5 - 7
3	Tombia, School of Nursing	BH3	Hand Auger	8 - 11
4	Tombia, Secondary School	BH4	Hand Auger	12 - 15
5	Amarata, Ompadec Road	BH5	Percussion	16 - 18
6	Swali, Beside UBA	BH6	Percussion	19 - 22
7	Opolo, JTF Road	BH7	Percussion	23 - 26
8	Opolo, Alamieyesegha Road	BH8	Percussion	27 - 30

4.1 GRAIN SIZE DISTRIBUTION

Grain size analysis is a typical laboratory test conducted in engineering geology to derive the particle size distribution of soils.The particles that make up soil are categorized into three groups by size – sand, silt, and clay. Sand particles are the largest and clay particles the smallest. Most soils are a combination of the three. The relative percentages of sand, silt, and clay are what give soil its texture. A clay loam texture soil, for example, has nearly equal parts of sand, slit, and clay. These textural separates result from the weathering process.The distribution of different grain sizes affects the engineering properties of soil. Grain size analysis provides the grain size distribution, and it is required in classifying the soil.The analysis is conducted via two techniques. Sieve Grain Size Analysis which is capable of determining the particles' size ranging from 0.075 mm to 100 mm. Any categorization of grains larger than 100mm will be conducted visually whereas particles smaller than 0.075 mm can be distributed using the hydrometer Method. The results of the grain size laboratory tests are presented in Tables 4.9 to 4.12.

Table 2: Grain size distribution for BH1

Sieve size (mm)	Mass of sieve (g)	Mass of sieve + soil retained (g)	Mass of soil (g)	% Retained	Cumulative % retained	% Finer
Sample 3						
0.71	316	316	-	-	-	100
0.59	312	315	3	1.6	1.6	98.4
0.30	307	314	7	3.8	5.4	94.6
0.21	303	314	11	6.0	11.4	88.6
0.125	298	370	72	39.1	50.5	49.5
0.075	294	346	52	28.3	78.8	21.2
0.044	291	325	34	18.5	97.3	2.7
Pan	263	268	5	2.7	100	0
Total			∑X = 184	∑R =100		
Sample 4						
0.59	312	318	6	2.9	2.9	97.1
0.30	307	318	11	5.3	8.2	91.8
0.21	303	318	15	7.2	15.4	84.6
0.125	298	398	100	48.3	63.7	36.3
0.075	294	347	53	25.6	89.3	10.7
0.044	291	305	14	6.8	96.1	3.9
Pan	263	271	8	3.9	100	0
Total			∑X = 207	∑R =100		

Table 3: Grain size distribution for BH2

Sieve size (mm)	Mass of sieve (g)	Mass of sieve + soil retained (g)	Mass of soil (g)	% Retained	Cumulative % retained	% Finer
Sample 7						
0.59	312	315	3	11.6	1.6	98.4
0.30	307	319	12	6.2	7.8	92.2
0.21	303	321	18	9.4	17.2	82.8
0.125	298	368	70	36.5	53.7	46.3
0.075	294	334	40	20.8	74.5	25.5
0.044	291	324	33	17.2	91.7	8.3
	263	279	16	8.3	100	0
			∑X = 192	∑R =100		

Table 4: Grain size distribution for BH3

Sieve size (mm)	Mass of sieve (g)	Mass of sieve + soil retained (g)	Mass of soil (g)	% Retained	Cumulative % retained	% Finer
Sample 10						
1.00	324	324	-	-	-	100
0.71	316	329	13	6.6	6.6	93.4
0.59	312	328	16	8.1	14.7	85.3
0.30	307	330	23	11.6	26.3	73.7
0.21	303	311	8	4.0	30.3	69.7
0.125	298	325	27	13.6	43.9	56.1
0.075	294	330	36	18.2	62.1	37.9
0.044	291	354	63	31.8	93.9	6.1
Pan	263	275	12	6.1	100	
Total			∑X = 198	∑R =100		
Sample 11						
1.00	324	324	-	-	-	100
0.71	316	329	17	8.0	8.0	92.0
0.59	312	321	9	4.2	12.2	87.8
0.30	307	320	13	6.1	18.3	81.7
0.21	303	323	20	9.4	27.7	72.3
0.125	298	336	38	17.9	45.6	54.4
0.075	294	359	65	30.7	76.3	23.7
0.044	291	332	41	19.4	95.7	4.3
Pan	263	272	9	4.3	100	
Total			∑X = 212	∑R =100		

Table 5: Grain size distribution for BH4

Sieve size (mm)	Mass of sieve (g)	Mass of sieve + soil retained (g)	Mass of soil (g)	% Retained	Cumulative % retained	% Finer
Sample 14						
1.00	324	324	-	-	-	100
0.71	316	320	4	1.9	1.9	98.1
0.59	312	324	12	5.6	7.5	92.5
0.30	307	324	17	7.9	15.4	84.6
0.21	303	362	59	27.6	43.0	57.0
0.125	298	374	76	35.5	78.5	21.5
0.075	294	326	32	15.0	93.5	6.5
0.044	291	300	9	4.2	97.7	2.3
Pan	263	268	5	2.3	100	
Total			∑X = 214	∑R =100		
Sample 15						
1.00	324	324	-	-	-	100
0.71	316	329	13	6.4	6.4	93.6
0.59	312	321	9	4.4	10.8	89.2
0.30	307	324	17	8.3	19.1	80.9
0.21	303	326	23	11.3	30.4	69.6
0.125	298	340	42	20.6	51.0	49.0
0.075	294	360	66	32.4	83.4	16.6
0.044	291	317	26	12.7	96.1	3.9
Pan	263	271	8	3.9	100	
Total			∑X = 204	∑R =100		

Table 6: Grain size distribution for BH5

Sieve size (mm)	Mass of sieve (g)	Mass of sieve + soil retained (g)	Mass of soil (g)	% Retained	Cumulative % retained	% Finer
Sample 17						
0.71	316	326	10	4.7	4.7	95.3
0.59	312	325	13	6.1	10.8	89.2
0.30	307	329	22	10.3	21.1	78.9
0.21	303	339	36	16.9	38.0	62.0
0.125	298	370	72	33.8	71.8	28.2
0.075	294	330	36	16.9	88.7	11.3
0.044	291	315	24	11.3	100	0
Pan	263	263	0	0		
Total	∑M=2384	∑N = 2597	∑X = 213	∑R =100		
Sample 20						
2.38	349			-	-	-
2.00	342					
1.00	324	327	3	1.3	1.3	98.7
0.71	316	324	8	3.6	4.9	95.1
0.59	312	331	19	8.5	13.4	86.6
0.30	307	342	35	15.6	29.0	71.0
0.21	303	326	23	10.3	39.3	60.7
0.125	298	377	79	35.3	74.6	25.4
0.074	294	325	31	13.8	88.4	11.6
0.044	291	317	26	11.6	100	0
Pan	263					
Total			∑X=224			

Table 7: Grain size distribution for BH6

Sieve size (mm)	Mass of sieve (g)	Mass of sieve + soil retained (g)	Mass of soil (g)	% Retained	Cumulative % retained	% Finer
Sample 21						
2.38	349			-	-	-
2.00	342			-	-	-
1.00	324	337	13	6.3	6.3	93.7
0.71	316	340	24	11.7	18.0	82.0
0.59	312	347	35	17.0	35.0	65.0
0.30	307	369	62	30.1	65.1	34.9
0.21	303	330	27	13.1	78.3	21.7
0.125	298	319	21	10.2	88.5	11.5
0.074	294	310	16	7.6	96.1	3.9
0.044	291	299	8	3.9	100	0
Pan	263					
Total			$\sum X = 206$			
Sample 22						
2.38	349	358	9	3.7	3.7	96.3
2.00	342	363	21	8.7	12.4	87.6
1.00	324	360	36	14.9	27.3	72.7
0.71	316	384	68	28.2	55.5	44.5
0.59	312	353	41	17.0	72.5	27.5
0.30	307	334	27	11.2	83.7	16.3
0.21	303	326	23	9.5	93.2	6.8
0.125	298	314	16	6.8	100	0
0.074	294					
0.044	291					
Pan	263					
Total			$\sum X = 241$			

Table 8: Grain size distribution for BH7

Sieve size (mm)	Mass of sieve (g)	Mass of sieve + soil retained (g)	Mass of soil (g)	% Retained	Cumulative % retained	% Finer
Sample 24						
0.71	316	323	7	3.3	3.3	96.7
0.59	312	332	20	9.5	12.8	87.2
0.30	307	333	26	12.3	25.1	74.9
0.21	303	338	35	16.6	41.7	58.3
0.125	298	375	67	31.8	73.5	26.5
0.074	294	328	34	16.1	89.6	10.4
0.044	291	313	22	10.4	100	0
Total			$\sum X=211$			
Sample 25						
1.00	324	328	4	1.8	1.8	98.2
0.71	316	324	8	3.7	5.5	94.5
0.59	312	347	25	11.5	17.0	83.0
0.30	307	343	36	16.5	33.5	66.5
0.21	303	354	51	23.4	56.9	43.1
0.125	298	339	41	18.8	75.7	24.3
0.074	294	334	40	18.3	94.0	6.0
0.044	291	304	13	6.0	100	0
Total			$\sum X=218$			
Sample 26						
2.00	342	349	7	3.8	6.0	94.0
1.00	324	341	17	9.2	15.2	84.8
0.71	316	340	24	13.0	28.2	71.8
0.59	312	340	28	15.2	43.4	56.6
0.30	307	344	37	20.1	63.5	36.5
0.21	303	324	21	11.4	74.9	25.1
0.125	298	328	30	16.3	91.2	8.8
0.074	294	310	16	8.8	100	0
Pan	263	263	-	-		
Total			$\sum X=184$			

Table 9: Grain size distribution for BH8

Sieve size (mm)	Mass of sieve (g)	Mass of sieve + soil retained (g)	Mass of soil (g)	% Retained	Cumulative % retained	% Finer
Sample 28						
0.71	316	320	4	2	2.0	98.0
0.59	312	322	10	5.2	7.2	92.8
0.30	307	325	18	9.3	16.5	83.5
0.21	303	330	27	13.9	30.4	69.6
0.125	298	358	60	30.9	61.3	38.7
0.074	294	330	36	18.6	79.9	20.1
0.044	291	313	22	11.3	91.2	8.8
Pan	263	280	17	8.8	100	0
Total			$\sum X=194$			
Sample 29						
2.00	342	344	2	1.0	1.0	99
1.00	324	335	11	5.5	6.5	93.5
0.71	316	338	22	10.9	17.4	82.6
0.59	312	336	24	11.9	29.3	70.7
0.30	307	338	31	15.4	44.7	55.3
0.21	303	353	50	24.9	69.6	30.4
0.125	298	335	37	18.4	88.0	12.0
0.074	294	314	20	10.0	98.0	2.0
0.044	291	295	4	2.0	100	0
Total			$\sum X=201$			
Sample 30						
2.00	342	345	3	1.6	1.6	98.4
1.00	324	334	10	5.4	7.0	93.0
0.71	316	347	31	16.7	23.7	76.3
0.59	312	348	36	19.4	43.1	56.9
0.30	307	330	23	12.4	55.5	44.5
0.21	303	319	16	8.6	64.1	35.9
0.125	298	345	47	25.3	89.4	10.6
0.074	294	314	20	10.6	100	0
Total			$\sum X=186$			

4.2: GRAIN SIZE DISTRIBUTION CURVE

The results of mechanical analysis (sieve and hydrometer analyses) are generally presented by semi-logarithmic plots known as particle-size distribution curves. The particle diameters are plotted in log scale, and the corresponding percent finer in arithmetic scale.In science and engineering, a semi-log graph or semi-log plot is a way of visualizing data that are changing with an exponential relationship.One axis is plotted on a logarithmic scale.

This kind of plot is useful when one of the variables being plotted covers a large range of values and the other has only a restricted range. The advantage being that it can bring out features in the data that would not easily be seen if both variables had been plotted linearly. The particle-size distribution curve does not only show the range of particle sizes present in a soil but also the type of distribution of various size particles. Some typical grain size distribution curve types are shown in Fig. 2

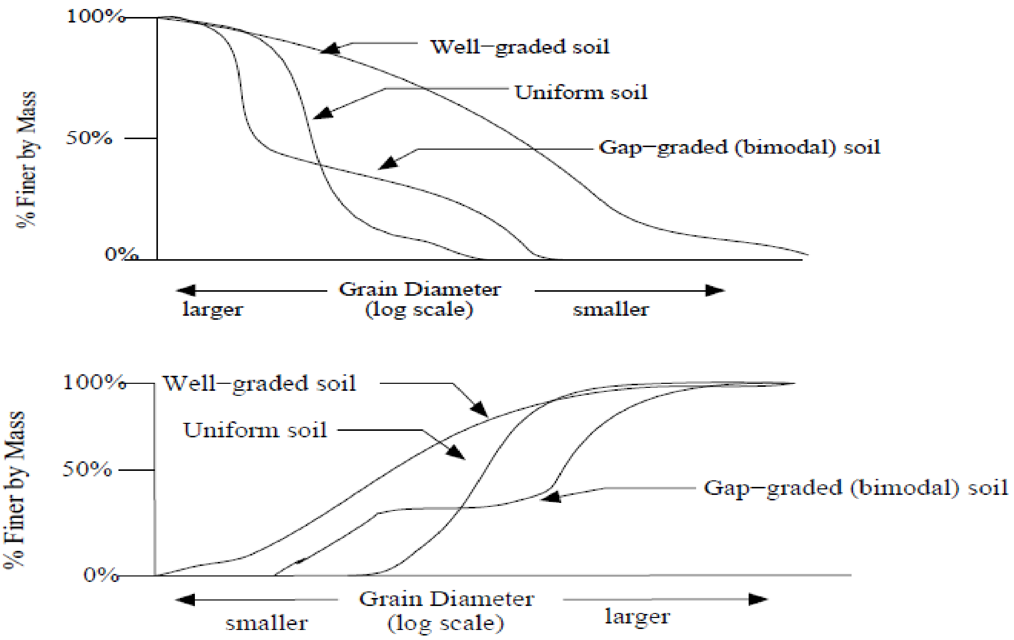

Fig 2: Typical grain size distribution curve types

The particle size distribution curves are presented in Fig. 3 to 8. The particle size distribution curves show that the soil samples were predominantly composed of fine-medium sands, with a lesser proportion of coarse sand and gravel fractions. The sands were generally poorly graded with coefficient of uniformity ranging between 2.8 to 4.3 while the minimum and maximum values for the coefficient of curvature is 0.77 and 2.1 respectively.

4.2.1 Grading Characteristics

Four basic soil parameters can be determined from the grainsize distribution curves:

- ❖ Effective size
- ❖ Uniformity coefficient
- ❖ Coefficient of gradation
- ❖ Coefficient of sorting

The quantitative analysis of the grain size distribution curves was based on the determined grading characteristics such as D_{10}, D_{25}, D_{30}, $D_{60}$and D_{75}. The values of D_{10}, D_{25}, D_{30}, $D_{60}$and D_{75}refers to the grain or particle diameter on the X-axis of the curves corresponding to percentage finer at 10%, 25%, 30%, 60% and 75% on the Y-axis. From these geometric values, the effective size, uniformity coefficient, coefficient of sorting and coefficient of gradation were derived. Uniformity coefficient (Cu) is equal to D_{60}/D_{10}. Soils with Cu less than or equal to 3 are considered to be “poorly graded” or “uniform”. Coefficient of gradation (Cc) = $(D_{30})^2/(D_{60}\times D_{10})$. For well-graded soils, Cc is approximately equal to 1. The Sorting Coefficient SO = $(D_{75}/D_{25})^{1/2}$. This measure tends to be used more by geologists than engineers. The larger the value of SO, the more well-graded the soil. The parameterd10 is referred to as the "effective size" of the soil. Empirically, D_{10} has been strongly correlated with the permeability of fine−grained sandy soils.

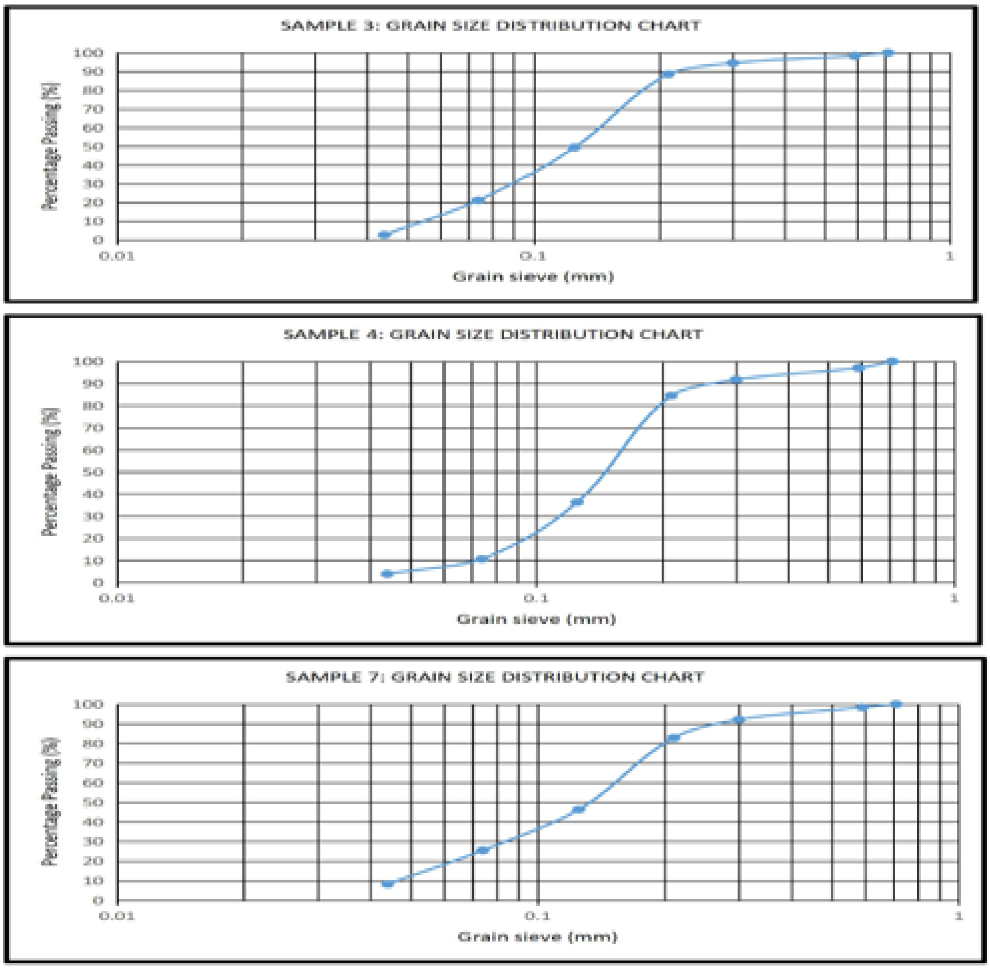

Fig. 3: Grain size distribution charts for BH1 and 2 soil samples

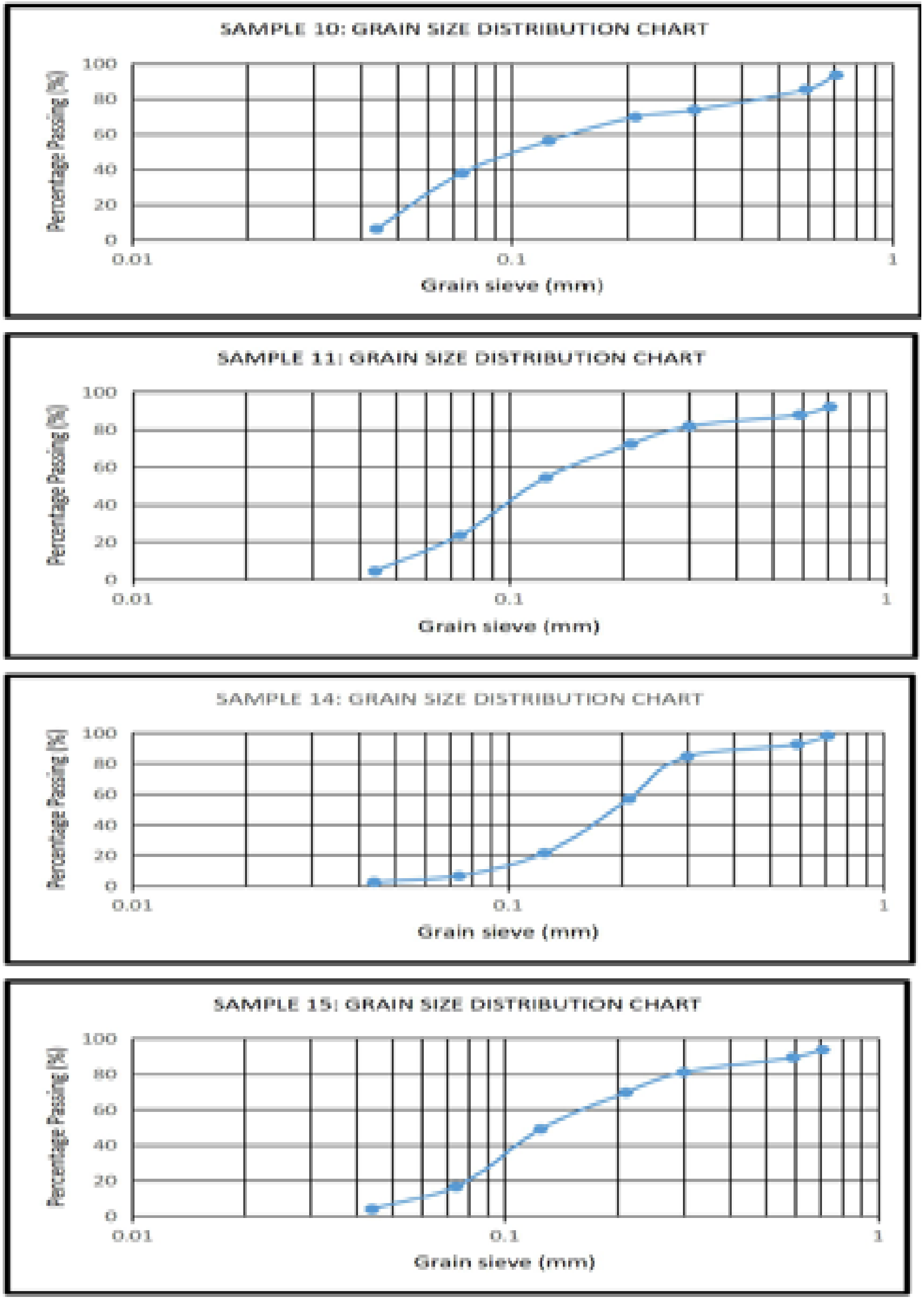

Fig. 4: Grain size distribution charts for BH3 and 4 soil samples

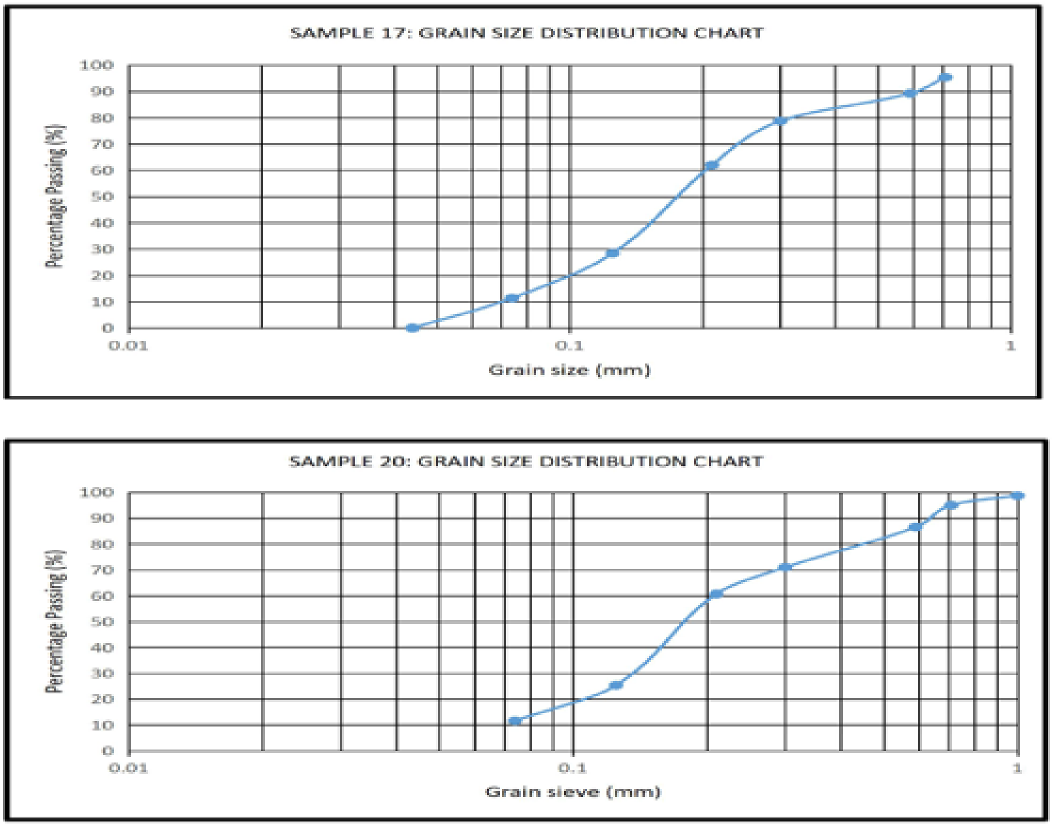

Fig. 5: Grain size distribution curves for BH5

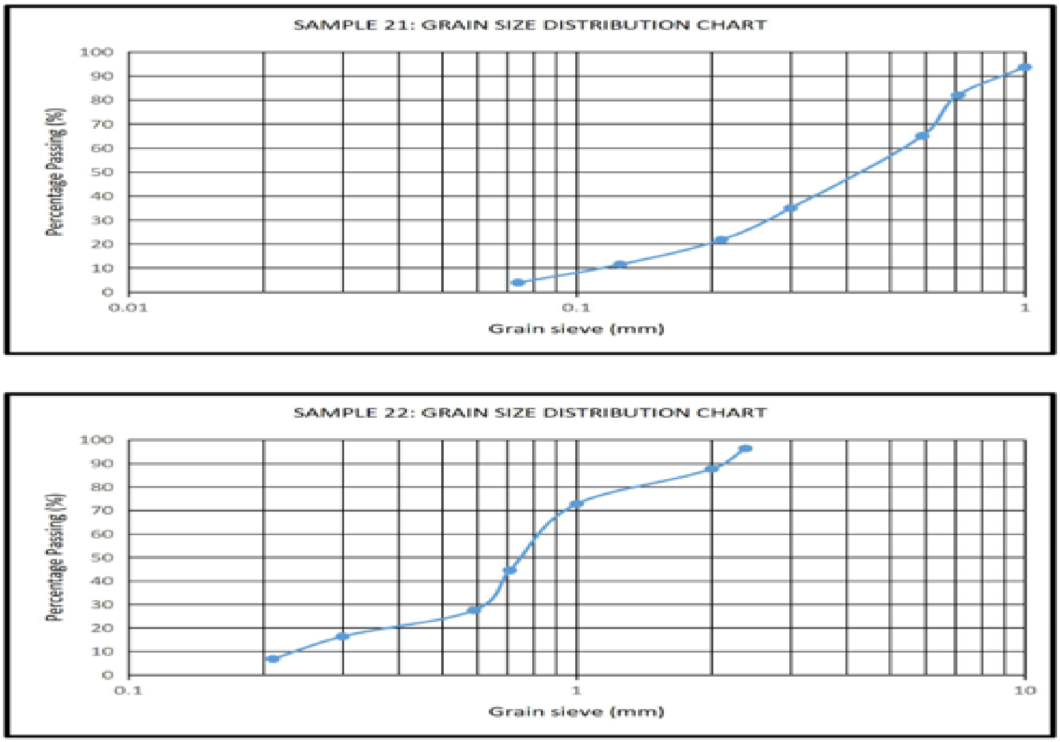

Fig. 6: Grain size distribution curves for BH6

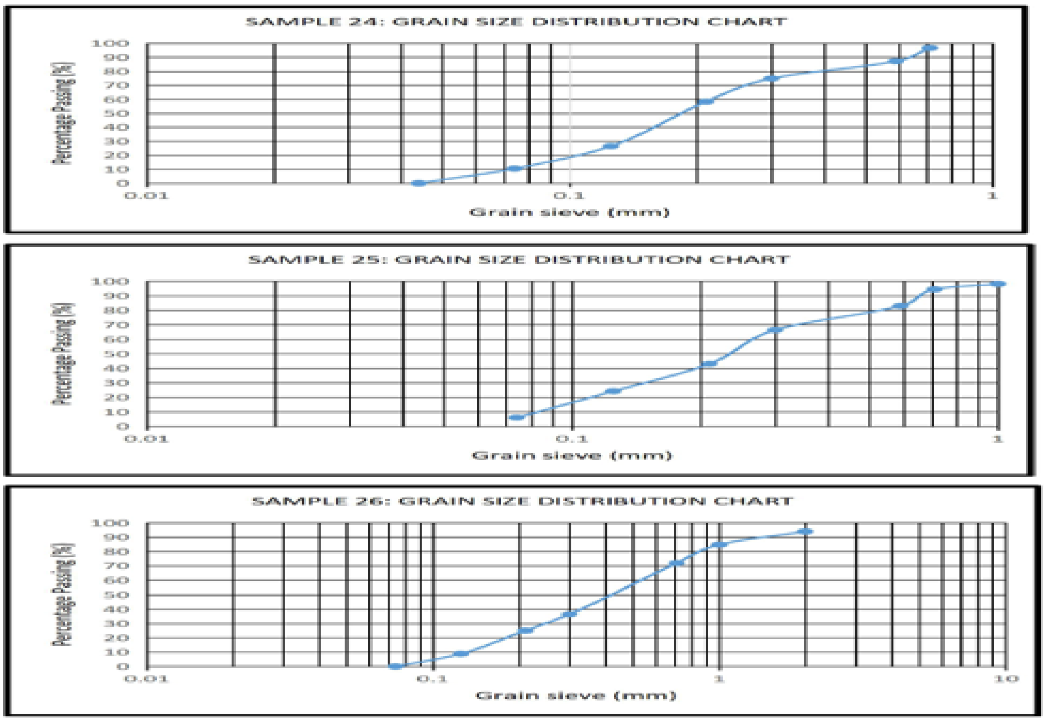

Fig. 7: Grain size distribution curves for BH7

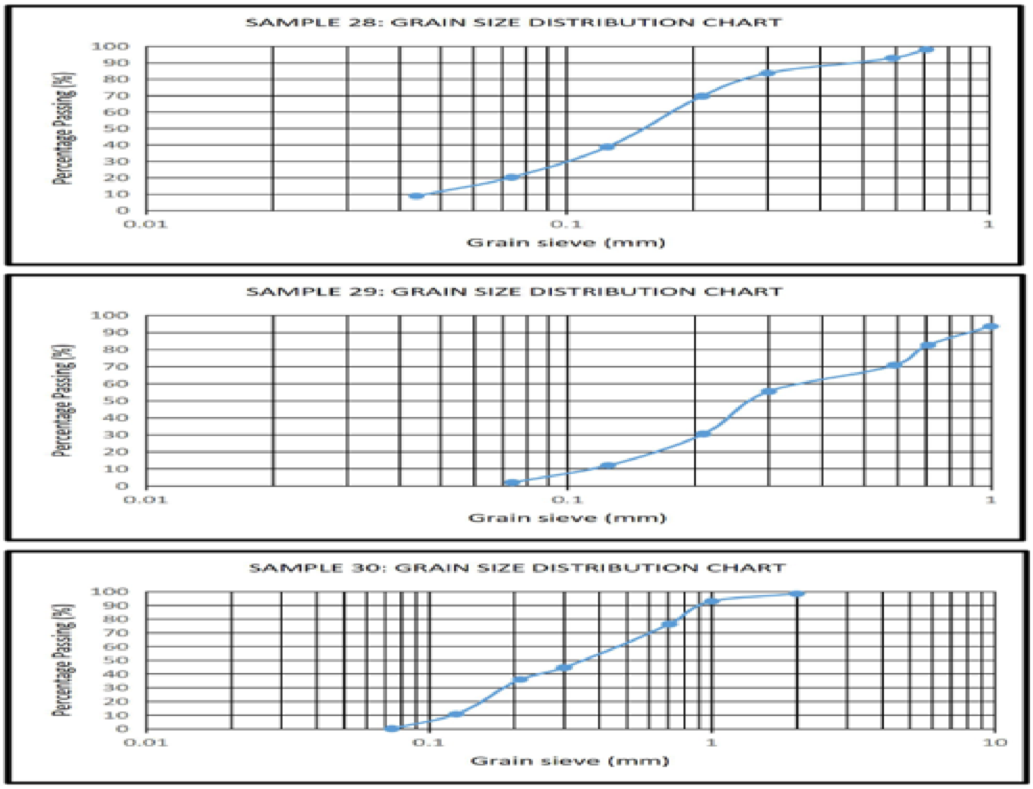

Fig. 4.18: Grain size distribution curves for BH8

4.3 Soil Classification

The purpose of a soil classification is to group together soils with similar properties or attributes. Soil classification systems are used to help predict soil behaviour and provide information to geologists, engineers, builders, agricultural extension agents, community planners, and government agencies. Geoscientists and engineers use soil classification systems to characterize soils, determine potential behaviour, and understand

limitations of the soils encountered in construction projects. This knowledge is critical when designing airfields, roads, buildings, dams, bridges, and other infrastructure.
Several soil classification schemes exist and are used by engineers, geologists, and soil scientists. Some of the schemes include (1) Unified Soil Classification System (USCS), (2) British Soil Classification System (BSCS) (3) AmericanAssociation ofStateHighway andTransportationOfficials(AASHTO) and (4) United State Department of Agriculture (USDA). The USCS is the most widely accepted scheme and is used in this study for the classification of the soil samples.

4.3.1 USCS Criteria and Results

The basic criteria for determination of the USCS classification for soil samples include: (a) % passing through 0.075mm sieve, (b) % retained in 0.075mm sieve (c) the value of LL (d) the section in which PI against LL of sample plots with respect to the A-line on the Cassagrande plasticity chart and (e) gradation of the sample. From the results, classification of the thirty soil samples was such that, 6 samples each were of Fat Clay (CH) or Elastic Silt (MH) and Lean Clay categories respectively, 10 samples were classified as Clayey Sand (SC) or Silty Sand (SM), while 4 samples each were Poorly Graded Sand with Silt (SP-SM) and Poorly Graded Sand (SP) respectively. Generally, the upper sections (< 10m depth) were dominated by fine (clay and silt) sediments, while the proportion of coarse (sand and gravel) increased with depth.

4.3.2 Fat Clay (CH) Soil Type

The unique symbol for Fat Clay soils as per the USCS classification scheme is CH. Using the USCS procedures, samples 1,5,6,8, and 19 are classified as Fat Clay soil type. Each of these soil samples have the following characteristics:

- ❖ Greater than 50% of the soil sample passed through the 0.075mm sieve
- ❖ Liquid limit of the soil was > 50% and plasticity index against liquid limit plots above the A-line on the Cassagrande plasticity chart
- ❖ Less than 15% of the soil sample was retained in the 0.075mm sieve

4.3.3 Lean Clay (CL) Soil Type

Samples 2, 9, 10, 13, 16, and 23 of the samples analysed are classified in the category referred to as Lean Clay soil type. These samples are basically fine grained soils just like the Fat Clay group but generally have relatively lower liquid limit and plasticity index values. The geotechnical index characteristics of the Lean Clay soils are as follows:

- ❖ Greater than 50% of the soil sample passed through the 0.075mm sieve
- ❖ Liquid limit of the soil was < 50% and plasticity index against liquid limit plots above the A-line on the Cassagrande plasticity chart
- ❖ Less than 15% of the soil sample was retained in the 0.075mm sieve

4.3.4 Clayey Sand (SC) and Silty Sand (SM) Soil Types

Ten (10) out of the thirty (30) soil samples recovered from the boreholes in this study are classified as either Clayey Sand, Silty Sand or Silty Clayey Sandafter analysis of their laboratory test results. Samples 3, 4, 11, 14, and 15 are of the Clayey Sand category, samples 7 17, and 27 belong to the Silty Sand group, while samples 8 and 18 were classified in the Clayey Silty Sand category. The symbols for Clayey sand Silty Sand Clayey Silty Sand are SC, SM and SC-SM based on the USCS classification scheme. The geotechnical index characteristics of the SC, SM and SC-SM soils are as follows:

- ❖ Greater than 50% was retained in 0.075mm sieve
- ❖ % sand > % gravel
- ❖ Greater than 12% are fines with plot of plasticity indexagainstliquid limit plotting in the CL section for SC and in the ML section for SM
- ❖ Less than 15% was gravel

Clay and Silt are both fine soils and cannot be distinguished by sieve analysis. The particle size ofclay is less than 2 microns, while particle the size of silt ranges between 75 microns to 2 microns.An experiment to demonstrate the difference between silt and clay constituents of a soil sample is to agitate the soil in a clear plastic bottle filled with water. The soil is dispersed throughout the water and it appears very cloudy. Any sand particles will settle to the bottom very quickly. Silt will settle to the bottom over the course of a couple of hours, leaving lightly cloudy water remaining. The cloudiness is clay particles which will take a few days to settle on top of the silt. You can then see the layers as they form in the bottle.Silt has less water holding capacity as compared to clay.Silt has uniform and non-sticky particles. If you touch clay with your hands it will be sticky. Clay is very easy to mould into any shape, whereas silt is difficult to mould into a particular shape. Finally, clay has higher plasticity when compared to silt.

4.3.5 Poorly Graded Sand with Silt (SP-SM)
Samples 20, 21, 24 and 25 were classified as poorly graded sand with silt or clay. These category of soil samples have the under-listed properties:
- ❖ Greater than 50% of soil sample was retained in 0.075mm sieve
- ❖ % sand > % gravel
- ❖ 5- 12% of sample are silts or clays
- ❖ Less than 15% are gravels
- ❖ Coefficient of uniformity (Cu)<6 and/or coefficient of curvature(Cc)< 1 or > 3

4.3.6 Poorly Graded Sand (SP)
Samples 22, 26, 29 and 30 were classified as Poorly Graded Sand. They have the following distinguishing characteristics:
- ❖ Greater than 50% of soil sample was retained in 0.075mm sieve
- ❖ % sand > % gravel
- ❖ Less than 5% of sample are silts or clays
- ❖ Less than 15% are gravels
- ❖ Soil is non-plastic
- ❖ Coefficient of uniformity (Cu)<6 and/or coefficient of curvature(Cc)< 1 or > 3

According to the USCS classification, inorganic soilsbroadly divided into: coarse-grained soil and fine-grained soil. The particle size distribution of soil and consistence limits are used in soil classification.

❖ The soil is classified as fine-grained (coherent soil) if more than 50 % of the total quantity of dry sample passes through the sieve No. 200 – 0.075 mm.

❖ The soil is classified as coarse-grained (incoherent soil) if more than 50 % of the total quantity of dry sample is retained on the sieve No. 200 – 0.075 mm.

4.4 Classification of Fine-grained Soil
The soil is considered to be an inorganic clay if the pair of values [liquid limit (LL), plasticity index (PI)] in the plasticity diagram is situated at or above the A line, the index of plasticity is greater than 4.Inorganic clays have the following sub groups:
- ❖ The soil is classified as lean clay, CL, if the liquid limit is smaller than 50 %.
- ❖ The soil is classified as fat clay, CH, if the liquid limit is greater than 50 %.
- ❖ The soil is classified as silty clay, CL-ML, if the pair of values (LL, IP) is situated at or above the A line, and the value of the index of plasticity ranges from 4 to 7.

The soil is considered to be an inorganic silt if the pair of values (LL, IP) in the plasticity diagram is situated below the A line or the plasticity index is smaller than 4. Inorganic clays have the following sub groups:
- ❖ The soil is classified as silt, ML, if the liquid limit is smaller than 50%.
- ❖ The soil is classified as elastic silt, MH, if the liquid limit is greater than 50%.

4.8 Coarse-grained Soil
❖ If less than or equal to 12% of the sample mass passes through the sieve No. 200 (0.075mm) then the grading curve is used to calculate the uniformity coefficient (Cu) and the curvature coefficient (Cc). Where Cu = D_{60}/D_{10}; Cc = $(D_{30})^2/(D_{10}*D_{60})$.

❖ If the Cu is equal to or greater than 4 for gravel, or equal to or greater than 6 for sand, and if the Cc is equal to 1 and not greater than 3, the soil is classified as the well graded gravel, GW, or as the well graded sand, SW.

❖ If coefficients of uniformity and curvature do not meet criteria for well graded soil, the soil is classified as a poorly graded gravel, GP, or as a poorly graded sand, SP.

If more than 12 % of the sample mass passes through the sieve No. 200 – 0.075 mm, the soil is considered to be a coarse-grained material with fine grains. At that, it should be established whether fine grains are clay or silt, which is determined from the plasticity diagram using the plasticity index and liquid limit

V. Conclusion
The USCS was used in this study for the classification of the soil samples. Soil sampling from boreholes and laboratory testing reveals 3 subsoil categories namely clayey-silty sediments, clayey-silty sands and poorly graded sands.

Reference
[1]. Holtz, R. and Kovacs, W. (1981), An Introduction to Geotechnical Engineering, Prentice-Hall, Inc. ISBN 0-13-484394-0
[2]. George, G. C. and Oki, O. A. (2018) Determination of Aquifer Hydraulic and Statistical parameters using Granulometric method in Yenagoa, Southern Nigeria. Asian Journal of Geologocal Research. 1(1); 1 – 10, 2018

[3]. Cosenza, P., Marmet, E., Rejiba, F., Cui, Y. J., Tabbahgh, A. (2006). Correlations between geotechnical and electrical data: A case study at Garchy in France. J ApplGeophys 60: 165−178.

[4]. Adeyemo, I. A., Omosuyi, G. O., Olayanju, G. M. and Omoniyi, G. K. (2014). Hydrogeologic and geoelectric determination of groundwater flow pattern in Alaba-Apatapiti layouts, Akure, Nigeria. International Journal Engineering Science 3: 44–52

[5]. George, G., C. and Biere, P., E. (2021).American Journal of Advanced Scientific Research, Vol. 2, Issue. 7, pp. 278-285, 2021

[6]. Akana T. S, George G. C. and Oki O. A. (2016) Aquifer Vulnerability Assessment in Some Town of Yenagoa, South-South Nigeria. Journal of Scienece and Technology; Vol. 6, Issue (1), pp 15 – 23.

[7]. George G. C. and OgobiriG. (2021) Investigation of Soil Liquefaction Susceptibility Using Seismic Refraction Method; a Case Study of Opolo Town, Bayelsa State, South-Southern Nigeria.Journal of Research in Environmental and Earth Sciences, Vol. 7, Issue 11 (2021) pp: 56-68

[8]. Akinshipe R. B., Kenneth S. O. and Geoffrey C. S. O. (2021). Determination of elastic moduli and bearing capacity of sediments using geophysical and cone penetration test techniques in Yenagoa, Southern Nigeria,NRIAG Journal of Astronomy and Geophysics. 1 – 17.

[9]. Etu-Efeotor J.O; (1981). Preliminary hydrogeochemical investigations of surface water in part of the Niger Delta: Bulletin of the Nigeria mining GeoScience Association, V.18, 103-110.

[10]. Etu–Efeotor, J. O. (1997). Fundamentals of petroleum geology. Paragraphic publications, Port Harcourt, Nigeria, Press page 135.

[11]. Offodile, M. E (1992). An approach to groundwater study and development in Nigeria, Jos, Mecon Services Ltd.

[12]. Reijers, T. J. A. (2011). Stratigraphy and Sedimentology of the Niger Delta. Geologic, The Netherlands, 17(3), p.133-162.

[13]. Reyment R. A. (2018), Ammonitologistsensulatissimo and founder of Cretaceous Research Bengtson. Cretaceous Research- 1926 - 2016, 88, 5 – 35

[14]. Short, K. C. and Stauble, A. J. (1965). Outline of Geology of the Niger Delta. American association of petroleum geologist (AAPG) Bulletin. 51: 761 – 779

[15]. Udom, G.J; Esu, EO; Ekwere, SJ (1998). Quality status of groundwater in Calabar Municipality, Southeastern Nigeria. Global Journal of Pure and Applied Sciences. 4(2), 163 - 169.

Akpoku, Bello .M. “Investigation of Grading Characteristics and Soil Classification Using Grain-Size Analysis: A Case Study of Yenagoa And Its Environs, Bayelsa State.” *IOSR Journal of Applied Geology and Geophysics (IOSR-JAGG)*, 11(1), 2023, pp. 35-49.