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Research Paper

Effect of Grain Size Distribution on Field Resistivity Values of Unconsolidated Sediments

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ABSTRACT: *Vertical electrical sounding (VES) data and particle size distribution of soil samples obtained within Yenagoa and environs were analysed to determine the relationship between sediments' grain sizes and their response to the passage of electrical current. Considering that the use of geophysical testing in site characterization is sometimes looked at as a probable rather than certain approach, the soil samples were obtained from boreholes drilled at the centre of each VES spread. A total of twelve vertical electrical soundings were conducted and fifty-two disturbed soil samples were collected within the area under investigation. The recovered geomaterials were subsequently separated into 4 groups according to their geotechnical index properties determined from the relevant laboratory tests, while the geoelectric field measurements were digitally processed to obtain the corresponding true layer resistivity of the soil samples. The results show that soils in the first category which comprised predominantly of CH and CL soil types as per USCS classification had an average resistivity of 68.2 Ωm. The second category which was composed mainly of clayey sand (SC) sediments recorded a mean resistivity value of 120.9 Ωm. The third and fourth groups had average resistivity values of 236.4 Ωm and 483.7 Ωm and comprised of silty sand (SC) and poorly sorted sand (SP) respectively. From the foregoing results, it is seen that the soil type with the least proportion of fines (clay and silt) recorded the highest resistivity value, while soils with the highest percentage composition of fines had the lowest recorded resistivity value. The correlations established between the geoelectrical and geotechnical parameters in this study, help to further ratify the field electrical resistivity method and thus contribute to a meaningful VES interpretation.*

Keywords: *Geophysical, borehole, geotechnical, geomaterials, classification, resistivity*

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I. INTRODUCTION

Civil engineering structures (buildings, bridges, airport, runways, and roadways) reside directly or indirectly on the ground. Hence, a good knowledge of the condition of the subsurface will help in the design of such structures. The relationship between sediments' texture and its electrical response to the passage of electrical current is the concept that underlies this study. Soil texture and other parameters form the basis for soil classification schemes commonly used by geotechnical engineers. Texturally, soils are classified as either coarse-grained (sands and gravels) or fine-grained (silts and clays) with the dividing line being whether the soil is retained on or passes through the No. 200 (75 um) sieve. Soil electrical resistivity is increasingly used in near-surface soil applications because it is related to many soil characteristics and electrical survey information. It, therefore, represents a rapid flexible tool to predict spatial soil variability in site investigations [1, 2].

The purpose of an electrical resistivity survey is to determine the resistivity distribution of electric potential in earth materials. Artificially generated electric currents are supplied to the material and the resulting potential differences are measured. The potential differences patterns provide information on the form of subsurface heterogeneities and their electrical properties. Electrical resistivity of soil can thus be considered as a proxy for the variability of soil physical properties [3]. The electrical resistivity of soil is affected by porosity, grain size, shape and matrix mineralogy [4]. These are known to be responsible for changes in the form of current flow through soils and sediments, resulting in variations in the distribution of electric potential in earth materials. These variations in electric potential reflect the changing resistivity of the soil in response to variabilities in the above mentioned physical properties. At the centre of the listed parameters is grain size.

Grain size affects both porosity and grain shape and is closely related to matrix mineralogy. Sediment may be made up of particles of different shapes ranging from spheres to plates. Usually, particles in the sand and silt size range are closer to a sphere in shape than the plate-like clay particles. The different particle shapes affect the path lengths that migrating ions take when current flows. In coarse-grain soils, pore-water facilitates current conduction as ions can freely move in the fluid medium, thus generating electrolytic conduction. Clayey soils generally have lower resistivity values than sandy soils because the current conduction takes place through electrolytic as well as electronic conduction. In general, soils with more fines often contain a higher percentage of conductive clay particles [5]. However, saturated sandy soils may exhibit low resistivity than dry compacted clayey soil. Due to these factors, the overlapping of resistivity values is observed for different soil types. Considering the above, extensive testing and correlation of the geoelectrical and geotechnical parameters is essential to avoid errors that may arise from generalization and assigning specific values of resistivity on the basis of lithology alone.

This work is aimed at investigating the effect of grain sizes on measured soil resistivity values and establish an empirical relationship between the two phenomena such that the later can be used as a tool to evaluate the geotechnical index property. This nexus serves as a tool to complement drilling and testing programs, and also provide a volumetric image of the subsurface rather than a point assessment.

II. LOCATION OF STUDY

The study area lies between latitudes 4^0 55'N and 5^0 51'N and longitudes 6^0 10'E and 6^0 25'E (Figure 1). In the East, it is bounded by Rivers state, in the West and North by Delta state, in the south and west by the Atlantic Ocean. The geomorphology of this region is characterized by lowlands and plains with small rivers and creeks all discharging into the Atlantic Ocean. The main vegetation is mangrove/freshwater swamp.

Aspects of the geology of the area have been published by [6, 7]. The tertiary section of the Niger Delta is divided into three formations Benin, Agbada and Akata, representing prograding depositional facies distinguished mainly on the basis of sand-shale ratio and further divided into depobelts as progradation proceeds into deeper waters. The Benin formation is the water-bearing zone of the area. It is overlain by Quaternary deposits (40-150m) thick and generally consists of rapidly alternating sequences of sands and silty clay which becomes increasingly prominent seaward [8]. Generally, multi-aquifer systems have been identified in the Delta based on strata logs. The first aquifer is mostly unconfined, while the rest are confined. The average depth of boreholes in Yenagoa is between 10 and 40 metres. Deep boreholes in the area tap water from depths up to about 200m or more [9]. Average annual rainfall in the area is about 3000 mm and this serves as the major source of groundwater recharge, [10, 11].

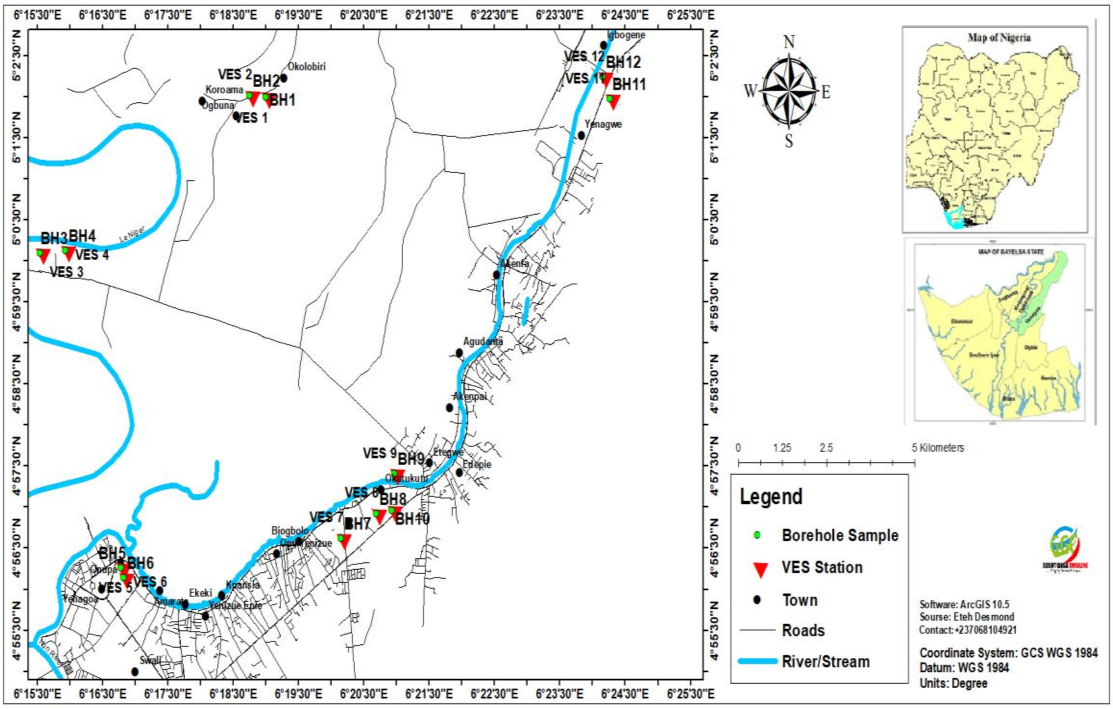


Figure 1: Map of the study area showing VES and borehole location

III. MATERIALS AND METHOD

This study was conducted in three stages. First was the field geoelectrical survey which was followed by soil boring and sample collection and lastly, laboratory analysis was carried out on representative soil samples.

3.1: Geoelectrical survey

Vertical electrical sounding (VES) was performed using the ABEM SAS 1000 Terrameter. The data acquisition was carried out using the Schlumberger array. Four steel electrodes placed at predetermined positions as specified in the field procedure template were connected to the current and potential cables and properly hammered into the ground to ensure good contact. The process of obtaining resistance values of the sub-surface earth materials comprise injection of controlled current through the outer current electrodes and measuring resulting potential difference via the inner pair of electrodes. The electrodes were systematically moved while maintaining the geometry of the Schlumberger configuration until the target depths were deemed to have been reached. After the data acquisition and manual computation of both the geometric factors and apparent resistivities, the field data was transferred to the computer and processed using IP2WIN, 1-D inversion software.

3.2: Soil sampling

Fifty-two disturbed samples were obtained from twelve boreholes sunk at or very close to the centre of each VES line. Soil boring was performed using hand auger to a depth of 6m in 4 borehole sites and manual percussion rig to a depth of 30m in 8 locations. The soil samples were secured in waterproof bags and brought to the laboratory for grain size distribution tests.

3.3: Grain size analyses

The grain size characteristics of each sample were determined using standard sieving technique as stipulated in the American Society for Testing and Materials [12]. Considering the wide variation in the grain size characteristics, large samples of up to 400 g were used to achieve a more accurate distribution. Since most of the soil samples collected, contained significant proportions of fine sediments, as well as sand fractions, dry and wet sieve tests were performed for determination of particle size distribution as appropriate. Materials used include a range of mesh sizes of sieves, weighing balance readable to 1.0g and 0.1g, thermostatically controlled oven, evaporating dish, sieve brushes, Sodium hexametaphosphate (dispersing agent, and mechanical sieve shaker. After sieving, the percentage of mass retained was used to compute the cumulative percentage passing each sieve. The particle size distribution of each sample was obtained by plotting the percentage passing against the grain size (mm).

IV. RESULTS AND DISCUSSIONS

Based on the laboratory tests performed on the samples, 4 soil types denoted by the alphabets A, B, C and D in order of increasing grain size were identified to help determine the effect of sediment grain size on the resistivity values. Soil samples in group A were the finest in terms of grain size, comprising predominantly of Fat Clay (CH) and Lean Clay (CL) class sediments while group D sediments which were basically Poorly Graded Sands (SP) were relatively the coarsest. Group B samples were made up up of Clayey Sands (SC), while group C was comprised of Silty Sands (SM) and Poorly Graded Sand with Silt (SP-SM) based on the USCS soil classification.

Summary of the electrical resistivity results conducted at the 12 locations is presented in Table 1, while Figure 2 displays the modelled resistivity curves of location 6 and 12. The average grain size distribution for group B, C and D samples are shown in Fig. 3. The results as presented in Table 1, show that the average soil resistivity value was highest for the group D (483.7 Ωm) followed by group C (236.4 Ωm) and then group B (120.9 Ωm). The least value of average resistivity (68.2 Ωm) of the soils was recorded in the group A samples.

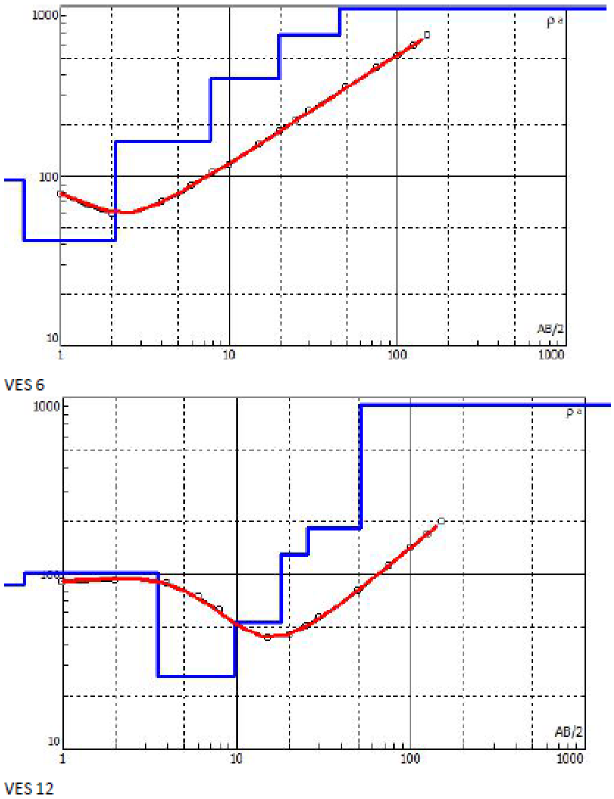
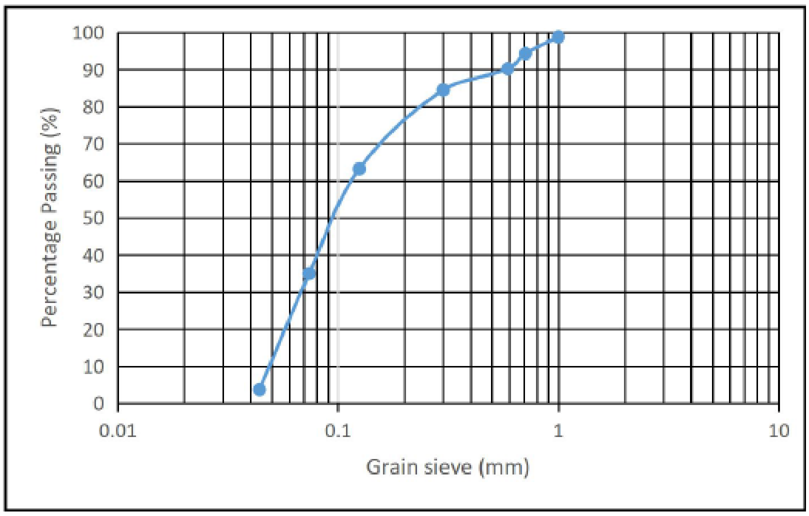


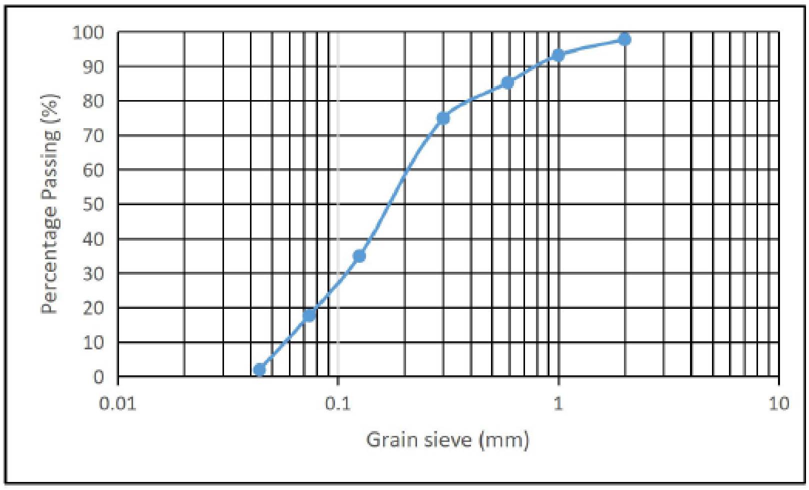
Figure 2: VES modelled curves for location 6 and 12

Table 1: Average grain size composition and resistivity values of soil samples

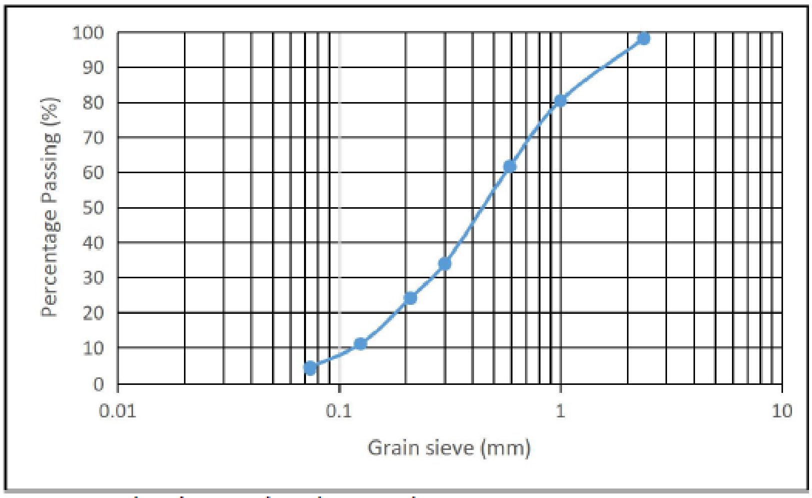
Sample group	Grain size	Average composition %	Resistivity (Ωm)
A	Gravel	-	68.2
	Coarse sand	1.1	
	Medium sand	2.5	
	Fine sand	5.8	
	Silt	22.4	
	Clay	68.2	
B	Gravel	-	120.9
	Coarse sand	5.7	
	Medium sand	17.3	
	Fine sand	42.0	
	Silt	14.3	
	Clay	20.7	
C	Gravel	-	236.4
	Coarse sand	6.8	
	Medium sand	35.1	
	Fine sand	40.4	
	Silt	12.2	
	Clay	5.5	
D	Gravel	8.1	483.7
	Coarse sand	30.3	
	Medium sand	37.5	
	Fine sand	19.8	
	Silt	4.3	
	Clay	-	



Grain size distribution chart (Group B)



Grain size distribution chart (Group C)



Grain size distribution chart (Group D)

Figure 3: Grain size distribution for group B, C, and D soil samples

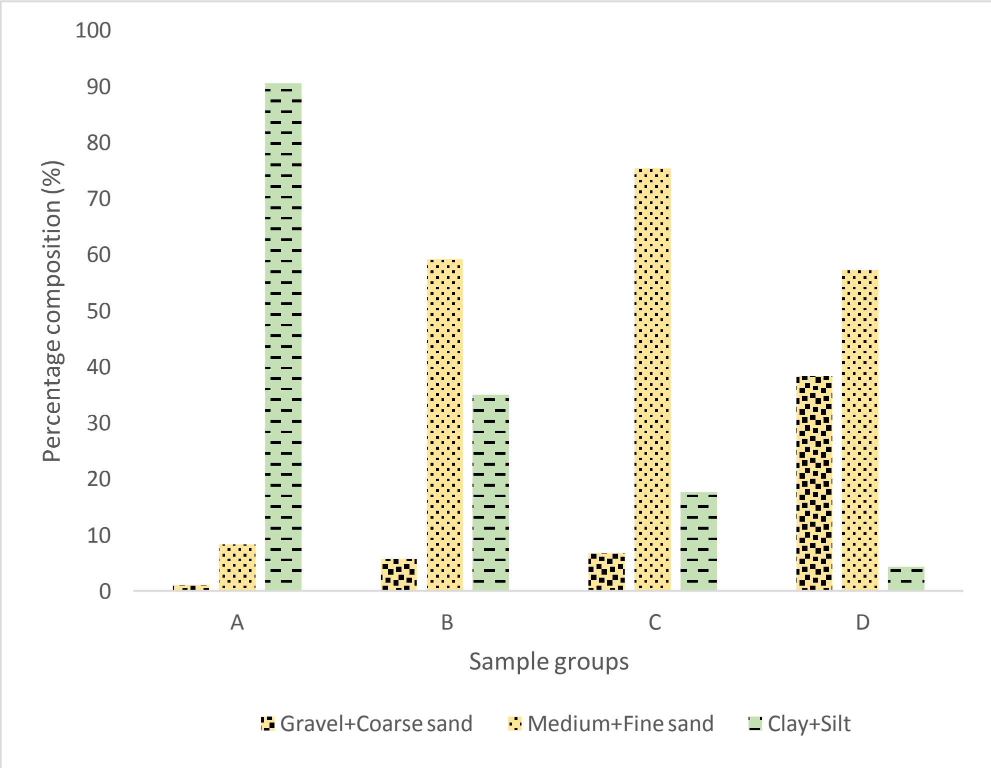


Figure 4: Percentage composition of grain type in soil samples

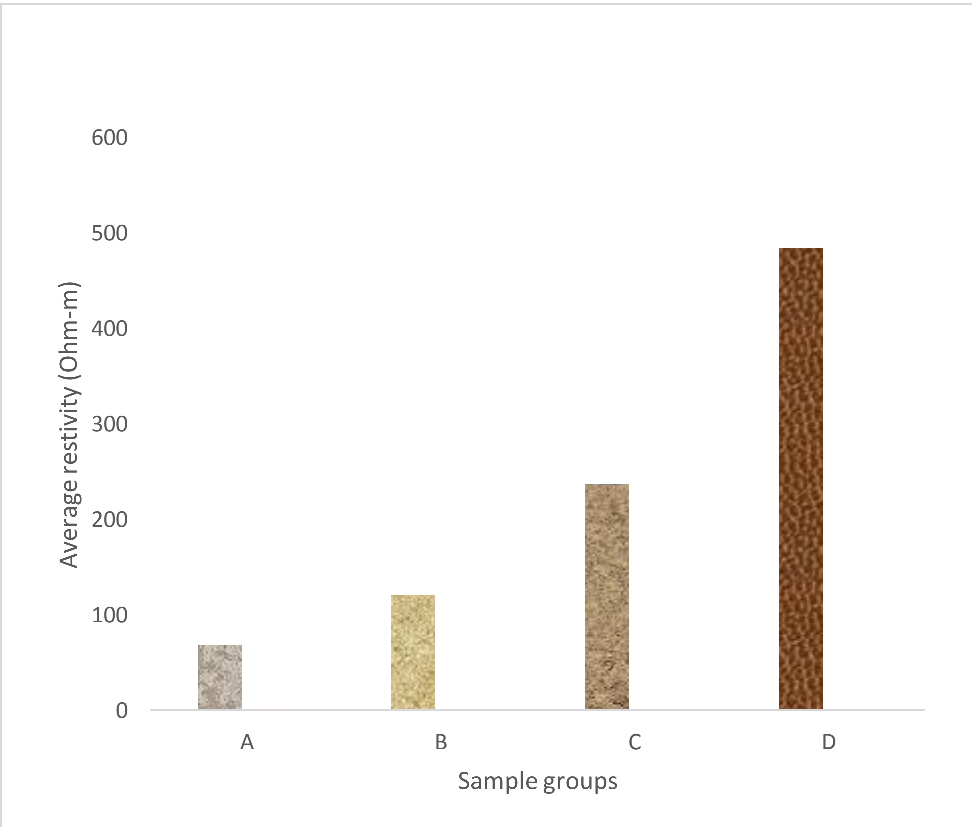


Figure 5: Average resistivity of soil samples

Results of the sieve analysis (Table 1 and Fig. 4) show that the average composition of gravel and coarse sand was highest in D (38.4 %) compared to group C (6.8 %), group B (5.7 %) and 1.1 in group A. The mean distribution of medium and fine sand was such that group D had 57.3 %, group C 75.5 % group B 23.0 %, and

group A 8.3 %, whereas, the quantity of silt and clay sediments was recorded to be the highest in group A (90.6 %), 35.0% in B, 17.7% in group C and 4.3% in group D.
Relationship between the resistivity values and composition of the soil samples with respect to each group (Fig. 5) shows lowest resistivity values for fine-grain sediments like clay and silt, median values for medium and fine sands, while the coarser sediments such as coarse sand and gravel exhibited the highest resistivity values.

V. CONCLUSION

Resistivity values are significantly influenced by the grain size of geomaterials. Soils with a greater proportion of fines like silt and clay tend to exhibit lower resistivity values while soils composed of comparatively coarser sediments like sand and gravel result in higher resistivity measurements. On account of the above, geoelectric surveys can thus assist in delineating subsoil boundaries based on differences in their textural grain sizes.

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