International Journal of Basic Science and Technology
April, Volume 10, Number 2, Pages 102 – 118 http://www.ijbst.fuotuoke.edu.ng/ 102
https://doi.org/10.5555/KAZV2900 ISSN 2488-8648

Site Geophysical and Geotechnical Evaluation of the Subsurface Formation Around a Hydropower Plant Station Ofurekpe, Nigeria

Adebiyi, A.D. and *Bamidele, O.E.
Department of Geophysics, Federal University Oye Ekiti, Ekiti State, Nigeria

Article Information

Article # 10013
Received: 15th Sept. 2023
1st Revision:14h Jan. 2024
2nd Revision:18th Feb. 2024
Acceptance:2nd March 2024
Available online:
22nd April 2024.

Key Words
Hydropower plant,
Engineering,
Geophysical,
Geotechnical

Abstract

Integration of geophysical and geotechnical methods was adopted in evaluating the subsoil conditions and electrical properties of the soil(s) at a proposed hydropower plant station in Ofurekpe, Southeastern Nigeria. The geophysical investigation involving the Vertical Electrical Sounding (VES) technique utilizes the Schlumberger array and the geotechnical investigation involved manual soil sampling for laboratory tests and field Dynamic Cone Penetration (DCP) tests. Sixteen (16) VES stations were occupied within the study area with a maximum half-current electrode spread length (AB/2) of 100 m. The geotechnical samplings were done to a depth of 2 m. Three subsurface layers were delineated within the study area, which include: the clay/sandy clay/clayey sand/sandy topsoil, the clay/siltstone/mudstone formation and the indurated shale/sandstone formation. The indurated shale/sandstone formation is considered the only fairly competent layer within the study area on which the foundation of the proposed superstructure can be placed. The geotechnical results show that the soils generally fall under the A-7 soil group except for stations 7 and 11 which fall under soil group A-2-4. The CBR results are generally < 20% (less than the required specification of ≥ 80%) except at stations 6 and 13 where the DCP test terminates on hard formation, hence, the subgrade is of low competence. It can be concluded that the subgrade within the study area is generally not competent. Therefore, the proposed structure should be relocated or piled. Electrical power can be earthed to a depth of 5 m while metallic materials must be well galvanized before burial.

***Corresponding Author: Bamidele, O.E.; odunayo.bamidele@fuoye.edu.ng**

Introduction

There is an increasing number of structural damages which were accompanied by collateral losses (Akintorinwa and Adeusi, 2009). The non-linear behavior of soils under stress, the difficulty in analysing soil properties in-situ, and high spatial inconsistency make it very difficult to predict the exact behavior of soils in time and space. These challenges call for the implementation of safety measures that enable adequate margin against unexpected deviations in the predicted performance in construction. In engineering geophysics and site investigation, subsurface structural information and physical properties of a site are required (Sharma, 1997). This is because the durability and safety of the engineering structure usually depend on the nature of the subsurface structures, competence of the subsurface materials and the mechanical properties of the overburden materials (Adelusi *et al.*, 2013).

Civil engineers most times neglect the inclusion of pre-construction investigation in their job schedule basically to reduce cost. In instances where such studies are conducted, the results were not implemented in the design and construction stage. The effect of these lapses (These omissions) usually resulted in a failed structure which can manifest as ground subsidence, major cracks, failed road segment, and fractional settlement of the structure (Olorunfemi *et al.*, 2000; Olorunfemi *et al.*, 2004). As a result of these, geological and geophysical experts often emphasize the lack of adequate information on the nature of subsurface conditions before construction as a major contributor to structural failure. After all, every engineering structure is seated on geological earth materials (Mesida, 1987; Ajayi, 1987; Momoh *et al.*, 2008; Oladapo *et al.*, 2008; Adiat *et al.*, 2009; Adeyemo and Omosuyi, 2012; Adiat *et al.*, 2017). Pre-construction studies provide information to civil engineers on the competence of subsurface layers on which the engineering structure will be erected and the depth at which the foundation could be placed. These will mitigate the failure of any proposed civil structure and prevent the enormous economic loss that always accompanies such failure. Therefore, this research was aimed at determining the geophysical and

https://doi.org/10.5555/KAZV2900 **ISSN 2488-8648**

geotechnical characteristics of the subgrade soil underlying the study area, with the view of evaluating the suitability of the subgrade soil for the proposed superstructure (Hydropower plant station), installation of electrical system earthing and other buried metallic materials.

Location of the Study Area

The study area is located in Akahufu Inyimagu village near Ofurekpe town, Ikwo Local Government Area, Ebonyi State, Southeastern Nigeria. It lies within latitudes 6° 02.32'N and 6° 03.42'N and longitudes 8° 15.72'E and 8° 16.49'E corresponding to Northings 667406 mN and 669439 mN and Eastings 418400 mE and 419824 mE respectively in the UTM Zone 32N coordinate system (Figure 1). The annual weather regime comprises two distinct seasons: the dry and the wet (rainy) seasons. The dry season begins in November and ends in March, while the wet (rainy) season begins in April and ends in October. However, a short dry period is usually experienced during August, which is termed as August Break. Ofurekpe has a semi-tropical climate with plenty of rainfall. During the rainy season, lush vegetation, thick forests,

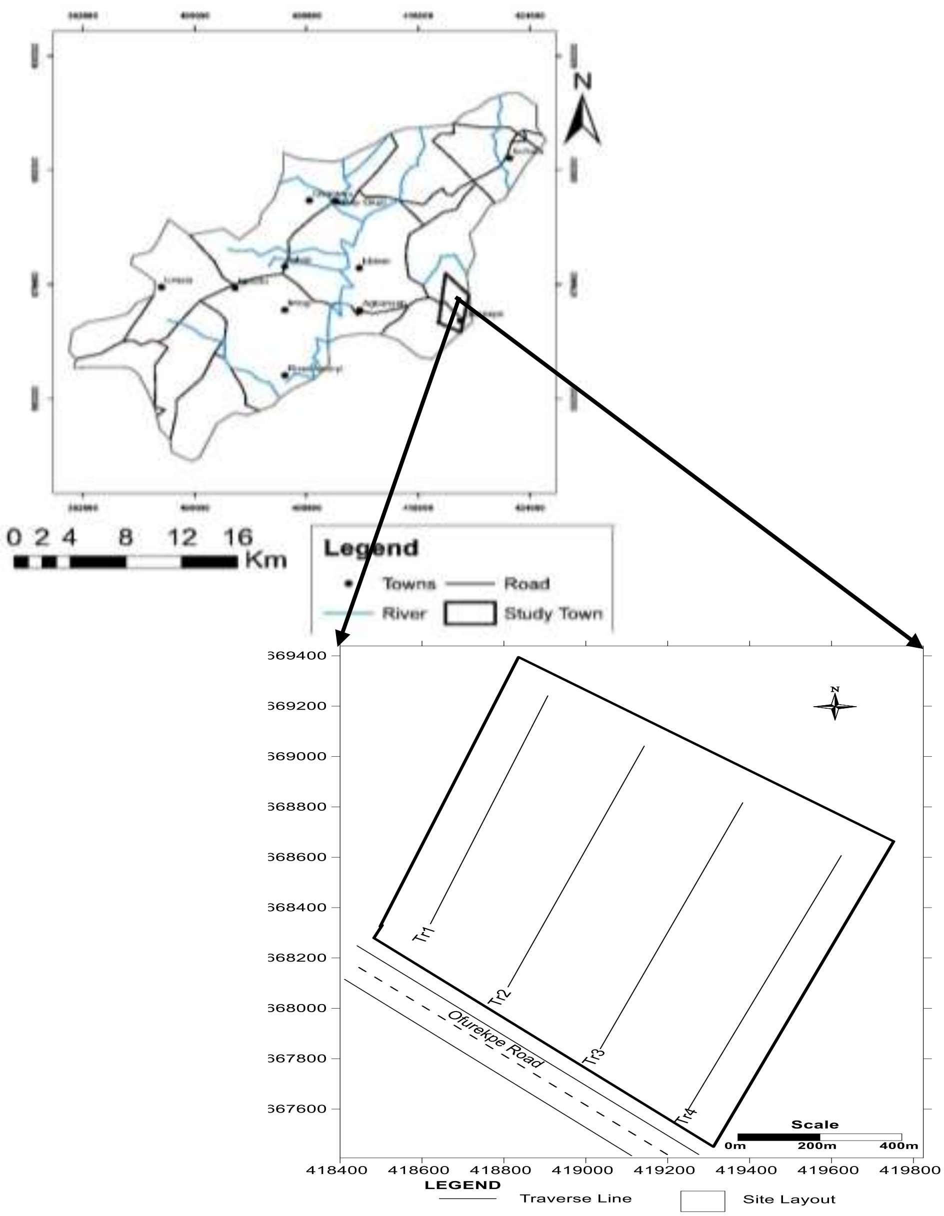

Figure 1: Location Map of the Study Area

https://doi.org/10.5555/KAZV2900 ISSN 2488-8648

ponds and small pools mark the landscape (Ande *et al.*, 2016). The rainfall usually peaks in July and September. The annual rainfall is 1230 ± 28 mm with the onset and cessation of rain being 12th April (± 3 days) and 17th November (± 4 days), respectively (Ande *et al.*, 2016). The mean monthly temperature ranges between 24 and 29°C. The temperature is highest in February and lowest in July. The relative humidity ranges between 68.7% in January and 92% in July. The vegetation is within the sub-humid agroecological zone, southeast of the derived savanna belt of Nigeria (Ande *et al.*, 2016). The dominant vegetation is characterized by tree shrubs with abundant palm trees, while the lowland is devoted to rice cultivation. The groundwater level is shallow, ranging from 0 – 60 cm below the surface in most of the area and the plain is flooded during the wet season.

Geology of the Study Area

The study area is underlain by the Asu-River group (Lower Cretaceous) (Offodile, 1989). The soil deposit within southeastern Nigeria (containing the study area) was studied in detail by Obasi *et al.*, 2013, and concluded that the lithofacies identified consist majorly of Eze-Aku shale formation and Nkporo shale formation made up of shales (which are detrimental to civil and geotechnical engineering work), siltstones, mudstones with sandstone facies (Figure 2). The sediments were later folded and gave rise to two major structural features, which are the Abakaliki anticlinorium and the corresponding Afikpo synclinorium. The group is also associated with small dykes, sills and many igneous intrusives (Offodile, 1989; 2002). The formation underlying the study area is composed of over 200 m thick bluish-grey to olive brown shales and sandy shales, fine-grained micaceous and calcareous sandstones, and siltstones.

Methodology

Geophysical Survey

Sixteen (16) vertical electrical soundings were conducted along 4 traverses established in the NE-SW direction within the study area (Figure 3) using ABEM-SAS 4000 Terrameter. The Schlumberger array was employed. The geographical coordinate of each sounding station was recorded with the aid of a GARMIN GPS 12 channel personal navigator unit in the Universal Transverse Mercator (UTM) coordinate system.

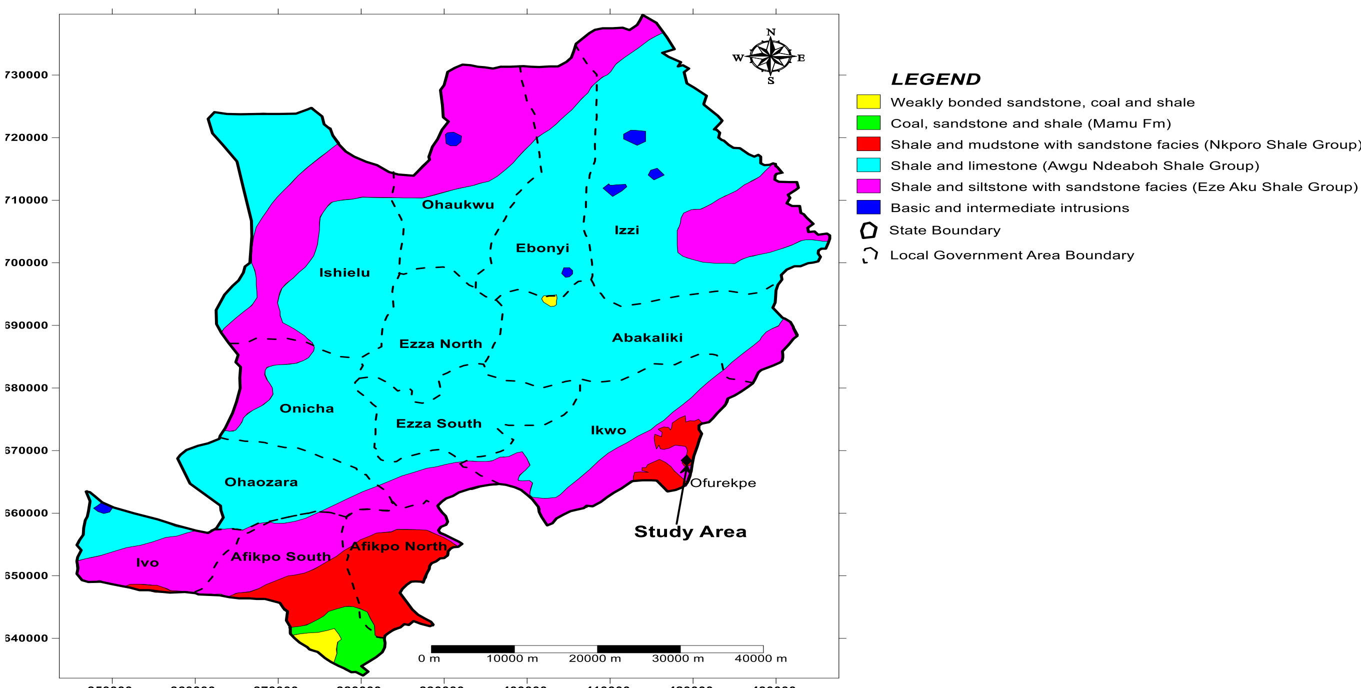

Figure 2: Geological Map of Ebonyi State showing the Study Area (modified after Salahudeen and Aghayan, 2018)

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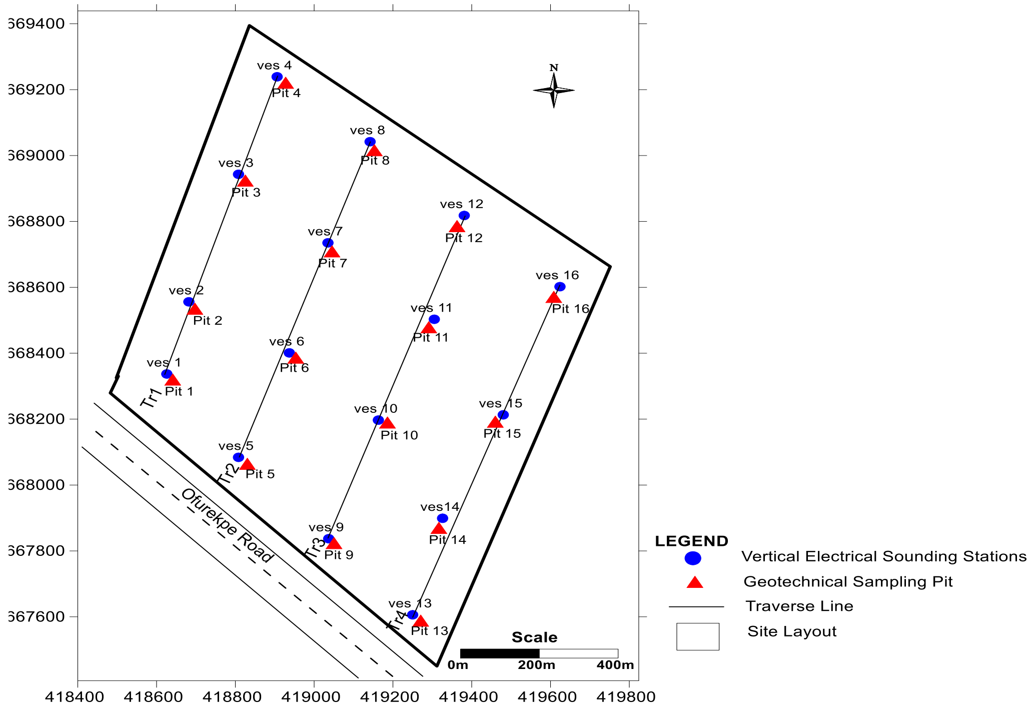

Figure 3: Data Acquisition Map of the Study Area showing the Vertical Electrical Sounding (VES) Stations and Geotechnical Sampling Points

The electrode spacing was varied between 1 and 100 m. The resistivity data were presented as field curves (by plotting the apparent resistivity (ρ_a) against half the spread length (AB/2) on a bi-logarithmic paper). The data were interpreted qualitatively by visual inspection of the field curves and further interpreted quantitatively by the method of partial curve matching (Koefoed, 1979) with the aid of a two-layer master curve (Orellana and Mooney, 1966) and auxiliary point charts (Zohdy, 1965; Keller and Frischknecht, 1966) to obtain an initial estimate of resistivities and thicknesses of the various geoelectric layers at each VES location. These geoelectric parameters were used as starting models for a 1-D computer-assisted interpretation (Vander Velpen, 2004). The program took the manually derived parameter as a starting geoelectric model, and successively improved on it until the error is minimized to an acceptable level. The improved geoelectric parameters were used to generate 2-D geoelectric sections.

Geotechnical Survey

Sixteen (16) exploratory pits were dug manually (Figure 3). Soil samples were collected through soil boring conducted using a 4-in. inner diameter hollow-stem auger. Each location was drilled to an average depth of about 1.8 m. Disturbed and undisturbed samples were taken at any change in strata for visual observation and laboratory testing to an average sampling depth of 1.8 m. The analyses carried out on the samples include sieve analysis, atterberg limits, natural moisture content, and triaxial test. Mechanical sieving assisted in determining the particle size distribution of gravel and sand proportions of the dried coarse fraction. Consistency Limit Tests generally known as the Atterberg limits gave the plasticity characteristics of the cohesive fraction of the sieved samples. The consistency limit test includes; liquid limit, plastic limit and linear shrinkage test. The liquid limit (LL) is the moisture content at which fine-grained soils no longer flow like a liquid. It is determined by subtracting the plastic limit (PL) from the natural moisture content (NMC) of the sample and dividing the result by the plasticity index (PI).

$$LL = \frac{PL - NMC}{PI} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad 1$$

Where, LL = liquid limit, PL = plastic limit, PI = plasticity index, and NMC = natural moisture content. Also, the plastic limit (PL) is the moisture content at which a thread of soil with a 3.2 mm diameter begins to crumble showing that it has changed from a plastic to a semi-solid state. Linear shrinkage (LS) is the moisture content where the further loss of moisture does not cause a decrease in the volume of the soil. The plasticity index, which is the difference between the liquid and plastic limits gives the range of moisture contents over which the soil remains plastic.

$PI = LL - PL$……………………...……..….. 2

Where, PI = plasticity index, LL = liquid limit, PL = plastic limit.

The soils were classified using the Unified Classification System. The group names are based on the American Standard for Testing and Materials (ASTM) D-2487.

California Bearing Ratio (CBR) which is widely used to characterize and access subgrade materials for use in construction works was determined using a dynamic cone penetrometer (DCP). In situ CBR was preferred because of the site's soil type and the moisture condition to access the CBR of the subgrade in its natural field condition. The penetration (in mm) using 60° cone was plotted against the blows from the drop weight of 8 kg. The penetration index (PI) was determined graphically from the slope of the curve. The CBR value was determined using the Kleyn and Van Heerden Model curve (Figure 4).

Dynamic Cone Penetration (DCP) Tests

The Dynamic Cone Penetrometer (DCP) has been described by ASTM 6951-03 (2003). A typical DCP (Figure 5) comprises an 8 kg hammer that drops over a height of 575 mm. Based on the effect of the drop, it yields a theoretical driving energy of 45 J. It makes use of a 60° cone tip with 20 mm base diameter that drives vertically into the subgrade layer (Mohammadi *et al.*, 2008). The cone is attached to a steel rod having a diameter (16 mm) smaller than the cone to reduce the effect of skin friction. During the operation, the number of blows with depth of penetration is recorded. The slope of the curve defining the relationship between the number of blows and depth of penetration (in millimeters per blow) at a given linear depth segment is recorded as the DCP penetration index (DPI). DPI for each depth can also be calculated using Eq. (1) by (Embacher, 2005):

$$DPI = \frac{P_{a+1} - P_a}{B_{a+1} - B_a} \quad \text{………………….…………. 3}$$

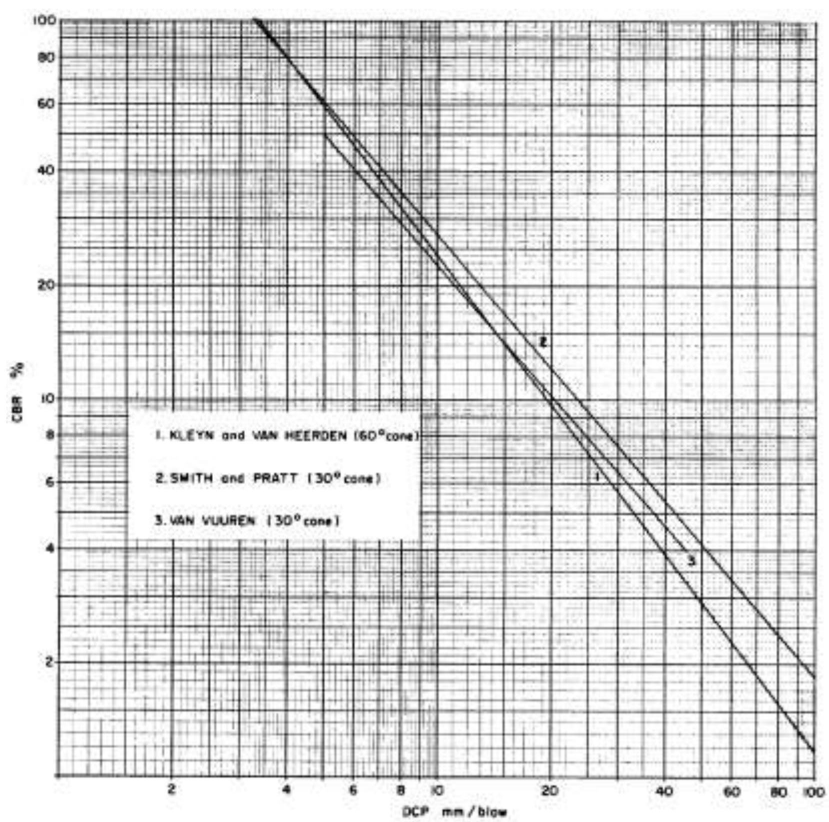

Figure 4: DCP – CBR Relationship (Kleyn and Van Heerden, 1983)

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April, Volume 10, Number 2, Pages 102 – 118 http://www.ijbst.fuotuoke.edu.ng/ 107
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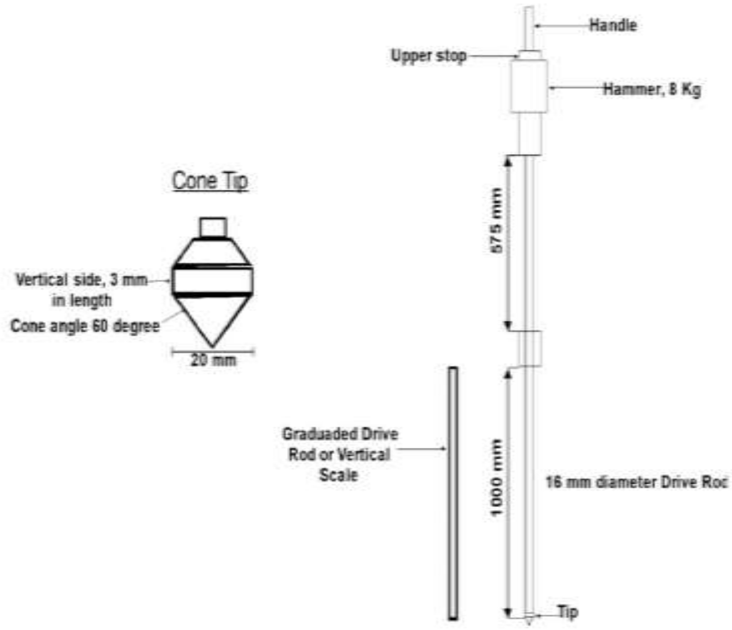

Figure 5: Typical Dynamic Cone Penetrometer (DCP) (Edil and Benson, 2005; Mohammadi *et al.*, 2008)

Where:
DPI = DCP Penetration Index (mm/blow)
P = Penetration at a or a+1 hammer drops (mm)
B = blow count at a or a+1 hammer drops

Results and Discussion
The results of the study were presented as Depth Sounding Curves, Histograms, Geoelectric sections, Tables, and Maps.

VES Curves
Table 1 gives a summary of the interpretation results of the VES curves at each of the studied locations. The number of geoelectric layers varies between 3 and 5. Six typical curve types were identified within the study area, which are the H, HK, KH, QH, HKH, and QQH types, with the KH curve type dominating (Figure 6) with 32.5%. The HK, HKH, and QQH curve types have 6.25% while the H and QH curve types have 25%. Typical VES curves are presented in (Figures 7a-f).

Table 1: Summary of the Vertical Electrical Sounding Interpretation Results

VES Stations	Thickness (m) $h_1/h_2/h_3…./h_n$	Resistivity (Ohm-m) $\rho_1/\rho_2/\rho_3…../\rho_n$	Curve Types
1	0.8/16.3	115/52/791	H
2	0.7/0.9/5.5	21/135/8/∞	KH
3	0.9/1.9/7.3/25.2	51/28/3/11/∞	QH
4	0.8/3.1/8.8	465/40/3938/102	HK
5	1.0/1.6/10.2/12.7	28/9/44/13/952	HKH
6	1/10.2	34/8/3116	H
7	0.7/7.6/25.0	643/449/70/∞	QH
8	1.2/17.8	218/32/∞	H
9	1.1/3.4/9.8/25.7	73/55/22/4/240	QQH
10	1.2/5.6/32.2	1086/164/30/∞	QH
11	0.5/0.8/26.7	768/2414/324/1372	KH

https://doi.org/10.5555/KAZV2900 ISSN 2488-8648

12	0.8/1.5/21.3	19/236/25/607	KH
13	0.4/0.6/16.5	36/143/13/492	KH
14	1.5/0.3/12.6	117/21/13/∞	QH
15	1.4/6.7	219/41/∞	H
16	0.5/1.6/6.8	14/84/6/∞	KH

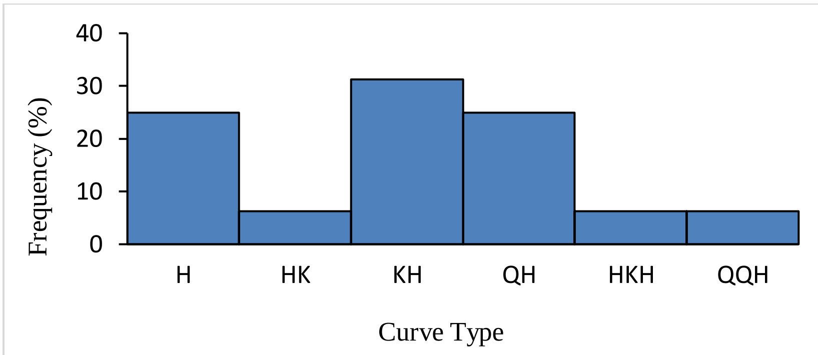

Figure 6: Histogram showing the Frequency of VES Curve Types in the Study Area

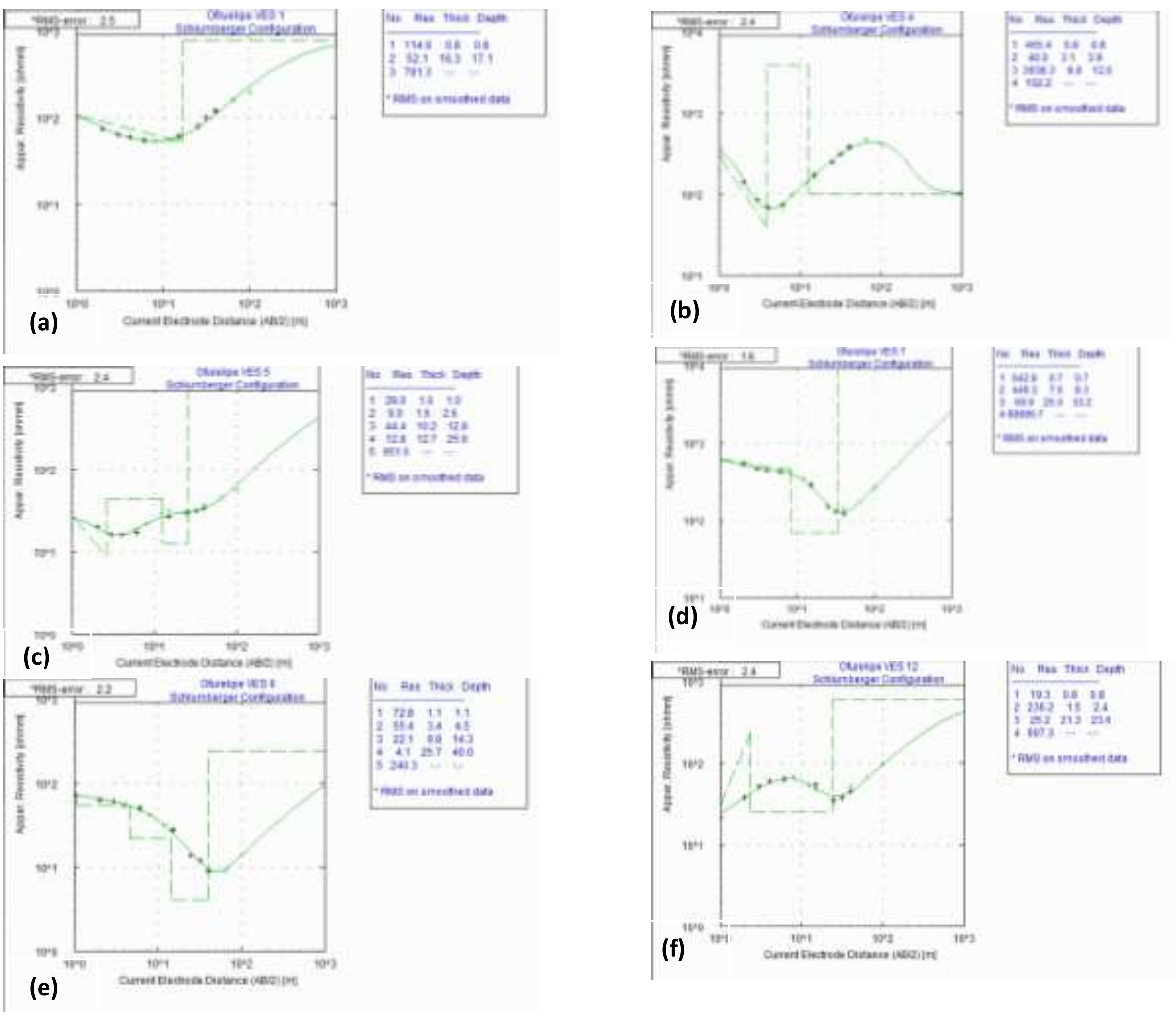

Figure 7: Typical (a) H (b) HK (c) HKH (d) QH (e) QQH (f) KH Curve Types in the Study Area

Geoelectric and Lithological Characteristic

The Vertical Electrical Sounding (VES) interpretation results were used to prepare 2-D geoelectric sections displayed in Figures 8a - d. The geoelectric sections identified three major geologic subsurface layers comprising the topsoil, clay/siltstone/mudstone, and the indurated shale/sandstone layers. The clay/sandy clay/clayey sand/sandy topsoil has a resistivity variation from 14 to 2414 ohm-m and thickness ranging from 0.7 to 2.8 m. This layer is generally thin and has little or no engineering significance to hold the proposed structure as most of it would have been excavated during land processing and the sandy (competent) portions of it are sparse. The second layer comprises clay/siltstone/mudstone with resistivity varying from 3 to 324 ohm-m and thickness ranging between 3.1 and 38.9 m. This layer has a great tendency to loosen strength in contact with water and is therefore considered incompetent to hold the foundation of the proposed super-structure (Hydropower Plant Station). The third layer comprises indurated shale/sandstone formation with resistivity varying from 102 ohm-m to ∞ and the depth to this layer ranges between 3.9 and 40 m. The third layer is considered the only fairly competent layer within the study area on which the foundation of the proposed super-structure can be placed. Nevertheless, care must be taken as this layer is fractured beneath VES 4 with a resistivity value of 102 ohm-m. A local sandy unit was also delineated beneath VES 7 with a resistivity value of 449 ohm-m and thickness of 7.6 m. The thick/moderately thick overburden identified beneath VES 3, 7, 9, 10, 13, the moderately high resistivity (typical of a sandy unit or alluvial sand) identified at the topsoil beneath VES 4, 7, 8, 10, 11, 12, 15 and at the layer(s) beneath the topsoil underlying VES 7 and 11 and the topography of the competent layer (especially the V-shapes identified in Figures 8a-b) suggest the presence of a suspected buried stream channel flowing approximately from northwest to southeast (NW-SE) within the study area.

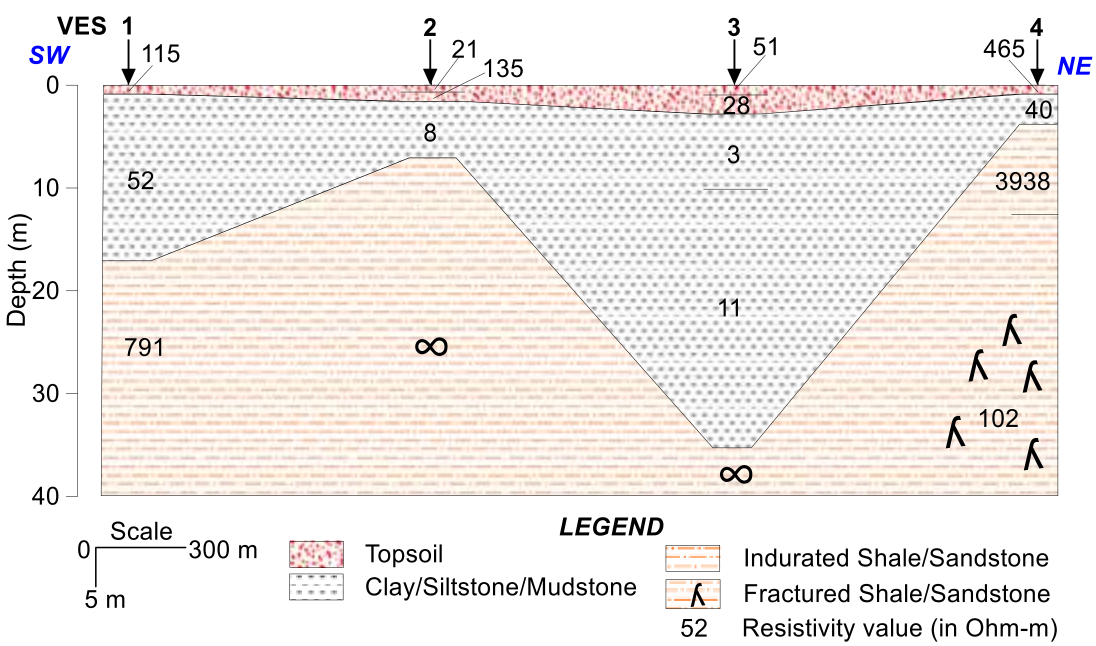

Figure 8a: Geoelectric Section obtained along Traverse 1

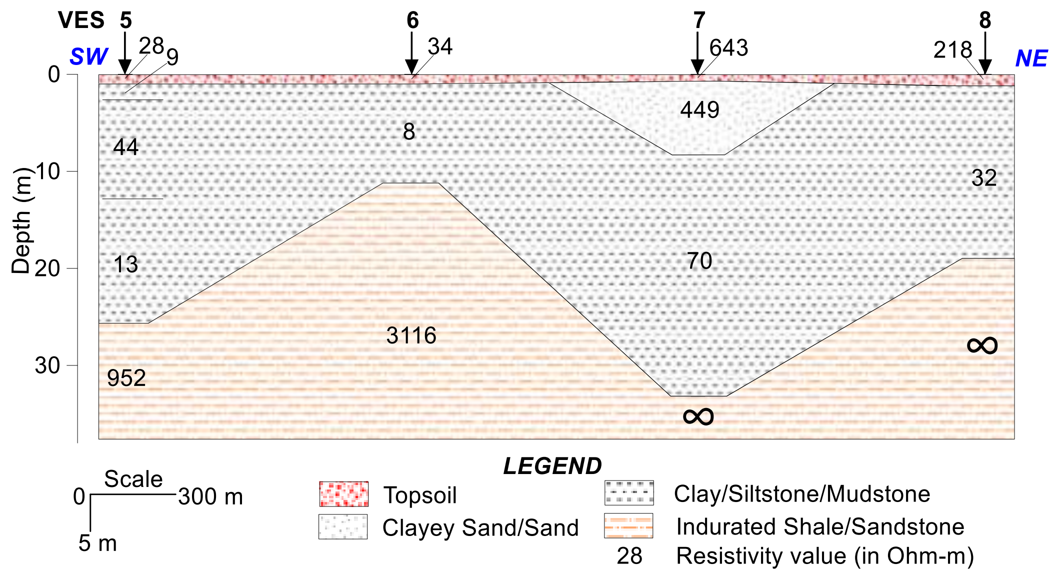

Figure 8b: Geoelectric Section obtained along Traverse 2

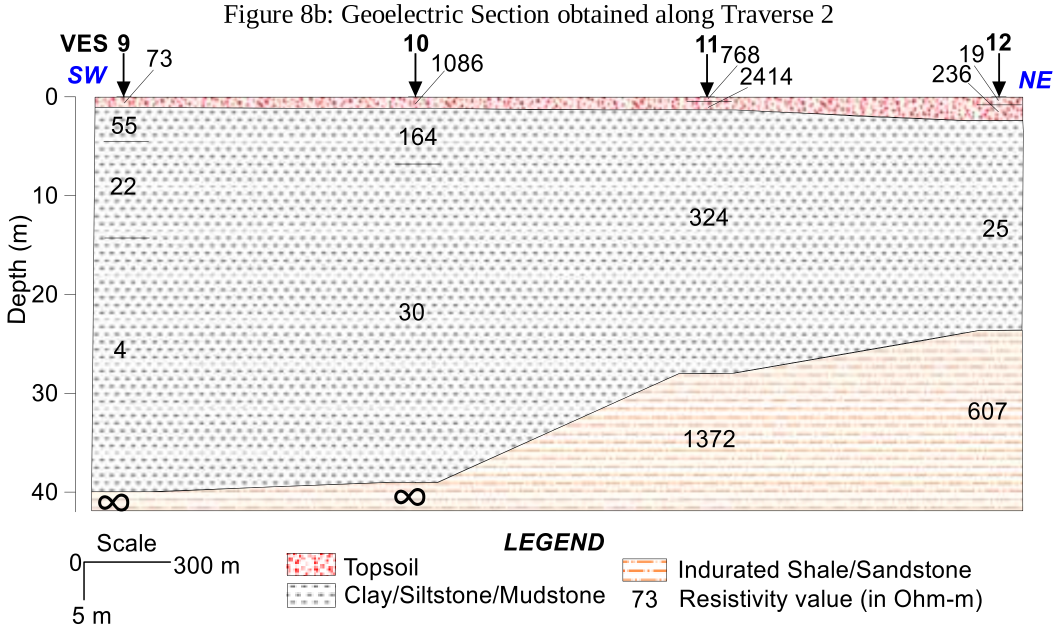

Figure 8c: Geoelectric Section obtained along Traverse 3

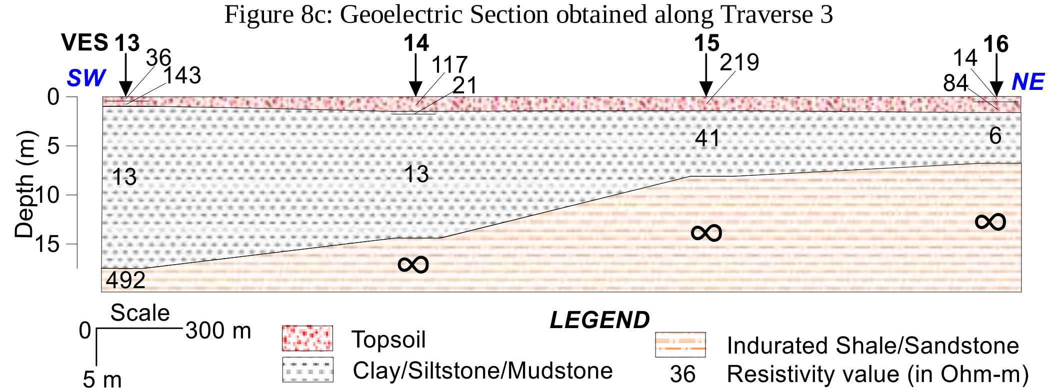

Figure 8d: Geoelectric Section obtained along Traverse 4

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Isoresistivity and Isopach Maps

To view the spatial distribution of layer resistivities and thicknesses within the study area, isoresistivity and isopach maps of the different subsurface layers were generated. Figures 9 and 10 show the isoresistivity and isopach maps of the topsoil respectively. The topsoil consists of clay, sandy clay, clayey sand and sand. The east, central and northern parts of the study area show relatively high resistivity values varying from 200 to about 1600 ohm-m (Figure 9). The western and southern parts of the study area show relatively low resistivity values (< 200 ohm-m). The topsoil thickness ranges from 0.7 – 2.8 m (Figure 10). The topsoil is very thin (< 1.5 m) in the northern and southern parts of the study area while it is relatively thick (1.5 – 2.8 m) in the northwest and east/northeastern parts. It is observed that the relatively high resistivity zones are thin and vice versa, therefore the topsoil cannot be recommended for any engineering structure.

Figures 11 and 12 show the isoresistivity and isopach maps of the second layer respectively. The second layer comprises clay, mudstone and siltstone with resistivity values ranging from 6 to 324 ohm-m and the predominant resistivity values are in the range of 6 to 97 ohm-m (Figure 11). Relatively high resistivity values (100 - 324 ohm-m) were identified towards the eastern flank of the study area while low resistivity values (< 100 ohm-m) were identified at the western, southern, and northern flanks. The isopach map of the second layer (Figure 12) shows that the thickness ranged from 2 to 40 m. A thick zone (> 18 m) can be observed at the northwest, extending to the north, central and southern portions of the study area while the layer is thin (< 18 m) in the east, west/southwest and extreme northwestern part. The second layer can be considered a good layer for earthing the proposed Power Plant due to its major high conductivity (< 100 ohm-m) except in the eastern part where the resistivity is greater than 100 ohm-m.

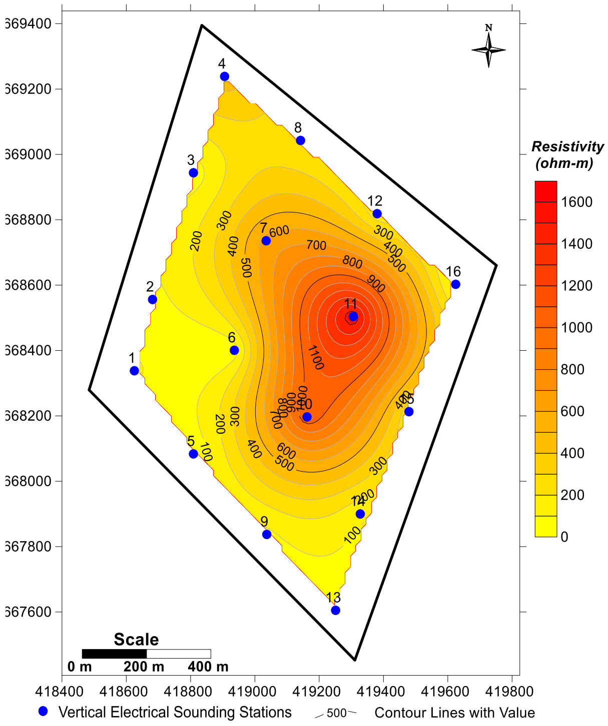

Figure 9: Iso-resistivity Map of the Topsoil of the Proposed Ofurekpe Power Plant Station

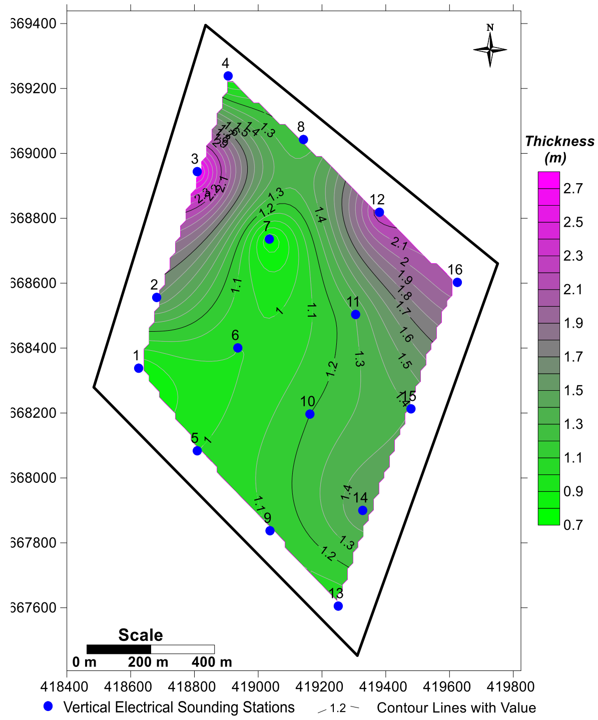

Figure 10: Isopach Map of the Topsoil of the Proposed Ofurekpe Power Plant Station

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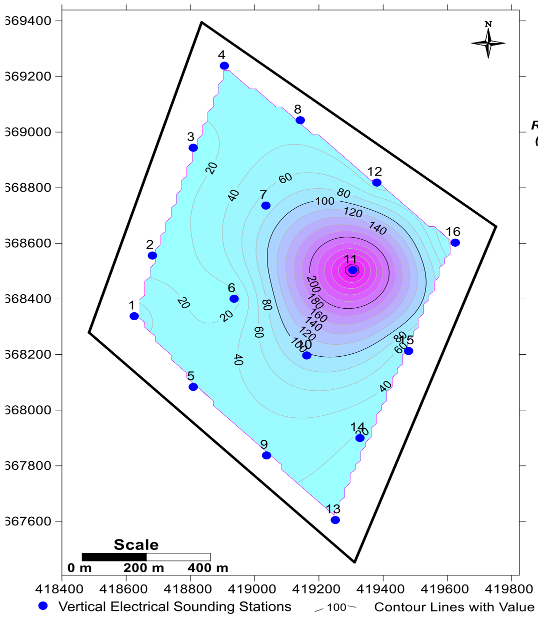

Figure 11: Iso-resistivity Map of the Second Layer of the Proposed Ofurekpe Power Plant

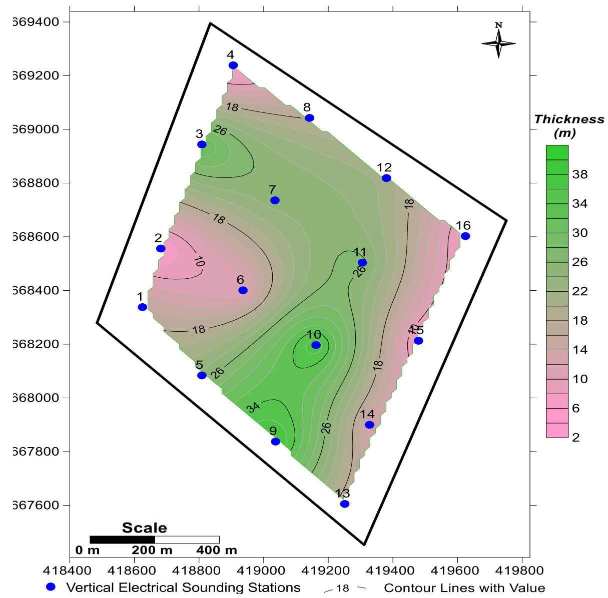

Figure 12: Isopach Map of the Second Layer in the Proposed Ofurekpe Power Plant Station

The overburden thickness map (Figure 13) shows that the depth to the bedrock ranged from 4 to 40 m and it is similar to the isopach map of the second layer. The thickest zones were observed at the north/northwestern, central and southern parts of the study area stretching beneath VES 3, 7, 11, 10 and 9. These thick overburden zones suggest the presence of a suspected buried stream channel initially flowing from northwest to southeast (NW-SE) but changing direction in the central portion (around VES 11 and 12) and flowing in the approximately northeast-southwest (NE-SW) direction within the study area. The moderately high resistivity (> 600 ohm-m, typical of clayey sand or alluvial sand) identified at the topsoil beneath VES 7, 10, 11 and at the layer(s) beneath the topsoil (324 - 449 ohm-m) underlying VES 7 and 11 corroborates this deduction.

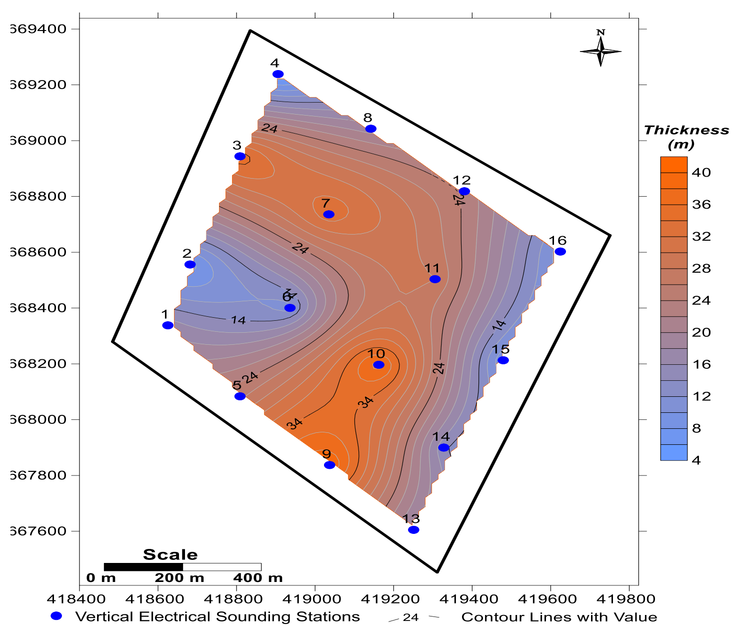

Figure 13: Overburden Thickness Map of the Proposed Ofurekpe Power Plant Station

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Geotechnical Results

Table 2 shows the summary of the geotechnical results. The natural moisture content of tested soil samples ranged from 22.8 – 38%. This shows that the natural moisture content of the soil in the study area is relatively high in its natural state, which may be a result of the swampy nature (clay, silt and mud) of the area. Moisture variation is generally determined by intensity of rain, depth of collection of sample and texture of the soil (Jegede, 2000; Akintorinwa and Adeusi, 2009).

The soils within the study area are generally fine-grained soils with the liquid limit of the soil samples ranging from 23-83%. The plastic limit ranges from 20-58%, and the plasticity index of soils ranges from 2-25%. Soils having high values of plasticity index, liquid, and plastic limits are considered not competent as foundation materials. According to the Federal Ministry of Works specifications (FMW, 1997), soils with liquid limit and plasticity index of ≤ 35% and ≤ 12% respectively are good for subgrade materials. Generally, the liquid limit and plasticity index of the soil samples from the study area are > 35% and >12% respectively except for station 7 having a liquid limit and plasticity index of 23 and 2% respectively. Hence, the subgrade soil in the study area shows poor engineering properties and less competent as foundation materials. The soil classification shows that the soil group within the study area is predominantly A-7. However, the A-2-4 soil group is obtainable at stations 7 and 11.

The triaxial (strength) test results derived from the remolding of the soil samples in the study area are also presented in Table 2. The undrained cohesion varies from 7.20 to 38.73 KPa, while the friction resistance angle range of between 7.82° and 39.81° are recorded on the tested samples. The soil dry unit weight ranges from 5.86 to 19.56 KN/m^3. This shows that the soils are clayey (Swiss Standard S N 670 010b) and will not be suitable to carry the proposed superstructure(s).

Table 3 shows the summary of the subgrade California Bearing Ratio (CBR) and bearing capacity results within the study area using a dynamic cone penetrometer (DCP). The subgrade CBR is generally low hence the bearing capacity. The CBR values vary from 0 to 20%and bearing capacity ranges from 0 to 52 PSI in most of the sampling stations, except at stations 6 and 13 where extremely high values were recorded. The CBR values are generally less than the required specification of ≥ 80%, hence the subgrade soil is of low competence. The soil strength (CBR) increases with increase in depth. In Stations 8 and 14, the DCP is suspected to terminate on localized indurated sandy clay/sandy formation, hence, its refusal at a maximum depth of 0.9 m.

Table 2: Summary of the Geotechnical Results obtained from the Proposed Ofurekpe Power Plant Station.

Station No	Depth of Sample (m)	Natural Moisture Content (%)	Liquid Limit (%)	Plastic Limit (%)	Plasticity Index (%)	Dry Unit Weight ϒ (KN/m^3)	Undrained Cohesion (KPa)	Friction Angle (φ°)
1	1.70	35.1	56	38	18	17.3	30.94	7.93
2	1.85	37.5	83	58	25	11.47	37.29	17.63
3	1.60	36.1	74	52	22	17.66	16.45	37.33
4	> 1.80	31.5	38	24	14	18.78	10.46	33.87
5	1.40	37.2	76	53	23	17.40	38.73	12.35
6	1.00	33.9	76	54	22	5.86	38.72	8.14
6	1.80	33.9	70	49	21	5.86	38.61	8.33
7	> 1.50	22.8	23	21	2	15.96	15.00	7.82
8	> 0.90	38.0	42	26	16	15.57	14.32	35.49
9	1.40	30.8	40	20	20	19.56	15.11	33.32
10	1.50	35.8	55	34	21	18.61	23.49	35.30
10	1.80	31.8	50	33	17	18.61	24.50	37.10
11	1.40	36.1	36	22	14	16.88	16.72	31.62
12	1.40	34.8	80	57	23	18.21	7.20	28.55
13	1.00	32.5	78	57	21	18.78	11.65	34.97
13	>1.00	31.0	76	54	22	17.50	16.50	33.95
14	1.00	37.9	37	23	14	15.84	22.46	36.81

14	1.40	37.9	40	22	18	15.84	33.60	34.72
15	1.80	31.3	36	24	12	15.36	16.29	37.17
15	>1.80	36.0	40	25	15	13.66	15.27	39.81
16	1.40	35.7	82	58	24	15.81	18.73	12.77
Specification			≤ 35%		≤ 12 %			

Table 3: Summary of DCP Test Results

STATION NO	DEPTH (m)	CBR (%) Specification ≥ 80 %	BEARING PRESSURE (KN/m^2)	ULTIMATE BEARING CAPACITY (PSI)
S1	0 - 0.2	0	0	0
	0.2 - 0 .7	3.2	57	8
	1.7 - 2.1	6.6	92	13
	2.1 - 2.5	18	178	26
S2	0 - 0.34	2	41	6
	0.34 - 0.84	6.8	93	14
	1.40 - 1.66	5.8	84	12
	1.66 - 2.20	16	165	24
S3	0 - 0.8	2	41	6
	1.4 - 1.41	2.3	45	7
	1.41 - 2.28	6.2	88	13
S4	0 - 0.2	1.8	39	6
	0.2 - 0.38	11	129	19
	0.38 - 0.90	4.6	72	10
	1.40 - 1.66	7.2	97	14
	1.66 - 2.46	13	144	21
S5	0 - 0.14	1.6	36	5
	0.14 - 0.54	0.4	14	2
	0.54 - 0.70	4.6	72	10
	0.70 - 0.90	2.6	49	7
	1.85 - 2.13	2.3	45	7
	2.13 - 2.45	3.8	63	9
	2.45 - 2.65	10	121	18
S6	0 - 0.42	1.4	33	5
	0.42 - 0.82	2.6	49	7
	1.50 - 1.69	100	557	81
S7	0 - 0.30	2.9	53	8
	0.30 - 0.56	9	113	16
	0.56 - 0.98	9.4	116	17
	1.4 - 2.26	4.6	72	10
S8	0 - 0.8	3.8	63	9
	0.8 - 0.9	19	185	27
S9	0 - 0.28	2.3	45	7
	0.28 - 0.64	2.3	45	7

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https://doi.org/10.5555/KAZV2900 ISSN 2488-8648

	0.64 - 0.86	2.3	45	7
	1.80 - 2.60	20	191	28
S10	0 - 0.20	0	0	0
	0.2 - 0.60	3	54	8
	0.60 - 0.92	5	76	11
	1.70 - 2.50	3.7	62	9
S11	0 - 0.32	2	41	6
	0.32 - 0.62	5.4	80	12
	0.62 - 0.86	12	136	20
	1.50 - 1.66	8.4	107	16
	1.66 -1.82	3.3	58	8
	1.82 - 2.38	7.8	102	15
S12	0 - 0.50	1.7	37	5
	0.50 - 0.90	2.4	47	7
	1.40 - 1.80	2	41	6
	1.80 - 2.60	9.6	117	17
S13	0 - 0.22	1.6	36	5
	0.22 - 0.50	12	136	20
	1.50 - 1.55	52	361	52
	1.55 - 1.65	100	557	81
S14	0 - 0.40	2.8	52	8
	0 - 0.83	17	172	25
S15	0 - 0.28	0.5	17	2
	0.28 - 0.082	2.7	51	7
	1.50 - 2.00	2.9	53	8
	2.00 - 2.32	8	104	15
S16	0 - 0.90	4	66	10
	1.50 - 1.62	27	233	34
	1.62 - 2.40	11	129	19

Subsoil Evaluation of the Study Area

The geoelectric sequence beneath the survey area is composed of topsoil, clay/siltstone/mudstone, and indurated shale/sandstone. The basal indurated shale/sandstone constitutes the layer within which the foundation of the proposed civil engineering structure can be found. The construction of the proposed civil engineering structure (Hydropower plant) will generally include the laying of metallic structures and the burying of earthing electrodes. Buried metallic structures are susceptible to corrosion and subsequent failure if the host soil medium is corrosive or aggressive. The formation which can lead to severe corrosion and failure is known to be associated with low resistivity or high conductivity. Low electrical resistivity is indicative of a good electrical conducting path arising from reduced aeration, increased electrolyte saturation or high concentration of dissolved salts in soils (Akintorinwa *et al.*, 2011). Soil resistivity can therefore be classified in terms of the degree of soil corrosivity as shown in Table 4. The topsoil in the study area varies from moderately corrosive to practically non-corrosive (14 to 2414 ohm-m, Table 1), while the clay/silty layer generally varies from very strongly corrosive to slightly corrosive (generally between 3 and 70 ohm-m) (Figure 11). Any metal or steel structures within these areas are practically exposed to corrosion. The medium for earthing (usually clayey) must have high electrical conductivity or low electrical resistivity. Clays are

https://doi.org/10.5555/KAZV2900 ISSN 2488-8648

characterized by resistivity values in the range of 1 to 100 ohm-m. The resistivity of the clay/silty layer generally ranges from 3 to 70 ohm-m. This indicates that the formation is highly conductive and it can serve as a good medium for burying of earthing electrodes.

The *in situ* CBR/Strength of the overburden up to the depth of >2.0 m is too low to carry the proposed superstructure(s) as expected in the hydropower plant project.

Table 4: Classification of Soil Resistivity in terms of Corrosivity (Agunloye, 1984; Akintorinwa and Abiola, 2011)

Soil Resistivity (ohm-m)	Soil Corrosivity
< 10	Very Strongly Corrosive (VSC)
10 – 60	Moderately Corrosive (MC)
60 – 180	Slightly Corrosive (SC)
180 and Above	Practically Non-Corrosive (PNC)

Conclusion

The subsoil evaluation within a proposed site for civil engineering structure using integrated geophysical and geotechnical methods of investigation was carried out at the proposed Ofurekpe hydropower plant station in the southeastern part of Nigeria. The investigation is to provide information on the stratigraphy, nature, structural disposition and competence of the subsoil.

The electrical resistivity geophysical investigation delineated three major geologic layers which include the clay/sandy clay/clayey sand/sandy topsoil, clay/siltstone/mudstone and the indurated shale/sandstone. The resistivity parameters of the upper two layers show that the layers are incompetent while the third layer is considered the only fairly competent layer within the study area on which the foundation of the proposed superstructure(s) can be placed. The depth to the fairly competent indurated shale/sandstone layer ranges between 3.9 and 40 m, therefore, piling of engineering structures will be required (if construction is inevitable). The geotechnical result shows that the soils within the depth of 1 to 2 m are majorly composed of clayey/silty materials. Earthing electrodes can be buried within the second layer due to their highly conductive nature (resistivity < 100 ohm-m) but burial of metallic structures within the study area would need to be properly galvanized to reduce the effect of chemical corrosion due to the aggressive nature of the subsoil (resistivity < 180 ohm-m). The values of data obtained from the triaxial test results are relatively high possibly because the samples tested were remolded and deviated from the field condition. The *in situ* CBR/Strength of the overburden up to the depth of >2.0m is too low to carry the proposed superstructure(s) as expected in the hydropower plant project.

It can be concluded that the subsoil on or within which engineering structures can be found within the study area is generally not competent for construction but for earthing of electrical materials. The area is suspected to be a buried stream/river channel area. Therefore, it is recommended that the proposed hydropower plant station be relocated to another site with competent top layer(s) but if construction within the site is inevitable pile foundation with pile length ranging from 3.9 to 40 m to the basal indurated shale/sandstone formation will be recommended.

References

Adelusi, A.O., Akinlalu, A.A. and Nwachukwu, A.I. (2013). "Integrated Geophysical Investigation for Post-construction Studies of Buildings around School of Science Area, Federal University of Technology, Akure, Southwestern, Nigeria". *Int. J. Phys. Sci*. 8(15): 657– 669.

Adeyemo, I.A. and Omosuyi, G.O. (2012). Geophysical Investigation of Road Pavement Instability along part of Akure-Owo Express way, Southwestern Nigeria. *Am. J. Sci. Ind. Res*. 3(4): 191–197.

Adiat, K.A.N., Adelusi, A.O. and Ayuk, M.A. (2009). Relevance of Geophysics in Road Failures Investigation in a Typical Basement Complex of Southwestern Nigeria. *Pac. Jour. Sci. Tech*. 5(1): 528–539.

Adiat, K.A.N., Akinlalu, A.A., and Adegoroye, A.A. (2017). Evaluation of Road Failure Vulnerability Section through Integrated Geophysical and Geotechnical Studies. *NRIAG Journal of Astronomy and Geophysics*, doi.org/10.1016/j.nrjag.04.006

Agunloye, O. (1984). Soil Aggressivity along Steel Pipeline Route at Ajaokuta. *J. Mining Geol*. 21(1 & 2): 97-101.

Ajayi, L.A. (1987). Thought on Road Failures in Nigeria. *Nigerian Eng*. 22(1): 10–17.

Akintorinwa, O.J. and Abiola, O. (2011). Subsoil Evaluation for Pre-foundation Study using Geophysical and Geotechnical Approach. *Journal of Emerging Trends in Engineering and Applied Sciences (JETEAS)*, 2(5): 858-863.

Akintorinwa, O.J. and Adeusi, F.A. (2009). Integration of Geophysical and Geotechnical Investigations for a Proposed Lecture Room Complex at the Federal University of Technology, Akure, SW, Nigeria. *Ozean Journal of Applied Sciences* 2(3): 241-254.

Akintorinwa, O.J., Ojo, J.S., and Olorunfemi, M.O. (2011). Appraisal of the Causes of Pavement Failure along the Ilesa - Akure Highway, Southwestern Nigeria Using Remotely Sensed and Geotechnical Data. *Ife Journal of Science* 13(1): 185-197.

American Society of Testing Materials, ASTM (2003). Standard Test Method for use of the Dynamic Cone Penetrometer in Shallow Pavement Applications (D 6951-03). *ASTM International, West Conshohocken, PA.*

Ande, O.T., Ojo, O.A., Adeyolanu, O.D., Are, S.K., Adelana, A., Oke, A., Adetayo, A.A. and Oluwatosin, G.A. (2016). Digital Soil Mapping and Morphogenetic Characterization of Soils of Ebonyi Formation in South Eastern Nigeria. *Earth Science Research,* 5(1).

Edil, T.B. and Benson, C.H. (2005): Investigation of the DCP and SSG as Alternative Methods to Determine Subgrade Stability. *Department of Civil and Environmental Engineering, University of Wisconsin-Madison.*

Embacher, R.A. (2005). Duration of Spring-thaw Recovery for Aggregate-surfaced Roads, TRB Annual Meeting. *American Engineering Testing, Inc*.

Jegede, G. (2000). Effect of Soil Properties on Pavement Failure along F209 Highway at Ado-Ekiti, Southwestern Nigeria. *Journal of Construction and Building Materials*, 14: 311-315.

Keller, G.V. and Frischknecht, F.C. (1966). Electrical Methods in Geophysical Prospecting. *Pergamon Press, Oxford, UK.*

Klyen, E.G. and Van Heerden (1983). Using DCP Soundings to optimize Pavement Rehabilitation. *Proc. Of Annual Transportation Convention, Report LS/83 Materials Branch*, South Africa: Transvaal Roads Department.

Koefoed, O. (1979). Geosounding Principles, 1. Resistivity Sounding Measurements. *Elsevier Scientific Publishing Comp., Amsterdam, the Netherlands* 275.

Mesida, E.A. (1987). The Relationship between the Geology and the Lateritic Engineering Soils in the Northern Environs of Akure, Nigeria. *Bull. Int. Assoc. Eng. Geol.* 35: 65–69.

Mohammadi, S.D., Nikoudel, M.R., Rahimi, H. and Khamehchiyan, M. (2008). Application of the Dynamic Cone Penetrometer (DCP) for determination of the Engineering Parameters of Sandy Soils. *Engineering Geology* 101: 195–203.

Momoh, L.O., Akintorinwa, O. and Olorunfemi, M.O. (2008). Geophysical Investigation of Highway Failure – A Case Study from the Basement Complex Terrain of Southwestern Nigeria. *J. Appl. Sci. Res.* 4(6): 637–648.

Nigerian Federal Ministry of Works and Housing (FMW) (1997). General Specification for Roads and Bridges. *Federal Highway Department*.

Obasi, A.I., Okoro, A.U., Nweke O.M. and Chukwu, A. (2013). Lithofacies and Paleo-depositional Environment of the Rocks of Nkpuma-Akpatakpa, Izzi, Southeast Nigeria. *African Journal of Environmental Science and Technology* 7(10): 967 – 975.

Offodile, M.E. (1989). A Review of the Geology of the Cretaceous of the Benue Trough. In: C.A. Kogbe (ed.), Geology of Nigeria (2nd Edition). *Rockview Nigeria Ltd., Jos* 265-376.

Offodile, M.E. (2002). Groundwater Study and Development in Nigeria. *Mecon Eng. Services Ltd. Jos, Nigeria* 239-345.

Oladapo, M.I., Olorunfemi, M.O. and Ojo, J.S. (2008). Geophysical Investigation of Road Failures in the Basement Complex Areas of Southwestern Nigeria. *Res. J. Appl.* 3(2): 103–112.

Olorunfemi, M.O., Idornigie, A.I., Coker, A.T. and Babadiya, G.C. (2004). Assessment of Anomalous Seepage Conditions in the Opa Dam Embankment, Ile-Ife South-Western Nigeria. *Global Journal of Geological Sciences* 2(2): 191-198.

Olorunfemi, M.O., Ojo, J.S., Sonuga, F.A., Ajayi, O. and Oladapo, M.I. (2000). Geoelectric and Electro-magnetic Investigations of Failed Koza and Nassa - rawa Earth Dams around Katsina, Northern Nigeria. *Journal of Mining and Geology* 36(1):51 – 65.

Orellana, E. and Mooney, H.M. (1966). Master Tables and Curves for Vertical Electrical Sounding over Layered Structures. *Interientia, Madrid, Spain.*

Salahudeen, A.B. and Aghayan, S. (2018). Settlement Modelling of Raft Footing Founded on Oferekpe/Abakaliki Shale in South East Region of Nigeria. *Journal of Computational Engineering and Physical Modeling* 1-1, 68-82.

Sharma, P.V. (1997). Environmental and Engineering Geophysics. *Cambridge University Press, Cambridge, U.K*, 228-235.

Swiss Standard S N 670 010b, Characteristic Coefficient of Soils. *Association of Swiss Road and Traffic Engineers*.

International Journal of Basic Science and Technology
April, Volume 10, Number 2, Pages 102 – 118 http://www.ijbst.fuotuoke.edu.ng/ 118
https://doi.org/10.5555/KAZV2900 **ISSN 2488-8648**

Vander Velpen, B.P.A. (2004). WinRESIST Software Version 1.0. *ITC, IT-RSG/GSD, Delft, Netherlands*.

Zohdy, A.A.R. (1965). The Auxiliary Point Method of Electrical Sounding Interpretation and its Relationship to Dar Zarrouk Parameters. *Geophysics* 30: 644–650.