INTEGRATED GEOSCIENTIFIC INVESTIGATION AROUND THE PROPOSED NNFURU DAM SITE IN NUNYA AREA ISUIKWUATO SOUTHEASTERN NIGERIA

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ABSTRACT

Integrated Geoscientific (Geological, Geoelectrical and Geotechnical) methods were employed in the study of the subsurface conditions of soils within the vicinity of Nnfuru river in Nunya area Isuikwuato, Southeastern Nigeria. The geological studies indicate a subtle change from semi-permeable shale units to permeable fine-grained sand units of the Nsukka Formation in the NE-SW direction. The Geophysical results revealed a resistivity range of 0.3Ωm - 1000Ωm, 0.8Ωm - 1600Ωm, and 0.1Ωm - 1661Ωm for $A – A^I$, $B – B^1$ and $C – C^1$ profiles respectively - a gradation of shale to sandy-shale to Shaly-sand and finally to sand at different depths along the profiles.The Undrained Triaxial Test indicate a good Bearing Capacity range of $107KN/m^2$ – $229KN/m^2$, Cohesion range of $27KN/m^2$ – $51KN/m^2$, Angle of Internal Friction range of 12^0 - 15^0 and Natural Moisture content range of 3.6% - 22.4%. The permeabilty values ranged from $1,4685x10^{-3}$cm/sec – $6.743x10^{-4}$cm/sec while the Consolidation result varied from $8.85m^2$/yr - $13.7m^2$/yr. The Compaction test showed the Maximum Dry Density (MDD) and Optimum Moisture Content (OMC) ranges from $1.7mg/m^3$ – $1.90mg/m^3$ and 5.2% - 21.6% respectively. The Atterberg Limit test shows the Liquid limit, the Plasticity Index and Plastic Limits to be in the range of 36.0 % - 58.0%, 18.7% - 28.6% and 13.2% - 29.7% respectively. The range of values obtained from the Grain Size Analysis plots within A-3, A-5, A-6 and A-7 of the AASHTO M145 or ASTMD 3282 Soil Classification System indicating the rocks of the area to be basically composed of fine sand, clayey sand, and silty-clay at a depth of 1.50m. The sands are non- plastic and are not susceptible to rapid surface deterioration on exposure to weathering , hence will serve as good Abortment ends. The shales are plastic with medium to high swelling potential, good Bearing Capacity, semi-permeable and medium to high rate of consolidation. Mechanical compaction of these shales will improve their use for foundation, embankment and blanket materials.The results obtained agree strictly to the specification recommended by some notable standard regulation authorities and as such the soils within and around the Nnfuru river can support the weight of any dam, though little seepage problems envisaged which could be overcomed using adequate blankate material.

Keywords: Abortment end, Dam, Maximum Dry Density, Nunya, Optimum Moisture Content.

1.0 INTRODUCTION

The Nnfuru river is one of the many rivers in southeastern Nigeria that constantly empties into the ocean through the many river channels within the region. Hence, the ultimate objective must be to conserve and control all the fresh water of the Nnfuru river through adequate dam construction such that what is so freely provided by nature might be applied efficiently and effectively for the future well being of the Nunya dwellers in particular and Southeastern Nigeria in general.
Globally, dams have been built to store water for irrigation, domestic use, recreation, hydropower electricity generation and for flood control. Factors such as amount of available water, topography, geology, strength, permeability and other hydraulic parameters determine the type and suitability of any site for dam construction.

The history of dam failures all over the world indicates that dam failures are largely due to adverse conditions of the underlying rocks. Deleterious subsurface conditions cannot be detected unless a pre-construction study of the dam site, such as this, is undertaken.

Geological, Geophysical, and Geotechnical studies have extensively been used in foundation and dam site evaluation (Leulalem et al., 2016; Nnokwe et al., 2014; Adeyinka et al., 2014; Ibe et al, 2014; Ibeneme et al., 2013a; Ibeneme et al., 2013b; Ryeshak et al., 2015; Ojulari et al, 2014; Salami et al., 2012.). These studies are carried out in order to locate features that will be deleterious to the dam foundation. Hence some selected sites for dams and their corresponding reservoirs are many times changed on the basis of such subsurface studies, or several remedial measures are undertaken to mitigate the problems associated with such deleterious subsurface conditions of the chosen site (Garg, 2003). If such studies are ignored, the safety of the dam and surrounding environment as well as humans are put at risk. These losses highlight the need for construction of dams that will guarantee safety of lives, properties and the environment.

2.0 STUDY AREA

The study area is Nnfuru river, Nunya town of Isuikwuato in Abia state, Southeastern Nigeria. It extends from longitude 7^0 26.0^1 15.66^{11} E to 7^0 25.0^1 51.54^{11} and latitude $5^{\mathbf{0}}$ 42^1 50.58^{11} to 5^0 42^1 27.48^{11}. The river is at the centre of the study area and flows in a southeastern direction in a fairly undulating topography with elevations between 240ft – 431ft above sea level, where it empties loads of clay and silts into the Imo River (Fig 1). The area is typical of rain forest vegetation with cash crops such as palm trees. The river increases in water volume during the rainy season, and correspondingly reduces its volume during the dry season. The town is accessible through the Okigwe–Umuahia express road, which serves as a gateway to the study area.

2.1 GEOLOGY OF THE STUDY AREA

The Outcrops in the area are accessible through tarred roads and foot paths. Two different Geologic Formations outcrop within the study area. They are: the Danian Nsukka Formation (formally referred to as the Upper coal Measures) and the Paleocene Imo Formation (formally called the Imo Shale) (Fig 2). The Nsukka Formation lies conformably on the Ajali Formation and consists of an alternating succession of sandstone, dark shale, and sandy shale, with thin coal seams at various horizons (Kogbe, 1989). On the other hand, the Imo Formation is essentially a mudrock unit consisting mainly of dark-grey to bluish-grey shale, with occasional admixtures of clay, ironstone, thin sandstone bands and limestone intercalations (Nwajide, 2013). Anyanwu and Arua (1990) observed the tendency of the Imo Formation to become sandy upwards. Nwajide (2013) noted that the precise boundary of the Nsukka Formation and the overlying Imo Formation is often difficult to determine.

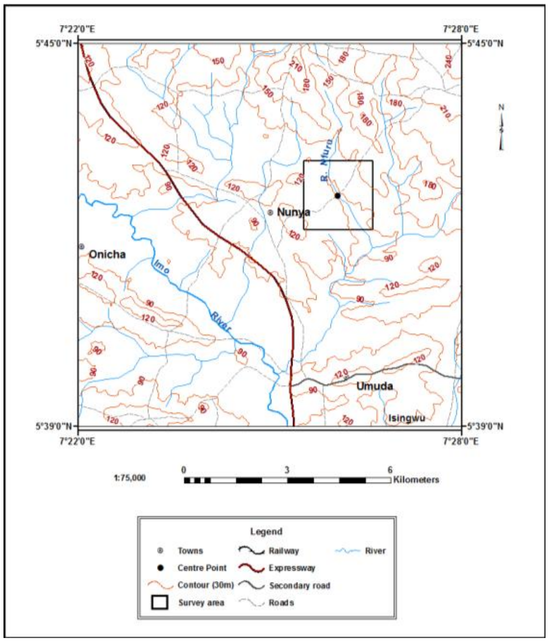

Fig. 1: Topographic Map of the Study Area

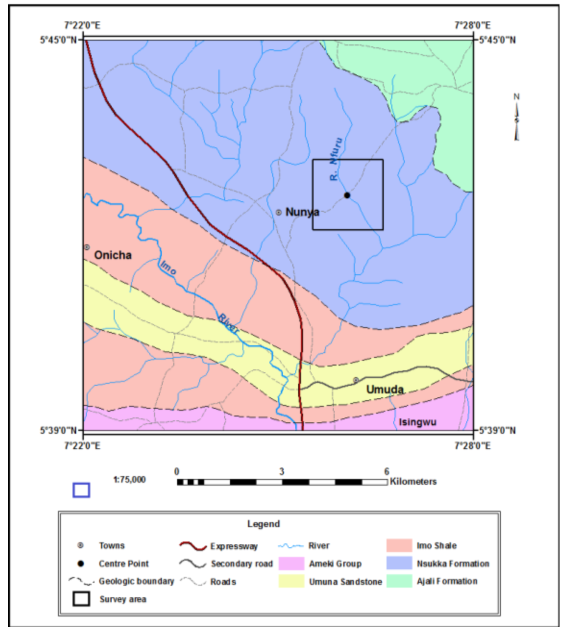

Fig. 2: Geologic Map of the Study Area

3.0 MATERIALS AND METHODS

Geological, Geoelectrical and Geotechnical methods were employed in the study of the rocks of the area. The geological method includes Reconnaisance Survey, Location of outcrops, measurement of dip direction, dip amount, strike, orientation and height above mean sea level. These measurements were done with a compass. Description of the outcrops in terms of lithology, colour, texture, hardness, relative strength, or induration, degree of weathering, texture, structure, discontinuities were done in the field.

Geophysical data acquisition was achieved with aid of the Vertical Electrical Sounding (VES) technique using the Schlumberger electrode configuration. ABEM Terrameter (SAS) 1000B with a liquid crystal digital read-out and automatic signal averaging microprocessor was used. The soundings were laid out in three (3) profiles with eight VES points on each profile. A total of 24 VES points were conducted. The total spread length in each of the VES points is 110m (AB/2 of 55m). The current electrodes (C_1, C_2) were moved outward symmetrically at 1.5m, 2.0m, 2.6m, 3.4m, 4.5m, 6.0m, 8.0m, 10.5, and 14.0m while keeping the potential electrodes (P_1,P_2) fixed at MN/2 = 0.5m. The cross-over distance was encountered at 10.5m and 14.0m of AB/2. It is the position of the potential electrode where voltage readings become so small that they make very significant change in the resistance reading (Ibe et al, 2014).The current electrode remained fixed at 14.0m while the potential electrodes were moved to MN/2 = 3.5m and readings were taken at 14m of AB/2. The current electrodes were then moved back to 10m, and subsequent reading were taken until AB/2 = 55m. The distance from one VES point to another is 150m. The data were acquired under favourable weather conditions. A 100metres measuring line was employed for accurate distance measurement. Compass and Geographical Positioning System (GPS) were used to obtain the profile direction, coordinates and elevations of different VES points.

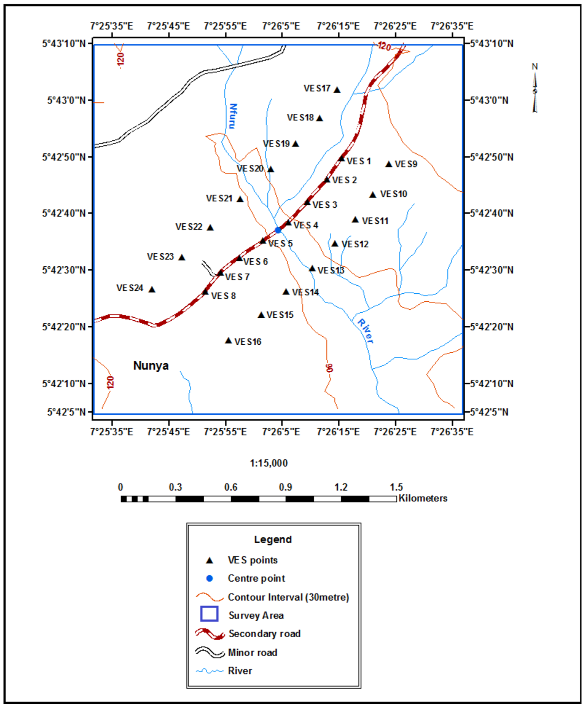

Fig 3. Location Map of the area showing VES points.

In reducing the geophysical data, the equation: $\boldsymbol{\rho_a = 2\pi R\ (V/I) = 2\pi GR = kR}$ was used to obtain a succession of Apparent Resistivity values by multiplying the Geometric Factor, K and the Resistance, R. The sounding curve for each sounding station was obtained by plotting the Apparent Resistivity Values **(ρ_a)** against the Electrode Spacing (AB/2) on a Log-Log graph. A quantitative estimate of the relationship between electrode spacing and the depth of penetration was made using the Rule of the Thumb: Depth Penetrated = 2/3(AB/2)**.** More Qualitative results were obtained with a computer software - Zohdy. Parameters such as Apparent Resistivity and Half- Electrode Spacing were used as input data for the computer modeling. The relationship between MN/2 and AB/2 were converted into a relationship between Apparent Resistivity ρ_a and actual depth penetration by the computer software. The final interpreted results were used to generate a geo-electric section for each of the three profiles.

Geotechnically, eight (8) undisturbed soil samples were collected at a depth of 1.5m within the VES points of Profile A - A^I. These samples were preserved and transported to the laboratory, where Permeability, Triaxial, and Consolidation tests were performed on them within 24-hour period in compliance with ASTM D 2434, ASTM D 2166, ASTM D 2435 methods respectively. The Moisture Content, Specific Gravity, Grain Size Analysis, Atterberg Limit, and Compaction tests were determined in the lab after air-drying in accordance with ASTM D 2216, ASTM D 854-00, ASTM D422-63, ASTM D 4318, and ASTM D 1557 respectively.

4.0 RESULTS AND DISCUSSION

4.1 GEOLOGIC MAPPING RESULTS

Six outcrops exposed within the area showed varying lithology – sandstone, shale and lateritic rocks (Plates 1 to 4). The dip of the sandstone and shale layers is in the same direction and range of 6^0 – 14^0 NE-SW. Nwajide (2013) noted that the Nsukka Formation dips west to South-West at 2 - 7^0 all over its outcrop area. This direction of dip is observed in all the outcrop locations observed in the study area, but with a slightly increased amount of dip.

The sandstone layers contain burrows (Plate 5), indicating trace fossils and an oxygen-rich environment. The shales are grey in color and exhibit slide/slump effect and retain appreciable amount of flood (Plate 2). All streams within the area flow in the strike direction. This is an evidence of stratigraphic control of the streams.

Plate 1: An outcrop of Nsukka Formation at Umuebere-Nkuma road, 500m from the Study area.

Plate 2: Shale outcrop 200m SW of VES 08. This expansive shale can be used as blanket material for the dam to prevent seepage.

Plate 3: A thick unit of sandstone 100m to VES 08.

Plate 4: Shale Exposure at VES 06.

Plate 5: Location 4 (100m to VES 08). The Sandstone here has evidence of Trace Fossils Indicating Oxygen-Rich Environment.

Plate 6: Slumping effect due to shale unit of the Nsukka Formation at VES 06 of the study area.

4.1 GEOPHYSICAL DATA RESULT

The result of the geophysical survey conducted on 24 locations is displayed in table 1. It shows that the rock of the study area is basically composed of four distinct layers that could be explained as gradation from Fine sand toShaly sand to Sandy Shale and to shale.

Table 1: Interpretation of VES data along the three Profiles

PROFILE A - A^I												
	LAYER 1			**LAYER 2**			**LAYER 3**			**LAYER 4**		
VES NO	**Depth (M)**	**ρ (Ωm)**	**LITHO -LOGY**	**Depth (M)**	**ρ (Ωm)**	**LITHO -LOGY**	**Depth (M)**	**ρ (Ωm)**	**LITHO -LOGY**	**Dept h (M)**	**ρ (Ωm)**	**LITHO -LOGY**
1	3.30	2000	LFS	6.30	1000	Fe SS	9.60	500	WFS	25.6	380	SFS
2	3.0	696	LFS	15.0	4.8	Fe SS	18.1	1.5	WFS	22.7	0.5	SHS
3	1.5	444	LFS	6.0	51	WFS	20.0	4	SHS	27.5	1	SSH
4	1.3	461	LSHS	4.3	22.6	SHS	22.8	4.2	SSH	28.4	1.4	SH
5	1.2	1023	LSHS	2.7	54	SHS	14.4	4.5	SSH	18.3	0.3	SH
6	1.4	87.9	LSHS	2.8	6.0	SHS	12.3	17.3	SSH	16.5	0.1	SH
7	1.2	400	LSHS	4.4	16.6	SHS	15.8	2.5	SSH	21.4	0.1	SH
8	1.0	255	LSHS	4.7	12.4	SHS	15.4	0.8	SSH	21.2	0.03	SH
	PROFILE B - B^I											
9	3.2	1477	LFS	5.9	651	Fe SS	17.0	235	WFS	26.6	280	SFS
10	2.9	940	LFS	12.2	63	Fe SS	15.2	6.0	WFS	26.7	0.7	SHS
11	1.7	426	LFS	5.1	58	WFS	27	1.25	SHS	30.0	0.001	SSH
12	1.0	580	LSHS	3.0	23.0	SHS	30.0	1.9	SSH	34.0	0.01	SH
13	1.0	1929	LSHS	3.3	35	SHS	17.7	1.39	SSH	22	0.12	SH
14	1.7	50.8	LSHS	8.8	1.8	SHS	10.5	5.4	SSH	18.5	0.2	SH
15	1.6	450	LSHS	4.7	16.5	SHS	12.7	1.6	SSH	19.0	0.02	SH
16	1.0	275	LSHS	3.8	23.3	SHS	14.5	1.4	SSH	19.3	0.01	SH
	PROFILE C-C^I											
17	3.0	1661	LFS	3.3	890	Fe SS	9.5	495	WFS	15.8	298	SFS
18	2.60	677	LFS	7.7	18.7	Fe SS	10.3	1.94	WFS	18.2	0.8	SHS
19	1.6	438.2	LFS	5.8	58.2	WFS	25.5	4.43	SHS	32.9	0.05	SSH
20	1.34	445	LSHS	4.1	14.3	SHS	24.2	5.8	SSH	29.6	0.6	SH
21	1.0	1903	LSHS	3.5	47	SHS	16.4	4.0	SSH	20.9	0.2	SH
22	1.1	79	LSHS	2.4	5.6	SHS	12.5	27	SSH	16.1	0.08	SH
23	1.2	562	LSHS	5.4	28	SHS	14.6	2.8	SSH	21.3	0.01	SH
24	0.8	429	LSHS	4.1	20.2	SHS	15.6	1.0	SSH	20.4	0.001	SH
SH= Shale. **FeSS**= Iron-stained Sand. **WFS** = Wet Fine Sand. **SHS**= Shaly Sand. **LSHS** = Lateritic Shaly Sand **SSH**= Sandy Shale **LFS**= Lateritic Fine Sand **SFS** = Saturated Fine Sand												

PROFILE A - A^{I}

Profile is 1.05km long and appears at the centre of the other two profiles. The litho-units observed along this profile are four (Table 1). The overburden layer is mainly lateritic material grading from Lateritic fine sand with a resistivity of 1900Ωm to lateritic shaly sand with resistivity of 85Ωm. The second layer is a sandy layer that was inter-fingered by shales. The Resistivity of these layers along the profile direction varied from 7.5Ωm to 1000Ωm. The third unit is a wet fine sand layer that graded into shaly sand and then into shale as one moves along the Profile direction, with resistivity ranging from 0.7Ωm to 500Ωm. Shaly sand at the base which graded into shale as one traverses along the profile, with resistivity ranging from 0.3Ωm -380Ωm.

PROFILE B-B^{I}

This profile is also 1.05km long and 300m East of profile A-A^{I}. The sections and models deduced from this profile as shown in Table 1, reveal four basic litho units. The first layer is a lateritic sandstone that graded into a lateritic shaly sand with resistivities ranging from 95Ωm -1600Ωm. The second layer graded from sand to shaly sand and to sandy shale with resistivities ranging from 2.1Ωm to 95Ωm. The third layer graded from sand to shaly sand and to shale with resistivities ranging from 0.8Ωm to 235Ωm. The last layer graded from shaly sand to sandy-shale and to shale. This last layer has resistivities ranging from 0.1Ωm to 380Ωm

PROFILE C – C^{1}

This profile is equally 1.05km long and 300m west of profile A-A^{I}. The first is lateritic sandstone that graded into lateritic shaly sand with resistivity ranging from 90Ωm -1661Ωm (Table 1). The second layer graded from sand to shaly sand and to Sandy shale with resistivity ranging from 5.5Ωm to 890Ωm as one moves along the profile. The third layer graded from sand to shaly sand and to shale with resistivity ranging from 0.65Ωm to 495Ωm. The last layer graded from shaly sand to sandy shale and to shale. This last layer has resistivity ranging from 0.01Ωm to 298Ωm.

The competence of a soil as a foundation material can be qualitatively evaluated from the layer Resistivities of that soil. This is so because sandstone layers, which are good foundation materials are known for higher resistivity values while shale layers known as poor foundation materials, are usually characterized by low resistivity values (Nwokoma et al., 2015)

From the result obtained, the best foundation area for the Nnfuru dam will be within the vicinity of VES 01, VES 02 and VES 03 where sand materials were mapped to a depth of more than 25m

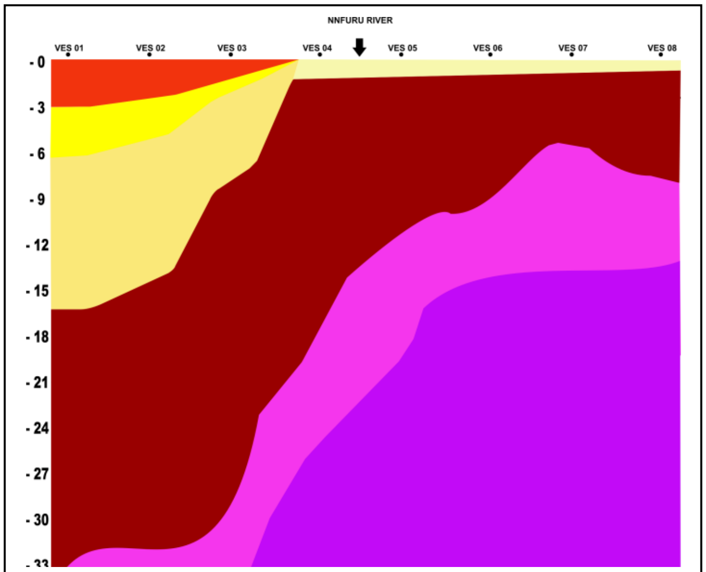

FIG 4: CORRELATED GEOELECTRIC SECTION ALONG A - A[I]

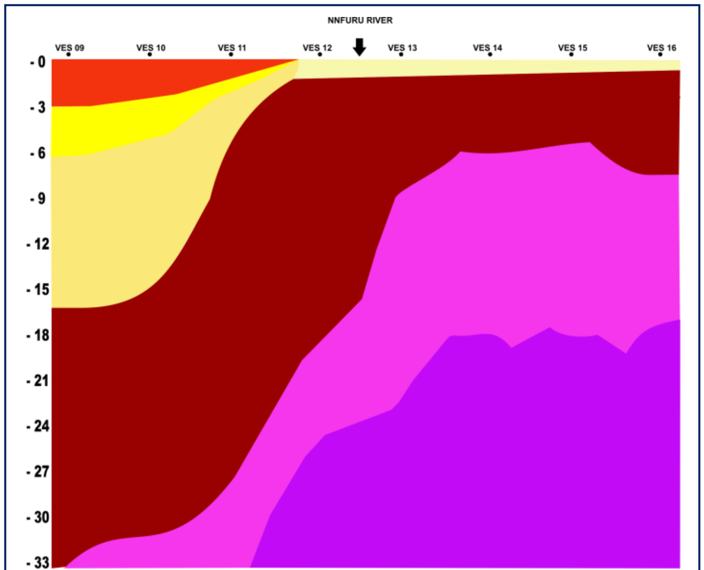

FIG 5.: CORRELATED GEOELECTRIC SECTION ALONG B – B[I]

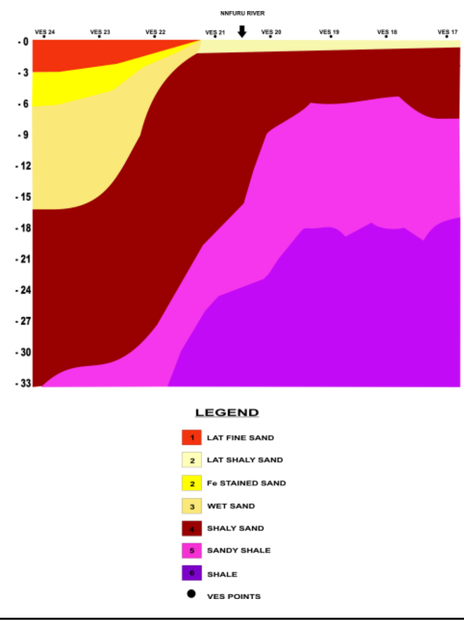

FIG 6.: CORRELATED GEOELECTRIC SECTION ALONG C – C[I]

4.3 GEOTECHNICAL RESULTS

Table 2: Atterberg Limit, Sieve Analysis, Triaxial and Compaction results of the Study Area

LOCATION	ATTERBERG LIMIT			SIEVE ANALYSIS	STANDARD LABORATORY COMPACTION		UNDRAINED TRIAXIAL TEST				
	LL	PI	PL	% PASSING 0.075µm	MDD (mg/m^3)	OMC (%)	NATURAL MOISTURE CONTENT (%)	BULK DENSITY (Mg/m^3)	ANGLE OF SHEARING (Q)	COHESION (KN/m^2)	BEARING CAPACITY (KN/m^2)
VES 01	0	0	0	8	1.88	5.2	3.6	1.93	13	27	118
VES 02	0	0	0	22	1.87	11.6	7.6	1.70	12	26	107
VES 03	48.7	21.5	27.2	76	1.92	17.2	22.4	1.92	13	31	135
VES 04	47.7	18.7	29.0	72	1.79	19.2	19.0	2.04	15	50	229
VES 05	38.7	20.7	18.0	43	1.90	17.2	16.7	1.97	14	40	184
VES 06	58.0	28.3	29.7	86	1.66	21.6	21.2	1.94	12	26	108
VES 07	51.9	28.6	23.3	54	1.90	17.4	15.0	2.03	12	49	200
VES 08	36.0	22.8	13.2	34	1.83	18.5	19.2	2.06	12	51	216

CLASSIFICATION OF NNFURU SOIL

The results of the Grain Size Analysis, Plasticity Index and Liquid Limit (Table 2) were compared with the AASHTO specification in order to classify the rock materials of the area. The rocks of VES 01 and VES 02 have mass passing through Sieve No. 200 as 8% and 22% respectively with 0 values for Plasticity Index and Liquid Limits. These **range of values plot within the A-3 of the AASHTO M145 or ASTM D3282** soil classification system (Table 3) and therefore classified as medium fine sand. The soil materials from VES 03 – VES 07 have range of values passing through sieve No. 200 as **43% - 86%.** The range of Plasticity values is from **18.7 to 28.3**, while the Liquid Limit values ranged from **38.7 – 51.9.** These range of values plot within the **A-5, A-6 and A-7** of the AASHTO M145 or ASTM D3282 soil classification system (Table 3) and therefore are classified as Medium compacted clayey sand and silty clay. Soil materials from these VES points will be ***poor materials for Subgrade*** due to the clay content in them. However, they will be good material for blanket and, or embankment of the Nnfuru dam.

Table 3: Classification of Soil of the study area using the AASHTO classification system

LOCATION	LL	PI	GRAIN SIZE % PASSING 0.075µm	AASHTO CLASSIFICATION	TYPICAL MATERIAL
VES 01	0	0	8	**A – 3**	MEDIUM DENSE FINE SAND
VES 02	0	0	22	**A-3**	MEDIUM DENSE FINE SAND
VES 03	48.7	21.5	76	**A-7**	MED. COMPACTED CLAYEY SAND
VES 04	47.7	18.7	72	**A-7**	MED. COMPACTED CLAYEY SAND
VES 05	38.7	20.7	43	**A-6**	MED. COMPATED CLAYEY SAND
VES 06	58.0	28.3	86	**A-6**	MED. COMPACTED CLAYEY SAND
VES 07	51.9	28.6	54	**A-7**	MED. COMP. LAT. CLAYEY SAND
VES 08	36.0	22.8	34	**A-5**	MED. COMP. LAT. SILTY CLAY

The FMWH (1997) specified **<35%** value for sand grains passing through the no. 200 sieve, **≤12%** value for PI and **>30%** Liquid Limit values for rock materials that are suitable for use as Subgrade. Hence these medium fine sands of VES 01 and VES 02 will be excellent for use as ***Subgrade*** .
The FMWH (1972) recommend Liquid Limit of **≤50% for Subbase and base materials.** Rock materials from VES 03, VES 04, VES 05 and VES 08 with Average Liquid Limit value of 42.78% meet these specification while materials from VES 06 and VES 07 with values above **50%** do not meet these specification.

SWELLING POTENTIAL

The Swelling Potential of the soil of the study area was computed using the Plasticity Index values. The Plasticity Index is related to the Swelling Potential of soils by the relation: $\mathbf{S = 2.16x10^{-3}(PI)^{2.44}}$**.** The degree of swelling or severity was determined using the specification of the Bureau of Indian Standards and Peck et al., 1974. The specifications are shown in Tables 4 and 5.

Table 4: Degree of expansion in fine-grained soils, after Bureau of Indian Standards (BIS) 1972.

LL	PI	DEGREE OF EXPANSION	DEGREE OF SEVERITY	NUNYA VALUE
20 - 35	<12	LOW	NON-CRITICAL	
35 - 50	12 -23	MEDIUM	MARGINAL	LL : 36.0 – 58.0 PI : 18.7 – 28.6
50 - 70	23 - 32	HIGH	CRITICAL	
70 – 90	>32	VERY HIGH	SEVERE	

Table 5: Comparison of relationship between swelling potentials of soils and Plasticity Index (after Peck, Hanson and Thornburn) with values from the study area

SWELLING POTENTIAL	PLASTICITY INDEX	NUNYA VALUE
LOW	0 – 15	
MEDIUM	10-20	
HIGH	20 – 30	**18.7 – 28.6**
VERY HIGH	>30	

Therefore, the soil of VES 03 – VES 08 have medium to high degree of expansion, while the swelling potentials of soils derived from VES 01 and 02 will be very low.

COMPACTION TEST RESULT

The result of the compaction test of the study area is shown in Table 2. It shows the MDD and OMC values range from **1.7 – 1.90mg/m^3, and 5.2 – 21.6%** with mean values of 1.84mg/m^3 and 15.98% respectively.

The Nigeria **specification (Dams and Bridges), Control No.53, Govt of East Central State of Nigeria** (Table 6) specified that for a material to be suitable for embankment, it must have MDD>0.047 and OMC <18%. This specification is satisfied by the soil of the Nnfuru dam.
Jegede (2000) noted that the best soil for foundation is the soil with high MDD at low OMC. Ibeneme et al (2013b) observed that rocks with MDD and OMC range of 1.7 – 1.98mg/m^3 and 12 – 16.2% could be classified as Moderate and will be good for foundation.
According to O'Flaherty (1988) the range of values that may be anticipated when using the Standard Proctor Test methods are: for clay, the MDD may fall within 1.44mg/m^3 and 1.685mg/m^3 while the OMC may fall within 20%-30%. For Silty-clay, the MDD may fall within 1.6mg/m^3 and 1.845mg/m^3 and OMC ranges between 15% - 25%. For Sandy-Clay, MDD varies from 1.76mg/m^3 and 2.165mg/m^3 and OMC between 8% and 15%
Considering the above, it is inferred that the soil of the area could be classified as ***Sandy Clay***.The rock units from VES 04, VES 06, and VES 08 with average OMC of **19.8%** are ideal for ***embankment and general filling***.
The best rock materials for the dam foundation will be between VES 1 and 02 with mean MDD and OMC of 1.87mg/m^3 and 8.4% respectively.

Table 6: Comparison of Soil of the study area with Nigerian Specification (Dams and Bridges), Control No.53 and FMWH, 1997.

Nigerian Specification (Dams and Bridges), Control No. 53, Government of East Central state of Nigeria									
SUB-BASE/SUBGRADE		**BASE COURSE**			**General Filling and Embankment**				
Liquid Limit	**Plasticity Index**	**Liquid Limit**	**Plasticity Index**	**Mass Passing Sieve No. 200**	**Liquid limit**	**Plasticity Index**	**MDD**	**OMC**	**Mass passing Sieve no. 200**
<35%	**<16%**	**<30%**	**<15%**	**5 -15%**	**<40%**	**<20%**	**>0.047**	**>18%**	**<35%**
VES 01, 02	**VES 01, 02**	**VES 01, 02**	**VES 01, 02**	**NONE**	VES 05, VES 08	**VES 04, 05**	**ALL**	**VES 04, 06 & 08**	**VES 01, 02, 08**
FEDERAL MINISTRY OF WORKS AND HOUSING (FMWH), 1997									
SUB-BASE		**BASE COURSE**			**General Filling and Embankment**				
Liquid Limit	**Plasticity Index**	**Liquid Limit**	**Plasticity Index**	**Mass Passing Sieve No. 200**	**Liquid Limit**	**Plasticity Index**			
40%	**≤20%**	**≤30%**	**≤13%**						
VES 01, 02, 05, 08	**VES 01, 02, 04**	**VES 01, 02**	**VES 01, 02**						

NATURAL MOISTURE CONTENT

The Natural Moisture Content values range from 3.6 – 22.4%. Moisture variation is generally determined by factors such as intensity of rains, which could increase the water table, depth of sample collection and texture of the soil (Jegede, 2000).

The lowest values of 3.6% and 7.6% observed at VES 01 and 02 respectively could be as a result of increased porosity and permeability as the ***sands*** in these VES points could not retain appreciable amount of water. This is so because unconsolidated soils loose moisture very easily on exposure to heat as a result of little or no matrix (Ibe et al, 2014).

The relatively high values of 15.0 – 22.4% observed at other VES point could be attributed to rock units with lower permeability, and increased porosity. - ***shale***

BULK DENSITY

The Bulk Density values obtained from the area range from 1.70 -2.06mg/m^3. Paige-Green (2007) noted that low bulk density values (<2.6 mg/m^3) of a soil material is indicative of its susceptibility to weathering and deterioration.

Generally shales have lower Bulk density values (1.0 -1.8 mg/m^3) than sands (Pravin, 2013). The slightly higher values observed in the area is largely due to consolidation/compaction of the **shales** and **sands** in the area.

BEARING CAPACITY

The Compressive strength test result shows the Bearing Capacities values range from **107KN/m^2 – 229KN/m^2**, with an average value of **162.13KN/m^2**. The National Building Code, 1983 specification of **150KN/m^2** for moist clay and sand clay is met by the average Bearing value of **162.13KN/m^2**.

The **Angle of Shearing Resistance, ϕ** values obtained are in the range of $12^0 – 15^0$. These range of values are low and may be explained as a result of greater input of clay matrix in the rock of the area. Angle of Shearing Resistance results from grain-to-grain contacts in a soil sample without cohesive matrix. In cohesive rock samples, the clay matrix is trapped between rock particles, thereby reducing the grain-to-grain contact producing the Angle of shearing Resistance.

The **cohesion** results are in the range of 26 – 51KN/m^2. The lowest values averaging 26.5KN/m^2 are domiciled at VES 01 and 02, while the highest average value of 41.2KN/m^2 is located in VES 03 – 08. There is a general increase in cohesion with clay or silt content. As more clay or silt is introduced into the sandy material, the fine particles fill the void spaces in between the sand particles and begin to induce the sand with interlocking. Hence, clayey-sand soils are expected to exhibit low cohesion whereas the cohesion increases with increase in clay content.

Thus the rocks between VES 03 – 08 are more cohesive, as a result of greater percentage of clay than those at VES01 and 02.

PERMEABILITY

The range of Permeability values obtained from the study area is **$1.4685x10^{-3}$ – $6.74x10^{-4}$**. VES 01 and 02 have the highest permeability values of **$1.6476X10^{-3}$** and **$1.4685X10^{-3}$** respectively. VES 03 – VES 08 have values ranging from **$4.34x\ 10^{-4}$ to $6.74x\ 10^{-4}$.** Lamb (1978) observed that soils with Permeability values of **10^{-3} – 10^{-5}** have low degree of permeability. According to the US Bureau of Reclamation, soils are classified as Impervious (Impermeable) for K < 10^{-5}cm/sec., Semi-pervious (semi-permeable) if $10^{-5} \leq K \leq 10^{-3}$cm/sec and Pervious (Permeable) for K>10^{-3}cm/sec.

Hence the soil of the area falls in the semi-permeable range with low seepage potentials and will be good for use as embankment of the dam, as the amount of water that will seep into, or away from the dam will be relatively small.

Table 7: Result of Consolidation, Permeability and Specific Gravity of the study area

LOCATION	AVERAGE CONSOLIDATION	COEFFICIENT OF PERMEABILITY	SP. GRAVITY
VES 01	13.15	$1.6476X10^{-3}$	2.53
VES 02	13.7	$1.4685X10^{-3}$	2.58
VES 03	12.52	$6.144X10^{-4}$	2.55
VES 04	11.6	$5.844X10^{-4}$	2.61
VES 05	9.3	$5.994X10^{-4}$	2.45
VES 06	8.85	$4.346X10^{-4}$	2.50
VES 07	9.42	$7.043X10^{-4}$	2.38
VES 08	10.75	$6.743X10^{-4}$	2.45

Table 8: Degree of Permeability after Lambe, (1978) compared with values from the study area

DEGREE OF PERMEABILITY	K (cm/s)	NUNYA VALUE
HIGH	$>10^{-1}$	
MEDIUM	$10^{-1} – 10^{-3}$	
LOW	$10^{-3} – 10^{-5}$	$1.4685x10^{-3} – 6.74x10^{-4}$
VERY LOW	$10^{-5} – 10^{-7}$	
PRACTICALLY IMPERMEABLE	$<10^{-7}$	

CONSOLIDATION ANALYSIS

The result of the Consolidation tests is shown in Table 7 . The values fall within 8.85 **m^2/year – 13.7m^2/year**. According to Lambe and Whiteman (1979), soils with Consolidation values between 1 – 10 m^2/year contain 15 – 25% of clay and are said to be of medium rate of consolidation. Therefore, the rate of consolidation of the Nnfuru dam soil is medium to high.

CONCLUSION

The Geological, Geoelectrical and Geotechnical studies carried out on soils underlying the proposed Nnfuru dam site reveals the following:

- There are four distinct litho-units in the area at a depth of about 20m. They are: lateritic sand overburden, fine sand, sandy- shale and shale layers. The sandstone and shale layers are from the Maastrichtian Nsukka Formation.
- The sand layers are classified as medium fine sand, well consolidated, of medium permeability, good Bearing Capacity and are not plastic.
- The shales are plastic with medium to high swelling potential, good Bearing Capacity, semi-permeable and medium to high rate of consolidation

5. RECOMMENDATION

The areas mapped as sand, or sandy shale within the survey area are recommended for use as abortment ends for the proposed Nnfuru dam.

The shales in the area are recommended for use as embankment and reservoir blanket because of their semi-permeable property. ***However, these shales should be further compacted mechanically to improve their impermeability***. These shales are also good for abortment ends because they graded from sands to shale and are thus embedded with sands as revealed by the VES results.

Thus it is recommended that the area can support the weight of any dam, though with little seepage problems.

REFERENCES

Adeyinka M O, Isaac O.B, Adebisi O.O (2014). Integrated Geophysical and Geotechnical Investigation of a Proposed dam Site, Southwestern Nigeria. RMZ – M&G vol 61 pp. 257-267

Anyanwu , N.P.C and Arua, I (1990). Ichnofossils from the Imo Formation and Their Paleoenvironmental Significance. Journal of Mining and Geology, Vol. 26, pp 1-4.

ASTM D 854-00 – Standard Test for Specific Gravity of Solid soils by Water Pycnometer

ASTM D422-63 – Standard Test Method for Particle Size Analysis of Soils

ASTM D 2216 – Standard Test Method for Laboratory Determination of Water (moisture) Content of Soil, Rock, and Soil-Aggregate Mixtures

ASTM D 4318 – Standard Test Method for liquid Limit, Plastic Limit, and Plasticity Index of Soils

ASTM D 2434 – Standard Test Method for Permeability of Granular Soils (Constant Head)

ASTM D 1557 – Standard Test Method for Laboratory Compaction Characteristics of Soil Using Modified Effort

ASTM D 2166 – Standard Test Method for Unconfined Compressive Strength of Cohesive Soils

ASTM D 2435 – Standard Test Method for One-Dimensional Consolidation Properties of Soils

Ibe K K, Ibeneme S I and Nwankwo I S (2014). Geoelectrical and Geotechnical Evaluation of Foundation Beds at Naze, Owerri Southeastern Nigeria. Journal of Earth Sciences and Geotechnical Engineering, Vol. 4 no.3 pg 77-94.

Ibeneme, S.I, Ibe K.K, Selemo A.O, Udensi S.C, Nwagbara J.O, Ubechu B.O, Onwuka C.O (2013a). Geoelectrical Assessment Of a Proposed Dam Site Around Ehuhe Area Of Oji River, South-Eastern Nigeria; Journal of Natural Sciences Research, Vol. 3 No. 13

Ibeneme S.I, Ibe K.K, Selemo A.O, Nwagbara J.O, Eze I.O, Ubechu B.O, Ibeneme I.L, Nwankwo E.J, Oparaocha J.O (2013b). Geoelectrical and Geotechnical Data as Veritable Tools for Feasibility Study of the Proposed Imo River Dam Site at Owerrinta, Southeastern Nigeria. Asian Journal of Science and Technology Vol. 4 Issue 12 pp. 37 – 44.

Jegede, G (2000). Effects of Soil Properties on Pavement Failure along the F209 Highway at Ado-Ekiti, Southwest Nigeria. Journal of Construction and Building Materials No 14 Pg 311- 315

Kogbe, C.A (1989). The Cretaceous and Paleogene Sediments of Southern Nigeria: in Kogbe C.A (Ed.), Geology of Nigeria. Elizabethan Pub. Vol. 1, Nigeria, 273 - 286

Lambe, T.W and Whiteman, R.V(1979). Soil Mechanics, SI version, Wiley, New York

Leulalem, S.B, Kifle W. and Nata T. (2016). Geological and Geotechnical Investigation of Axum Dam site, Tigray, Northern Ethiopia. Internatonal Journal of Scientific and Technology Research Vol. 5, Issue 10. Pp 84 – 111.

Lambe, T.W and Whiteman, R.V(1979). Soil Mechanics, SI version, Wiley, New York.

National Building Code of Nigeria (1983). Pg 256

Nnokwe, N.N, Ibe K.K, Chinyem F.I, Ikoro D.O and Ibeneme S.I (2014). Geological and Soil Bearing Capacity Studies On the Proposed Idonyi River Dam Site, Amaeke Abam Area of South-Eastern Nigeria. International Journal of Engineering Research and Science and Technology Vol. 3 No.1

Nwajide C.S (2013) Geology of Nigeria's Sedimentary Basins. CSS Press, Nigeria.

Nwokoma E.U, Chukwu G.U and Amos-Uhegbu C (2015). Geoelectrical Investigation of Soils as Foundation Materials in Umudike Area, Southeastern Nigeria. Physical Science International Journal, Vol 6 Issue 2 pp 82-95.

O'Flaherty A C (1988). Highway Engineering. Edward Arnold Publishers, London UK Vol 2 Pp 57.

Ojulari, A.Y; Ologe O and Oyiloye S (2014). Geophysical and Geotechnical Investigation of the Proposed Dam Axis of the River Butulu, Northwestern Nigeria. Pacific Journal of Science and Technology. Issue 15 Vol. 2 pp 270-277.

Paige-Green, P (2007). Improved Material Specification for Unsealed Roads. Quarterly Journal of Engineering Geology and Hydrogeology, Vol 2 pp 175 – 179

Pravin, R C (2013). Soil Bulk Density as Related to Soil Texture, Organic Matter Content and Available Total Nutrients of Coimbatore Soil. International Journal of Scientific Research Publication Vol. 3 Issue 2.

Ryeshak A.G, Wazoh H.N, Daku SS (2015). The Geological and Geotechnical Properties of Earth materials of Plateau State University, Nigeria in relation to its suitability for facility layout. International Journal of Scientific Research, volume 6, issue 10

Salami, B M, Falebita D.E, Fatoba J.O and Ajala M.O (2012). Integrated Geophysical and Geotechnical Investigation of a Bridge Site - A case Study of a Swamp/ Creek Environment in Southeast Lagos, Nigeria. Ife Journal of Science Vol 14, No 1. Pg 75.