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Assessment of the Implications of Geotechnical Properties of Sub-soils along Electricity Transmission Route in the Recent Coastal Plain of the Eastern Niger Delta

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ABSTRACT

This study aims at ascertaining the litho- stratigraphic sequence along Electricity Transmission Line route, evaluating the engineering properties of the underlying soil and recommend appropriate foundation types to support the towers to be erected. The transmission route runs from Ban-Ogoi, Afam passing through Eleme to Onne, Elelenwo and terminating at Rukpokwu; all in Rivers State. The investigation involved seventeen (17) borings to the depth of 10m below ground level (BGL) and 17nos Dutch Cone Penetration Tests (CPTs) to maximum depth or refusal. Geologically, the areas of study lie within the fluvial deposits of the recent coastal plain of eastern Niger Delta.Field investigations revealed that the underlying lithology along the transmission route reveal that the areas are characterized predominantly by Type '2' soil class. The soils are moderately competent and homogenous in texture. Correlation with N-values for the clays and granular soils reveal clayey formation of firm consistency and sands of medium densities. Generally, the soil formation encountered along the entire electricity transmission line is predominantly lateritic clayey materials of medium to firm consistency. However, the lithology at Okrika presented a different formation. The silty clayey formation encountered at the location is homogenous in nature and with firm consistency in textural characteristics. Sand layers exhibited fairly high SPT values indicating sands of medium densities. Groundwater was analyzed for pH values and soluble chloride and sulphate. pH values ranges from 4.56 to 5.06 indicating acidic properties. Chloride content ranges from 4.96mg/l to 30.50mg/l and sulphate content ranges from 19.70mg/l to 31.92mg/l. To support the towers to be built, it is suggested that the installation of isolated pad/chimney footings within considerable depth after excavation. At Okrika, the towers should be supported on pile foundations installed between the depths of 5.0m – 7.0m. Settlement of the soils is within permissible limit. However, where the superstructure is found to be excessive, it could be supported by means of continuous footings with foundation beams to minimize the problem of differential settlements. It is recommended that the installation of Isolated Pad/Chimney footing be provided; a standardized pad footing designed in square dimension to mobilize adequate support for the super-structures.

Keywords: *Subsoil, Foundation, Engineering Properties, Litho-Stratigraphy, Coastal Plain, Electricity Transmission.*

INTRODUCTION

Assessment of geotechnical properties of sub-soil is necessary for generating relevant input data for design and construction of foundations for proposed structures (Oke & Amadi, 2008). Oghenero *et al*., 2014; Ngah & Nwankwoala, 2013; Nwankwoala & Amadi, 2013 have stated that proper design and construction of civil engineering structures prevent an adverse environmental impact or structural failure or post construction problems.

Geotechnical properties of soils have different behavior on the structures (Warmate & Nwankwoala, 2019). Higher the specific gravity, higher will be the load carrying capacity of soils. Knowledge of the rate at which the compression of the soil takes place is essential from design consideration. The properties of the soil such as plasticity, compressibility or strength of the soil always affect the design in the construction. Lack of understanding of the properties of the soil can lead to the construction errors (Arora, 2008). The suitability of soil for a particular use should be determined based on its engineering characteristics and not on visual inspection or apparent similarity to other soils. The loading capability of soil depends upon the type of soil (Verstraetan, 1987). Generally, fine grained soils have a relative smaller capacity in bearing of load than the coarser grained soils {Jain *et al*, 2015}.

Plasticity index and liquid limit are the important factors that help an engineer to understand the consistency or plasticity of clay. Though shearing strength constants at liquid limits but varies for plastic limits for all clays {Murthy, 2002}. Permeability influences the civil engineering structures. The shear strength of soils is of special relevance among geotechnical soil properties because it is one of the essential parameters for analyzing and solving stability problems (calculating earth pressure, the bearing capacity of footings and foundations, slope stability or stability of embankments and earth dams (Karsten *et al.*, 2006}.

This study, therefore involved detailed geotechnical investigation along the Afam-Eleme-Onne-Elelenwo-Rukpokwu electricity transmission line in order to ascertain the underlying sub-soil conditions prior to the construction of foundations to support the towers to be erected. This study presents the results of the soil boring campaign. It also contains a factual data and interpretation of this work based on the results of the borehole drilling and laboratory tests. The transmission route runs from Ban-Ogoi, Afam passing through Eleme to Onne, Elelenwo and terminating at Rukpokwu; all in Rivers State, Nigeria were carried out to ascertain the litho-stratigraphic sequence along the proposed 132KV Electricity Transmission Line route. This study is also aimed at ascertaining the engineering properties of the underlying soil and recommend appropriate foundation types to support the towers and superstructures to be erected.

Geology/Hydrogeology of the Study Area

The study area is predominantly made up of soils ranging from fine silts, sand and fine gravel types. The geology (Figure 2) generally shows a coarsing upward sequence indicating a regressive deposition which is in line with the geology of Niger Delta (Akpokodje, 1987). The surface elevation of the area is a gentle slope towards the west. The upper cretaceous deposits of the Niger delta are fluvial and marine in nature formed about 50million years ago. An accumulation of over 12,000m^3 of marine deltaic sediments overtime transported mainly from river Niger and its tributaries. It is characterized by three major lithofacies: (i) varying thickness of marine shale's and clay stones at the base; (ii) alternating clay stones, sandstones and siltstones with a progressively upward increase of sand percentage; (iii) topmost alluvial sands. Benin Formation, the uppermost geological layer is made up of multiple layers of sand, clays, conglomerate, lignite and peat of various thickness and textures and covered by thick overburden soil. ''The deltaic plain is flat lying at about 40m above sea level towards the interior, and less than 8m above sea level on approaching the coast'' (Akpokodje, 1987; Short and Stauble, 1967). The area is a flat lowlying plains, crisscrossed by creeklets, riversand its tributaries that drain the entire area to the sea.

The hydrogeology of the area have been studied by Nwankwoala and Ngah (2015); Ngah and Nwankwoala (2013); Etu-Efeotor and Akpokodje (1990); Odigi, (1989); Etu- Efeotor, (1981); Weber and Dakouru (1975). They described the Benin Formation as a highest yielding water bearing zone of the area. Overlying the 40m-150m thick Quaternary deposits, the Benin Formation consists of sequences of sands and silty clay alternating which later become increasingly prominent seawards (Etu-Efeotor and Akpokodje, 1990). Based on strata logs in the area, described the aquifer in the area as a stack of alternating aquifers lying upon each other in a multiple fashion such that the uppermost ones are mostly unconfined and underlain by the confined aquifers. The Niger Delta consists of three diachronous units, namely Akata (oldest), Agbada and Benin (youngest) formations. The Benin Formation (Oligocene to Recent) is about 2100m thick at the basin centre and consists of medium to coarse grained sandstones, thin shales and gravels (Weber and Dakouru, 1975). The Niger Delta has spread across a number of ecological zones comprising sandy coastal barriers, brackish or saline mangrove, freshwater and seasonal swamp forests. The Niger Delta has two most important aquifers, Deltaic and Benin Formations. With a typically dendritic drainage network, this highly permeable sand of the Benin Formation allows easy infiltration of water to recharge the shallow aquifers. Nwankwoala *et al.*, 2013 described the aquifers in this area as a set of multiple aquifer systems stacked on each other with the unconfined upper aquifers occurring at the top. Recharge to aquifers is direct from infiltration of rainfall, the annual total of which varies between 5000mm at the coast to about 2540mm landwards. Groundwater in the area occurs in shallow aquifers of predominantly continental deposits encountered at depths of between 45m and 60m (Figure 3). The litho logy comprises a mixture of sand in a fining up sequence, gravel and clay. Well yield is excellent, with production rates of 20,000 litres /hour common and borehole success rate is usually high (Efeotor and Odigi, 1983; Nwankwoala & Mzaga, 2017). Surface water occurrence includes numerous networks of streams, creeks and rivers.

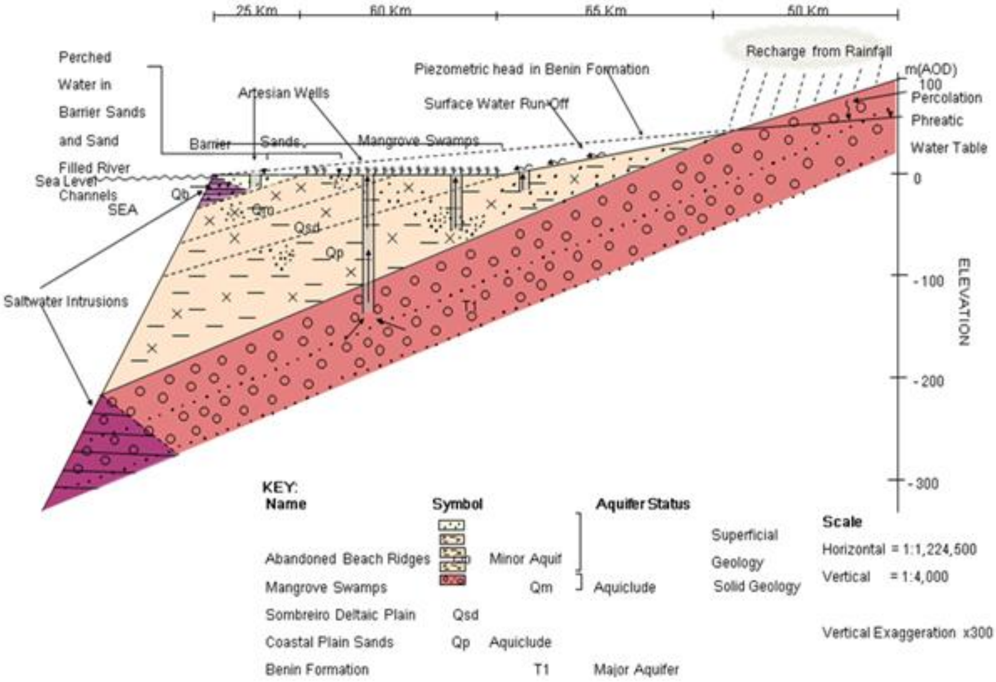

Figure3. *Hydrogeological features across the Niger Delta (Source: SPDC, 2002)*

METHODS OF STUDY

The auger is fitted with a free fall auger. The auger is lifted to a height of about 1.0m above ground level, using gloved hands, and allowed to free-fall under gravity to advance the boring. As the auger falls it cuts through the soil such that the cut soil material is retained inside it by means of a clerk. The auger is then brought to the surface where the soil retained in it is emptied out. To prevent collapse of the borehole wall, the hole is lined with casings or shell corresponding to the size of the auger being used for the drilling. As the drilling continues, Representative undisturbed and disturbed samples were taken at regular intervals of 0.75m depth. The samples were used for a detailed and systematic description of the soil in each stratum in terms of its visual properties and for laboratory analysis. Standard Penetration Tests (SPT) was carried out on granular sediments in order to assess their densities. In this test, the number of blows required to drive the standard.

The study involved seventeen (17) borings to the depth of 10m below ground level (BGL) and 17 Dutch Cone Penetration Tests (CPTs) to maximum depth or refusal. Geologically, the areas of investigation lie within the fluvial deposits of the recent coastal plain of eastern Niger Delta. The depositional sequence exhibits massive continental sand stones overlying an alternation of sandstones and clays of marginally marine origin, but eventually grading downwards into marine clays. Sands, by far, form the largest group of rock types in Rivers State. From the field information, the underlying litho logy along the transmission route revealed that the areas are characterized predominantly by Type '2' soil class. The soils are moderately competent and homogenous in texture. Correlation with N-values for the clays and granular soils reveal clayey formation of firm consistency and sands of medium densities. Cone Penetrometer of 100KN capacity was used in the cone resistance soundings.

Continuous sounding procedure was adopted in the test. The cone is first forced into the ground a distance of 10cm by the application of force to the outer sounding tubes. The cone is then pushed out a distance of about 4cm by the application of force to the inner rods only and the magnitude of the force required to achieve this, is measured on the pressure gauges and recorded. The principal feature of the penetrometer is that the end resistance to penetration by the cone and the friction resistance acting on the jacket can be assessed separately. The end resistance of the cone is called the cone penetration resistance, denoted by Qc and it is defined as the force required to advance the cone divided by the end area. The cone penetration diagrams are presented in this report with estimated undrained cohesive strength; ultimate bearing capacity and allowable bearing strength derived from the CPT readings.

Moisture Content Determination

Moisture Content was determined by drying selected moist/wet soil material for at least 12 hours to a constant mass in a 11^0 C drying oven. The difference in mass before and after drying was used as the mass of the water in the test material. The mass of material remaining after drying was used as the mass of the solid particles. The ratio of the mass of water to the measured mass of solid particles was the water content of the material.

Atterberg Limit

This was determined on soil specimens with a particle size of less than 0.425mm. The Atterberg limits refer to arbitrary defined boundaries between the liquid limit and plastic states (Liquid Limit, WL), and between the plastic and brittle states (Plastic Limit, Wp) of fine- grained soils. They are expressed as water content, in percent.

The liquid limit is the water content at which a part of soil placed in a standard cup and cut by a groove of standard dimensions flow together at the base of the groove, when the cup is subjected to 25 standard shocks. The one-point liquid test was carried out. Distilled water was added during soil mixing to achieve the required consistency. The plastic limit is the water content at which a soil can no longer be deformed by rolling into 3 mm diameter threads without crumbling. The range of water contents over which a soil behaves plastically is the Plasticity Index, I^{p}. This is the difference between the liquid limit and the plasticity limit (WL-WP). Reference test standard: BS 1377: Part 2: 1990.

Undrained Shear Strenght

This was performed on relatively undisturbed cohesive soils. Depending on the consistency of the cohesive material, the test specimen was prepared by trimming the sample or by pushing a mould into the sample. Depending on the consistency of the cohesive material, the test specimen was prepared by trimming the sample or by pushing a mould into the sample. A latex membrane with thickness of approximately 0.2 mm was placed around the specimen. A lateral confining pressure of 25kPa to 150kPa is maintained during axial compression loading of the specimen. Consolidation and drainage of pore water during testing is not allowed. The test is deformation controlled (strain rate of 60%/h), single stage, and stopped when an axial strain of 15% is achieved. The deviator stress is calculated from the measured load assuming that the specimen deforms as a right cylinder. The presentation of test results includes a plot of deviator stress versus axial strain. The Undrained shear strength, C^u, is taken as half the maximum deviator stress. When a maximum stress has not been reached at strains of less than 15%, the stress at 15% strain is used to calculate undrained shear strength.

The Unit Weight

The Unit weights were determined from measurements of mass and volume of the soil. The unit weight (kN/m^3) refers to the unit weight of the soil at the sampled water content. The dry unit was determined from the mass of oven-dried soil and the initial volume.

Particle Size Analysis

These were performed by means of sieving and/or hydrometer readings. Sieving was carried out for particles that would be retained on a 0.075 mm sieve, while additional hydrometer readings were carried out when a significant fraction of the material passes a 0.075 mm sieve. Dry sieving was carried out by passing the soil sample over a set of standard sieve sizes and then shakes the entire units for few minutes with sieve shaker (machine). Particle size is presented on a logarithmic scale so that two soils having the same degree of uniformity are represented by curves of the same shape regardless of their positions on the particle size distribution plot.

The general slope of the distribution curve may be described by the coefficient of uniformity Cu, where Cu = D60/D10, and the coefficient of curvature Cc, where Cc = $(D30)^2$/D10 x D60.

D60, D30 and D10 are effective particle sizes indicating that 60%, 30% and 10% respectively of the particles (by weight) are smaller than the given effective size.

Consolidation

Consolidated tests were also carried out on relatively undisturbed samples with the object of determining the compressibility properties of the soils.

The plot of void ratio (e) against effective pressure (P) for the samples tested, with calculated values of the coefficients of consolidation (Cv) and of the coefficients of compressibility (Mv) are presented.

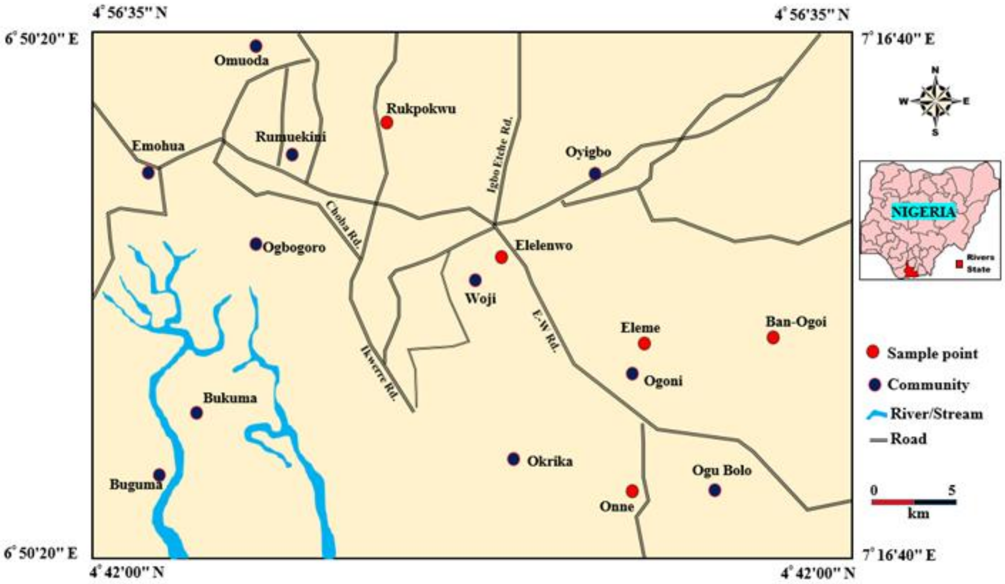

Figure1. *Map Showing the Study Locations*

Results and Discussions

Eleme

The top soils were characterized by grey and brownish grey silty clay, silty sand and fine sand, respectively to about 0.20m. Underlying the topsoil in AP -1 is firm, yellow lateritic clay to 7.0m and further underlain to the terminal depth at 10.0m by yellow loose to medium dense, fine to medium sand. In AP-2, the topsoil is underlain to 3.0m by firm yellow and brown lateritic clay which in turn is underlain by soft, yellow lateritic silty clay of 5.0m thick. From 8.0m to the terminal depth is similar to AP-1. The topsoil in AP-3 overlies a formation of medium to firm, yellow lateritic clay to 8.0m with presence of gravels from 6.50m to8.0m. Underlying the lateritic clayey material is loose to medium yellow fine to medium sand. The topsoil at AP -4 is brownish grey fine silty sand and underlain by firm, yellow lateritic clay to 6.50m. From 6.50m to 8.0m is soft to medium, yellow silty clay with gravels and from 8.0m to the terminal depth is medium dense, fine to medium sand. Groundwater was encountered at 7.20m. At AP-5 and AP- 9, the entire depths explored revealed formation of firm, yellow lateritic clay. However, in AP-9, the lateritic clay became stiff from 5.0m with presence of gravels at 10.0m. Groundwater was not encountered in both holes.

Okrika

The topsoil at the two holes is soft, grey silty clay with fibrous root in AP-8. The topsoil in AP-6 is underlain to 1.50m by medium, light grey mottled clay and further underlain by firm, light yellow silty clay of 6.50m thick. The above layer of silty material is underlain to the terminal depth at 10.0m by soft, grey silty clay. In AP- 8, the topsoil overly medium, light grey mottled clay of 1.0m thick which is in turn underlain by medium to firm, light grey silty clay to 8.0m. From 8.0m to the terminal depth is soft, grey silty clay. Groundwater depths are 1.60m and 1.50m in AP-6 and AP -8 respectively.

Elelenwo-Rukpokwu

The soils in the area are brownish grey, brown and dark grey fine sands and silty sandy clay respectively. Immediately underlying the topsoil in Tw.1.3 and extending to the end of the hoe at 10.0m is firm, yellow lateritic clay with tiny gravels between 7.0m to 10.0m. Groundwater was not encountered in this borehole. Similarly in Tw.11.3, the topsoil is underlain to the end of the hole at 10.0m by firm, yellow lateritic clay. No groundwater encountered. In Tw.17.3 and Tw.23.3, underlying the topsoil is firm, yellow lateritic silty clay which extends to 5.0m in Tw.17.3 and further underlain by medium to firm yellow silty sandy clay to 10.0m with occasional gravels at 7.0m. The lateritic underlying the topsoil in Tw.23.3 extends to 4.0m and in to support the proposed towers, we suggest the installation of isolated Pad/Chimney Footings within considerable depth after excavation. At Okrika, the towers should be supported on pile foundations installed between the depths of 5.0m to 7.0m. Bearing pressures are provided in the report. Settlement of the soil is with permissible limit. However, where the super structure is found to be excessive, it could be supported by means of continuous footings with foundation beams to minimize the problem of differential settlements.

Table1. *Depths of groundwater*

	Afam-Eleme-Onne-Elelenwo-Rukpokwu AP-1	8.00m
S/No.	**BH No.**	**GW Depth**
1.	AP-2	6.00m
2.	AP-3	4.00m
3.	AP-4	7.20m
4.	AP-6	1.60m
5.	AP-8	1.50m
6.	Tw.17.3	6.00m
7.	Tw.23.3	5.00m
8.	Tw.34.3	4.50m
9.	Tw.45.3	2.80m
10.	Tw.53.3	4.00m
11.	Tw.60.3	3.50m
12.	Tw.71.3	3.50m

Table2. *Load Carrying Capacity of Single Pile at Okrika*

Depth (m)	**Pile Diameter**			
	250mm		**300mm**	
	Ultimate (kN)	**Allowable (kN)**	**Ultimate (kN)**	**Allowable (kN)**
5.00	155.82	62.33	191.87	76.75
6.00	182.92	73.17	224.39	89.75
7.00	210.02	84.01	256.91	102.76
8.00	237.12	94.85	289.43	115.77
9.00	264.22	105.69	321.95	128.79
10.0	291.32	115.53	354.46	141.79

Table3a. *Alowable Bearing Capacity along Afam-Eleme-Onne Route*

Df(m)	1 **B(m)**	0.5 **B/L**	54 **Cu**	**Γ**	374.09 **Qf**	149.64 **Qa**
1.00	1	1	54	20.12	420.26	168.10
1.50	1	0.5	54	20.12	384.15	153.66
	1	1	54	20.12	430.32	172.13
200	1	0.5	54	20.12	394.21	157.68
	1	1	54	20.12	440.38	176.15
250	1	0.5	54	20.12	404.27	161.71
	1	1	54	20.12	450.44	180.18

Table3b. *Alowable Bearing Capacity at Okrika*

Df(m)	1 **B(m)**	0.5 **B/L**	46 **Cu**	**Γ**	320.13**Qf**	128.05**Qa**
1.00	1	1	46	18.6	359.46	143.78
1.50	1	0.5	46	18.6	329.43	131.77
	1	1	46	18.6	368.76	147.50
2.00	1	0.5	46	18.6	338.73	135.49
	1	1	46	18.6	378.06	151.22
2.50	1	0.5	46	18.6	348.03	139.21
	1	1	46	18.6	387.36	154.94

Table3c. *Alowable Bearing Capacity along Elelenwo-Rukpokwu*

Df(m)	1 **B(m)**	0.5 **B/L**	46 **Cu**	**Γ**	320.13**Qf**	128.05**Qa**
1.00						
	1	1	46	19.19	360.05	144.02
1.50	1	0.5	46	19.19	330.32	132.13
	1	1	46	19.19	369.65	147.86
200	1	0.5	46	19.19	339.91	135.96
	1	1	46	19.19	379.24	151.70
250	1	0.5	46	19.19	349.51	139.80
	1	1	46	19.19	388.84	155.53

Table4. *AtterbergLimit atAfam –Eleme*

Borehole No	**Depth (m)**	**Moisture Content %**	**Liquid Limit %**	**Plastic Limit %**	**Plasticity Index %**	**Liquidity Index**	**USCS Classification**
AP-1	1.00	24	30	19	11	0.455	CL
	6.00	23	29	19	10	0.400	CL
AP-2	2.00	24	28	20	8	0.500	CL
	5.00	31	38	24	14	0.500	CL
AP-3	1.00	26	35	20	15	0.400	CL
	4.00	23	33	17	16	0.375	CL
AP-4	3.00	21	27	14	13	0.538	CL
	6.00	20	31	17	14	0.214	CL
AP-5	1.00	23	27	17	10	0.600	CL
	8.00	23	31	18	13	0.385	CL
AP-9	3.00	24	33	18	15	0.400	CL
	9.00	22	26	16	10	0.600	CL

Table5. *Atterberg limit at Okrika*

Borehole N	**Depth (m)**	**Moisture Content**	**Liquid limit**	**Plastic limit**	**Plasticity Index**	**Liquidity Index**	**USCS Classification**
		%	%	%	%		
AP-6	3.00	27	41	23	18	0.222	CL
	7.00	28	44	23	21	0.238	CL
AP-8	1.00	34	40	25	15	0.600	CL
	6.00	35	39	23	16	0.750	CL

Table6. *Atterberg limit for Elelnwo-Rukpokwu*

Borehole No	**Depth (m)**	**Moisture Content**	**Liquid limit**	**Plastic limit**	**Plasticity Index**	**Liquidity Index**	**USCS Classification**
		%	%	%	%		
Tw.1.3	2.00	31	39	27	12	0.333	CL
	8.00	23	37	20	17	0.176	CL
Tw.11.3	3.00	27	38	22	16	0.313	CL
	6.00	24	37	21	16	0.188	CL
Tw.17.3	1.00	27	37	21	16	0.375	CL
	8.00	29	40	23	17	0.353	CL
Tw.23.3	2.00	28	38	23	15	0.333	CL
	6.00	30	39	26	13	0.308	CL
Tw.34.3	3.00	29	38	22	16	0.438	CL
	8.00	26	35	20	15	0.400	CL
Tw.45.3	3.00	33	43	25	18	0.444	CL
	5.00	24	38	21	17	0.176	CL
Tw.53.3	1.00	31	42	27	15	0.267	CL
	6.00	29	39	23	16	0.375	CL
Tw.60.3	3.00	25	35	19	16	0.375	CL
	7.00	30	36	25	11	0.455	CL
Tw.71.3	2.00	27	37	20	17	0.412	CL
	6.00	26	38	19	19	0.368	CL

Table7a. *UndrainedTriaxial Compression Test for Okrika*

Borehole No		Bulk Unit	Dry Unit	Undrained Cohesion	Angle of Friction	Poisson's Ratio	Submerged	Normal Stress
	Depth	Weight	Weight					
	mts	γ_3 kN/m	γd 3 kN/m	Cu $_2$ kN/m		μ	δ3 kN/m-	δ2kN/m-
AP-6	3.00	19.10	15.02	47	6	0.472	9.29	
AP-8	1.00	18.09	13.40	45	7	0.468	8.28	

Table7b. *UndrainedTriaxial Compression Test for Elelenwo-Rukpokwu*

Borehole No		Bulk Unit	Dry Unit	Undrained Cohesion	Angle of Friction	Poisson's Ratio	Submerged	Normal Stress
	Depth	Weight	Weight			μ		
	mts	γ_3 kN/m	γd 3 kN/m	Cu $_2$ kN/m			δ3 kN/m-	δ2kN/m-
AP-6	3.00	19.10	15.02	47	6	0.472	9.29	
AP-8	1.00	18.09	13.40	45	7	0.468	8.28	
Tw.1.3	3.00	18.76	14.21	48	7	0.468	8.95	26.85
Tw.11.3	3.00	19.45	15.31	50	4	0.482	9.64	28.92
Tw.17.3	1.00	19.31	15.09	43	6	0.472	9.50	9.50
Tw.23.3	2.00	19.30	15.07	47	8	0.463	9.49	18.98
Tw.34.3	3.00	19.16	14.84	42	5	0.477	9.35	28.05
Tw.45.3	3.00	18.62	14.00	40	6	0.472	8.81	26.43
Tw.53.3	1.00	18.88	14.40	45	2	0.490	9.07	9.07
Tw.60.3	3.00	19.76	15.80	48	5	0.477	9.95	29.85
Tw.71.3	2.00	19.46	15.33	52	6	0.472	9.65	19.30

Table7c. *UndrainedTriaxial Compression Test for Afam-Eleme-Onne*

Borehole No		Bulk Unit	Dry Unit	Undrained Cohesion	Angle of Friction	Poisson's Ratio	Submerged	Normal Stress
	Depth	Weight	Weight			μ		
	mts	γ_3 kN/m	γd 3 kN/m	Cu $_2$ kN/m			δ3 kN/m-	δ2kN/m
AP-1	1.00	19.94	16.08	54	6	0.472	10.13	10.13
AP-2	2.00	19.92	16.01	50	4	0.482	10.11	20.22
AP-3	1.00	19.60	15.55	48	7	0.468	9.79	
AP-4	3.00	20.46	16.91	58	3	0.487	10.65	31.95
AP-5	1.00	20.90	16.13	56	5	0.477	11.09	11.09
BH-9	3.00	19.89	16.04	56	4	0.482	10.08	30.24

Table8. *Lateral Pressure for Afam-Eleme-Elelenwo-Rukpokwu-Onne*

Borehole No	Depth	Bulk Unit Weight	Angle of Friction	Rankine Co-efficient of Active Earth Pressure	Rankine Co-efficient of Passive earth Pressure	Rankine Co-efficient of Earth Pressure at Rest	Poisson's Ratio
	mts	r kN/m	Degree	Ka	Kp	Ko	μ
AP-1	1.00	19.94	6	0.810	1.235	0.895	0.472
AP-2	2.00	19.92	4	0.870	1.150	0.930	0.482
AP-3	1.00	19.60	7	0.783	1.278	0.878	0.468
AP-4	3.00	20.46	3	0.901	1.110	0.948	0.487
AP-5	1.00	20.90	5	0.840	1.191	0.913	0.477
AP-6	3.00	19.10	6	0.810	1.235	0.895	0.472
AP-8	1.00	18.09	7	0.783	1.278	0.878	0.468
BH-9	3.00	19.89	4	0.870	1.150	0.930	0.482
Tw.1.3	3.00	18.76	7	0.783	1.278	0.878	0.468
Tw.11.3	3.00	19.45	4	0.870	1.150	0.930	0.482
Tw.17.3	1.00	19.31	6	0.810	1.235	0.895	0.472
Tw.23.3	2.00	19.30	8	0.756	1.323	0.861	0.463
Tw.34.3	3.00	19.16	5	0.840	1.191	0.913	0.477
Tw.45.3	3.00	18.62	6	0.810	1.235	0.895	0.472

Tw.53.3	1.00	18.88	2	0.925	1.081	0.961	0.490
Tw.60.3	3.00	19.76	5	0.840	1.191	0.913	0.477
Tw.71.3	2.00	19.46	6	0.810	1.235	0.895	0.472

Table9. *Particle Size Statistics*

BH No	Depth	Effective Particle Size D_{10}	D_{30}	Mean Particle Size D_{50}	D_{60}	Coef. of Uniformity $Cu=D_{60}/D_{10}$	Coef. of Curvature $Cc=D_{30}^2/(D_{10}*D_{60})$	Coef. of Permeability $K=C*D_{10}^2$
	8.00	0.085	0.260	0.400	0.470	5.529	1.692	0.00058
	(m)	(mm)	(mm)	(mm)	(mm)			(m/sec)
AP-1	10.00	0.090	0.270	0.390	0.450	5.000	1.800	0.00065
AP-2	9.00	0.120	0.220	0.340	0.390	3.250	1.034	0.00115
	10.00	0.110	0.250	0.360	0.400	3.636	1.420	0.00097
AP-3	9.00	0.425	2.100	4.800	5.200	12.235	1.995	0.01445
AP-4	10.00	0.110	0.250	0.350	0.400	3.636	1.420	0.00097

Table10. *Particle Size Statistics for Elelenwo-Rukpokwu*

BH No	Depth	Effective Particle Size D_{10}	D_{30}	Mean Particle Size D_{50}	D_{60}	Coef. of Uniformity $Cu=D_{60}/D_{10}$	Coef. of Curvature $Cc=D_{30}^2/(D_{10}*D_{60})$	Coef. of Permeability $K=C*D_{10}^2$
	9.00	0.120	0.300	0.380	0.400	3.333	1.875	0.00115
	(m)	(mm)	(mm)	(mm)	(mm)			(m/sec)
Tw.60.3	10.00	0.130	0.300	0.380	0.400	3.077	1.731	0.00135
Tw.71.3	9.00	0.110	0.230	0.340	0.370	3.364	1.300	0.00097
	10.00	0.120	0.270	0.350	0.390	3.250	1.558	0.00115

CONCLUSION

Seventeen (17) soil boring points and cone penetration tests each were executed along the electricity transmission route. Eight (8) borings and CPTs each were executed along Afam-Eleme-Onne route and nine (9) points were executed between Elelenwo and Rukpokwu. Field investigations revealed within the depth explored; presence of medium to firm lateritic clayey formation along the transmission route from Afam-Eleme-Onne.

At Okrika, the formation is predominantly silty clay of firm consistency. The lithologies along Elelenwo-Rukpokwu are similar to the ones encountered at Afam-Eleme-Onne. The lower sands exhibited fairly high SPT values indicating medium densities. Groundwater table was measured and the water samples tested for chemical properties.

The laboratory test results of the soil revealed appreciable values for the undrained shear strength and natural specific weight unit for soil which is typical for Type ‘2’ soil class. To support super-structures, it is suggested that the installation of Isolated Pad/Chimney footing be provided; a standardized pad footing designed in square dimension to mobilize adequate support. At Okrika, the super-structures should be supported on pile. However, where the super-structure is found to be excessive, it could be supported by means of continuous footings with foundation beams to minimize the problem of differential settlement.

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