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AN INTEGRATED GEOTECHNICAL INVESTIGATION FOR STRUCTURAL FOUNDATION SUITABILITY ACROSS NIGER RIVER, NORTH CENTRAL NIGERIA

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Abstract - **The need to assess the suitability of foundation soil for oil and gas installations, such as pipeline, stations, and all other ancillary facilities, necessitated this study across the Niger River of north central Nigeria. A total of 17 boreholes and cone penetration tests were conducted. Samples were recovered from the boreholes and tested in the laboratory to obtain soil parameters. The investigation revealed that the subsurface is essentially composed of FINE SAND/SAND and CLAY. The FINE SAND is largely the superficial soil except in BH1 where CLAY is the superficial soil. The FINE SAND is loose at the top becoming medium dense and clayey at the base as it grades into CLAY. It has a greyish colour, with moisture content between 6% and 29% and bulk unit weight between 15.17 kN/m^3 and 21.76 kN/m^3. The CLAY underlies the FINE/SAND and SAND. It is generally greyish in colour, with moisture content between 12% and 29% and bulk unit weight between 15.17 kN/m^3 and 21.30 kN/m^3 and an average strength of 156 kN/m^2 except where it is the surficial soil and soft (strength < 25 kN/m^2). Oversize materials were not encountered during the investigation and as such shall not pose any risk to horizontal directional drilling operation. However, on the Island, within the FINE SAND, bed of gravel occurs in BH8 and BH9. In terms of plasticity, due to saturation, the soils are not expected to swell. Nevertheless, it is advisable to add polymers to the drilling mud to prevent transfer of water from the drilling fluid into the soil as a precaution for clayey soils at the entry and exit points and on the Island. Most of the soil contains fines less than 30% and therefore, specific measures may be employed to improve borehole stability during drilling and installation.**

Keywords: **Cone penetration test; Geotechnical investigation; Niger River; Oil and gas installation.**

I. INTRODUCTION

The suitability of foundation materials is paramount in the design and construction of engineering structures on the Earth surface [1]. This is often carried out by means of engineering and geotechnical soil investigations. Recently, the Nigerian government has increased their interest in expending the oil and gas infrastructure with a view of increasing the oil and gas revenue accruing to the country. An example of such project is the Ajaokuta – Kaduna – Kano (AKK) Section of the Trans Nigeria Gas Pipeline Project. The objective of developing the AKK Section is to install all required facilities such as pipeline, stations, and all other ancillary facilities.

The purpose of this study was to carry out a geotechnical investigation within the project area, along the Right of Way (ROW) of the Proposed Trans-Niger Gas Pipeline Project (Segment 1) Ajaokuta-Abuja-Kaduna-Kano (AKK). The study entailed boreholes and cone tests at the pipeline entry (land) at Ogbongoro, the pipeline exit (land) at Adamago, on the island, and inside the water.

The geotechnical investigation was carried out along the Right of Way between Ogbongoro and Adamago sections of the River Niger in Kogi State. Figure 1 shows the general project area, while figures 2 and 3 show the digital elevation model

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and the 3D visualization of the boreholes sunk in the study area.

Three (3) distinct components characterise the Geology of the country Nigeria. The components are the Basement Complex, the Younger Granites and Sedimentary Basins. Present extensively within the region, is the basement complex of North Central and Northwest Nigeria. Within the basement complex of Nigeria, four major petro-lithological units are distinguishable [2, 3] these are Migmatite-Gneiss Complexes, the Schist Belt, the Older Granites (Pan African granitoids), and the undeformed Acid and Basic Dykes.

The area of investigation lies within one of the seven sedimentary basins in Nigeria. The investigation was conducted on a section of cretaceous undifferentiated sedimentary strata that is part of the middle Niger basin, commonly known as the Bida basin; this basin is an intracratonic basin. [4, 5]. The Bida Basin is a NW-SE trending inland basin, stretching from Shegwa (NW) to Dekina (SE). It is approximately 350 km long and varies in width from 75 to 150 km. It is roughly elliptical in ground plan and runs perpendicularly to the western margin of the NE-SW trending Benue Trough Complex. Unlike other sedimentary basins in Nigeria, it is characterized by the absence of volcanics, carbonates and rocks of Tertiary age [6].

Structurally, the basin occupies a gently down warped trough and stratigraphically, the basin's strata are late cretaceous in age and generally called Nupe Sandstone which may be sub-divided into four formations, Bida sandstone, Sakpe Ironstone, Enagi Siltstone and Batati Ironstone [7, 8].

The vegetation is mainly savannah, it comprises tall grasses inter-spaced with scattered species. The general area experiences two weather conditions annually. This includes a warm, humid rainy season and dry season. In between the two, there is a brief interlude of harmattan occasioned by the northeast trade wind, with the main feature of dust haze and dryness. The warm, humid rainy season characterized by heavy downpour is usually between April to October with an annual rainfall ranging between 1000mm and 1600mm (and an average of 1250mm) while the dry season lasts from November to March.

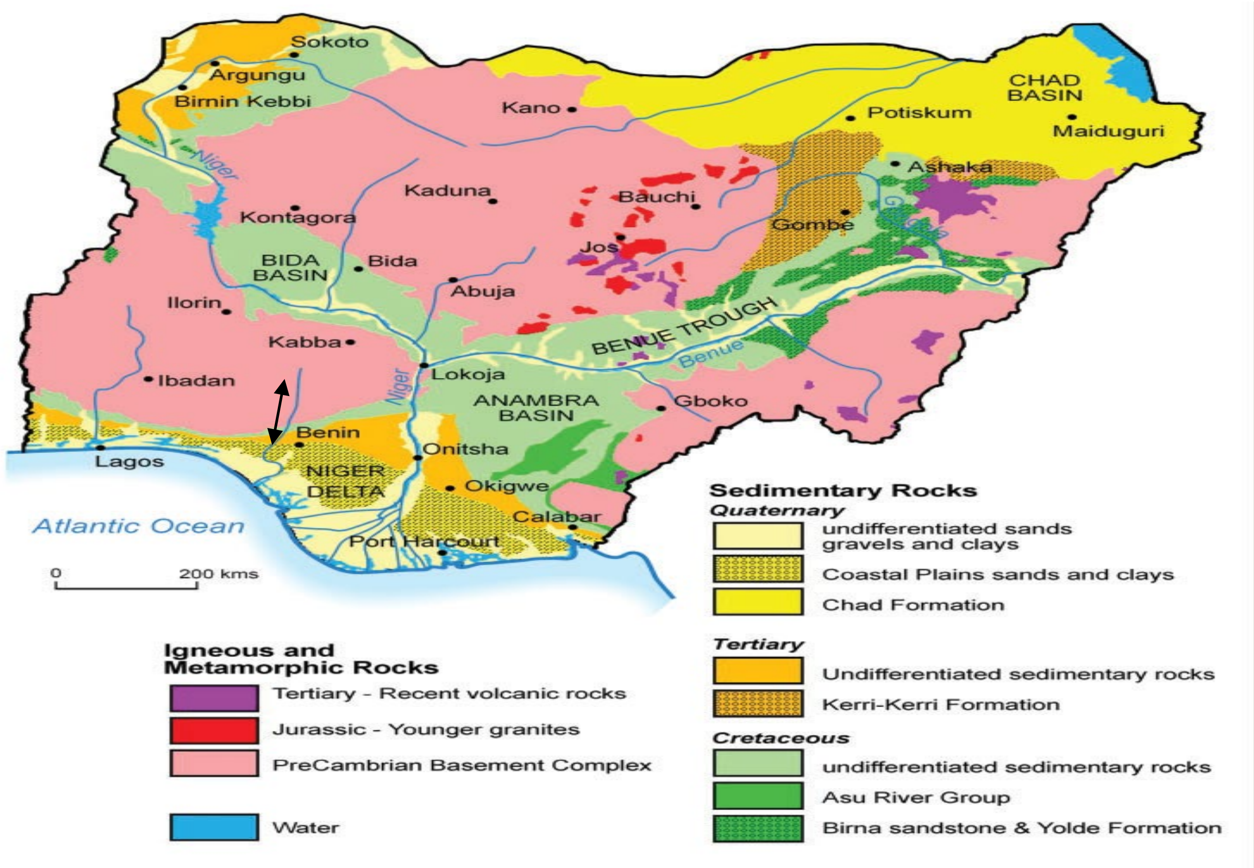

Figure 1. Geological Map of Nigeria showing Project Location

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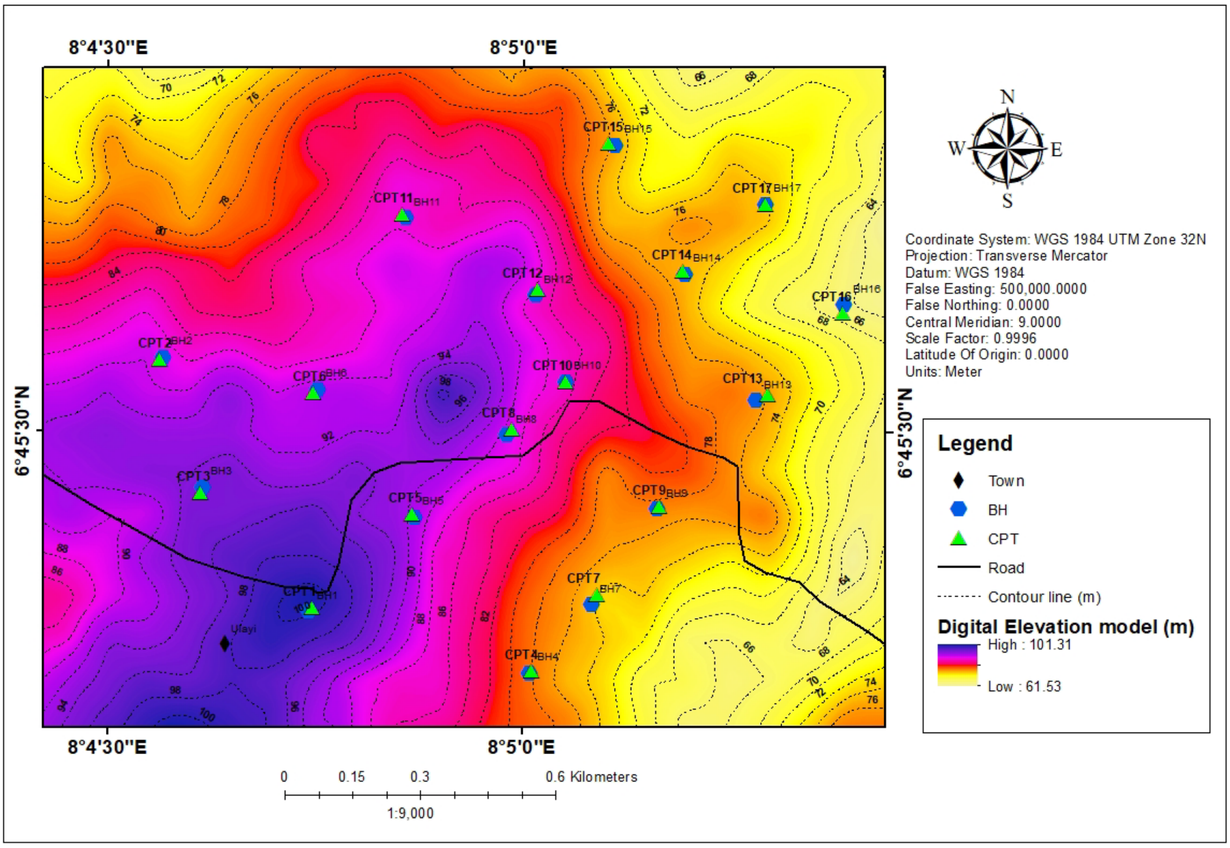

Figure 2: Digital elevation model of the study area

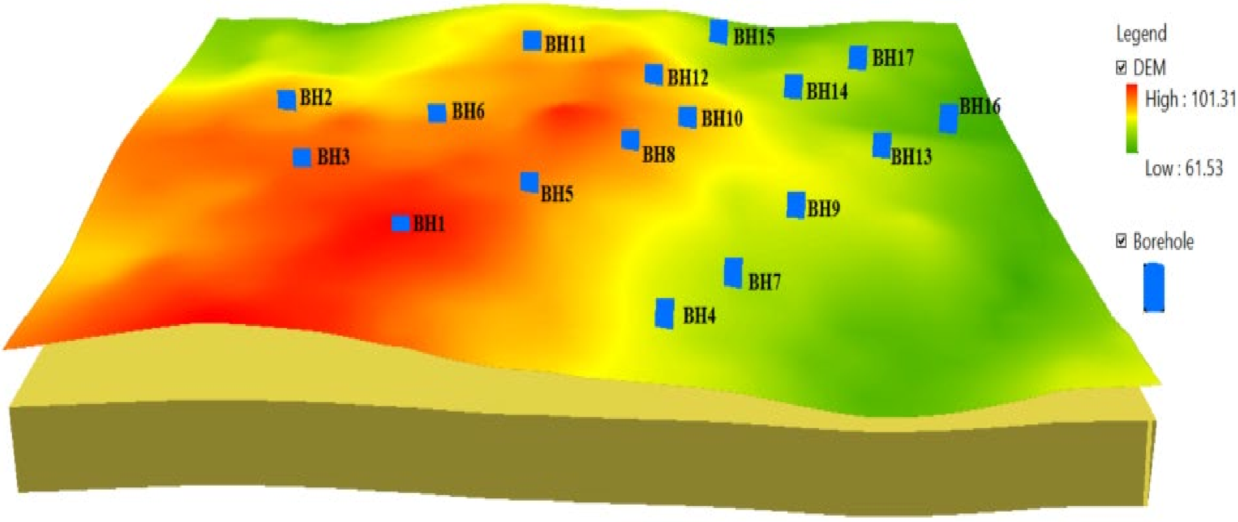

Figure 3: 3D visualization of borehole

II. METHODOLOGY

A. Boring and Standard Penetration Test

The fieldwork consists of borehole drilling with soil sampling/rock coring. Rotary rigs were deployed for the investigation. The overburden soils were excavated with SPT recorded at 1.50m intervals in cohesionless soil. The clay cutting bit cuts through the soil to advance the boring such that the soil material is retrieved from the holes. Soil samples and Standard Penetration Test (SPT)were taken at intervals of 1.50m depth until weathered rock was encountered. The test locations and their coordinates are presented in the Table 1, with coordinates in UTM.

Sampling was carried out in the boreholes and trial pits to obtain samples for laboratory analysis. In boreholes, disturbed samples were collected by means of the split spoon sampler and from the drilling spoils. These were properly labelled and placed in watertight bags to ensure sample integrity while undisturbed samples were collected by means of open-tube sampler. Both ends of the tube were properly sealed, labelled and secured. In the trial pits, bulk samples were collected at regular intervals and when there was a change in the lithology. The samples were labelled and bagged in a large bag. During the investigation, the samples were adequately protected and well preserved, after which they were transported to the laboratory for analysis.

Table 1. Summary of Test Points

Test ID	Easting (m)	Northing (m)	Elevation (m)	Depth (m)	Location
Boreholes					
BH1	252560.760	893721.761	65.693	40.00	On Land
BH2	252605.669	893773.359	63.418	40.00	On Land
BH3	252649.846	893824.960	63.646	40.00	River Bank
BH4	252707.872	893885.831		40.00	In Water
BH5	252770.640	893953.970		40.00	In Water
BH6	252831.420	894024.380		40.00	In Water
BH7	252892.680	894091.850		40.00	In Water
BH8	252953.350	894158.890	63.189	40.00	On Island
BH9	253013.630	894224.660	62.711	40.00	On Island
BH10	253071.351	894287.873	64.148	40.00	On Island
BH11	253131.540	894355.570		40.00	In Water
BH12	253193.050	894425.170		40.00	In Water
BH13	253251.790	894487.750		40.00	In Water
BH14	253310.780	894551.210		40.00	In Water
BH15	253388.873	894639.712	64.994	40.00	River Bank
BH16	253427.960	894683.422	63.978	40.00	On Land
BH17	253466.343	894728.258	63.498	40.00	On Land
Cone penetration test (CPT)					
CPT1	252567.859	893728.550	65.535		On Land
CPT2	252606.094	893773.530	63.479		On Land
CPT3	252654.983	893828.272	63.879		River Bank
CPT4	252714.260	893880.719			In Water
CPT5	252775.820	893951.020			In Water
CPT6	252837.140	894017.780			In Water
CPT7	252901.290	894087.950			In Water
CPT8	252964.802	894170.346	63.189		On Island
CPT9	253009.105	894218.774	63.129		On Island
CPT10	253071.679	894288.768	64.199		On Island
CPT11	253136.797	894347.597			In Water
CPT12	253197.310	894412.620			In Water
CPT13	253259.380	894483.870			In Water
CPT14	253318.458	894546.276			In Water
CPT15	253385.739	894643.037	64.898		River Bank
CPT16	253427.529	894682.531	63.094		On Land
CPT17	253465.771	894728.887	63.524		On Land

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B. Cone penetration test (CPT)

The cone penetration test (CPT) was carried out using a Piezo-Cone. The Piezo-Cone penetration test (PCPT) sounding is conducted by drilling the cone tip first into the ground, at the designated location. The cone is pushed into the ground at a rate of 20 mm/s, using an electrically powered ram from the Cone Penetrometer. The Cone Penetrometer is a machine that houses an ‘A’ frame with provisions for transducers that are connected to a computer. Before commencing the tests at the location, the upper part of the electric cone was screwed to the base of the pipe shaft with the upper end of the pipe shaft supporting the push rod of the Penetrometer. Passing through the pipe shaft is an electrical cable that leads to the transducer. The transducer is connected to a computer. From the computer monitor, the progress of the test was observed. The cone in position was advanced by continuously pushing the pipe shaft by means of the push rod. Continuous measurements were made of the resistance to penetration of the cone tip and the frictional sliding resistance of the sleeve of the cone. Pore pressure was also measured during the test.

After the cone and first pipe, measuring 1000 mm long, were completely pushed into the ground, the push rod was released and slide up on the ‘A’ frame to allow another pipe to be screwed on. The lower part of the new pipe was screwed to the upper part of the pipe in the ground while the upper part supports the push rod. Continuous readings were taken throughout the test. The process was repeated until the target depth or refusal was attained. Refusal is the point where it is no longer safe for either the operator or the machine to continue the test. To provide reaction to the lifting force experienced by the Penetrometer while advancing the cone, the penetrometer was held to the ground by screwing pickets into the ground. The pickets were then screwed to the base frame of the penetrometer. The results of the test are presented as a plot of depth against cone tip resistance, **qc**, sleeve friction, **qs**, frictional ratio and pore pressure. A chart that matches these measurements with the physical characteristics of different soils can be used to determine the kind of soil.

C. Laboratory Tests

Selected soil samples were analysed for engineering properties. The tests were carried out in accordance with standard procedures as stipulated in [9] for moisture content,[10] for Atterberg Limits, and [11] for Unit Weight. Unconsolidated Undrained Triaxial test and Direct Shear Box Test were were carried out following [12] and [13] respectively. Specific Gravity, Particle Size Analysis, and Hydrometer Test were also conducted on the recovered samples.

III. RESULTS AND DISCUSSION

A. Sub-Surface Stratigraphy

The subsurface stratigraphy is presented in this section from both the observed stratigraphy from the boreholes and laboratory tests on samples recovered and from soil behaviour type (SBT) as recorded by the cone penetration tests. Cone Penetration Test points are generally taken at a radius of 5m – 10m around the respective borehole test point. The test points (boreholes and CPTs) and the test points layout are presented in Figure 4. Composite cross section along the pipeline crossing route is presented in Figure 5 below. However, in the following discussion, the stratigraphy is described in sections; entry point, island, boreholes in water and exit point as shown in Figures 6, 7, and 8. Tables 2 to 5 provide a summary of the soil layers.

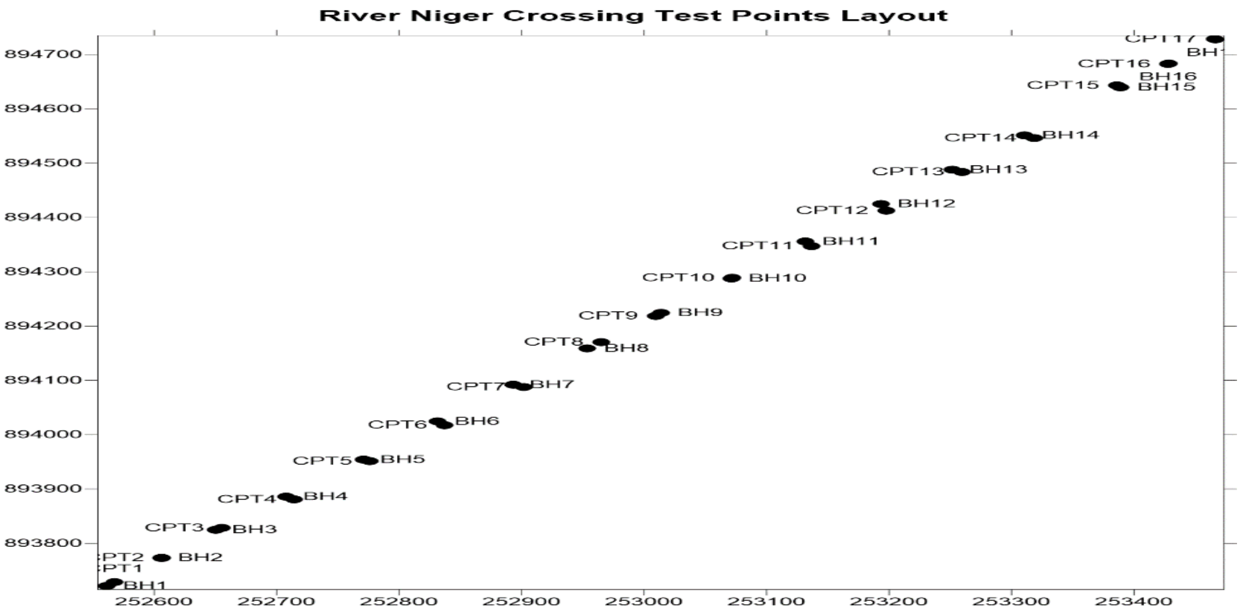

Figure 4. River Niger Crossing Test Points Layout

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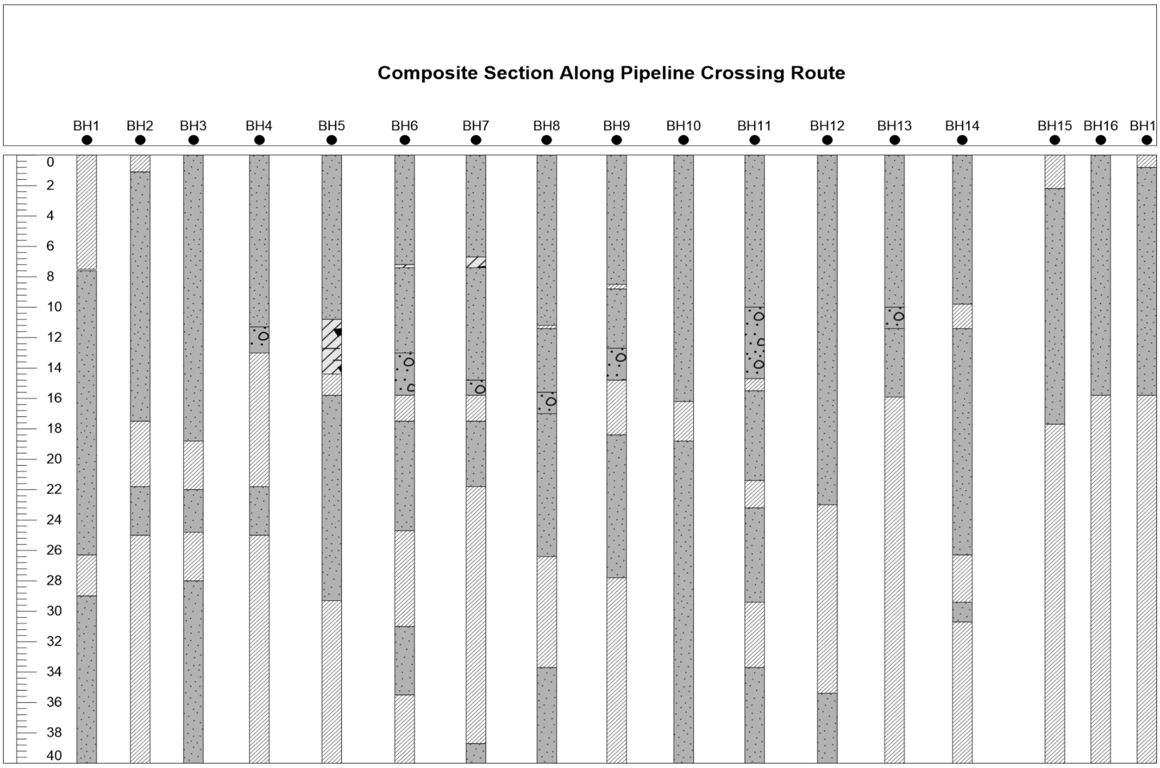

Figure 5. Composite Cross Section Along River Niger Pipeline Crossing Route

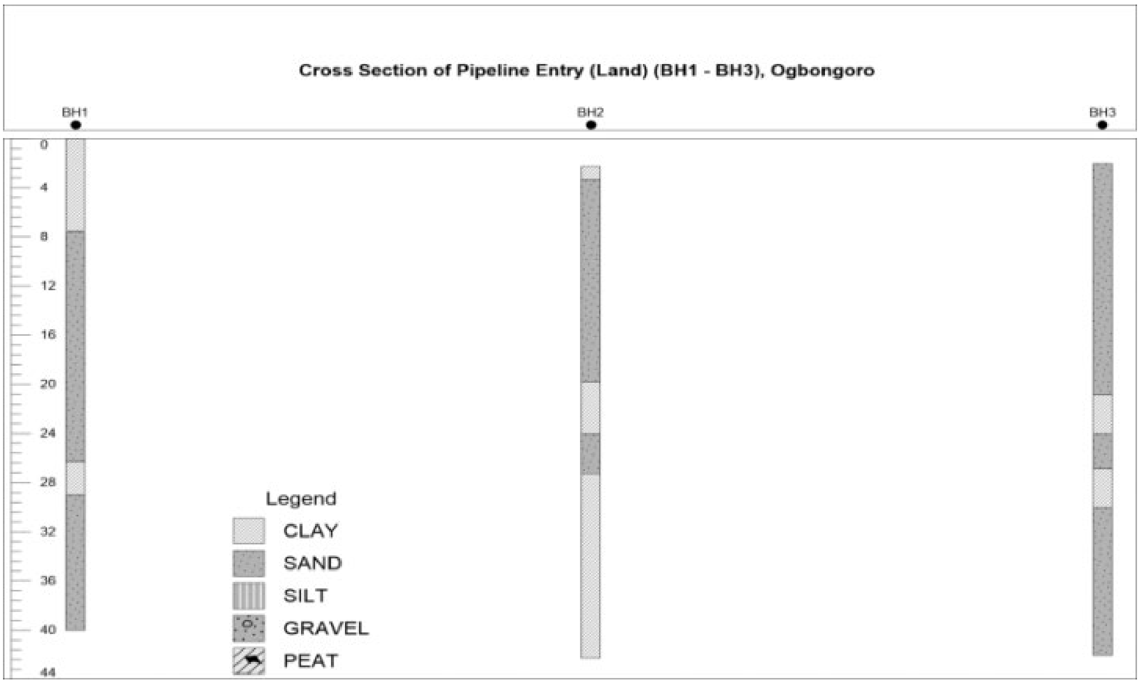

Figure 6. Cross Section of Pipeline Entry (Land) (BH1 - BH3), Ogbongoro

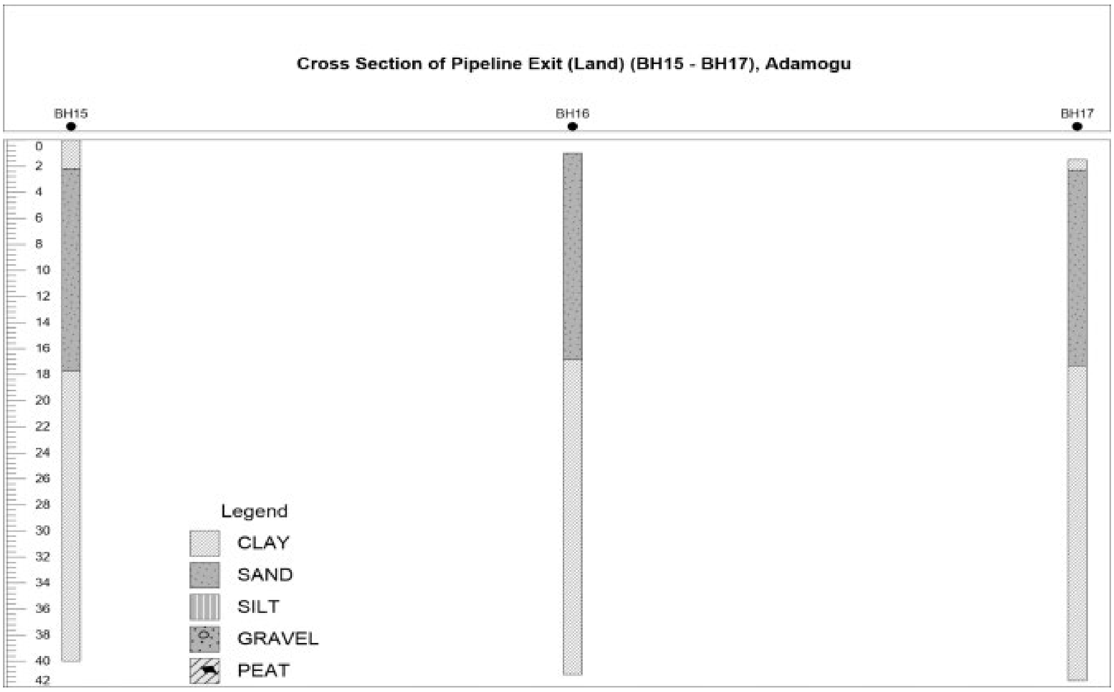

Figure 7. Cross Section of Pipeline Exit (Land) (BH15 - BH17), Adamogu

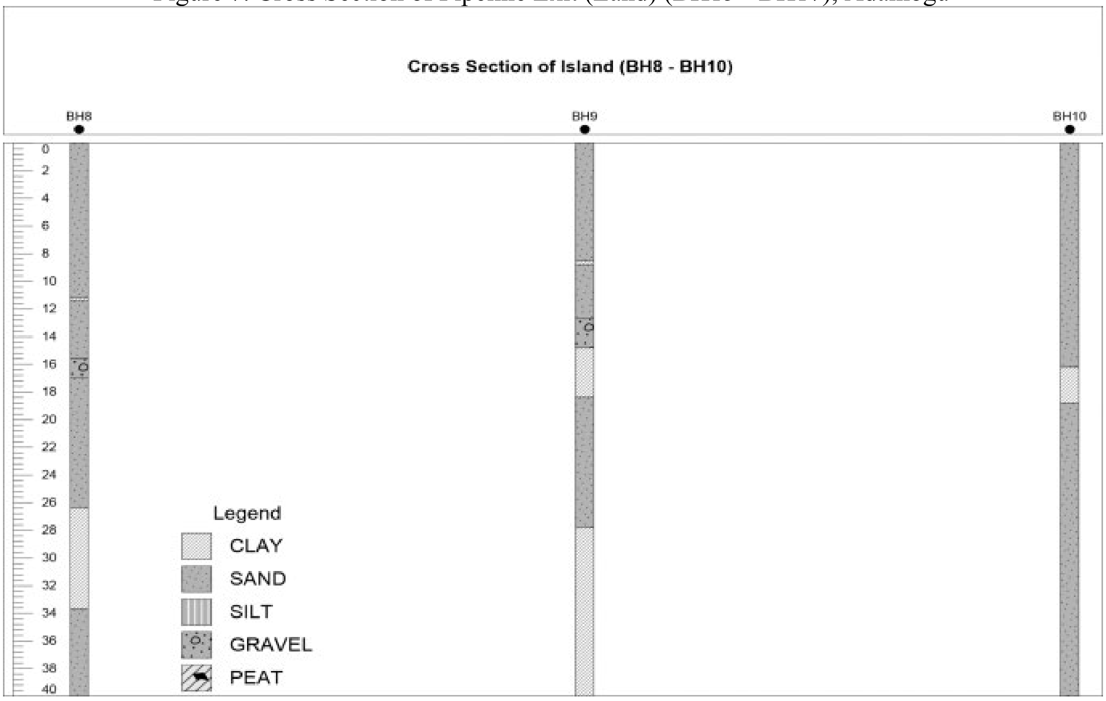

Figure 8. Cross Section of Island (BH8 - BH10)

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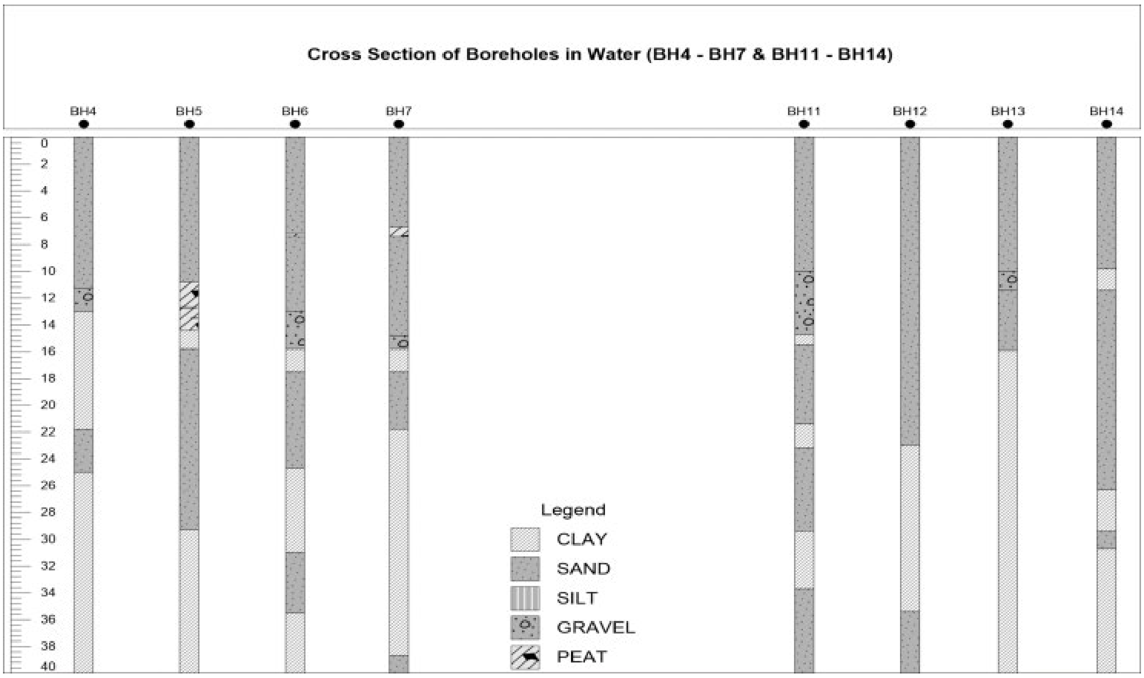

Figure 9. Boreholes in Water (BH4 - BH7 & BH11 - BH14) Pipeline Entry (Land), Ogbongoro

Table 2. Summary of Stratigraphy - Pipeline Entry (Land), Ogbongoro

Layer	BH1	BH2	BH3
1	CLAY	CLAY	
2	SAND	SAND	SAND
3	CLAY	CLAY	CLAY
4	SAND	SAND	SAND
5		CLAY	CLAY
6			SAND

Table 3. Summary of Stratigraphy - Pipeline Entry (Land), Ogbongoro

Layer	BH8	BH9	BH10
1	SAND	SAND	SAND
2	CLAY	CLAY	CLAY
3	SAND	SAND	SAND
4		CLAY	

i. Boreholes on Land

BH1 consists of four (4) strata while BH2 and BH3 consists of five (5) strata. However, the first stratum of CLAY in BH1 and BH2 is missing in BH3. This superficial CLAY layer is 7.5m thick in BH1 and 1.1m thick in BH2. SPT values suggest the CLAY is soft and occurs as a dark grey stratum. It has a moisture content of 20%, unit weight of 16.37kN/m^3 and a liquid limit ≥ 50%. FINE SAND which constitutes the second stratum of BH1 and the first stratum of BH3 occurs as FINE SAND, very loose to medium dense and grey in colour except in BH3 where it was brown. In BH1, it was found to be clayey at the base as it grades into CLAY. It is 18.80m, 16.40m and 18.80m thick in BH1, BH2 and BH3 respectively. It has a

moisture content between 21% and 24% and unit weight between 18.31kN/m^3 and 19.79kN/m^3.
The CLAY layer underlying the FINE SAND constitutes the third stratum of BH1 and BH2 and second stratum of BH3. It is sandy, gravelly (in BH2), greyish in colour and SPT values suggest it is very stiff. It has a moisture content between 14% and 27%, unit weight between 18.22kN/m^3 and 20.84kN/m^3 and classifies as 'lean clay' (CL) with liquid limit less than 50%. SAND constituting the fourth layer of BH1 and BH2 and basal layer in BH1, is clayey, gravelly (in BH2) and very dense. It is 11.00m, 4.00m and 2.80m thick in BH1, BH2 and BH3 respectively. It has a moisture content between 9% and 16%, unit weight between 17.94kN/m^3 and 19.21kN/m^3. CLAY layer was found to underlie the SAND in BH2, and it is the basal stratum encountered in the borehole, but it was not encountered in BH1. It is sandy and grey in colour. This CLAY is underlain by SAND in BH3 to the terminal depth of BH3.

ii. Boreholes on Island

On the Island, three (3) boreholes were drilled, BH8, BH9 and BH10. BH8 and BH10 consists of three (3) strata while BH9 consists of four (4) strata. FINE SAND constitutes the superficial strata on the Island and was found across the three boreholes. It occurs as FINE SAND, very loose to medium dense with a medium bedded dark grey PEATY CLAY and thickly bedded to very thickly bedded gravel both present in BH8 and BH9 but absent in BH10. The FINE SAND is greyish in colour. It is 26.40, 14.80 and 16.20 m thick in BH8, BH9 and BH10, respectively. It has a moisture content between 17 and 21% and unit weight between 18.00 and 18.70kN/m^3.
The CLAY layer underlying the FINE SAND constitutes the second stratum on the Island. SPT values suggest it is very stiff to hard, sandy, and brownish in colour with a thickness of 7.30, 3.60 and 2.60 m in BH8, BH9 and BH10, respectively. It has a moisture content between of 20% and unit weight between of 15.17 kN/m^3. The third stratum on the Island is SAND which is the basal layer in BH8 and BH10. It is clayey, very dense and greyish in colour. It has a moisture content between 15% and 18% and unit weight between 17.55 and 17.72kN/m^3. The fourth stratum on the Island is the CLAY layer underlying the SAND and only encountered as the basal unit in BH9. It is very stiff to hard, sandy, and greyish in colour.

iii. Boreholes in Water

Eight boreholes in total were drilled, 4 apiece of the island. BH4, BH5, BH6 and BH7 on one side with BH11, BH12, BH13 and BH14 on the other side. The stratigraphy has been interpreted to be fairly continuous across the sides of the Island. Group 1 consists of only BH6 with 4 strata consisting of FINE SAND, CLAY, SAND and CLAY. Group 2 consists of BH4, BH7, BH11 and BH12 presenting with similar lithostratigraphy consisting of three (3) strata of FINE SAND, CLAY, and SAND while Group 3 consists of BH5, BH13 and BH14 presenting with similar lithostratigraphy consisting of two (2) strata of FINE SAND and CLAY. The sequence as obtained in Group 1 corresponds to the sequence obtained in BH9 on the Island while Group 2 corresponds with the sequence obtained in BH8 and BH10 on the Island. The lithologies also presents with similar properties. However, in the water, the boreholes encountered additional soil bodies within the surficial FINE SAND that vary from thinly bedded (60mm to 200mm) to very thick bedded (>2000mm) as shown on the borehole logs.

Table 4. Summary of Stratigraphy – Boreholes in Water

Layer	**BH4**	**BH5**	**BH6**	**BH7**	**BH11**	**BH12**	**BH13**	**BH14**
1	**Group 2**	**Group 3**	**Group 1**	**Group 2**	**Group 2**	**Group 2**	**Group 3**	**Group 3**
2	SAND	SAND	SAND	SAND	SAND	SAND	SAND	SAND
3	CLAY	CLAY	CLAY	CLAY	CLAY	CLAY	CLAY	CLAY
4	SAND		SAND	SAND	SAND	SAND		
5			CLAY					

Table 5. Summary of Stratigraphy - Pipeline Exit (Land), Adamogu

Layer	**BH15**	**BH16**	**BH17**
1	CLAY	SAND	CLAY
2	SAND	CLAY	SAND
3	CLAY		CLAY

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iv. Pipeline Exit (Land), Adamogu

Three boreholes were drilled, BH15, BH16 and BH17. BH15 and BH17 consists of three (3) strata in the same lithostratigraphy while BH16 consists of two (2) strata. However, the first stratum of CLAY in BH15 and BH17 is missing in BH16. This superficial CLAY layer is very thin; 2.2m thick in BH15 and 0.8m thick in BH17. FINE SAND which constitutes the second stratum of BH15 and BH17 and the first stratum of BH16 occurs as FINE SAND, very loose to medium dense, clayey and greyish in colour. It is 15.50m, 15.80m and 15.00m thick in BH15, BH16 and BH17 respectively. This SAND unit has an occurrence of SANDSTONE with RQD of 30 between 15.50 and 16.00m in BH15. It has a moisture content between 12 and 27% and unit weight between 15.75 and 21.30 kN/m^3. The CLAY layer underlying the FINE SAND constitutes the basal layer in the three boreholes. It is sandy, greyish in colour and SPT values suggest it is very stiff. It has a moisture content between 12 and 27%, unit weight between 15.75 and 21.30 kN/m^3 and classifies as 'lean clay and lean silt' (CL and ML) with liquid limit less than 50%.

B. Soil Behaviour Type (SBT)

The Soil Behaviour Type (SBT) are presented on the Cone Penetration Charts in Figures 10a and 10b. The SBT is fnction of the friction ratio given in percent. It is the ratio of skin friction divided by the tip resistance. It is used to classify the soil, by its behavior, or reaction to the cone being forced through the soil. High ratios generally indicate clayey materials, while lower ratios are typical of sandy materials (or dry desiccated clays). Typical skin friction to tip friction ratios are 1% to 10%.. Sands are generally identified by exhibiting a ratio < 1%.

C. Geotechnical Consideration for River Crossing

i. Soil Parameters

The geotechnical properties of the subsurface encountered were determined by field and laboratory investigations. The summary of the parameters of the lithologies encountered as obtained from laboratory tests are presented in Tables 6 to 9.

Table 6 Soil Parameters of the Lithologies at Entry Point, Ogbongoro

SAND					
S/N	**Parameter**		**Min**	**Max**	**Mean**
1	Moisture content	%	9	29	19
2	Bulk unit weight	kN/m^3	16.39	20.84	18.46
3	Dry unit weight	kN/m^3	14.04	18.23	15.54
4	Submerged unit weight	kN/m^3	6.58	11.03	8.65
5	Particle density	t/m^3	2.56	2.66	2.60
6	Angle of frictional resistance	^{o}			

CLAY					
1	Moisture content	%	12	29	20
2	Bulk unit weight	kN/m^3	16.37	20.84	18.28
3	Dry unit weight	kN/m^3	13.60	18.23	15.26
4	Liquid limit	%	24	52	35
5	Plastic limit	%	15	34	21
6	Plasticity index	%	4	27	14
7	Cohesion	kN/m^2			

Table 7 Soil Parameters of the Lithologies in the Water

SAND					
S/N	**Parameter**		**Min**	**Max**	**Mean**
1	Moisture content	%	6	24	16
2	Bulk unit weight	kN/m^3	16.06	21.76	18.88
3	Dry unit weight	kN/m^3	15.06	19.30	16.24
4	Submerged unit weight	kN/m^3	6.25	11.95	9.07
5	Particle density	t/m^3	2.61	2.64	2.62
6	Angle of frictional resistance	^{o}	29	40	33
CLAY					

SAND					
S/N	**Parameter**		**Min**	**Max**	**Mean**
1	Moisture content	%	13	21	17
2	Bulk unit weight	kN/m^3	17.56	20.80	18.80
3	Dry unit weight	kN/m^3	15.06	17.44	16.11
4	Liquid limit	%	20	24	21
5	Plastic limit	%	10	22	15
6	Plasticity index	%	2	10	6
7	Cohesion	kN/m^2	150	170	156

Table 8 Soil Parameters of the Lithologies on the Island

SAND					
S/N	**Parameter**		**Min**	**Max**	**Mean**
1	Moisture content	%	15	21	18
2	Bulk unit weight	kN/m^3	15.17	18.70	17.59
3	Dry unit weight	kN/m^3	12.60	15.81	14.93
4	Submerged unit weight	kN/m^3	7.74	5.36	8.89
5	Particle density	t/m^3	2.55	2.59	2.57
6	Angle of frictional resistance	^{o}			
CLAY					
1	Moisture content	%	20	20	20
2	Bulk unit weight	kN/m^3	15.17	15.17	15.17
3	Dry unit weight	kN/m^3	12.60	12.60	12.60
4	Liquid limit	%			
5	Plastic limit	%			
6	Plasticity index	%			
7	Cohesion	kN/m^2			

Table 9 SoilParameters of the Lithologies at Exit Point, Adamogu

SAND					
S/N	**Parameter**		**Min**	**Max**	**Mean**
1	Moisture content	%	9	27	19
2	Bulk unit weight	kN/m^3	16.47	19.94	18.49
3	Dry unit weight	kN/m^3	13.90	16.89	15.59
4	Submerged unit weight	kN/m^3	6.66	10.13	8.68
5	Particle density	t/m^3	2.57	2.64	2.60
6	Angle of frictional resistance	^{o}			
CLAY					
1	Moisture content	%	12	27	19
2	Bulk unit weight	kN/m^3	15.75	21.30	18.46
3	Dry unit weight	kN/m^3	13.82	18.31	15.55
4	Liquid limit	%	26	33	29

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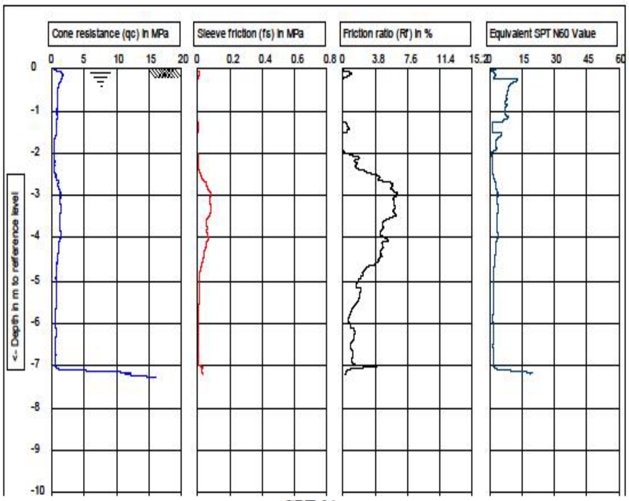
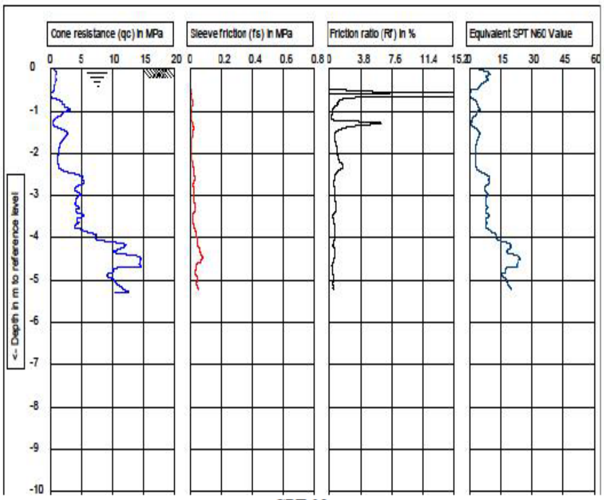
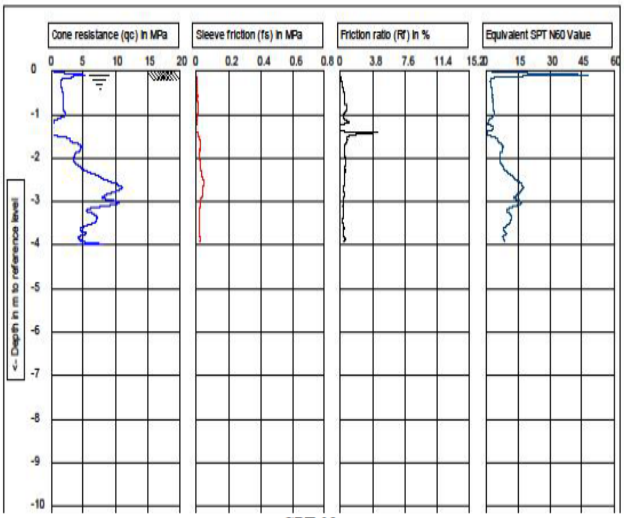
SAND					
S/N	**Parameter**		**Min**	**Max**	**Mean**
5	Plastic limit	%	22	22	22
6	Plasticity index	%	2	11	7
7	Cohesion	kN/m^2			



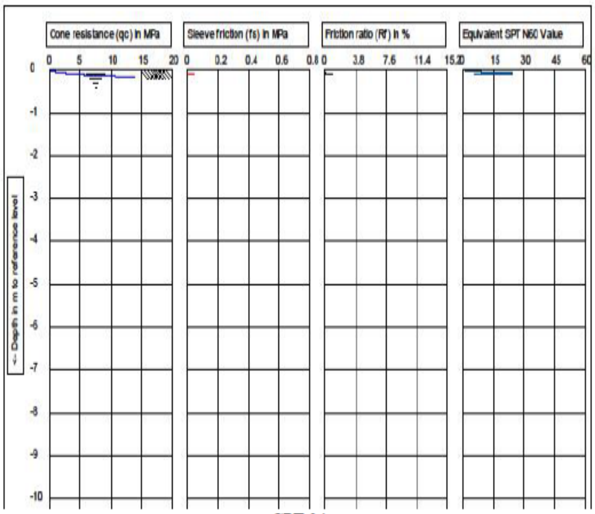
CPT 01



CPT 03



CPT 02



CPT 04

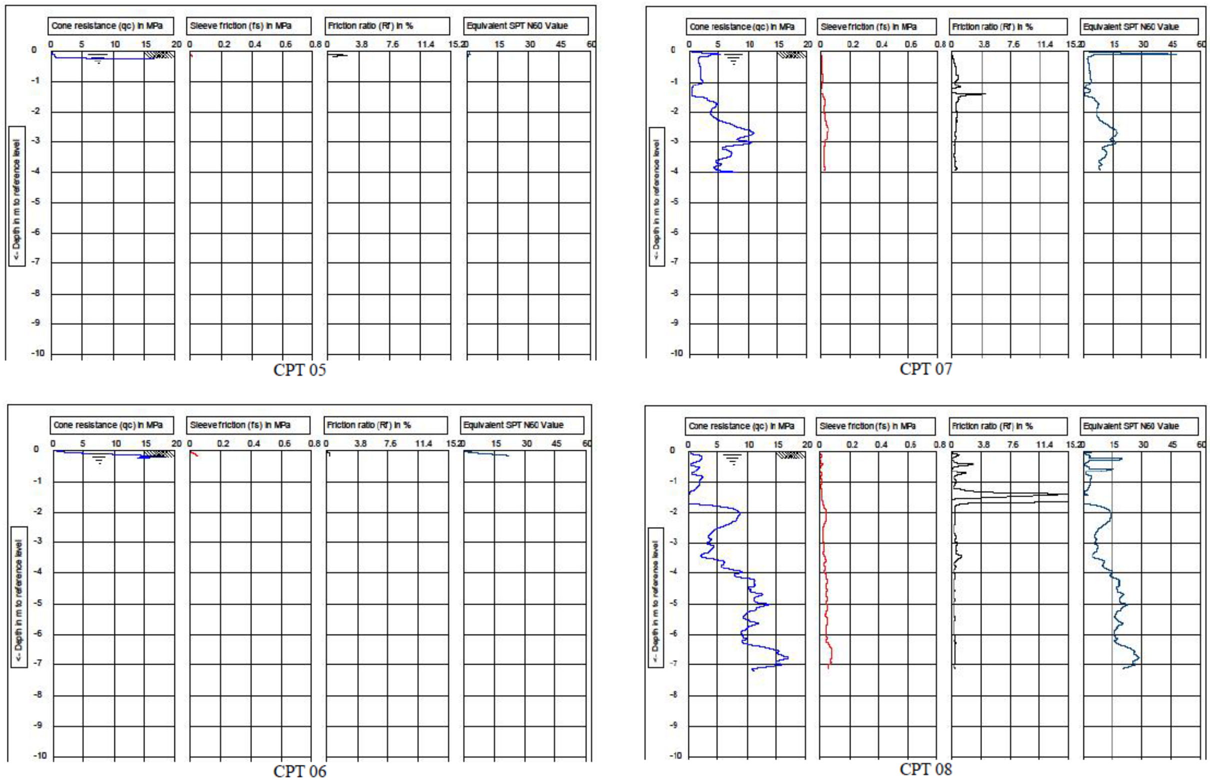
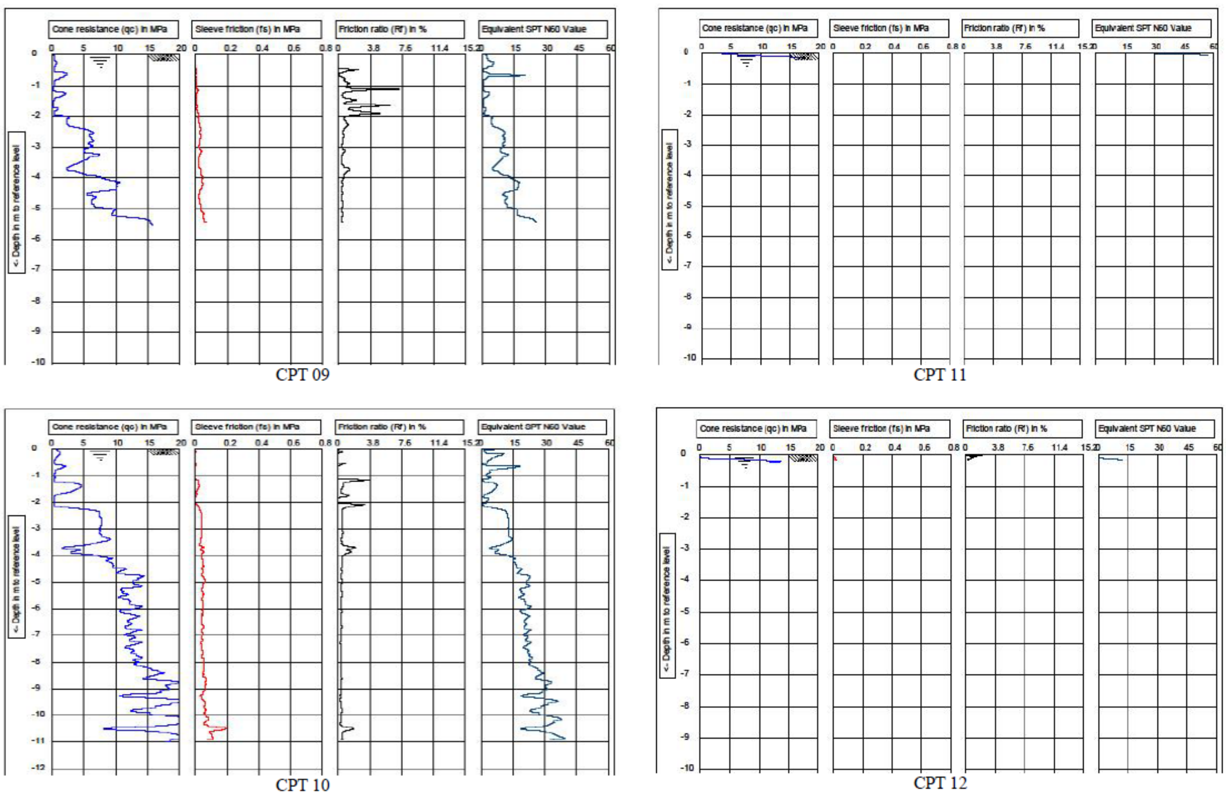


Figure 10a: CPT 1-8 results



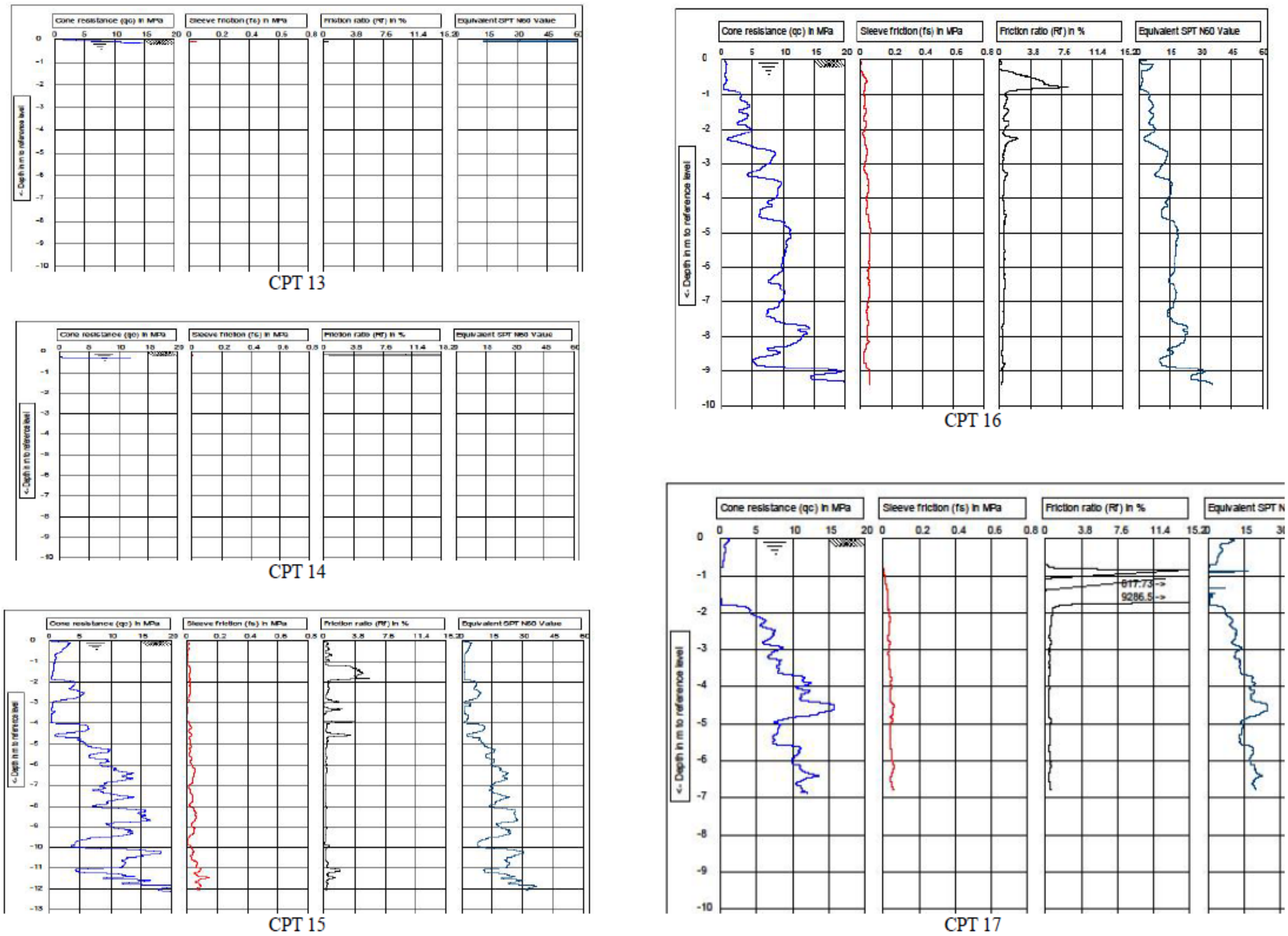


Figure 10B: CPT 9-17 results

D. Geotechnical Consideration for Installation

Successful drilling and installation of oil and gas facilities significantly depends on the subsurface conditions along the pipeline alignment to determine its viability and operational parameters. According to [14], during drilling, the reaming tools or the product pipe itself may occasionally physically remove particles that are too big or heavy to be suspended in the drilling fluid, but these particles can also gather to form an unbreakable barrier inside the borehole. Similar to this, the majority of drilling fluid producers concur that soil particles 19mm [34 inch] or larger (coarse gravel size) cannot be suspended within an effective drilling fluid. This implies that, the driller should be aware of the sections within the FINE SAND where bed of gravel occurs in BH8 and BH9. Cobblestones and boulders, which have a diameter of more than 76 mm (3 inches), pose a clear and significant risk to drilling operations.

As it relates to the soil's propensity to swell when in contact with water, it is important to note the plasticity of fine-grained soils in the planning and course of drillin. In general, soils that are dry or desiccated are more prone to swell than soils that are moist or below the water table. Highly plastic soils are more likely to swell than low- to medium-plastic soils (such as those classified as lean clay or silt). Although the soils are not generally expected to swell, it is nonetheless prudent to add polymers to the drilling fluid to prevent water from the drilling fluid from penetrating the higher FINE SAND layer since it is clayey at the top.

The surficial layer of BH1 is soft CLAY. The FINE SAND constituting the bulk of the superficial soil across all test points at the top (up to first 5m) is significantly loose. This will pose challenges to the drilling operation. Essentially, it can be concluded that the subsurface is composed of SAND underlain by CLAY except in BH1. The SAND is substantial in the vertical, from ground level to a depth of about 20m across all locations and laterally continuous. However, the SAND at deeper depth is clayey as it degrades into the underlying CLAY. Fills, obstructions and contamination were not encountered during the investigation and will not pose any concern to the operation.

In order to offer some protection against surface heave and/or hydro fracture, the minimum depth of cover for an installed pipeline is typically determined. Specifically, for the River Niger crossing, adequate depth of cover is required as the crossing is susceptible to scouring going by the nature of material on the riverbed. Nevertheless, it is anticipated that in line with standard practice, trenchless crossing shall provide a minimum of 4.60m and up to 7.60m depth of cover [15] with the entry point about 100m away from the riverbank.
Typically, only clean, coarse-grained soils—that is, sands and gravels with less than 12% fines—are a concern for drilling fluid loss. It is anticipated that there may be loss of drilling fluid at some section where the FINE SAND/SAND are clean but not so much where the soil SAND is clayey which is entirely dependent on the drill design. A coarse-grained soil's capacity to withstand unrestrained running or flowing is directly correlated with its fines concentration. In general, specific countermeasures will be required to address borehole stability whenever the fines content (i.e., the percentage, by weight, of particles smaller than 75 m in diameter) is less than about 30%, as it is in the upper occurrence of FINE SAND across most of the test points.

IV. CONCLUSION

The Geotechnical Investigation for the River Niger Pipeline Crossing Route was conducted by means of boreholes and Cone Penetration Tests. Samples were recovered from the boreholes and tested in the laboratory to obtain soil parameters. The investigation revealed that the subsurface is essentially composed of FINE SAND/SAND and CLAY. The FINE SAND is largely the superficial soil except in BH1 where CLAY occurs. The FINE SAND is loose at the top becoming medium dense and clayey at the base as it grades into CLAY. It has a greyish colour, with moisture content between 6% and 29% and bulk unit weight between 15.17kN/m^3 and 21.76kN/m^3. The CLAY underlies the FINE/SAND and SAND. It is generally greyish in colour, with moisture content between 12% and 29% and bulk unit weight between 15.17 kN/m^3 and 21.30 kN/m^3 and an average strength of 156 kN/m^2 except where it is surficial soil and soft.
Oversize materials were not encountered during the investigation and as such shall not pose any risk to the drilling operation. However, on the Island, within the FINE SAND stratum, bed of gravel occurs in BH8 and BH9. In terms of plasticity, due to saturation, the soils are not expected to swell. However, it is advisable to add polymers to the drilling mud to prevent transfer of water from the mud into the soil as a precaution for clayey soils at the entry and exit points and on the Island. Most of the soil contains fines less than 30% and therefore, specific measures may be employed to improve borehole stability during drilling and installation.

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