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Geotechnical Evaluation of the Escravos Beach Ridge for Onshore Pipeline Route Design, Western Niger Delta, Nigeria

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Abstract: This study evaluates the sub-soil geotechnical characteristics and ground conditions prior to excavation and placement of pipeline requirement for the feasibility of the pipeline network at the onshore pipeline route at Escravos terminal, Western Niger Delta, Nigeria. Acquisition of soil samples for geotechnical studies was done by conventional boring method using light shell and auger hand rig. Samples were analyzed in the laboratory using standard analytical procedures. The study reveals that the stratigraphy of the superficial layers indicate a reasonable degree of uniformity from BH2 to BH12 with a top soft organic silty clay underlain by sandy clay that grades into loose to medium fine grained sand towards 10m depth. In BH1, the entire 10m depth consists of sandy formation of loose to medium dense relative density. The water table is close to the ground surface and the sections of the pipeline route are periodically submerged by seasonal and sometimes tidal floods. Results of this study constitute useful preliminary information and data required for future planning and infrastructural development in the area.

Index Terms: Geotechnical, pipeline route, sub-soil, Escravos, Western Niger Delta, Nigeria

Introduction

The Beach Ridge is the new focus of development with the construction of an export pipeline at Escravos terminal as part of Escravos Export System Project with an onshore length of about 6km. The new export pipeline is routed in a pipeline corridor where many pipes have already been buried especially the Liquified Natural Gas (LNG) line and Shell Petroleum Development Company (SPDC) trunk. An important requirement for the feasibility of the pipeline network project is knowledge of the sub-soil geotechnical characteristics and ground conditions prior to excavation and placement of pipeline. Geotechnical investigations were needed specifically to determine the sub-soil stratigraphy and geotechnical properties from soil samples obtained at appropriate levels. Knowledge of this will guide in the assessment of ground conditions for pipeline placement. Geotechnical studies are highly important in such projects. Thus, a good estimate of the risk associated with geotechnical parameters has become a major issue since most of the new structures are located on sites with difficult conditions [1]. This study therefore forms part of an integrated geotechnical assessment of the project site and discusses the results of sub-soil geotechnical investigations carried out on the onshore pipeline route at Escravos terminal.

Location and Description of the Study Area

Escravos Island, located in the eastern part of the Niger Delta is a sandy beach ridge delta front environment of the Nigeria Atlantic coastal setting (Fig.1). The area is characterized by active wave attack on active beaches on the seaward sides. The surrounding Escravos River is characterized by fairly strong wave activity and tidal currents. Soil formation and plant growth on beach ridge is prevalent. The prevalent mangrove marshy swamp and criss-crossing creeks impose obvious difficulties in assessing the pipeline route.

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Fig.1. Map of Nigeria showing Niger Delta, Delta State and Escravos, the study location

Stratigraphically, the Niger Delta is divided into Akata, Agbada and Benin Formations in order of decreasing age. It is one of the most important petroleum provinces in the world; as a result the petroleum geology of the area has been a subject of intense study. Unfortunately, the surface and shallow Quaternary cover appear not to have received much attention. The major aquiferous Formation in this study area is the Benin Formation [2], [3]; [4]. It is about 2100m thick at the basin centre [5].

Geology of the area comprises Pleistocene - Recent sediments deposited and redistributed by fluvial and shallow continental shelf hydrodynamic processes [6]; [5]; [7]. The lithofacies include soft organic clay that forms the back swamp and the delta tip consisting mainly of evenly laminated clean grayish fine to medium sands, very fine sands, silts, clayey silt and silty clay with abundant plant debris [8]. Vegetation consists predominantly of mangrove swamps with thick marshy terrain. The ridge is low-lying in elevation with strong reversal tide and the terrain is submerged in places, at high tide [9]. The ground water level is high to the ground surface with flooded swamps at high tide. The study site is mostly submerged in water to depths varying from 0.2m to 0.5m in places.

Methods of Investigation

Acquisition of soil samples for geotechnical studies was done by conventional boring method using light shell and auger hand rig. The samples were examined, identified and roughly classified in the field and later taken to the laboratory for tests. A series of classification, strength and compressibility tests were carried out on the samples in strict compliance with relevant geotechnical engineering standards including British standards (BS 1377); [10]; [11]; [12]. Laboratory classification tests were conducted on a number of soil samples to verify and improve on the field identification. These tests include natural moisture content, unit weights, specific gravity, Atterberg limits (liquid and plastic) and grain size distribution.

Results and Discussion

The litho-stratigraphy of the boreholes is presented as Fig.2 while Table 1 shows the engineering properties of the soils along the pipeline route. The top layers of the soil formation on the pipeline route consist of soft organic silty clay underlain by sand. At the the tank farm area, it consists essentially of sands. Fig. 3 is the plasticity chart showing Casagrande classification by Atterberg. Particle size statistics are shown in Table 2 while Table 3 shows the shear strength parameters of the soils at depth along with ultimate and allowable bearing pressures. Finally, results of soil chemical analysis for organic content and carbonate along the pipeline route are shown as Table 4.

The stratigraphy of the superficial layers indicate a reasonable degree of uniformity from BH2 to BH12 with a top soft organic silty clay underlain by sandy clay that grades into loose to medium fine grained sand towards 10m depth. In BH1, the entire 10m depth consists of sandy formation of loose to medium dense relative density. The water table is close to the ground surface and sections of the pipeline route are periodically submerged by seasonal and sometimes tidal floods.

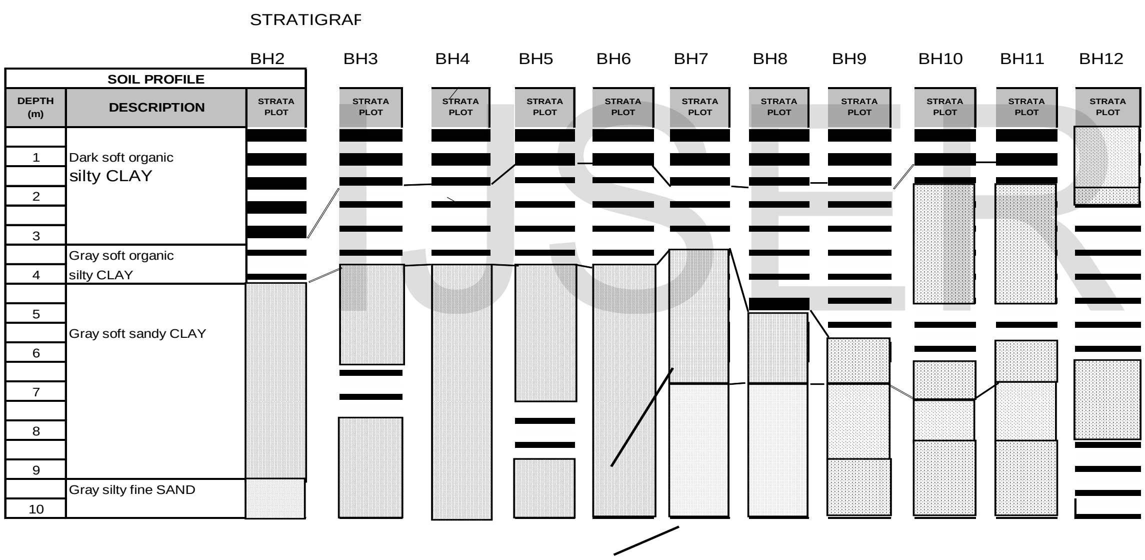

Figure 2: Sub-soil stratigraphy along proposed pipeline route

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TABLE 1: ENGINEERING PROPERTIES OF THE SOIL ALONG PIPELINE ROUTE

BH No.	Depth (m)	Natural Moisture Content (%)	Bulk Density (KN/m^3)	Liquid Limit %	Plastic Limit %	Plastic Index %	Remarks
2	1.5-1.95	130	12.3	151	36.2	114.8	Dark gray Very Soft silty organic Clay
	3.0-3.45	127	12.7	139	37.0	102	Dark gray Very Soft silty organic Clay
	4.50-4.95	117	13.6	142	36.5	105.5	Dark gray Very Soft silty Clay
3	1.5-1.95	121	12.8	137	36	101	Dark gray Very Soft silty organic Clay
	4.5-4.95	48	15.5	90	35	55	Dark gray very soft silty Clay
	6.00-6.50	91	14.3	97	26.5	70.5	Dark gray soft silty Clay
	9.00-9.45	32	18.9	101	48	53	Dark gray very soft silty sandy Clay
4	1.50-1.95	108	12.6	120	33	87	Dark gray very soft silty organic Clay
	3.00-3.45	101	13.4	124	35.3	88.7	Dark gray very soft silty Clay with fragments of rootlets
	6.00-6.45	80	15.0	118	25	93	Dark gray very soft silty Clay with fragments of rootlets
5	1.5-1.95	108	13.8	118	37	91	Dark gray very soft silty Clay
	4.50-4.95	84	14	128	37.5	90.5	Dark gray very soft silty Clay
	8.25-9.00	51	18.8				Dark gray very soft Clayey silty sands
6	1.5-1.95	88	13.7	127	36	91	Dark gray very soft silty Clay
	6.00-6.45	74	15.0	107	26.5	80.5	Dark gray very soft silty Clay
7	1.50-1.95	95	13.2	120	34	86	Dark gray very soft silty organic Clay
	3.0-3.45	82	14.3	90	37	53	Dark gray very soft silty Clay with fragments of rootlets
	6.00-6.45	63	16.0	62	22	40	Dark gray very soft silty Clay
8	1.50-1.95	105	12.1	122	32	90	Dark gray very soft silty organic Clay
	3.45-3.75	113	13.5	128.5	43.5	85	Dark gray very soft silty Clay
9	1.50-1.95	102	12.6	119	32	87	Dark gray very soft silty organic Clay
	4.50-4.95	62	15.5	81.5	12.5	69	Dark gray very soft silty Clay
	6.00-6.45	56	16.0	69	12	57	Dark gray very soft silty Clay
10	2.25-3.00	85	13.3	114	36	78	Dark gray very soft silty Clay
	6.00-6.75	62	15.2	95	37	58	Dark gray very soft silty Clay
11	1.50-1.95	95	12.9	108	36	72	Dark gray very soft silty organic Clay
	3.00-3.45	111	13.7	99.5	28	71.5	Dark gray very soft silty Clay
	5.25-6.00	70	15.2	71	22	49	Dark gray very soft silty Clay
12	3.0-3.50	100	12.1	117	36	81	Dark gray very soft silty organic Clay
	4.5-4.95	104	13.4	112	35	77	Dark gray very soft silty Clay
	7.5-7.95	37	15.6	92	24	68	Dark gray very soft silty Clay

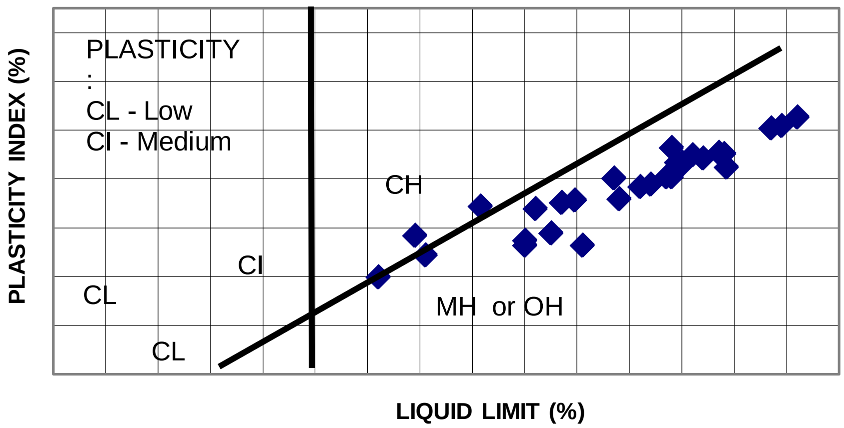

Figure 3: Plasticity chart showing Casagrande Soil classification by Atterberg limits

TABLE 2. PARTICLE SIZE STATISTICS

BH No	Depth (m)	D_{10} (mm)	D_{30} (mm)	D_{50} (mm)	D_{60} (mm)	$Cu=D_{60}/D_{10}$	$Cz=D_{30}^2/(D_{10}*D_{60})$	$K=C*D_{10}^2$ (m/sec)
1	1.50-1.95	0.15	0.19	0.22	0.25	1.667	0.963	0.00225
	3.0-3.45	0.16	0.19	0.21	0.23	1.438	0.981	0.00256
2	9.75-10.0	0.16	0.18	0.21	0.23	1.438	0.880	0.00256
6	7.95-8.0	0.17	0.19	0.22	0.24	1.412	0.885	0.00289
7	7.50-7.95	0.16	0.19	0.21	0.22	1.375	1.026	0.00256
9	7.50-7.95	0.17	0.19	0.21	0.22	1.294	0.965	0.00289

TABLE 3: SHEAR STRENGTH PARAMETERS OF THE SOILS AT DEPTH ALONG WITH ULTIMATE AND ALLOWABLE BEARING PRESSURE

Borehole	Depth Range (m)	Working Depth (m)	Cu	Φ	Ultimate Bearing Capacity kPa	Safe Bearing Capacity kPa
1	1	1	0	30	334	133.62
	2	2	0	31	388	155.22
	3	3	0	30	442	176.82
	4	4	0	33	496	198.42
	5	5	0	32	766	306.42
2	1.5-1.95	1.75	17	0	98.3	39.32
	3.0-3.45	3.25	17	0	99.5	39.8
	4.5-4.95	4.75	35	5	203.3	81.32
	6.00-6.45	6.25	23	0	136.1	54.44
	7.5-7.95	7.75	26	0	154.4	61.76
	9.75-10	9.85	24	3	144.68	57.872
	1.5-1.95	1.75	15	0	86.9	34.76
3	3.0-3.45	3.25	20	0	116.6	46.64
	4.5-4.95	4.75	16	3	95	38
	6.00-6.45	6.25	21	0	124.7	49.88
	7.5-7.45	7.75	23	5	137.3	54.92
	9.00-9.45	9.85	18	4	110.48	44.192

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	1.5-1.95	1.75	15	0	86.9	34.76
4	3.0-3.45	3.25	18	0	105.2	42.08
	4.5-4.95	4.75	18	5	106.4	42.56
	6.00-6.45	6.25	23	7	136.1	54.44
	7.5-7.95	7.75	32	5	188.6	75.44
	1.5-1.95	1.75	15	0	86.9	34.76
5	3.0-3.45	3.25	15	0	88.1	35.24
	4.5-4.95	4.75	18	3	106.4	42.56
	6.00-6.45	6.25	21	5	124.7	49.88
	7.5-7.95	7.75	35	0	205.7	82.28
	9.00-9.45	9.85	18	5	110.48	44.192

Borehole	Depth Range (m)	Working Depth (m)	Cu	Φ	Ultimate Bearing Capacity kPa	Safe Bearing Capacity kPa
	1.5-1.95	1.75	18	0	104	41.6
6	3.0-3.45	3.25	16	0	93.8	37.52
	4.5-4.95	4.75	26	3	152	60.8
	6.00-6.45	6.25	24	4	141.8	56.72
	7.5-7.95	7.75	21	3	125.9	50.36
	9.00-9.45	9.25	20	3	121.4	48.56
	1.5-1.95	1.75	12	0	69.8	27.92
7	3.0-3.45	3.25	18	0	105.2	42.08
	4.5-4.95	4.75	18	0	106.4	42.56
	6.00-6.45	6.25	35	6	204.5	81.8
	1.5-1.95	1.75	14	0	81.2	32.48
8	3.0-3.45	3.25	18	0	105.2	42.08
	4.5-4.95	4.75	18	0	106.4	42.56
	6.00-6.45	6.25	24	4	141.8	56.72
	9.00-9.45	9.85	29	5	173.18	69.272
	1.5-1.95	1.75	12	0	69.8	27.92
9	3.0-3.45	3.25	18	0	105.2	42.08
	4.5-4.95	4.75	15	0	89.3	35.72
	6.00-6.45	6.25	23	10	136.1	54.44
	9.00-9.45	9.25	35	3	206.9	82.76
	1.5-1.95		15	3	85.5	34.2
10	3.0-3.45		18	5	102.6	41.04
	4.5-4.95		17	0	96.9	38.76
	6.00-6.45		23	8	131.1	52.44
	9.00-9.45		18	5	102.6	41.04
	1.5-1.95		13	3	74.1	29.64
11	3.0-3.45		18	5	102.6	41.04
	4.5-4.95		18	0	102.6	41.04
	6.00-6.45		23	6	131.1	52.44
	9.00-9.45		20	3	114	45.6
	3.00-3.45		12	0	68.4	27.36

12	4.5-4.95	18	0	102.6	41.04
	6.00-6.45	17	0	96.9	38.76
	7.50-7.95	25	3	142.5	57
	9.00-9.45	27	3	153.9	61.56

TABLE 4: RESULTS OF CHEMICAL ANALYSIS OF SEDIMENT

S/No.	BH No.	Depth (m)	pH	µs/cm Electrical Conductivity	% Organic Carbon	Organic Matter	Carbonate
1	1	1.95	7.4		0.57	1.2	0.4
2		4.5	7.7		0.5	0.95	0.25
3	2	3	7.5	16,300	2.6	3.4	2.1
4		6	7.9	16,900	1.9	2.8	1.1
5	3	1.5	7.6	16,560	4.3	6.8	2.3
6		4.5	7.6	16,219	2.1	2.7	0.5
7	4	1.5	7.8	16,920	3.7	7.5	2.1
8		4.5	7.5	16,325	2.5	3.1	1.4
9	5	2.5-3.0	7.74	16,100	3.2	5.52	1.93
10		6	7.9	16,700	1.9	2.4	0.7
11	6	1.5-1.95	7.92	16,900	4.19	7.22	2.11
12		4.5	7.8	15,800	2.4	3.1	1.2
13	7	1.5	7.7	16,100	4.4	7.3	2.3
14		4.5	7.5	16,850	2.2	2.8	0.78
15	8	3	7.8	16,210	2.1	3.9	1.5
16		6	7.7	16,275	1.8	2.2	1.2
17	9	1.5	7.6	16,700	3.8	7.9	2.3
18		6	7.7	16,890	2.3	3.1	1.3
19	10	1.5-1.95	7.77	15,000	4.28	7.38	2.2
20		4.5	7.8	16,350	1.7	3.2	1.6
21	11	1.95-2.25	7.75	14,300	3.96	6.82	2.04
22		6	7.4	16,500	1.4	2.3	1.1
23	12	1.95	7.7	15,400	3.5	6.3	2.1
24		4.5	7.6	16,720	2.1	2.7	1.4

Conclusion

The litho-stratigraphy of the boreholes shows the engineering properties of the soils along the pipeline route. The top layers of the soil formation on the pipeline route consist of soft organic silty clay underlain by sand. At the tank farm area, it consists essentially of sands. The result of this study also revealed the sub-soil geotechnical characteristics and ground conditions prior to excavation and placement of pipeline requirement for the feasibility of the pipeline network at the onshore pipeline route at Escravos terminal, Western Niger Delta, Nigeria. The stratigraphy of the superficial layers indicate a reasonable degree of uniformity from BH2 to BH12 with a top soft organic silty clay underlain by sandy clay that grades into loose to medium fine grained sand towards 10m depth. The entire 10m depth consists of sandy formation of loose to medium dense relative density in BH1. The water table is close to the ground surface and the sections of the pipeline route are periodically submerged by seasonal and sometimes tidal floods. This study therefore, highlighted useful preliminary information and data required for future planning and infrastructural development in the study area.

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