American Journal of Civil Engineering and Architecture, 2015, Vol. 3, No. 1, 8-14
Available online at http://pubs.sciepub.com/ajcea/3/1/2

DOI:10.12691/ajcea-3-1-2

Geotechnical Properties of Sub- Soils in Escravos Estuary, Western Niger Delta, Nigeria

H.O Nwankwoala[1], A.N. Amadi[2,*], T. Warmate[3], M. O. Jimoh[2]

[1]Department of Geology, University of Port Harcourt, Nigeria
[2]Department of Geology, Federal University of Technology, Minna, Nigeria
[3]Geostrat International Services Limited, No.14 Mannila Pepple Street, D-Line, Port Harcourt, Nigeria
*Corresponding author: geoama76@gmail.com

Received November 22, 2014; Revised December 20, 2014; Accepted January 11, 2015

Abstract This study evaluates the sub-soil geotechnical characteristics at the onshore pipeline route at Escravos estuary, 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 samples explored showed a profile of very soft greenish dark grey and reddish brown clay formation. All samples observed confirmed this lithostratigraphy except for some of the grab samples. The entire formation generally, presents a low amount of organic content, low shear strength and high carbonate content. The unit weight showed an increase with high carbonate content. The samples gave a high amount of moisture content, higher than the liquid limit which indicates that on loading the pipeline route, the weight of the pipeline will dissipate a large amount of the pore water with a resultant increase in settlement. The pipeline should be placed on slippers pad at designated locations on the seabed along the survey route to avoid excessive settlement. This would distribute the anticipated pressure from the pipeline over a greater area and thus reduce the excessive settlement which is the characteristics of the very soft marine clay encountered in this investigation. The dimensions and bearing capacity of such slippers pads can easily be determined.

Keywords: *Geotechnical Properties, borehole, sub-soil, Settlement, Pipeline, Escravos Estuary, Western Niger Delta, Nigeria*

Cite This Article: H.O Nwankwoala, A.N. Amadi, T. Warmate, and M. O. Jimoh, "Geotechnical Properties of Sub- Soils in Escravos Estuary, Western Niger Delta, Nigeria." *American Journal of Civil Engineering and Architecture*, vol. 3, no. 1 (2015): 8-14. doi: 10.12691/ajcea-3-1-2.

1. Introduction

This study aims at evaluating the geotechnical characteristics of sub-soils along a pipeline route in Escrvos estuary, Western Niger Delta, Nigeria. 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 sub-soil properties is necessary as a guide in the assessment of ground conditions for pipeline placement. 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 (Haddou, *et al.*, 2013; Nwankwoala and Warmate, 2014 and Nwankwoala *et al.*, 2014; Nwankwoala and Oborie, 2014). This study therefore forms part of an integrated geotechnical assessment of the Escravos pipeline network project.

The aim of the pre-construction survey is to acquire the necessary information needed to confirm the engineering properties of the location of the routing of the one (1) 30" export oil pipeline (including the onshore and offshore portions of the route) and to confirm and supplement the geotechnical information. This analysis is necessary to obtaining foundation design parameter values for the placing of the pipeline.

1.1. The Study Area

The site which situates in the Escravos Estuary area is located in the western part of the Niger Delta which is a sandy beach ridge delta front environment of the Nigeria Atlantic coastal setting (Figure 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.

Generally, the stratigraphy of 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 (Etu – Efeotor, 1981; Etu-Efeotor & Odigi, 1983; Abam, 1999).

Geology of the area comprises Pleistocene - Recent sediments deposited and redistributed by fluvial and shallow continental shelf hydrodynamic processes (Allen, 1965; Short and Stauble, 1967; Amajor & Ofeogbu, 1988). 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 (Etu-Efeotor & Akpokodje, 1990). 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 (NDES, 1999).

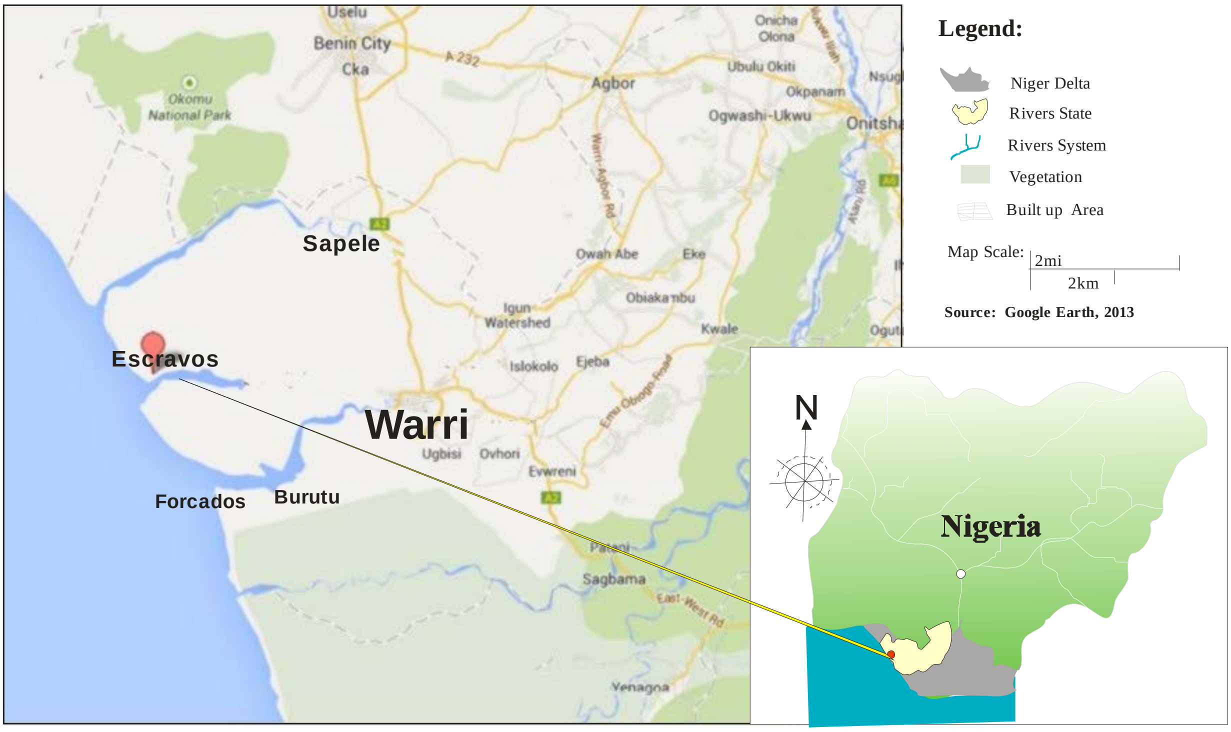

Figure 1. Map of Delta State Showing the Study Location - Escravos Island

2. Methods of Study

2.1. Sampling and Sample Description

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. Eighteen (18) gravity core samples and sixty-one (61) grab samples were recovered from the Escravos, Western Niger Delta. The sample tubes were cut open lengthwise and the samples contained therein were described visually. Sieve analysis was performed using standard method. Sieving was carried out for particles that would be retained on a 0.063 mm sieve, while additional hydrometer readings were carried out when a significant fraction of the material passes a 0.063 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). Sieve analysis was 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 C_u, where $C_u = D_{60}/D_{10}$, and the coefficient of curvature C_c, where $C_c = (D_{30})^2/D_{10} \times D_{60}$. D_{60}, D_{30} and D_{10} are effective particle sizes indicating that 60%, 30% and 10% respectively of the particles (by weight) are smaller than the given effective size. Reference test standard: BS 1377: Part 2, 1990.

2.2. Unconsolidated Undrained Triaxial (UU)

This test is usually performed on undisturbed samples of 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. A latex membrane with thickness of app. 0.2 mm was placed around the specimen. A lateral confining pressure of 600 kPa to 1000 kPa was maintained during axial compression loading of the specimen. Consolidation and drainage of pore water during testing were not allowed.

The test were deformation controlled (strain rate of 60 %), single stage, and stopped when an axial strain of 15% was achieved. The deviator stress was 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, was 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 was used to calculate undrained shear strength (Peck et al., 1973).

2.3. Shear Strength – Laboratory Vane

This test allowed the determination of soft undisturbed cohesive soil for a strength index test. The specimen was tested in the sample tube to avoid undue disturbance. The sample tube was mounted in the test apparatus and a rectangular vane pushed into the soil specimen. The vane was then rotated at 10^o/min and the maximum torsional moment is recorded. Calculation of the undrained shear strength was based on a cylindrical failure surface for which uniform stress distributions are assumed. The equation for undrained shear strength is given as:

$$Su = T_{max} / \pi D^2 \{H/2 + D/6\} \quad (1)$$

Where: Su=peak undrained shear strength [kPa]
T_{max}=maximum torsional moment [kNm]
D=vane diameter [m]
H=vane height [m]

2.4. Atterberg Limits

Atterberg limits were determined on soil specimens with a particle size of less than 0.425 mm. The Atterberg limits refer to arbitrary defined boundaries between the liquid limit and plastic states (Liquid Limit, W_L), and between the plastic and brittle states (Plastic Limit, W_p) of fine-grained soils and 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 **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 and is the difference between the liquid limit and the plasticity limit (W_L-W_P). Reference test standard: BS 1377: Part 2: 1990.

2.5. Water Content

The water content was determined by drying selected moist/wet soil material for at least 18 hours to a constant mass in a 110°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. This ratio can exceed 1 (or 100%). Reference test standard: BS 1377: Part 2: 1990.

2.6. Unit Weights

The unit weights were determined from measurements of mass and volume of the soil. For cohesive soils, a specimen was obtained from a standard steel cylinder with cutting edge, which was pushed manually into the extruded soil sample. Preference was given to a 100 ml cylinder (area ratio of 12%), but a volume of 33.3 ml (area ratio of 21%) may be used when insufficient homogenous sample is available. Specimens of non-cohesive soils were obtained by selecting a part of a cylindrical soil sample, trimming surfaces, and measuring height and diameter. The latter method also applies to (cohesive) specimens selected for triaxial and oedometer tests.

The **unit weight** γ (kN/m^3) refers to the unit weight of the soil at the sampled water content. The **dry unit weight** γ_d, is determined from the mass of oven-dried soil and the initial volume. The **submerged unit weight** γ'', is determined as the difference between the bulk unit weight and the unit weight of water, where the unit weight of water is taken as 9.8 kN/m^3 Reference test standard: BS 1377: Part 2: 1990.

2.7. Carbonate Content

The carbonate content was determined by drying selected soil material to a constant mass in a 110°C drying oven, and measuring the volume of dissipated carbon dioxide (CO_2) upon reaction of the soil with hydrochloric acid (HCl). The carbonate content was calculated from calibration values, and expressed as a percentage of dry mass of the original soil. The average results from two (2) determinations are reported. The allowed difference between the results depends on measured value, and ranges from 0.3% for carbonate contents below 5% to 5% for carbonate contents above 50%.

2.8. Organic Matter Content

300g of the sample whose organic content were to be measured was placed in the soil specimen in the container. The container with the soil specimen in the drying oven at 80 ± 5°C, and dry to constant weight was weighed for at least 12 hours and cooled in a desiccator. The sample was crushed in a mortal with pestle and sieve through a 425μm sieve and weighed a prepared empty crucible and the mass M_1 recorded accordingly. 5g of the samples passing through the 425μm sieve was weighed and placed in the same empty crucible. The mass of both crucible and sample, M_2 were also recorded. Heat crucible and sample in the furnace at 550°C ± 25°C for at least three (3) hours were cooled in a dessicator and weighed crucible as well as contents and the mass, M3 were recorded.

The organic content is calculated as:

$$\text{Los on ignition } (\%) = (M_2 - M_3) x100 / (M_2 - M_1) \quad (2)$$

Where M_1, M_2 & M_3 are as stated in the above procedure.

2.9. Hydrometer

The hydrometer method allows measurement of the density of a suspension consisting of fine-grained soil particles and distilled water, to which a dispersion agent was added. This suspension was mixed using a high-speed stirrer. Testing was performed in a thermostatically controlled water bath (25°C ± 0.5°C). The particle size was calculated according to Stokes' Law for a single sphere, on the basis that particles of a particular diameter were at the surface of the suspension at the beginning of sedimentation and had settled to the level at which the hydrometer was measuring the density of the suspension. A value of 2.65 t/m^3 was assumed. The hydrometer results for selected particle sizes are presented as a percentage of the total mass of the soil sample. The general slope of the distribution curve may be described by the coefficient of uniformity C_u, where $C_u = D_{60}/D_{10}$, and the coefficient of curvature C_c, where $C_c = (D_{30})^2/D_{10}$ x D_{60}. D_{60}, D_{30} and

D_{10} are effective particle sizes indicating that 60%, 30% and 10% respectively of the particles (by weight) are smaller than the given effective size. Reference test standard: BS 1377: Part 2, 1990.

3. Results and Discussion

Table 1 presents the coordinates of the intended and actual positions of the gravity core samples.

Table 1. Coordinates of Positions of the Gravity Core Samples

Core Id.	Intended Positions		Actual Positions		Water depth
	Easting (m)	**Northing (m)**	**Easting (m)**	**Northing (m)**	**(m)**
A	282740.3	160522.6	282732.1	160532.8	27.4
B	281803.4	159605.4	281811.4	159600.2	30
C	283670.2	159592.2	283674.2	159591.6	26.9
D	283650.4	161450.7	283658.7	161445.1	25.1
E	281810.2	161437.4	281816.6	161443,2	28
F	282734.3	163022.2	282731.7	163019.5	25.2
G	283081.1	165494.1	283081.6	165494.3	22.8
H	280568.8	164931.3	280567.2	164923.1	25
I	280594.3	166494.2	280599.1	166493.8	26.3
J	282644.2	167906.7	282642.5	167908.1	21.3
K	283631.9	167944.5	283634.8	167951.1	20.9
L	285103.1	169490.6	285106.5	169492.2	15.8
M	286646.7	171327.1	286635.6	171325.9	13.9
N	266156.3	173831.3	286381.1	174056.1	12.8
O	287284.4	176253.3	287290.5	176252.9	11.7
P	288926.1	177971.9	288932.8	176964.6	9.7
Q	291259.4	178790.6	291262.9	178804.6	7.1
R	293615.6	179569.4	293616.0	179575.0	5
S	296104.4	179631.9	No sample		5
T	298603.1	179630.6	No sample		5

Table 2. Description of the Grab Samples

Core	Description	Recovery (m)
A	**CLAY,** slightly sandy, very soft, greenish dark grey and reddish brown	**0.90**
B	**CLAY**, slightly sandy, very soft, greenish dark grey and reddish brown	**0.90**
C	**CLAY**, slightly sandy, very soft, greenish dark grey and reddish brown	**1.01**
D	**CLAY**, slightly sandy, very soft, greenish dark grey and reddish brown	**1.00**
E	**CLAY**, slightly sandy, very soft, greenish dark grey and reddish brown	**0.98**
F	**CLAY**, very soft, greenish dark grey and reddish brown with occasional shells	**0.95**
G	**CLAY**, very soft, greenish dark grey and reddish brown with occasional shells	**1.06**
H	**CLAY,** very soft, greenish dark grey and reddish brown in places	**1.00**
I	**CLAY,** very soft, greenish dark grey and reddish brown in places	**1.00**
J	**CLAY,** very soft, greenish dark grey and reddish brown in places with occasional shells	**1.00**
K	**CLAY,** very soft, greenish dark grey and reddish brown with occasional shells	**1.01**
L	**CLAY,** very soft, greenish dark grey and reddish brown with occasional shells	**0.95**
M	**CLAY**, very soft, greenish dark grey and reddish brown with occasional shells	**0.96**
N	**CLAY,** very soft, greenish dark grey and reddish brown in places	**1.00**
O	**CLAY,** very soft, greenish dark grey and reddish brown in places	**1.00**
P	**CLAY,** very soft, greenish dark grey and reddish brown in places	**0.80**
Q	**CLAY,** very soft, greenish dark grey and reddish brown in places	**0.50**
R	**CLAY,** very soft, greenish dark grey and reddish brown in places	**1.00**

3.1. Grab Samples

The Table 3 below presents the description of the grab samples.

Table 3. Description of the Grab Samples

Grab	Description
1	**CLAY,** very soft, greenish dark grey and reddish brown in places
2	**CLAY,** very soft, greenish dark grey and reddish brown in places
3	**CLAY,** very soft, greenish dark grey and reddish brown in places
4	**CLAY,** very soft, greenish dark grey and reddish brown in places
5	**CLAY,** very soft, greenish dark grey and reddish brown in places
6	**CLAY,** very soft, greenish dark grey and reddish brown in places
7	**CLAY,** very soft, greenish dark grey and reddish brown in places
8	**CLAY,** very soft, greenish dark grey and reddish brown in places
9	**CLAY,** very soft, greenish dark grey and reddish brown in places
10	**CLAY,** very soft, greenish dark grey and reddish brown in places
11	**CLAY,** very soft, greenish dark grey and reddish brown in places
12	**CLAY,** very soft, greenish dark grey and reddish brown in places
13	**CLAY,** very soft, greenish dark grey and reddish brown in places
14	**CLAY,** very soft, greenish dark grey and reddish brown in places
15	**CLAY,** very soft, greenish dark grey and reddish brown in places
16	Sample missing
17	**CLAY,** very soft, greenish dark grey and reddish brown in places
18	**CLAY,** very soft, greenish dark grey and reddish brown in places
19	**CLAY,** very soft, greenish dark grey and reddish brown in places
20	**CLAY,** very soft, greenish dark grey and reddish brown in places
21	**CLAY,** very soft, greenish dark grey and reddish brown in places
22	**CLAY,** very soft, greenish dark grey and reddish brown in places
23	**CLAY,** very soft, greenish dark grey and reddish brown in places
24	**CLAY,** very soft, greenish dark grey and reddish brown in places
25	**CLAY,** very soft, greenish dark grey and reddish brown in places
26	**CLAY,** very soft, greenish dark grey and reddish brown in places
27	**CLAY,** very soft, greenish dark grey and reddish brown in places
28	**CLAY,** very soft, greenish dark grey and reddish brown in places
29	**CLAY,** very soft, greenish dark grey and reddish brown in places
30	**CLAY,** very soft, greenish dark grey and reddish brown in places
31	**CLAY,** very soft, greenish dark grey and reddish brown in places
32	**CLAY,** very soft, greenish dark grey and reddish brown in places
33	**FINE SAND,** clayey, brownish grey
34	**FINE SAND,** clayey, brownish grey
35	**FINE SAND,** clayey, brownish grey
36	**FINE SAND,** clayey, brownish grey
37	**FINE SAND,** clayey, brownish grey
38-49	Samples not found
50	**CLAY,** very soft, greenish dark grey and reddish brown in places
51	**CLAY,** very soft, greenish dark grey and reddish brown in places
52	**CLAY,** very soft, greenish dark grey and reddish brown in places
53	**CLAY,** very soft, greenish dark grey and reddish brown in places
54	**CLAY,** very soft, greenish dark grey and reddish brown in places
55	**CLAY,** very soft, greenish dark grey and reddish brown in places
56	**CLAY,** very soft, greenish dark grey and reddish brown in places
57	**CLAY,** very soft, greenish dark grey and reddish brown in places
58	**CLAY,** very soft, greenish dark grey and reddish brown in places
59	**CLAY,** very soft, greenish dark grey and reddish brown in places
60	**CLAY,** very soft, greenish dark grey and reddish brown in places
61	**CLAY,** very soft, greenish dark grey and reddish brown in places
62	**CLAY,** very soft, greenish dark grey and reddish brown in places
63	Sample missing
64	**CLAY,** very soft, greenish dark grey and reddish brown in places
65	**CLAY,** very soft, greenish dark grey and reddish brown in places
66	**CLAY,** very soft, greenish dark grey and reddish brown in places
67	**CLAY,** very soft, greenish dark grey and reddish brown in places
68	**CLAY,** very soft, greenish dark grey and reddish brown in places
69	**CLAY,** very soft, greenish dark grey and reddish brown in places
70	**CLAY,** very soft, greenish dark grey and reddish brown in places
71	**CLAY,** very soft, greenish dark grey and reddish brown in places
72	**CLAY,** very soft, greenish dark grey and reddish brown in places
73	**CLAY,** very soft, greenish dark grey and reddish brown in places
74	**CLAY,** very soft, greenish dark grey and reddish brown in places
75	Sample missing
76	**CLAY,** very soft, greenish dark grey and reddish brown in places
77	**CLAY,** very soft, greenish dark grey and reddish brown in places
78	**CLAY,** very soft, greenish dark grey and reddish brown in places
79	**CLAY,** very soft, greenish dark grey and reddish brown in places
80	**CLAY,** very soft, greenish dark grey and reddish brown in places
81	**CLAY,** very soft, greenish dark grey and reddish brown in places
82	**CLAY,** very soft, greenish dark grey and reddish brown in places

Table 4. Summary of Soil Classification Tests

Sample					Atterberg Limits				
Core No.	Depth [m]	W [%]	γ	Carb. Cont. ppm	Org. Cont. [%]	w_p [%]	W_L [%]	I_p [%]	C_u kPa
A		124	16.19		8.7	45	113	68	6.57
B		135	16.09	23,567	9.6	41	108	67	4.58
C		118	15.99	27,358	7.8	51	95	44	5.76
D		102	15.99	16,986	6.9	37	89	52	7.98
E		115	15.94	9,728	7.3	42	93	51	6.31
F		131	15.83	589	10.1	46	107	61	4.32
G		109	15.70	117	8.4	38	87	49	8.35
H		124	15.70	<1.0	10.7	31	101	70	6.89
I		135	15.65	<1.0	11.9	25	110	85	4.20
J		94	16.09	45	7.3	39	78	39	9.10
K		96	16.19	128	7.1	36	70	34	8.87
L		83	18.74	34,166	6.7	28	56	28	7.39
M		101	18.34	25,678	8.0	37	84	47	8.45
N		111	17.56	27,908	8.4	29	89	60	7.48
O		95	17.02	34,467	7.2	25	71	46	10.9
P		87	18.05	26,349	4.5	28	65	37	11.5
Q		83	19.03	22,675	3.2	35	55	20	11.6
R		81	19.13	16,472	3.7	43	46	3	11.8

w_P	:	plastic limit
w_L	:	liquid limit
I_P	:	plasticity index
<63 μm	:	mass percentage of material passing 63 μm sieve
PP	:	pocket penetrometer test
TV	:	torvane test
FC	:	fall cone test
LV	:	laboratory vane
UU	:	unconsolidated undrained triaxial test
c_u	:	undrained shear strength

4. Discussion

The stratigraphy encountered in all locations explored revealed a seabed of very soft organic clay with a characteristic green colour indicating the presence of chlorine or chloride compounds in almost all the samples recovered to the laboratory. The only exception are grab samples ”33” to “37” which were predominantly clayey fine sand. The clay encountered in the area was homogenous, having similar behaviour almost throughout the entire route. Though, the clay is of very low strength which would have resulted from the very high moisture content, and presented a reasonably very high wet and dry unit weights. However, this high unit weight could have resulted from the high amount of carbonate content and low organic content present in the samples recovered to the laboratory.

A greater part of the soil contains a large amount of dead shells which resulted in the wide range of carbonate content. The samples encountered gave a range of carbonate content between <1mg/kg and 34,166mg/kg. The high amount of carbonate content is an indication that the shells present in the samples were carbonate shells which would have given the clay a slight increase in unit weight but not in strength.

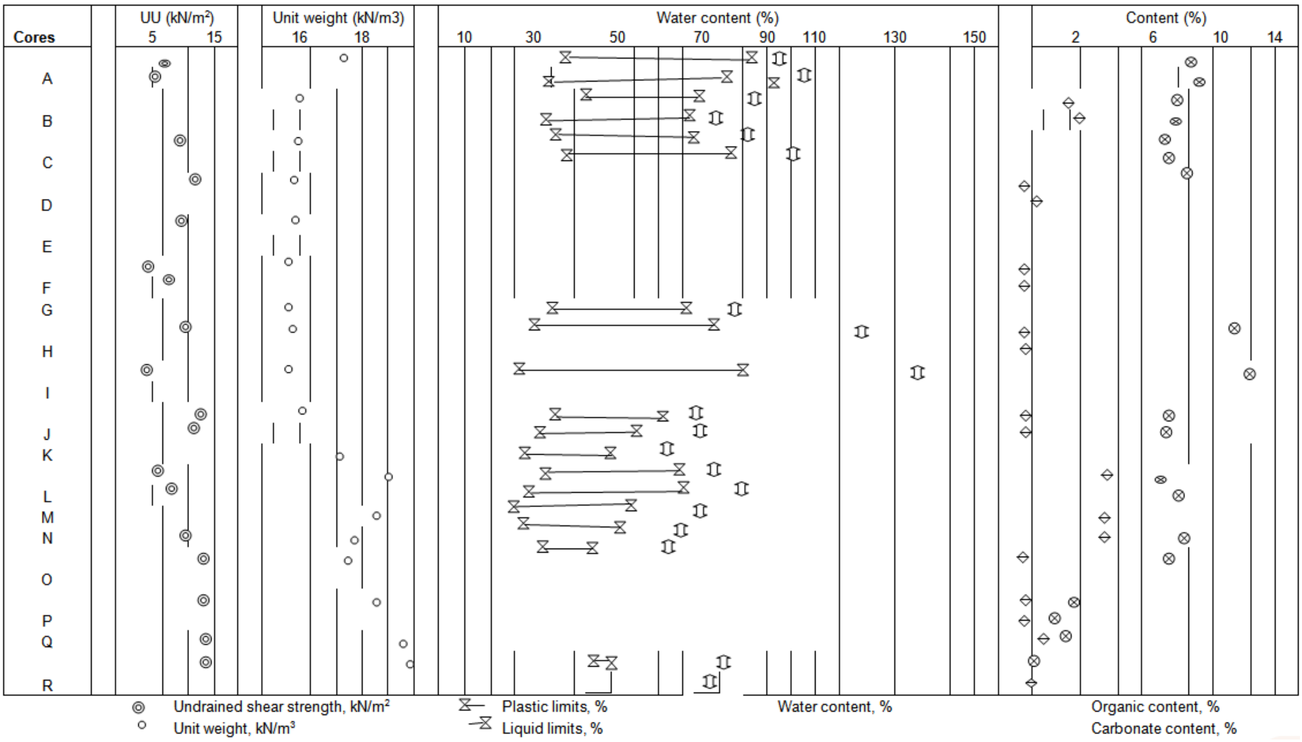

Figure 2. Summary of the Geotechnical results in the Study Area

Though the clay is in a normally consolidated state, utmost care is usually taken of the very low strength during design because of resultant low bearing capacity and the associated high settlement. Generally, there is an increase in shear strength as the locations progresses from "A" to "R".

The liquid limit decreases with progressive sampling of the locations from "A" to "R". However, the samples gave a high amount of moisture content, an amount higher than the liquid limit. The samples gave a high amount of moisture content, higher than the liquid limit which indicates that on loading the pipeline route, the weight of the pipeline will dissipate a large amount of the pore water with a resultant increase in settlement. The pipeline should be placed on slippers pad at designated locations on the seabed along the survey route to avoid excessive settlement.

4.1. Water Content

The results showed that the water content values of the very soft clay encountered throughout the route vary between 81% and 135%. Generally, the value of the water content lies well above the liquid limit. The unit weight of the clay encountered ranges between 15.65 and 19.13 $kN/m^{3.}$ The values of the liquid limits vary between 46% and 113% while the plastic limits vary between 43% and 51%. The corresponding plasticity index values lies between 3% and 85%. The undrained shear strength of the clays encountered in this site varies between 4.20kPa and 11.79kPa. The organic content of the clays encountered in the area varies between 3.20% and 11.9%. The clays encountered in the area has a carbonate content between <1mg/kg and 34,166 mg/kg giving a value of between <0.001% and 3.0%. Below is a summary of results of the tests carried out on the samples. Generally, the water table is close to the ground surface and sections of the pipeline route are periodically submerged by seasonal and sometimes tidal floods.

5. Conclusion

This study therefore, highlighted useful preliminary information and data required for future planning and infrastructural development in the study area. The entire formation presents a low amount of organic content, low shear strength and high carbonate content. The unit weight showed an increase with high carbonate content. The samples gave a high amount of moisture content, higher than the liquid limit which indicates that on loading the pipeline route, the weight of the pipeline will dissipate a large amount of the pore water with a resultant increase in settlement. The pipeline should be placed on slippers pad at designated locations on the seabed along the survey route to avoid excessive settlement. This would distribute the anticipated pressure from the pipeline over a greater area and thus reduce the excessive settlement which is the characteristics of the very soft marine clay encountered in this investigation. This study therefore, highlighted useful preliminary information and data required for future planning and infrastructural development in the study area.

References

[1] Abam T. K. S. (1999). Dynamics and quality of water resources in the Niger Delta. Proceedings of IUGG 99 Symposium HSS Birmingham) IAHS Publ. No. 259, pp. 429-437.

[2] Allen, J. R. L. (1965). Late Quatenary Niger Delta and adjacent areas: sedimentary environment and lithofacies. American Association of Petroleum Geologists, Vol. 49, pp. 549-600.

[3] Amajor, L. C. and Ofoegbu C. O. (1988). Determination of polluted aquifers by stratigraphically controlled biochemical mapping; Example from the Eastern Niger Delta, Nigeria. Groundwater and Mineral Resources of Nigeria, pp. 62-73.

[4] Dun,T.S, Anderson L.R. and Keifer (1980). Fundamental of Geotechnical Analysis – John Wiley Publisher, 414 pages.

[5] Etu-Efeotor, J.O (1981). Preliminary hydrogeochemical investigation of subsurface waters in parts of the Niger Delta. *Jour. Min. Geol.* 18(1):103-105

[6] Etu-Efeotor, J.O and Akpokodje, E.G (1990). Aquifer systems of the Niger Delta. *Journal of Mining Geology*, 26(2):279-284.

[7] Etu-Efeotor, J.O and Odigi, M.I (1983). Water supply problems in the Eastern Niger Delta. *Jour. Min. Geol.* 26(2):279-279.

[8] Haddou, M.B; Essahlaoui, A; Boujlal, M; Elouali, A; and Hmaidi, A (2013). Study of the geotechnical parameters of the different soils by correlation analysis and statistics in the Kenitra Region of Morocco. Journal of Earth Sciences and Geotechnical Engineering, 3(2): 51-60.

[9] Niger Delta Environmental Survey (1999) Physical Environment Report on the Hydrology of the Niger Delta.

[10] Nwankwoala, H.O and Oborie, E (2014). Geotechnical Investigation and Characterization of Sub-soils in Yenagoa, Bayelsa State, Central Niger Delta, Nigeria. Civil and Environmental Research, 6(7):75-83.

[11] Nwankwoala, H.O and Warmate, T (2014). Subsurface Soil Characterization of a Site for Infrastructural Development Purposes in D/Line, Port Harcourt, Nigeria. American International Journal of Contemporary Research, 4(6): 139-148.

[12] Nwankwoala, H.O; Amadi, A.N; Ushie, F.A & Warmate, T (2014). Determination of Subsurface Geotechnical Properties for Foundation Design and Construction in Akenfa Community, Bayelsa State, Nigeria. American Journal of Civil Engineering and Architecture, 2(4): 130-135.

[13] Osakuni M.U and Abam T.K.S: (2004) Shallow resisitivity measurement for cathodic protection of pipelines in the Nigeri Delta. Environmental Geology Vol. 45. No.6 747-752.

[14] Peck, R.B; Hanson W.E and Thornburn T.H (1973) Foundation Engineering 2nd Edition John Wiley and Sons 514pp.

[15] Short, K. C. and Stauble, A. J. (1967).Outline of Geology of the Niger Delta. American Association of Geologists, Vol. 51, No. 5, pp. 761-779.

[16] Tomlinson M. J (1999) Foundation Design and Construction 6th Edition, Longman, 536.