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BASELINE GEOTECHNICAL PROPERTIES AND BEARING CAPACITY ESTIMATION OF NIGERIA'S COASTAL SANDS: COMPARATIVE ANALYSIS OF LAGOS AND OPOBO ESTUARIES.

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ABSTRACT

This study presents a comparative analysis of the baseline geotechnical properties and bearing capacity estimation of coastal sands in Nigeria, focusing on the Lagos and Opobo estuaries. Bearing capacity is a key parameter needed for most geotechnical/structural designs. Accurate estimation of the Bearing capacity of soft clays can be challenging to obtain in the laboratory due to the difficulty in remoulding the clay to its in-situ conditions before testing, and as a result, the bearing capacity is estimated from the shear strength and index properties. The study employs field and laboratory investigations to gather data and employs established engineering principles to estimate bearing capacities. This study was carried out at Tarkwa bay site which is located in Lagos state, and ALSCON/Opobo harbor located in Imo state, Nigeria. A total of thirty (30) boreholes were drilled and soil samples were collected at 1.5 m intervals for Tarkwa bay and Opobo harbor up to a depth of 25 m. Laboratory tests were used to obtain the moisture content, bulk unit weight, liquid and plastic limit, while CPT was used in obtaining the shear strength. Laboratory Classification of the soil samples was done by adopting the Unified Soil Classification System and statistical analysis relating the shear strength with the soil properties were developed. The result showed the soils at both sites were predominately inorganic clay of high plasticity which are problematic due to the expansion and shrinking nature of this type of soil. The descriptive analysis showed that the shear strength ranged from 18kN/m^2 to 21 kN/m^2 for Tarkwa bay and from 12 kN/m^2 to 77 kN/m^2 for Opobo harbor. The mean ultimate bearing capacity was estimated as 106.24 kN/m^2 and 173.88 kN/m^2 for Tarkwa bay and Opobo harbor site, respectively. This research contributes to both practical engineering knowledge and broader scientific understanding of coastal geotechnics in Nigeria, with potential applications in infrastructure development, environmental conservation, disaster risk reduction, and policy formulation.

***Keywords**: Bearing capacity, bulk unit weight, liquid, plastic limit, shear strength*

1. INTRODUCTION

Coastal regions globally play a pivotal role in economic, environmental, and social dynamics due to their accessibility, resource-rich nature, and diverse ecosystems. However, these areas are also particularly vulnerable to natural forces such as erosion, flooding, and climate change impacts. In Nigeria, a country endowed with a vast coastline, the complexities of coastal development are further compounded by the geotechnical challenges posed by its coastal sands. The coastal areas of Nigeria are of paramount significance due to their strategic importance in trade, transportation, tourism, and natural resource exploitation. However, the soil characteristics and behaviors in these regions have far-reaching implications for engineering and development activities. One of the persistent challenges faced by the nation is the availability of petroleum products, a critical factor for economic growth and societal well-being. This challenge is marked by multifaceted issues, ranging from suboptimal refinery operations to logistical constraints at key import and handling facilities.

Notably, Nigeria's premier oil import and handling facility, the Atlas Cove petroleum products depot in Lagos, grapples with limitations posed by the draft depth for marine tankers. This constraint has led to increased costs associated with demurrage, trans-shipment, and waiting times for product discharge. To address this, an innovative solution involving an offshore-to-land pipeline has been proposed. This pipeline bypasses the draft limitations at the Atlas Cove facility, providing a potentially more efficient means of product transportation.

The present study delves into a comparative analysis of the baseline geotechnical properties and bearing capacity estimation of Nigeria's coastal sands, with a specific focus on the Lagos and Opobo estuaries. This research aims to provide essential insights for sustainable coastal development and the safe execution of infrastructure projects within these distinct regions.

Essentially therefore, the route characterization is an exercise in risk analysis. The various engineering properties of the soils that will be encountered represent different hazard states, either singly or in combination with other properties, which may produce undesirable outcomes when they interact with the proposed pipeline. The objective of this study is to determine these properties using geotechnical methods and make the data available to the engineers designing the pipeline for safe performance.

Based on the foregoing, we shall examine the concept of risk in some detail in this dissertation to gain a reasonable level of understanding of the concept of risk in the context of this research.

2. MATERIALS AND METHODS

2.1 Description of the study Area

2.1.1 Tarkwa Bay Segment

The work area is situated in the coastal zone of the city of Lagos, extending from the Apapa Petroleum Marketers' Jetty to about 13km offshore and terminating at the proposed location of an offshore SPM. Coastal zones are prone to various kinds of natural processes such as beach erosion, sand accretion, tidal flow and ebb which affect the morphology of the zones. Although these are apparently surface events, the water dumped on the land by storms eventually end up underground, affecting ground water levels, soil texture, soil erodibility, soil moisture content to mention a few. A good number of researchers have described the geology of the work area extensively. In general, the Lagos coastal area is located in the Nigerian sector of the Eastern Dahomey Basin. In stratigraphic terms, the area falls within the Cretacious tertiary geological sequence. The Eastern Dahomey may be divided into the Abeokuta group, the Iwo group, the Ilaro formation, the Coastal Plain sands and recent alluvium. The recent littoral alluvial deposits consist of sands with clay intercalations.

2.1.2 Alscon Harbour, Opobo

The work site straddles both banks of the Imo River, extending into the two states of Akwa Ibom and Rivers and extending south to the Imo River estuary and all the way to the fairway, about 17km south of the coastline. Operations were coordinated from the Alscon Harbour located in the Ikot Abasi part of the work area. The geological works started from the Alscon Harbour area and progressed southwards into the Atlantic.

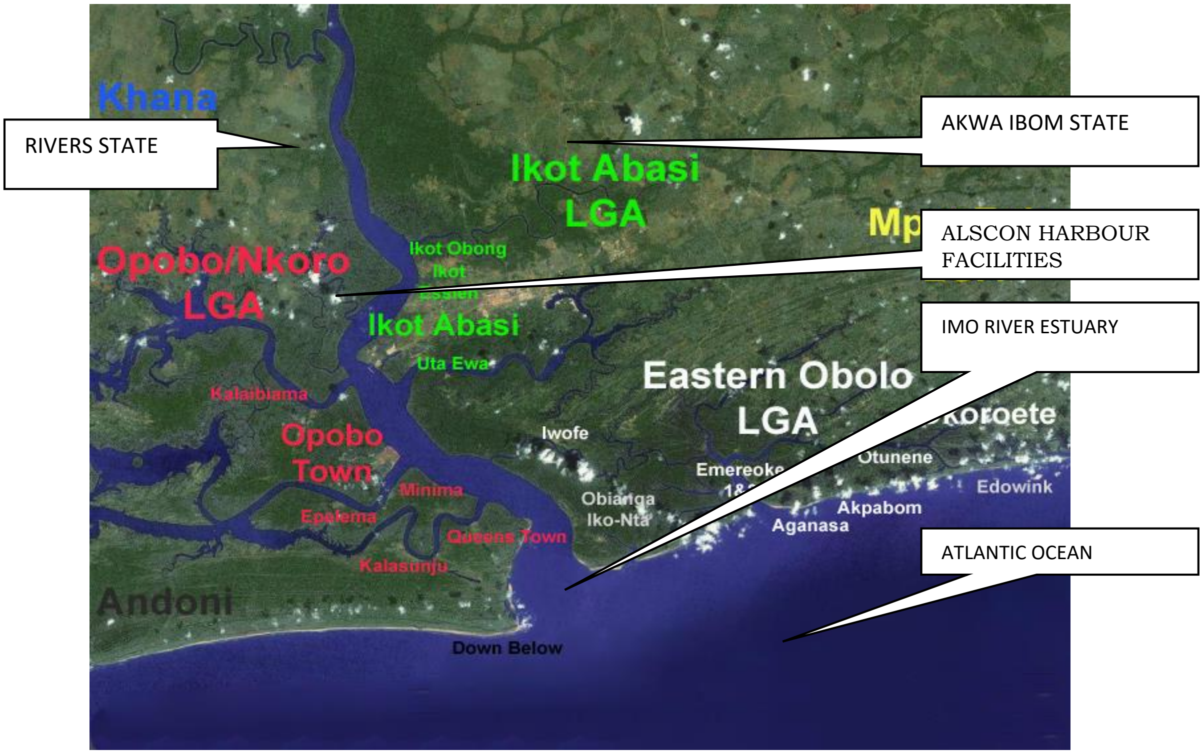

Figure 1: Location of the Study Area in Opobo

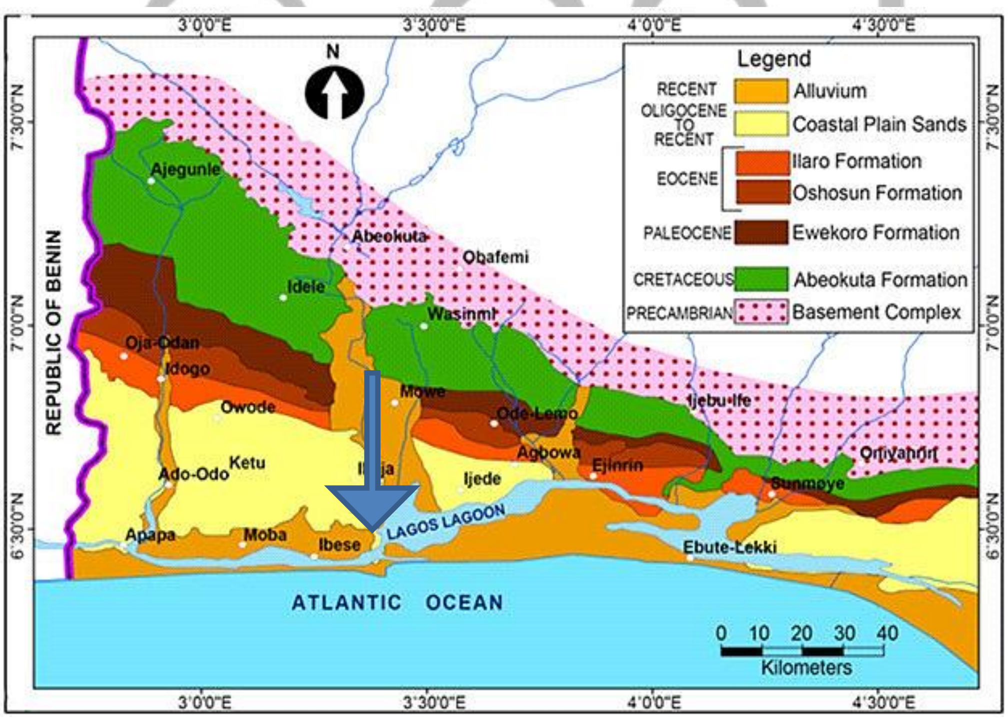

Figure 2: Geology of the Study Area in Tarkwa Bay (After Billman, 1976). The Blue Arrow Shows the Study Area

2.2 Field Analysis

The relevant geotechnical information for this study was obtained for Tarkwa bay by means of soil boring, using a 20 tonne cable percussion drilling system and in-situ Standard Penetration Testing (SPT). While for Opobo, the borings were done using a 1.5 ton cable percussive drilling rig, while the CPT was carried out using a ten (10) ton Cone Penetrometer machine powered by a hydraulic system. The system had digital log and playback. Soil samples may be cohesive such as clays of various consistencies or unconsolidated sands.

2.2.1 Boring, Sample Recovery and Handling

Borings were done to a depth of 25m below seabed and to 30m on the land portions of the proposed route. Sampling interval was 1.5m in unconsolidated layers and 3m in consolidated layers, except where there was observed change in the lithology. Groundwater level was measured in the boreholes. Undisturbed cohesive soil samples were recovered with a conventional open-tube sampler of 100mm diameter and 450mm length.

All samples recovered from the boreholes were examined, described and roughly classified in the field. The samples were wax sealed in PVC tubes for onward transmission to a shore based laboratory for analyses.

2.2.2 Standard Penetration Tests (SPT)

During the drilling, Standard Penetration Tests, (STP), were conducted at various depths to get an idea of the relative density of the sands penetrated, an indicator of the strength of the (non-cohesive) sand layers. SPTs were performed in the borehole every 3.0m of advance through cohesionless soils. In this test, a 50mm diameter split spoon sampler was driven 450mm into the soil with a 63.5Kg hammer falling freely a through a distance of 760mm. The sampler is driven into the soil in two stages. The initial 150mm penetration of the sampler is the seating drive and the last 300mm penetration, the test drive. The number of blows required to achieve the last penetration below the seating drive provides an indication of the relative density of the cohesionless soil stratum tested.

2.2.3 Dutch Cone Penetration Tests

Five (5) numbers Dutch cone penetration tests were carried out to a maximum depth of 25 metres below the riverbed. Readings of cone tip resistance, sleeve friction and pore water pressure were taken at every 0.2m interval of depth. A 10-ton electric CPT machine was used for the tests.

2.3 Laboratory Analyses

Laboratory analyses of the recovered soil samples to obtain the engineering characteristics of the lithological units traversed was conducted. Tests conducted were:

a. Moisture Content

b. Unit Weight

c. Particle Size Distribution

d. Atterberg Limits

e. Unconsolidated Undrained Triaxial (UU)

f. Consolidation Tests

3. RESULTS

3.1 Description of Observed Strata

3.1.1 Tarkwa Bay Segment

The detailed descriptions of the soil encountered during drilling and based on further tests in the laboratory are presented on individual borehole logs. The formation in presents a completely sand stratigraphy except for boreholes 1, 2, 3, 4, 1 1 and 12. Boreholes 1 and 2 present a clay stratum between 3 and 5m depth beneath the existing ground level. At borehole 3, the stratigraphy present a 2m thick clay layer at a depth of 15m; the clay extends to the final depth of investigation from a depth of 20m below the ground surface at borehole 4. At borehole 11 the clay stratum is present between 19m and the final depth of investigation while at borehole 12, the clay begins at a depth of 23m below the existing ground level and extends to the final depth of investigations.

3.1.2 ALSCON Harbour Segment

The geology of the area explored shows an alternating sequence of very soft greenish grey to dark clays and fine to silty sands of varying thickness, becoming sandier towards the coast along the proposed channel. The composite data from seismo – acoustic profiling and boreholes around the harbour present a complex geological sequence of alternating clays and sands with abrupt lateral terminations. This is most likely to have originated from previous construction work done during the installation of the harbour facilities and possible further maintenance work. These works would include dredging, excavation and piling. The particle size analysis shows that most of the material is in the fine - coarse sand grade and therefore very amenable to handling by dredgers. It is also evident from the bulk unit weights that material discharged from any proposed dredging will eventually settle to the bottom.

Table 1: Summary of Borehole Logs for Tarkwa Bay Segment

Stratum No.	Description	Depth Range (m)
1	SAND, loose to medium dense, silty, grey (with occasional clay at borehole 1,2, 3, 4, 11 & 12)	0 – 30.0

Table 2: Summary of Borehole Logs for ALSCON Harbour Segment

Stratum Number	**1**							
Fractional Porosity, e	1.32	1.46	1.40	2.07				
Maximum water content	51.13	56.1	53.97	78.13				
Water Saturation Factor	1	1	1	1				
Consistency	Very	Very	Very	Loose				
	soft	soft	soft					
Name of soil	CLAY,	CLAY,	CLAY,	SAND				
				clayey				

3.2 Descriptive properties of the Soil

The descriptive statistic of the clay properties for the two selected areas is presented in this section of the result.

3.2.1 Descriptive statistic on the Soil index properties of Tarkwa Bay soil.

Descriptive statistics results for the soil index properties for the soil samples at Tarkwa bay shows that the water content of the soil sample at Tarkwa bay site ranged from 10.8 to 71%. The mean water content for the soil samples at the site was 27.26% with a standard deviation of 22.14%. The bulk unit weight of the soil sample ranged from 14.3 to 15.2kN/m^3, with a mean bulk unit weight of 14.79 kN/m^3 and a standard deviation of 0.26kN/m^3. Result from Table 4.44 shows that the liquid limit of the soil sample ranged from 65 to 126%, with a mean liquid limit of 90.82% and a standard deviation of 25.11%. The plastic limit for the soil sample range from 25.5 to 37.2 %, with a mean plastic limit of 31.97% and a standard deviation of 5.33%. Plasticity index range from 38.7 to 89%, with a mean plasticity index of 59.22% and a standard deviation of 20.90%. The undrained shear strength (Cu) of the soil samples ranged from 18 to 21kN/m^2, with a mean value of 18.75kN/m^2 and standard deviation of 1.5kN/m^2.

Table 3: Descriptive statistic of soil index properties of Tarkwa bay soil

Variables	Water Content %	Bulk Unit wt. kN/m³	Dry Unit wt. kN/m³	Liquid Limit %	Plastic Limit %	Plastic Index %	Undrained shear strength Cu kN/m²
Mean	23.95	14.74	16.79	81.68	30.53	51.34	18.75
Median	16.20	14.80	16.90	71.35	29.85	42.40	18.00
Min	3.60	14.20	15.68	35.00	20.00	15.00	18.00
Max	100.00	15.20	17.15	126.00	38.60	89.00	21.00
Standard Deviation	21.00	0.29	0.43	27.29	6.07	22.41	1.16
Skewness	1.96	-0.22	-2.68	0.37	-0.14	0.45	1.36
Kurtosis	2.79	-0.59	7.71	-0.49	-1.31	-0.64	0.62
Coef. Var	87.67	1.95	2.55	33.41	19.89	43.65	6.21

3.2.2 Descriptive statistic on the Soil index properties of ALSCON Opobo harbor.

The descriptive statistics results for clay properties at Opobo harbor is presented in Table 4.45. The results from Table 4.45 showed that the water content of the soil sample ranged 10 to 219%. The mean water content for the soil sample at Opobo harbor was 70.99% with a standard deviation of 54.06%. The bulk unit weight of the soil sample ranged from 8.42 to 114.2kN/m^3, with a mean bulk unit weight of 14.89 kN/m^3 and a standard deviation of 9.05kN/m^3. The dry unit weight of the soil sample ranged from 3.42 to 93.63kN/m^3, with a mean dry unit weight of 9.88kN/m^3 and standard deviation of 7.16kN/m^3. The submerged unit weight of the soil sample ranged from -1.39 to 10.99 kN/m^3, with a mean submerged unit weight of 4.93kN/m^3 and standard deviation of 2.21kN/m^3. The liquid limit of the soil sample at Opobo harbor ranged from 16 to 130% with mean value for the liquid limit to be 69.07% and a standard deviation of 20.79%. For the plastic Limits, the values ranged from 21 to 67%, with mean plasticity limit of 34.91% and standard deviation of 10.32%. The plasticity index for the soil samples at Opobo harbor ranged from 9 to 78%, with mean plasticity index of 36.27% and standard deviation of 12.10%. The shear strength of the soil samples at Opobo harbor site ranged from 12 to 77 kN/m^2, with mean undrained shear strength of 31.44 kN/m^2 and standard deviation of 22.73%.

Table 4: Descriptive statistic of soil index properties of ALSCON Opobo harbor

Variables	Water Content %	Bulk Unit wt. kN/m^3	Dry Unit wt. kN/m^3	Sub. Unit wt. kN/m^3	Liquid Limit %	Plastic Limit %	Plastic Index %	Undrained shear strength Cu kN/m^2
Mean	70.99	15.95	9.88	4.93	69.07	34.91	36.27	31.44
Median	61.00	14.48	9.51	4.46	66.00	31.50	35.00	20.00
Min	10.00	8.42	3.42	-1.39	16.00	21.00	9.00	12.00
Max	291.00	114.20	93.63	10.99	130.00	67.00	78.00	77.00
Standard Deviation	54.06	9.05	7.16	2.21	20.79	10.32	12.10	22.73
Skewness	1.52	8.51	9.71	0.84	0.95	1.56	1.48	0.99
Kurtosis	2.43	86.23	113.43	0.47	1.80	2.51	3.61	-0.84
Coef. Var	76.16	56.74	72.41	44.82	30.11	29.56	33.37	72.29

3.3 Relationship between the soil properties.

The Pearson correlation was used to determine the relationship between the soil properties at two different sampling sites. The result from the Pearson correlation give indication if a soil property will be a good predictor variable in explaining the variation in the soil Engineering properties.

3.3.1 Correlation between the soil index properties for Tarkwa bay

The result of Pearson's correlation coefficient of the soil index properties with the shear strength shows that the R-value between the shear strength and the water content was 0.30 and the result was statistically significant at a level of significance of 5%. The result also showed that increase

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in the dry unit weight, and bulk unit weight will result to an increase in the undrained shear strength of the soil. The Pearson correlation between the bulk unit weight and the shear strength was positive with R-value of 0.99. The relationship between the bulk unit weight and the shear strength was statistically significant. The relationship between the shear strength and bulk unit weight indicated that increase in the bulk unit weight will result to an increase in the shear strength of the soil. The Pearson correlation between the dry unit weight and the Cu was 0.92, and it was statistically significant. Increase in the dry unit weight of the soil will result in an increase in the Cu. The relationship between the liquid limit and the Cu was positive with a Person R-value of 0.67.

Table 5: Pearson Correlation coefficient of the soil index properties for Tarkwa bay

Variables	WC	Bulk Unit wt.	Dry Unit wt.	LL	PL	PI	Cu
WC	**1.00**						
Bulk Unit wt.	0.19	**1.00**					
Dry Unit wt.	0.13	**0.93**	**1.00**				
LL	0.72	0.62	0.56	**1.00**			
PL	0.58	0.89	0.80	0.86	**1.00**		
PI	0.81	0.65	0.57	0.97	0.90	**1.00**	
Cu	0.30	**0.99**	**0.92**	0.67	0.93	0.71	**1.00**

3.3.2 Correlation between the soil index properties for ALSCON Opobo harbor

The result for the Pearson correlation shows that R-value between the water content and the Cu was 0.77, which indicate that the relationship was positive, but there was no evidence in stating that the relationship found in the sample will exist in the population. The relationship observed might just be due to chance or sampling error. Therefore, one cannot definitely say that increase in the water content will result in increase in the undrained shear for soil at Opobo harbor. The soil classification showed that the soil samples at Opobo harbor were all organic clay, the erratic behavour of organic clay might have resulted in the outcome in the relationship among the variables. The liquid limit had also had an R-value of 0.83, which indicate a positive relationship between the liquid limit and the shear strength. The Pearson correlation coefficient for the plastic limit and the Cu was 0.99 which indicate a positive and significant relationship between the two variables. The R-value between the plasticity index and the shear strength was 0.88, which also indicated a positive relationship between the two variables and statistically significant.

Table 6: Pearson Correlation coefficient of the soil index properties with the for Opobo harbor

Variables	WC	Bulk Unit Wt.	Dry Unit wt.	Sub. Unit wt.	LL	PL	PI	Cu
WC	**1.00**							
Bulk Unit wt.	0.77	**1.00**						
Dry Unit wt.	0.53	0.31	**1.00**					
Sub. Unit wt.	0.79	1.00	0.36	**1.00**				
LL	0.98	0.83	0.49	0.84	**1.00**			
PL	0.84	0.99	0.38	0.99	0.89	**1.00**		
PI	0.98	0.88	0.46	0.89	0.99	0.93	**1.00**	
Cu	0.77	1.00	0.32	0.99	0.83	0.99	0.88	**1.00**

3.4 Computation and Analysis of Bearing Capacities

3.4.1 Bearing Capacity Analysis (Shallow Foundation)

Table 7: Calculated Bearing capacities of the two Locations

	Tarkwa Bay		Opobo Harbor	
Depth (m)	**Ultimate Bearing Capacity (kPa)**	**Allowable Bearing Capacity (kPa)**	**Ultimate Bearing Capacity (kPa)**	**Allowable Bearing Capacity (kPa)**
1.5	103.77	34.59	170.81	56.94
2.0	106.24	35.41	173.88	57.96
2.5	108.70	36.23	176.95	58.98

***Factor of safety = 3**

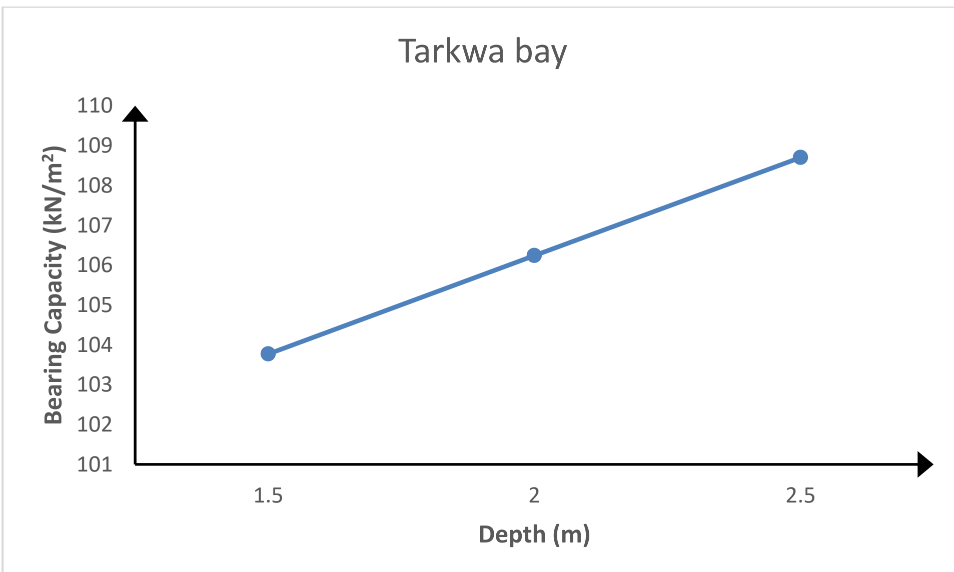

Figure 3: Bearing Capacity of Tarkwa bay

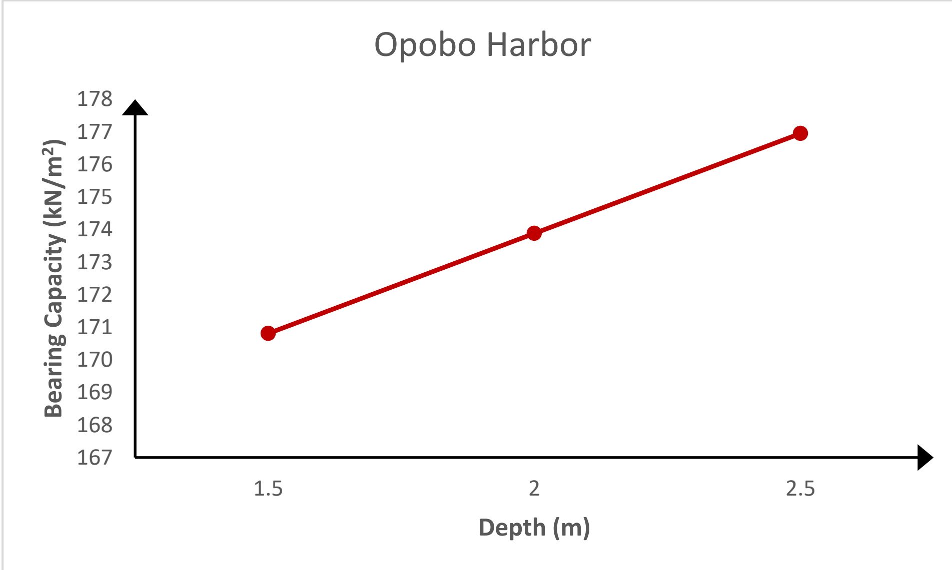

Figure 4: Bearing Capacity of Opobo harbor

3.5 Comparative Analysis for the two sites

The result showed that Opobo harbor had the largest variation in the shear strength value with the value ranging from 12 to 77 kN/m^2. The Tarkwa bay site had the least variation in the shear strength value with value ranging from 18 to 21 kN/m^2. The largest average value of shear strength was discovered in Opobo harbor site with mean value of 31.44 kN/m^2 while Tarkwa bay site had the least average value of shear strength. The result of the bearing capacity estimation showed that Opobo harbor had a higher ultimate and allowable bearing capacity value than that of Tarkwa bay soil.

Table 8: Comparative Values of the two sampling sites.

Parameters	Sampling Sites	
	Tarkwa Bay	Opobo Harbor
Range of shear strength	18 – 21 kN/m^2	12 – 77 kN/m^2
Mean shear strength	18.75 kN/m^2	31.44 kN/m^2
Mean Bearing Capacities	106.24 kN/m^2	173.88 kN/m^2

4. DISCUSSION

The undrained shear strength, Cu obtained for Tarkwa bay and ALSCON Opobo site ranged from 18 to 21 kN/m^2, and 12 to 77 kN/m^2 respectively. Murthy (2002) stated that soil with shear strength less than 25kPa are considered to be very soft clay while soil that their shear strength is between 25 to 50kPa are considered to be soft clay. Considering the statement by Murthy (2002), the soils found in the coastal regions are either soft or very soft clay. The result from the study showed that Tarkwa bay site which had soil samples that were predominately high plastic clay had the lowest shear strength. Prinz and Straub (2006) reported that high swelling clay minerals (e.g smectites) tend to reduce the shear strength of the soil significantly. This might be the reason of the low shear strength found on Tarkwa bay site which had highly plastic clay. The result from the present study and other studies provide evidence that the soil found in coastal regions are predominately soft weak clay.

The relationship between the soil properties were investigated using Pearson correlation coefficient which measure the degree of linear relationship between two variables. The linear relationship of the clay properties showed that there was a positive linear relationship between the shear strength and the liquid limit at the two sites. The result shows that as the liquid limit of the soil slightly increases the shear strength of the soil. The increase in the shear strength of the soil with increase in liquid limit can be attributed to the fact that the soil is erratic in nature and exhibits medium to high plasticity. Increase in the plasticity of the soil result to absorbing of water by the clay which result to decrease in the strength of the soil. The more water content in the soil the less resistance the clay become to external forces which will result to the shearing of the soil. Also, as the water content of the soil reduces the soil becomes less plastic and more resistance to external forces. The result of the relationship for the liquid limit and shear strength was statistically significant at the two sites which indicate in the positive relationship observed in the soil samples. This might be attributed to the number of soil samples used for the study, as several researchers have established that a negative relationship exist between the liquid limit and shear strength but some suggested that the relationship is no entirely linear.

The relationship between the plastic limit and the shear strength was also positive. The increase in the plastic limit indicates that the soil sample have more water in its voids which will eventually lead to easier deformation of the soil. Several researchers have opined that there is no really established relationship between the plastic limit and bearing capacity. The relationship between the plastic limit and the bearing capacity can be affected by several factor such as the soil type, grain size distribution and the stress history.

The relationship between the water content and the shear strength was positive. The increase in water in the clay soil will result the soil to be more cohesive which will reduce the ability of the soil resist deformation. The relationship between the water content in the soil and shear strength at the two site was statistically significant.

The bearing capacity of the soil found at Tarkwa bay and ALSCON Opobo site ranged from 103.77 to 108.70 kN/m^2, and 173.81 to 176.95 kN/m^2 with respect to their depths. The result for the bearing capacities at Opobo harbor site was observed to be larger than that of Tarkwa bay. This is due to the fact that the soil of the former has a higher shear strength value than the latter and is also more compact and closely packed together as can be noticed from the unit weight values.

5. CONCLUSIONS

The results showed that the shear strength of the soft clay found in the coastal region of the studied areas ranges as low as 18kN/m^2 to 21kN/m^2. The water content in the soil did not show any significant reduction in the shear strength as the unit weight tend to increase the strength of the soil. The positive relationship between the shear strength and water content may be due to the erratic nature of clay soils in coastal region as observed from the two sites. The high shear strength value contributed to a high bearing capacity value in ALSCON Opobo harbor site.

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