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Assessment of Some Geotechnical Properties of Nigerian Coastal Soil: A Case-Study of Port-Harcourt Beach Mud

[1*]OWAMAH, HI; [1]ATIPKO, E; [1]UKALA, DC; [2]APKAN, E

[1]Department of Civil Engineering, Delta State University, PMB 1, Abraka, Oleh Campus, Nigeria
[2]Department of Civil Engineering, Landmark University, Omu-Aran, Kwara State, Nigeria
**Email: owamah.hilary@gmail.com; hiowamah@delsu.edu.ng +2348035705814*

ABSTRACT: Soils naturally exhibit variable engineering properties and thus make the geotechnical characterization of soil for sustainable design and construction of infrastructure imperative. This study was undertaken to investigate the geotechnical properties of the underlying soils of the Port-Harcourt Beach Mud, Rivers State, Nigeria. Five boreholes namely BH1, BH2, BH3, BH4 and BH5 were drilled using hand auger at different depths of 300mm, 350mm, 400mm, 450mm and 500mm respectively. Basic geotechnical tests were then performed on the samples in the laboratory to determine their properties. Results obtained showed that the area is underlain predominantly by poorly graded sands based on the Unified Soil Classification System (USCS). The soil material had an average Moisture Content of 71%, Liquid Limit of 13%, Plastic Limit of 11%, Plasticity index (PI) of 2% and Hydraulic Conductivity (K)of 2.88 x 10^{-1} cm/s. The high values of K show that the aquifer system in the area is prolific. The soil material however met the requirements of the Nigerian General Specifications for use as subgrade in the construction of roads.

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Neglect of geotechnical investigation in the design of Civil Engineering projects in Nigeria had led to the collapse of many structures with its attendant effects on services provided by the structures and the Nigerian economy. Geotechnical site investigation is carried out to estimate properties of rock and soil, and for underground stratigraphic analysis of geotechnical systems (Clayton *et al*., 1995; Mayne *et al*., 2002). Geotechnical site investigation comprises six stages viz; desk-study, site reconnaissance, in-situ investigation, laboratory testing, analysis and interpretation of site observation data, and inferring soil and rock properties and underground stratigraphy (Wang *et al*., 2016; Cao *et al*., 2016). Frequent cases of structural failure in the Nigerian coastal cities such as Lagos, have become a source of worry to the populace; hence the need for a good understanding of the geotechnical properties of subsurface soils in these areas (Startrite, 2000).

Soil is the un-cemented aggregate of mineral grains and decayed organic matter (solid particles) with liquid and gas in the empty spaces between the solid particles (Das, 2013). Mud sediment (which is a soil type) is refered to as a set of loose particles of clay, silt and sand, formed from the erosion of rocks and soils (Life, 2002; Dubois *et al*., 2011). Geotechnical properties of mud sediment are like those of coastal mud deposits in many ways such as in strength, viscosity and density (Calliari and Fachin, 1993; Holland *et al*., 2009; Dias and Alves, 2009). The need for adequate understanding of the geotechnical properties of subsoil cannot be overemphasized (Youdeowei and Nwankwoala, 2011), in ensuring that the effects of engineering projects on the environment are well evaluated (Nwankwoala *et al*., 2009). Geotechnical characterization through subsoil investigation is very important in generating relevant data inputs for the design and construction of foundations for proposed structures (Nwankwoala and Oborie, 2014).

Because, soils and rocks are very important construction materials used either in their natural state in foundations or excavations or recompacted in dams and embankment (Atkinson, 2007), understanding the engineering properties of soil its crucial to obtaining the strength and economic value (Vitton, 2006). Many studies on the geotechnical properties of marine sediments have been done worldwide due to their roles in the design of offshore foundations (Dan *et al*., 2007); examples are studies of the coastal mud deposit in Kerala, India (Jiang and Mehta, 1996), the Amazon River, central and

**Corresponding author Email: owamah.hilary@gmail.com; hiowamah@delsu.edu.ng +2348035705814*

southern regions of Brazil (Gabioux *et al*., 2005; Reed *et al*., 2009), Surinam, Guyana, and Venezuela (Wells and Coleman, 1981; Allison and Lee, 2004; Winterwerp*et al*., 2007), Greece (Ferentinou *et al*., 2012), England (Ingliss and Allen, 1957), the Atchafalaya Basin, Southern Louisiana, USA (Jiang and Mehta, 1996; Allison *et al*., 2000; Fan *et al*., 2004; Sheremet *et al*.,2005) and Lagos, Nigeria (Afolayan *et al*., 2014). Enough attention has not really been given to mud deposits in the coastal regions of Nigeria, especially the coastal regions of the Niger-Delta part of the country and therefore underscores the importance of this study.This study provides general geotechnical information of the Port-Harcourt beach mud as basis for future development of sustainable infrastructure in the area. The knowledge of Port-Harcourt beach soil properties will enable the understanding of the general behavior of coastal soils in the region for recommendation, design and construction of foundations that will be suitable for coastal structures.

MATERIALS AND METHODS

Study Area

It is situated at Kolabi creek Port Harcourt, Rivers State. The tourist beach is arguably the most popular beach in Port Harcourt and good for a walk by the sea side and sun bathing. It lies within the geographical coordinates of Latitude 4.752°N and 4.753°N and between Longitude 7.046°E and 7.047°E. Figure 1 shows the location map of the sampling site. The area chosen for the collection of soil samples for further testing is located along a narrow but long strip by the Port-Harcourt beach. The narrow strip was caused by the reclamation of the beach interior for the purpose of tourism leaving behind a long narrow and undisturbed virgin land along the coast opening into the Amadi creek.

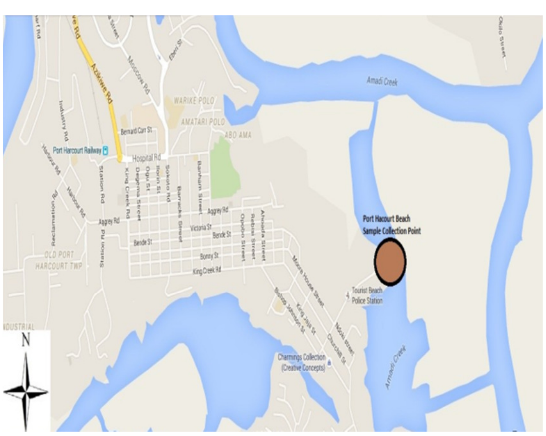

Fig 1. Location Map of Port Harcourt Beach (sampling site)

Collection of soil sample: The investigation comprised mainly five (5) well-spaced geotechnical boreholes with soil sampling executed with hand auger. The borings were taken to a maximum depth of 500mm at intervals of 50mm between each geotechnical boring. The mud samples were taken with the help of some tourist beach staff. The procedure adopted for boring was opening of the ground by rotating the hand auger clockwise until one gets to the required depth. The first three boreholes (BH1, BH2 and BH3) were located at about 1.83 into 2.44m from the coast of the river while the last two geotechnical boreholes were at about 3.35m from the coast. It was observed that BH4 and BH5 contained more vegetative materials as one drilled deeper into the earth more than the first three borings which were much closer to the coast. The sampling period was during the dry season. After sampling, the mud samples were packed in different polythene bags and were labeled and stored in readiness for laboratory analyses.

Experimental Program: Soil index property and classification tests namely; natural moisture content, specific gravity, particle size analysis and atterberg limits tests were performed on the mud samples. Compaction and California Bearing Ratio (CBR) tests were also performed on the mud samples to determine their strength characteristics. Permeability (constant head) was also performed on the mud samples. All tests were carried out in accordance to the British Standard (BS 1377, 1990).

RESULTS AND DISCUSSION

Results of Moisture Content Test: Table 1 shows the average moisture content of samples from the different boreholes.

Table 1. Average moisture content and specific gravity of samples collected

Boreholes Label	Depth of sample collection from borehole (mm)	Moisture content (%)	Specific Gravity
BH1	300	21.32	2.5
BH2	350	22.53	2.54
BH3	400	90.41	2.44
BH4	450	108.74	2.48
BH5	500	112.98	2.61

From Table 1, moisture content was found to increase with depth and can be attributed to the sites proximity to water which shows that the water table in the area is close to the surface. Results of the natural moisture content as determined for representative soil samples ranged from 21.3% to a maximum of 112.98%. These high values obtained indicate that the soil is well saturated and also possess the capacity to allow water to permeate through it because of their fine nature. Table 1 shows that BH3 and BH5 had the lowest and highest specific gravity values respectively. The average specific gravity of the Port-Harcourt Beach mud was obtained as 2.51.

Results of Particle Size Distribution test: Particle size distribution test was carried out on the different soil samples. Table 2 shows the particle size analysis and their various soil classifications. Result obtained from the particle size distribution curve (Fig 2) indicates that less than 5% passed the sieve No. 200 (0.075 mm) and more than 50% passed the sieve No. 40 (0.425 mm) showing that the soil samples are majorly sandy and according to the Unified Soil Classification System are Poorly Graded Sands (SP) with uniform gradation curve displaying very little or no fines.

Table 2. Particle size analysis

Boreholes Label	D_{10} (mm)	D_{30} (mm)	D_{60} (mm)	Coefficient of Uniformity C_u	Coefficient of Curvature C_c	USCS classification	AASHTO classification
BH1	0.18	0.28	0.42	2.33	1.04	SP	A-3
BH2	0.18	0.27	0.4	2.22	1.01	SP	A-3
BH3	0.19	0.29	0.52	2.74	0.85	SP	A-3
BH4	0.17	0.24	0.37	2.18	0.92	SP	A-3
BH5	0.18	0.28	0.4	2.22	1.09	SP	A-3

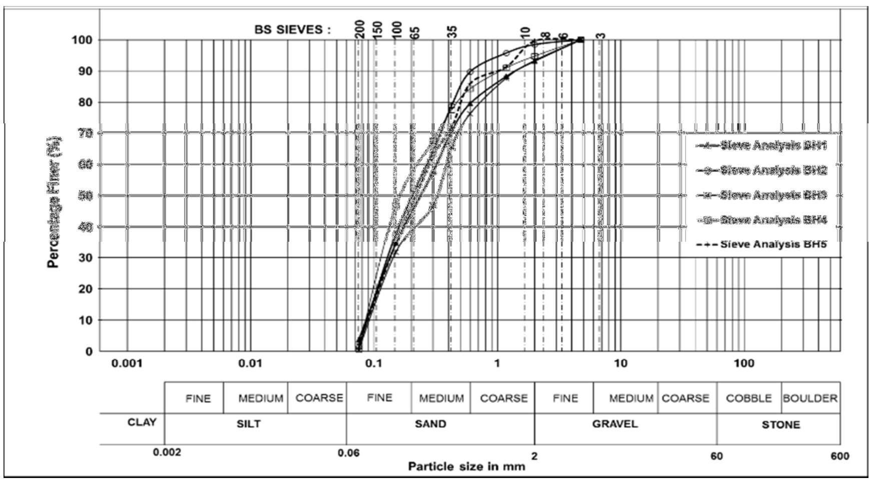

Fig 2. Particle Size Distribution Curve

Table 3. Atterberg Limit values

Boreholes Label	Liquid Limit (%)	Plastic Limit (%)	Plasticity Index (%)	Liquidity Index	Soil classification based on the plasticity Index
BH1	12.5	7	5.5	2.60	Low Plastic
BH2	12.5	13	-0.5	-19.06	Non-Plastic
BH3	11	12	-1	-78.41	Non-Plastic
BH4	14.01	9	5.01	19.91	Low Plastic
BH5	15	14	1	98.98	Low Plastic

Atterberg Limit: The particular state of consistency of any particular soil depends primarily upon the amount of water present in the soil-water system thereby making the behavior of soil directly related to the amount of water present. The atterberg limit represents a water content at which the soil changes from one state to another. The values of the atterberg limits of the soil samples are shown in Table 3.

The liquid limit ranges from 11% to 15% with an average liquid limit of 13%. The plasticity index which indicates the degree of plasticity of a soil ranges from - 1% to5.5% with an average plasticity index of 2%. From the results obtained, BH1, BH4 and BH5 can be classified as soils with low-plasticity because their plasticity indices were less than 7; while BH2 and BH3 are non-plastic soils. The soil samples all met the requirements of the Nigerian General Specifications (FMW&H, 1997) of not more than 35% passing sieve No. 200, maximum plasticity index (PI) of 30% and liquid limit (LL) of a maximum of 50% for soils used as a subgrade material in road construction

Hydraulic Conductivity: The constant head method was used to determine the hydraulic conductivity of the soil due to its sandy nature. Figure 3 shows the hydraulic conductivities of the five boreholes. The hydraulic conductivity values obtained for BH1toBH5 soil samples were1.5x10^{-1}, 2.4x10^{-1}, 3.5x10^{-1}, 3.5x10^{-1}, and 3.5x10^{-1}cm/sec respectively. These high hydraulic conductivity values indicate fine to medium sandy soil. Similar results were obtained by Onuoha and Mbazi (1988). The implication of high hydraulic conductivity values is that the aquifer system in the area is prolific (Etu-Efeotor, 2000 and Nwankwoala *et al*., 2008).

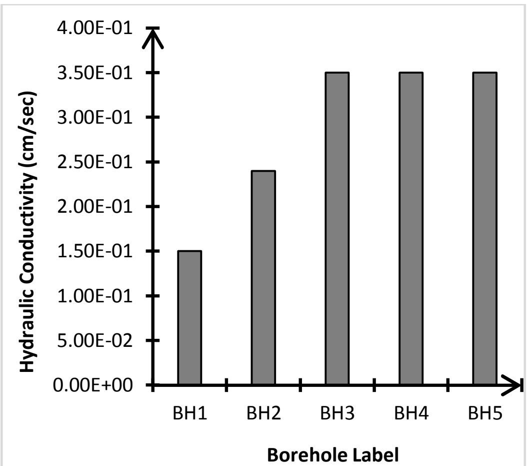

Fig 3. Hydraulic conductivity values of borehole soil samples

Compaction and California bearing ratio tests: Standard proctor compaction test was conducted on the soil samples from the various boreholes. Figure 4 shows the standard proctor compaction test results (maximum dry density [Y_{dmax}]/optimum moisture content [W_{opt}]) conducted on sampled soils under optimum proctor conditions. The compaction test indicates a good reconstitution of the soil under the necessary conditions to which it is expected to be subjected in the field during the any form of construction.

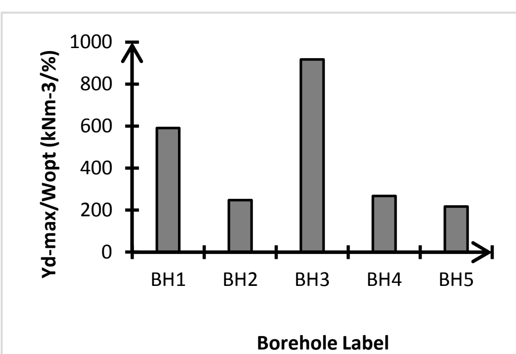

Fig 4. Standard Proctor Compaction test results

Figure 4 shows the ratio of the maximum dry density [$Y_{d\text{-}max}$] to the optimum moisture content [W_{opt}] of the soil sampled from the boreholes. From Figure 4, BH3 had the highest ratio of maximum dry density to optimum moisture content while BH5 had the lowest. The compacted samples at their optimum moisture content were then tested for their California Bearing Ratio (CBR) values. Figure 5 shows the soaked CBR test results conducted on the samples at optimum moisture content.

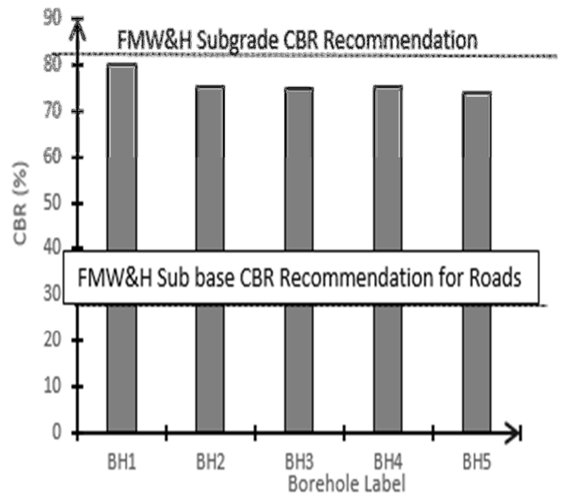

Fig 5. California bearing ratio test results

Figure 5 shows that only BH1 met the 80% minimum soaked CBR value of subgrade recommended by the Nigerian Federal Ministry of Works and Housing (FMW&H, 1997). However, all the soil samples met the 30% required standard for minimum soaked CBR value for sub base in road construction.

Conclusion: This study has shown that the soil in the Port-Harcourt Beach area is underlain predominantly by fine to coarse sands which are poorly graded and implies a relatively high permeability potential. The high proportion of silty clay size fractions in the soil indicates a considerable amount of compressibility. The strength properties of the soil evaluated based on CBR reveals that the soil materials are suitable for subbase and subgrade materials. Results of this study constitute useful preliminary information required for future planning and infrastructural development of Beach Areas in Nigeria.

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