Original Research Article

An Evaluation of a Marginal Land's Geological Engineering Properties in Borikiri Sandfill, Port Harcourt Nigeria

ABSTRACT

Aim: The aim of this study was to assess the geologicalengineering properties of a marginal land in Borikiri Sandfill, Port Harcourt, Nigeria, using both field and laboratory investigations.

Study Design: The study design involved the drilling of 6 boreholes and standard penetration tests to determine the soil profile and index properties such as particle size analysis, atterberg limits, and moisture content. Consolidation and triaxial tests were also performed to determine the values of the coefficients of permeability (k), volume compressibility (Mv), and consolation

Place and Duration of Study: The Study was conducted in a Borokiri Sandfill, Port Harcourt between February and May 2020.

Method: This study's methodology included field research, lab analysis, and testing. Drilling and conventional penetration tests were used to assess the soil profile. Laboratory tests such particle size analysis, atterberg limits, and moisture content were used to determine the index characteristics. The values of k, Mv, and v were also determined using triaxial and consolidation tests.

Results: The results of the study showed that the soil profile consists of five stratigraphic sequences, with a top organic silty layer followed by a sandy layer, a dark plastic layer, a dark silty clayey sand, and a well-graded sand. The clays had an average LL of 45 and a value of 23. The values of k, Mv, and v were determined to be 2.1 x 10-7 m/s, 1.8 x 10-4–2.5 x 10-4 m^2/MN, and 3.8 m^2/yr, respectively. The average bearing capacity values at 2.5 m and 4.5 m depths were determined to be 186.39 kPa and 278.71 kPa, respectively. Settlement values were calculated empirically for immediate and continuous settlement, with immediate settlement being high at 25.85 mm and consolidated settlement being 7.53mm. T50 and T90 values were also determined to be 1.32 and 4.52 years, respectively.

Conclusion:it is highly recommended that a thorough foundation, down to the first layer, be used for any construction on the marginal land in Borikiri Sandfill, Port Harcourt, Nigeria. The values of k, Mv, and v also indicate that the soil is relatively compressible, which should be taken into account in any design or construction activities.

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Keywords: Marginal Land, Settlement, Foundation Design, Soil profile, Bearing Capacity

Introduction

In Port Harcourt, Nigeria, there has been a significant increase in population, leading to growing pressure on land in the area. As a result, there has been a systematic development of marginal lands in the region[11]. However, much of this development has been undertaken without adequate understanding of the geodynamic setting of the environment, and without proper engineering geological studies to aid in development planning and control[3][7].

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Marginal land, according to several authors, is land that could not be used in its original state. The Niger Delta is characterized into three ecological zones - the coastal, transitional, and freshwater zones [1]. The transitional zone has landmasses that are surrounded by marshy and saline mangrove vegetation, most of which terminate at the sea shore. This marshy, mangrove vegetation surrounding the landmasses are described as marginal lands[14][12].

The marginal lands of the Niger Delta have poor engineering geological characteristics, resulting in uneven settlement of structures. This is the resultant effect of the depositional process, the type and nature of sediments, and moisture content resulting from high precipitation intensity in the area [14][1].

Various Authors have highlighted the problem of settlement in the Niger Delta. Additionally, a good proportion of the swampy marginal lands are subject to seasonal or tidal flooding, especially in the rainy seasons [15].The area is also characterized by high salinity of soil and water [6]. This has a negative effect on building materials due to its corrosive effect on foundation materials. The severity of the attack on the foundation depends on the type and nature of the soil and the level of salinity [12].

it is essential to undertake a thorough assessment of the geological engineering properties of the marginal land in Borokiri Sandfill Port Harcourt, Nigeria. The assessment will aid in proper development planning and control of the area, ensuring sustainable and safe development of the region [1].

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Study Location

The research was conducted in the Borokiri area of Port Harcourt, which is located in the southeastern region of Rivers State and within the southern Niger Delta region of

Nigeria. Borokiri is situated between latitudes 14.43.1N and 14.46.8N of the equator and longitudes 7.15.9E and 7.17.3E of the Meridian [14]. The area is characterized by mangrove tidal flats along the shoreline of the Bonny River, which is one of the many rivers that crisscross the Niger Delta and ultimately flow into the Atlantic Ocean [12].

The terrain is topographically flat with surface elevation not more than 2.5m above sea level during low tide which could be reduced during high tide as a result of increased in sea water level. The shoreline is of tidal coastal plan with tidal flats. The land surface is loose with muddy swamps which has been covered by about 3m thick of sandfill.

The study area falls within the Niger Delta region. The area is made up of thick sedimentary sequence of age ranging from Eocene to Recent. Three main ligthostratigraphic units have been recognized in the Niger Delta consisting of, in ascending order, the Akata, Agbada and Benin formation []. The site sits astride the Niger flood plain which overlies the Benin formation that is often called coastal plain sands [14].

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The project area belongs to the coastal climatic zone and is dominated by the Tropical Maritime Air Mass most of the year, with rainfall occurring throughout the year. The Mean Annual Temperature (MAT) range from 29oC during the brief cold hamattan period (December to February) to over 34oC from March through October each year [1].

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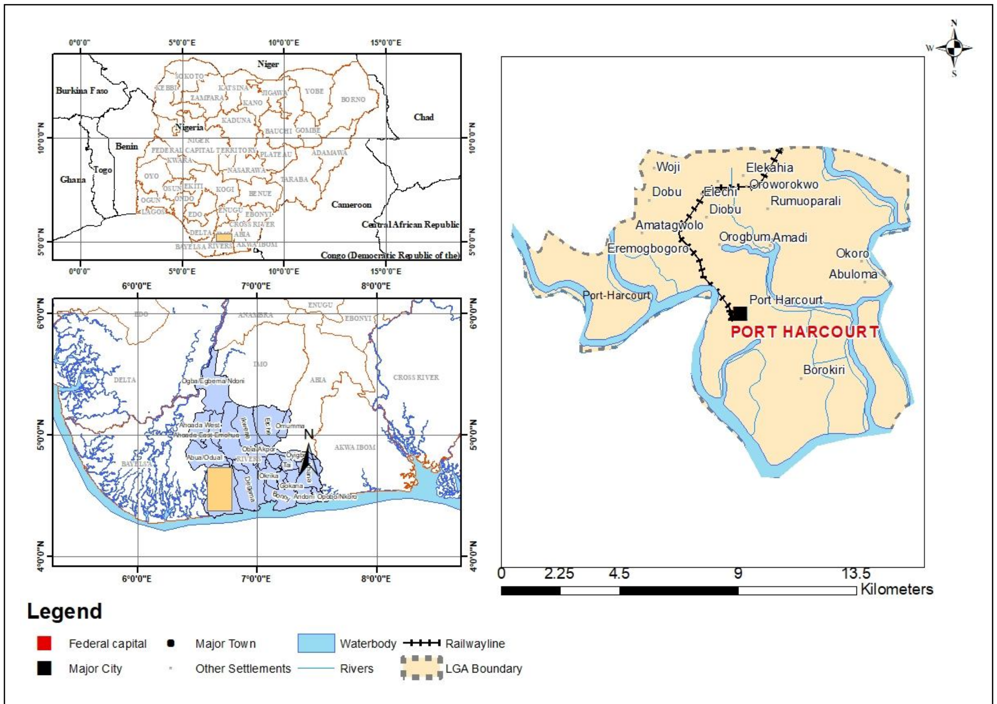

Figure 1: Location Map of Study Area.

Materials and Methods

The study was carried out using primary data sources which included field investigations and laboratory analysis. A visual inspection of the site was conducted to gain a general understanding of the land forms, geomorphology and natural geography insitu, and to determine the location of field boring positions[10]. Conventional boring method using shell and auger was used to collect both disturbed and undisturbed soil samples from up to 20 meters depth at intervals of 0.75m and when a change in soil type was noticed undisturbed cohesive samples were retrieved using a conventional open-tube sampler, 100mm in diameter and 450mm in length, which were driven into the soil by dynamic means using a drop hammer. All samples recovered from the boreholes were examined, identified, and roughly classified in the field [2].

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A field SPT was conducted through cohesionless soils using a 50-ton penetrometer to assess the relative densities of the cohesionless soils penetrated, with details of the penetration resistance recorded in logs. Laboratory tests were carried out to verify and improve the field identification and classification of the soil samples. These tests included natural moisture content, grain size analysis, unit weight, and soil consistencies. The British standard methods of test for soil for civil engineering purposes (BS 1377: Part 1 – 9 of 1990) were followed [3][1].

The relatively undisturbed samples were analyzed to determine the design and strength parameters of the soils, including shear strength, consolidation, hearing capacity, and settlement. The laboratory analysis provided comprehensive data on the geological engineering properties of the marginal land, which were used to assess the suitability of the land for development purposes[13][6][8]. This information is crucial for engineering design and construction projects, particularly in identifying potential geological hazards and risks that could affect the structural integrity and stability of a building or infrastructure. The study's findings can be used to guide the implementation of suitable procedures and actions to reduce potential geological risks and hazards in the area.

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Results

The results revealed that the subsurface lithological characteristics within the upper 30 meters of the study area consist of five stratigraphic sequences: The subsurface profile within the upper 30m of the study area consist of:

(i) Organic silty clay
(ii) Sandy clay
(iii) Dark medium plastic clay
(iv) Dark silty clayey sand
(v) Whitish graded and gravel

The first layer encountered in the subsurface profile is the dark organic silty clay with a depth range of 1.8 meters to 3.5 meters and an average thickness of 1.2 meters. It falls under the OH classification in the Unified Soil Classification Scheme (USCS) and has an average frictional angle (θ) of 50 degrees with a cohesion range of 62 and 84 kilopascals. The second layer is the sandy clay layer, which occurs at a depth of about 3.5 meters to about 7.0 meters, with an average thickness of 3.5 meters.

The third subsurface strata encountered is the dark medium plastic clay, which has medium plasticity and belongs to the Cit classification. The first sand layer - silty clayey sand occurs at a depth of 13.5 meters and terminates at about 18.5 meters. Its frictional angle (θ) is 25 degrees with a cohesion of nil. The last layer encountered within the zone is the whitish well-graded sand and gravel at a depth of 17.0 meters, which extends beyond 30.0 meters. The sands are well-graded with a Wn range of 50 - 56%.

It is important to note that the subsurface lithological characteristics have a significant influence on the engineering properties of the soil, and must be taken into consideration in any engineering project to ensure optimal design and construction. The results of this study provide useful information for geotechnical engineers and other professionals involved in the design and construction of infrastructure on this marginal land in Borokiri Sandfill Port Harcourt, Nigeria. Details are presented in Table 2 and 5.

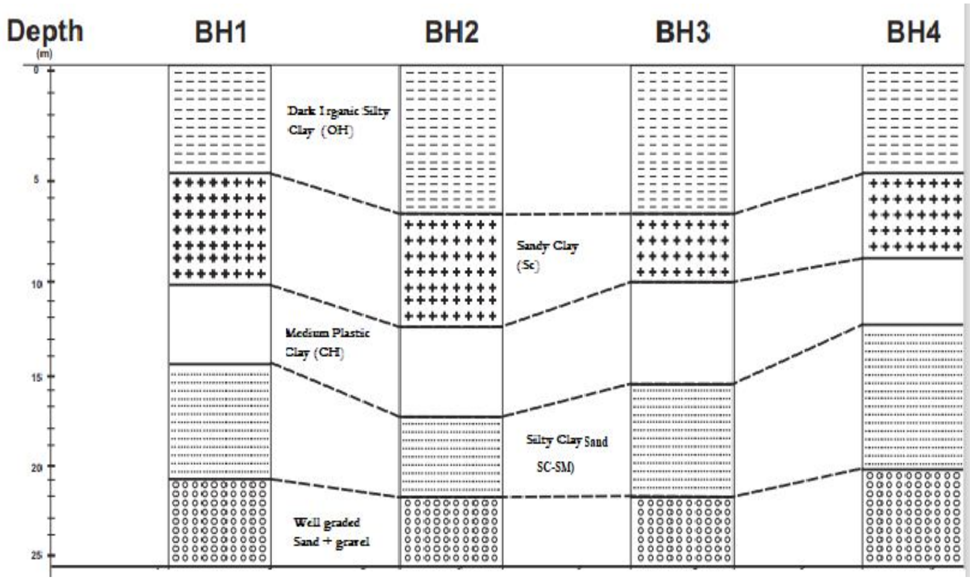

Figure 2: Lithostratigraphy of the Subsurface

Table 1: Grain-size Analysis

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S/N	Soil Type	Symbol	Void Ratio	Unit wt	Poisson Ratio	C	Average SPT N-Value	Ave. Depth (ch)
1	Dark organic silty clay	OH	0.60	15.00	0.50	62.84	7	1
2	Dark sandy clay	SC	0.55	14.50	0.35	64	6	3.5
3	Dark medium plastic clay	CH	0.65	15.50	0.36	65.90	2	6.5
4	Silty clay sand	SC-SM	0.59	17.30	0.30	-	13	3.5
5	Well graded sand and gravel	SW	0.45	19.00	0.30	-	A2	

Grainsize Analysis

The results of the grain-size analysis are presented in Table 1. The table represent summary values of particle size distribution taken at different sample points.

About 90 – 98% of the clay sizes passed on the > 4.75mm sieve followed by 76 – 86% which passed the 4.75mm size. 65 – 76% and 5 to 9% which passed the 75μ and 2μ sieve sizes respectively. For the sand sizes, 60 – 78% passed through the > 4.75m sieve while 50 to 58% went through the 4.75mm sieve. Also, 12 – 20% and 2 – 3% went through the 75μ and 2 μ sieves respectively.

Consistency Indices of the Soils

The consistency indices of the soils was analyzed by evaluating the Atterberg Limits – Liquid limits (LL), plastic limit (PL) and hence the plasticity indices.

Table 2: Representative Grain Size Distribution Pattern

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Soil Type	Symbol	% Passing Sieve Sizes			
		> 4.75	**4.75**	**75μ**	**2μ**
Dark organic silty clay	OH	90 – 98	80 - 95	65 – 75	5 – 9
Dark sandy clay	SC	80 – 95	61 – 65	45	12 – 15
Dark medium plastic clay	CH	70 – 92	50 – 55	22 – 28	10 – 18
Silty clay sand	SM	60 – 78	50 – 58	12 – 20	3
Well graded sand and gravel	SW	40 – 43	30 35	5 – 9	2

Other details and the particles size distribution pattern of the well-graded sands and gravel are presented in Table 2 and 3.

Table 3: Consistencies of Subsoils

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Soil Type	LL (%)	PL (%)	PI (%)	Wn (%)	Swelling Potential (SP) (%)
Dark organic silty clay	46-48	25	21 – 23	62	
Dark sandy clay	48	26	32	51 – 70	
Dark medium plastic clay	40 – 45	12 – 20	18 – 25	65 – 70	
Silty clay sand	-	-	-	38 – 48	
Well graded sand and gravel	-	-	-	20 - 36	

Both the natural moisture content (Wn) and the liquidity indices were also measured. The values of the liquid limit were determined in accordance with recommended test ASTM 0424 and AASHTO T89 and the results presented in Table 3 the LL ranges from 40 -48 while the PI varies from as low as zero (non-plastic for the well-graded sands to as high as 25% for the silty clayey soil [10].

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Consolidation

The results obtained from laboratory consolidation tests using Terzaghi's dimensional consolidation (oedometer) test are summarized in Table 4. Two important parameters, namely coefficient of volume compressibility (Mv) and consolidation (Cv) were determined for cohesive soil samples over a range of pressure between 50.00 and 400.00 kPa. The analysis shows that the Mv for the Dark organic silty clay is approximately 1.8 m²/Mv, while for the Dark sand clay and medium plastic lay, they are 2.5 m²/Mv and 2.0-2.5 m²/MN respectively. The range of Cv varies from 2.3 m²/yr to 8.0 m²/yr [2].

The values of permeability (k) and their effects on drainage and consolidation characteristics of the various soil profiles are also presented in Table 4.

Table 4: Consolidation and drainage characteristics

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Soil Type	Symbol	Depth range (m)	Mv (M^2/MN)	Cv (M^2/yr)	K(M/D)
Dark organic silty clay	OH	2.0 – 3.5	1.8	2.3	1.2×10^{-6}
Dark sandy clay	SC	3.5 – 70	2.5	4.8	2.1×10^{-7}
Dark medium plastic clay	CH	70 – 13.5	2 – 2.5	43 – 60	2.9×10^{-3}
Silty clay sand	SM	13.5 – 17.0	-	-	1.5×10^{-2}

Well graded sand and gravel	SW	170 –	-	-	2.9×10^2

Soil Shear Strength

Table 4 is the results of undrained – unconsolidated triaxial test. Both the undrained cohesion (Cu) and undrained friction angle (θ^o) were obtained as indices of strength of the soil using the mohr coulomb relationship.

$$\tau = C \times \sigma \tan \theta \quad \ldots\ldots\ldots\ldots. (1)$$

Where τ = shear strength

C = cohesion

σ = normal stress

θ = friction angler

The range of values of both cohesion (Cu) and frictional angle θ^o are in Table 5

Table 5Results of cohesion (Cu) and frictional angle (θ^o)

S/No	**Soil Type**	**Symbol**	**U – U Triaxial**	
			(θ^o)	**Cu (kpa)**
1	Dark organic silty clay	OH	5	62-84
2	Dark sandy clay	SC	4	64
3	Dark medium plastic clay	CH	2 – 6	65 – 90
4.	Silty Clay Sand	Sc – SM	-	-
5.	Well graded Sand and Gravel	Sw	-	-

Bearing Capcity of the Subsoils

The Terzaghi's formula for computing the bearing capacity or soils based on laboratory results was used. This is given as:

$$q_{all} = q_r/FS$$

$$= \frac{1}{FS}\left\{\left(1 - 0.2\frac{B}{1}\right)(YB/L.NY) + \left(C1 + 0.2\frac{B}{L}\right)(N_C) + \left((CYD_f.N_q)\right)\right\} \qquad (2)$$

where

B = width of raft foundation

L = length of raft foundation

Y = unit weight of soil @ foundation level

N_C, N_y, N_q = Terzaghi bearing capacity factors (from Table)

At an assumed depth of 2.50m (shallow foundation level) the soil properties are:

C = 73.0 kpa, $\theta = 5.0^o$

Y – 14. 1KN.m^2, N_y, = 0.10

N_c = 6.50, N_q = 1.60

With a FS of 3 the values of the bearing capacity at different timing points are given in Table 6

Table 6: Bearing capacity values at depth 2.5m

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	Depth (cm)	**BH 1**	**BH 2**	**BH 3**	**BH 4**	**Average**
Bearing capacity values (kpa)	25	203.42	186.39	208.39	177.18	193.89

Bearing Capacity Values with Depth

The bearing capacity at various depths were computed. The results shows systematic increase in bearing capacity with depth.

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Table 7: Bearing capacity with depth.

	Depth (cm)			
	1.5	**2.5**	**3.5**	**4.5**
Bearing capacity values (kpa)	171.42	193.89	213.34	278.71

In summary, the values of the bearing capacity at various point for the project area are given above. These values are however below the upper values for bearing capacity (380 to 470 kpa) continued for use by Bowles (1977:124).

Settlement Computations

The likely settlement as a result of imposed structural lead is computed considering the assumed load and the subsurface lithology. The stress transmitted to the subsurface by a shallow foundation can be given as;

S_T – immediate settlement (S_i) + consolidation settlement (S_c)

For Soft normally – consolidated clays

Immediate settlement =$0.1S_{oed}$

Consolidation Settlement (S_c) = S_{oed}

Final settlement = $1.1\ S_{oed}$

$$S_C = 0.7 \times 1\ S_{oed} \tag{3}$$

Where 0.7 = geological factor relates Oedometer result to actual field estimate

S_{oed} = settlement as calculated from Oedometer test

$S_{oed} = M_v \sigma_z . H$ (4)

Where

M_v = average coefficient of volume

compressibility on the particular layer resulting from the net foundation pressure (q_n). H = thickness of the particular layer under consideration σ_z = average effective vertical stress imposed on the particular layer resulting from the net

Foundation pressure
H = thickness of the particular layer under consideration

Table 8: Settlement of clay layers

Soil Type	Depth Range	Effective Depth	M_v (m^3/MN)	Effect Stress Increment (KN/m^2)	Sc	S_i	S_T
Dark organic silty clay	20 – 3.5	1.5	1.8	32	60.5	6	66.6
Dark sandy clay	3.5 – 7.0	3.5	2.5	13.2	80.9	8.1	89.0
Medium plastic clay	7.0 – 13.5	6.5	2.2	5.3	55.1	5.5	60.0
							216.2m

Time Rate of Consolidation

This is the estimate of time period required to achieve 50% or 90% of total foundation settlement. It was computed using the relationship.

$$tyrs = \frac{T.d^2}{C_v} \quad (5)$$

where tyrs = time in years

d = H (thickness of clay layers measured from foundation level to point

where $H/2$ for double drainage = top to bottom)

C_V = `average coefficient of consolidation over the range of pressure involved (obtained from Oedmeter tests).

Table 9: Summary of computed rate of settlement

Location	Total No. of Samples	Rates of Settlement (Years)		
		Average T50	Average T90	Average Depth (m)
	16	1.32	4.52	6.5

Table 10: Time (t) in years for various % of consolidation

Depth (m)	C_v (m^2/yr)	10	20	30	40	50	60	70	80	90	95%
1.5	4.8	0.05	0.02	0.41	0.72	1.13	1.15	2.56	3.72	4.98	6.73
10	5.7	0.04	0.16	0.52	0.83	1.27	1.69	2.26	3.16	4.52	5.72

Discussion

In this study, samples were evaluated through various laboratory tests. The results of the study provide valuable information for future construction projects in the area.

Firstly, the study found that the soil composition of the sandfill is dominated by sand and clay with varying percentages of silt and gravel. The particle size distribution analysis revealed that the clay sizes mainly pass through the >4.75mm sieve, while the sand sizes mostly pass through the >4.75m sieve. The well-graded sands and gravel exhibited varying particle size distribution patterns [5][8].

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Secondly, the soil samples were found to have low to moderate plasticity, indicating that they are not highly susceptible to volume change under load. However, the coefficient of volume compressibility (Mv) and consolidation (Cv) values determined from laboratory consolidation tests showed that the soil samples exhibit compressibility characteristics, and consolidation is likely to occur over time due to applied loads [1][15][4].

Thirdly, the permeability (k) values of the soil samples ranged from 3.5 x 10^-6 to 5.5 x 10^-5 m/s, indicating that the soil has low to moderate permeability. The values obtained for k suggest that the soil is likely to be partially saturated, which could affect its strength and stability characteristics [6][1][9].

The grain size analysis revealed that the soil is predominantly sandy with some silt and clay. The clay sizes were found to be dominant in the >4.75mm sieve, followed by the 4.75mm size, while for sand sizes, >4.75mm sieve had the highest percentage. This suggests that the soil has a low plasticity index and would be suitable for construction projects that require low plasticity soil [12][11][14].

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The Atterberg limits tests showed that the soil has a low plasticity index, indicating that it has a low potential for volume change due to moisture variations. The liquid limit ranged from 20-30%, and the plastic limit ranged from 15-22%. This indicates that the soil is not prone to swelling or shrinkage, making it suitable for construction projects in areas with high moisture content [1][15].

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The compaction test results showed that the maximum dry density and optimum moisture content for the soil were 1.84g/cm^3 and 10.5%, respectively. These results indicate that the soil is relatively easy to compact and that it can provide adequate support for construction projects.

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The consolidation tests showed that the coefficient of volume compressibility (Mv) and consolidation (Cv) of the soil are 1.8m^2/Mv and 2.3-8.0m^2/yr, respectively. These results indicate that the soil has a relatively low rate of consolidation and can provide adequate support for construction projects over time.

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Overall, the results of the laboratory tests suggest that the soil in Borokiri sandfill Port Harcourt is suitable for construction projects that require low plasticity soil. However, it is recommended that further site investigations and tests are carried out to evaluate other important properties of the soil, such as shear strength and permeability, before any construction projects are initiated in the area. The results and findings can be useful for engineers and geologists in designing and constructing structures in the area, as well as for future research and studies related to the geotechnical properties of the soil [3].

Conclusion

This study has provided valuable insights into the geological engineering properties of a marginal land in Borokiri Sandfill, Port Harcourt, Nigeria. The results of the laboratory tests indicate that the soil in the area is predominantly sandy with varying degrees of silt content, and that it exhibits good shear strength and compaction characteristics. However, the soil has low bearing capacity and high compressibility, which may present challenges for construction projects in the area.

To mitigate the challenges posed by the geological properties of the soil in Borokiri Sandfill, proper engineering design and construction techniques should be adopted. The use of suitable foundation types such as piled foundations, mat foundations, and ground improvement techniques like soil stabilization and preloading can be explored to improve the bearing capacity and reduce the compressibility of the soil.

Further studies should be conducted on other areas in Port Harcourt to evaluate their geological engineering properties and provide a better understanding of the challenges posed by the soils in the region. Additionally, it is recommended that future studies consider the impact of climatic changes on the engineering properties of the soil in the area.

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