Archives of Current Research International

Volume 23, Issue 4, Page 30-40, 2023; Article no.ACRI.97597
ISSN: 2454-7077

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

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Authors' contributions

This work was carried out in collaboration between both authors. Both authors read and approved the final manuscript.

Article Information

DOI: 10.9734/ACRI/2023/v23i4567

Open Peer Review History:
This journal follows the Advanced Open Peer Review policy. Identity of the Reviewers, Editor(s) and additional Reviewers, peer review comments, different versions of the manuscript, comments of the editors, etc are available here: https://www.sdiarticle5.com/review-history/97597

Original Research Article

Received: 18/01/2023
Accepted: 23/03/2023
Published: 29/03/2023

ABSTRACT

Aim: The aim of this study was to assess the geological engineering 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 4 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 consolidation (Cv).
Place and Duration of Study: The Study was conducted in Borikiri Sandfill, Port Harcourt between February and May 2020.
Methods: This study's methodology included field research, laboratory analysis, and testing. Drilling and conventional penetration tests were used to assess the soil profile. Laboratory tests such as particle size analysis, atterberg limits, and moisture content were used to determine the index characteristics. The values of permeability (k), volume compressibility (Mv), and consolidation (Cv) were also determined using triaxial and consolidation tests.

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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 Liquid limit (LL) of 45% and a Plastic Limit (PL) value of 23%. The values of k, Mv, and Cv 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 consolidation 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 recommended that a shallow foundation, down to the first layer, can be used for any light construction on the marginal land in Borikiri Sandfill, Port Harcourt, Nigeria. The values of k, Mv, and Cv also indicate that the soil is relatively compressible, which should be taken into account in any design or construction activities.

Keywords: Marginal land; settlement; foundation design; soil profile; bearing capacity.

1. 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 [1]. 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 [2,3].

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 [4,5,6]. 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 [7,8].

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 [7,4].

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 [9]. The Niger Delta area is also characterized by high salinity of soil and water [10]. 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 [8,6].

It is essential to undertake a thorough assessment of the geological engineering properties of the marginal land in Borikiri 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 [4,5].

1.1 Study Location

The research was conducted in the Borikiri area of Port Harcourt, which is located in the southeastern region of Rivers State and within the southern Niger Delta region of Nigeria. Borikiri 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 [7]. 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 [8].

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 [4]. 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 [6].

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 lithostratigraphic units have been recognized in the Niger Delta consisting of, in ascending order, the Akata, Agbada and Benin formation [1]. The site sits astride the Niger flood plain which overlies the Benin formation that is often called coastal plain sands [7,11].

The study location (Borikiri) 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 29^{o}C during the brief cold hamattan period (December to February) to over 34^{o}C from March through October each year [4,6].

2. MATERIALS AND METHODS

The purpose of this study is to assess the geological engineering properties of a marginal land in Borikiri Sandfill, Port Harcourt, Nigeria. The study involves a combination of field investigations and laboratory testing to determine the soil profile and index properties, including particle size analysis, Atterberg limits, and moisture content. Consolidation and triaxial tests were also performed to determine the values of permeability, volume compressibility, and consolidation. This methodology aims to provide a comprehensive understanding of the geological engineering properties of the land, which will inform the design and construction of any structures in the area.

- Inspection of the Site: The Study location was inspected to gain a general understanding of the land forms, geomorphology etc. and to determine the location of field boring positions.
- Conventional boring method using shell and auger was used: Soil samples were collected using conventional boring methods with shell and auger. The samples were collected from up to 20 meters depth at intervals of 0.75m.
- Retrieval of undisturbed cohesive samples using a conventional open-tube sampler: 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. The sampler was driven into the soil by dynamic means using a drop hammer.
- Examination, identification, and rough classification of all samples recovered from the boreholes in the field: This process was carried out for identification of soil type and soil characteristics.
- Oedometer consolidation tests using undisturbed samples of 75mm diameter x 20mm high at pressure range of 50kpa - 400kpa:. Consolidation parameters of the soil samples were determined [4,6].
- Analysis of data using Taylor square root fitting: The Taylor square root fitting method was used to analyze the data obtained from the soil samples. This method is used to determine the compression index of the soil samples [10].
- Determination of preconsolidation pressures using the Cassagrande method. The Cassagrande method was used to determine the preconsolidation pressures of the soil samples. This method is used to determine the maximum past pressure that the soil has experienced [4,12].
- Field SPT conducted through cohesionless soils using a 50-ton penetrometer. A 50-ton penetrometer was used to conduct the field SPT through cohesionless soils. This step was carried out to determine the soil density through its resistance to penetration [13].
- Laboratory tests carried out to verify and improve the field identification and classification of the soil samples: These tests were carried out to determine the soil type and characteristics. Tests included natural moisture content, grain size analysis, unit weight, specific gravity and soil consistencies [2,6].
- British standard methods of test for soil for civil engineering purposes (BS 1377: Part 1 – 9 of 1990) were followed. These methods were used to determine soil properties for engineering uses.

3. 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

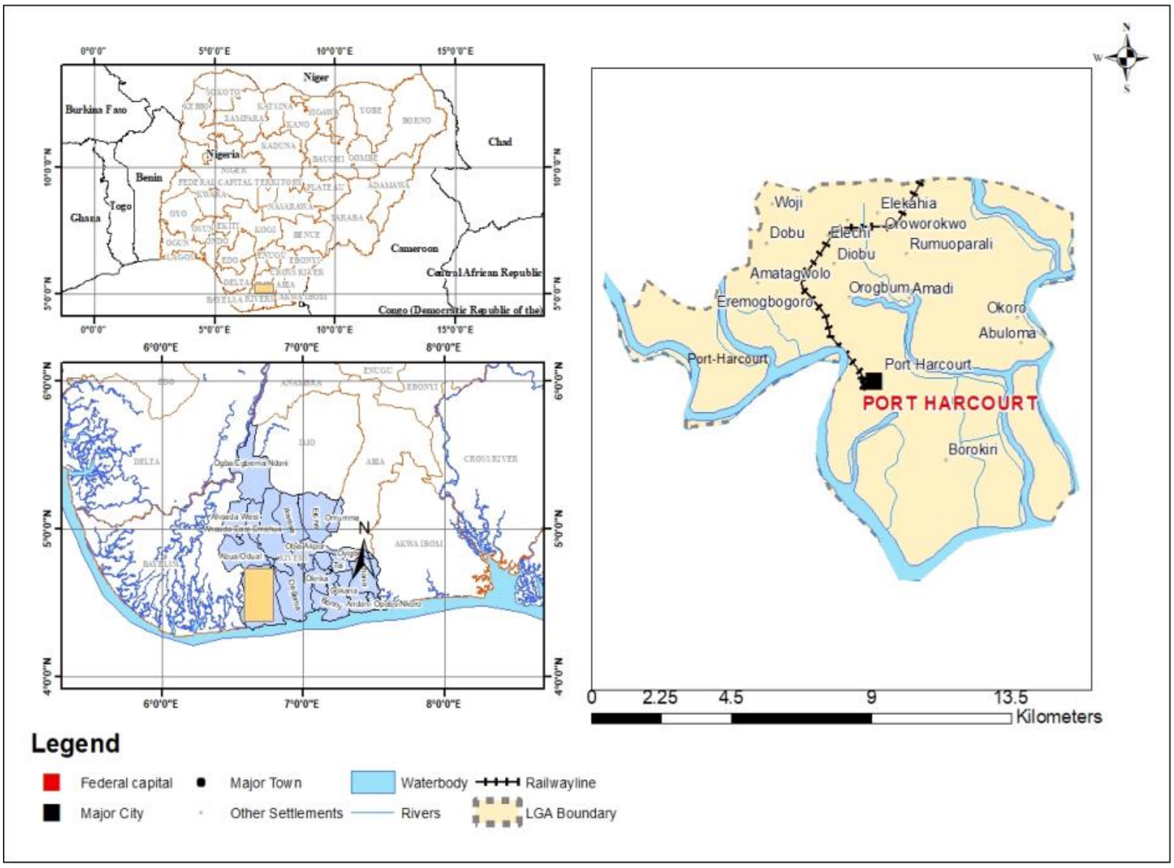

Fig. 1. Location map of study area

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 Borikiri Sandfill Port Harcourt, Nigeria. Details are presented in Tables 2 and 5.

3.1 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.

Table 1. Grain-size analysis

S/N	Soil Type	Symbol	Void Ratio (e)	Unit wt (γ)	Poisson Ratio	Average SPT N-Value	Ave. Depth (m)
1	Dark organic silty clay	OH	0.60	15.00	0.50	7	1
2	Dark sandy clay	SC	0.55	14.50	0.35	6	3.5
3	Dark medium plastic clay	CH	0.65	15.50	0.36	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	

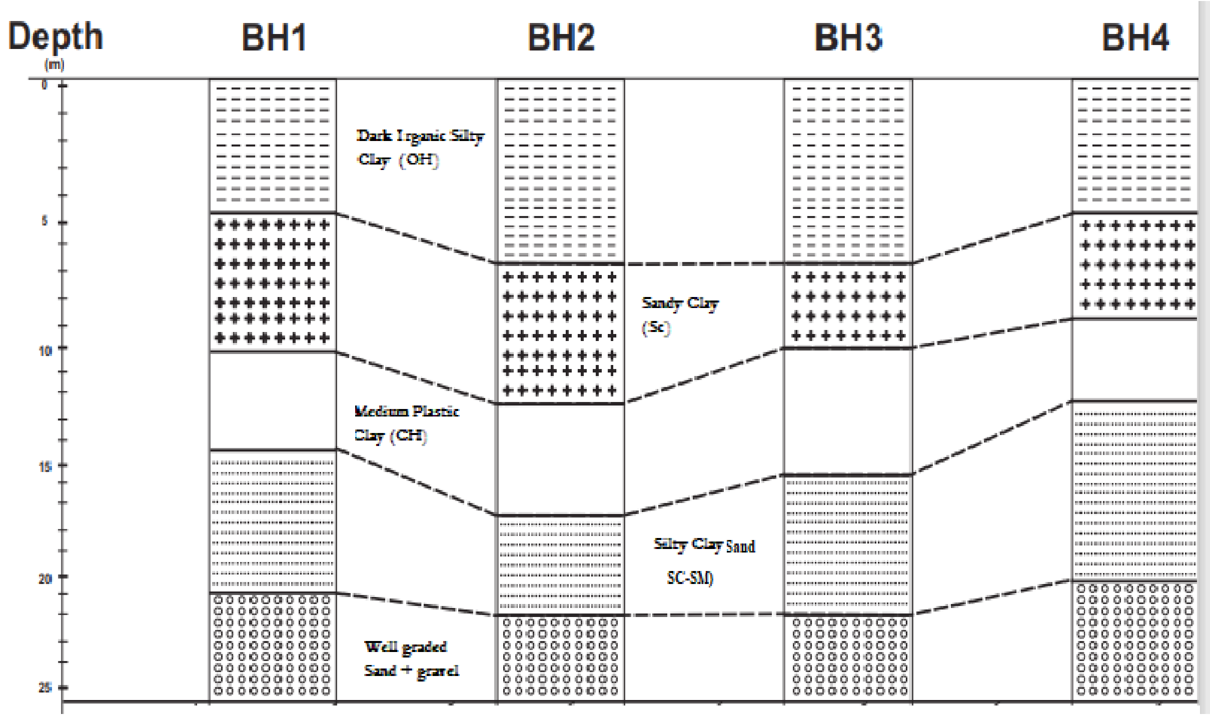

Fig. 2. Lithostratigraphy of the subsurface

3.2 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.

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

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 liquid limit (LL) ranges from 40 to 48, while the plasticity index (PI) varies from zero (non-plastic for well-graded sands to as high as 25% for silty clayey soil [13].

3.3 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 m^2/Mv, while the Dark sandy clay and medium plastic clay are 2.5 m^2/Mv and 2.0-2.5 m^2/MN respectively. The range of Cv varies from 2.3 m^2/yr to 8.0 m^2/yr [14].

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

3.4 Soil Shear Strength

Table 4 is the results of unconsolidated-undrained triaxial tests. 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.

$$\tau = C \times \sigma \tan \theta \tag{1}$$

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 2. Representative of grain size distribution pattern

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	SC-SM	60 – 78	50 – 58	12 – 20	3
Well graded sand and gravel	SW	40 – 43	30 35	5 – 9	2

Table 3. Subsoil's consistencies

Soil Type	Liquid Limit (LL) (%)	Plasticity Index (PI) (%)	Plastic Limit (PL) (%)	Moisture Content Wn (%)
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

Table 4. Consolidation and drainage characteristics

Soil Type	Symbol	Depth range (m)	Coefficient of Vol. Compressibity Mv (m^2/MN)	Coefficient if Consolidation Cv (m^2/yr)	Permeability k(m/s)
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	SC-SM	13.5 – 17.0	-	-	1.5×10^{-2}
Well graded sand and gravel	SW	170 –	-	-	2.9×10^{2}

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

S/No	Soil Type	Symbol	Undrained Consolidation-Undrained U – U Triaxial	
			Friction angle(θ^o)	Cohesion 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	-	-

3.5 Bearing Capacity of the Subsoils

The Terzaghi's (1943) formula for computing the bearing capacity of soils based on laboratory results was used. This is given as:

$$q_{all} = qu/FS = \frac{1}{FS}\left\{\left(1-0.2\frac{B}{L}\right)(YB/L.Ny)+\left(C1+0.2\frac{B}{L}\right)(CN_C)+\left((YD_f.N_q)\right)\right\} \quad (2)$$

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 sampling points are given in Table 6.

3.6 Bearing Capacity Values with Depth

At various depths, the bearing capacity was computed. The findings indicate a consistent rise in bearing capacitance with depth.

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).

3.7 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}

$$S_C = 0.7 \times 1\ S_{oed} \quad (3)$$

where 0.7 = geological factor relates Oedometer result to actual field estimate
S_{oed} = settlement as calculated from Oedometer test

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

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 6. Bearing capacity values at depth 2.5m

	Depth (m)	BH 1	BH 2	BH 3	BH 4	Average
Bearing capacity values (kpa)	2.5	203.42	186.39	208.39	177.18	193.89

Table 7. Bearing capacity with depth

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

Table 8. Settlement of clay layers

Soil Type	Depth Range (m)	Effective Depth (m)	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

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

3.8 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 Oedometer tests).

4. DISCUSSION

In this study, the soil 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 [15,12]. 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 [4,9,16]. 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 [10,4,17]. 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 [8,1,7]. 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 highly susceptible to volume change under load [4,9,16].

Overall, the laboratory test findings imply that the soil in Port Harcourt's Borikiri sandfill is adequate for building projects that call for soil with minimal plasticity. Before beginning any building projects in the region, it is advised that additional site examinations and testing be conducted to assess additional significant soil attributes, such as shear strength and permeability. The outcomes and conclusions can assist engineers and geologists in planning and building buildings in the region as well as in upcoming investigations and studies pertaining to the geotechnical characteristics of the soil [2,18-21].

5. CONCLUSION

This study has provided valuable insights into the geological engineering properties of a marginal land in Borikiri 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 Borikiri 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.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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Peer-review history:
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