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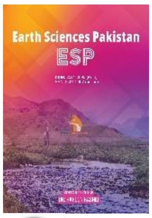

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RESEARCH ARTICLE

THE GEOTECHNICAL PROPERTIES OF THE BRACKISH SHORELINE OF ABONNEMA, NIGER DELTA, NIGERIA

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ABSTRACT

The purpose of this study was to investigate the geotechnical properties of the brackish shoreline of Abonnema, Niger Delta, Nigeria using both in-situ and laboratory means. The study aimed to provide essential information for development planning and design of structures in the area. The study utilized borehole drilling, particle size analysis, oedometer tests, and triaxial tests. Five boreholes were drilled, and four lithostratigraphic layers were identified, with silty peaty clay at the top and medium-coarse sand at the bottom. The analysis was carried out using approved methods, and the in-situ results were compared with laboratory geotechnical properties. The study found that the clay had a very high proportion of fines, with atterberg limits ranging from 21.0 to 22.9% for the plasticity index and corresponding liquidity index values of 0.49 to 0.63, respectively. The clay had an average moisture content of above 35%, which is expected to vary with the season. The coefficient of permeability (k) averaged at 1.39 x 10^{-4}, while the coefficient of the volume of compressibility (Mv) and coefficient of consolidation (Cv) ranged from 1.65 x 10^{-4} to 1.98 x 104m^2/MN for Mv and 1.84 to 2.48m^2/yr for Cv. The strength parameters showed cohesive clay with values from 21kPa to 24kPa with an average frictional angle of 4^{o}. The bearing capacity values increased from 75.154kPa at the top clay layer to 207.733 kPa at the bottom medium-coarse sand. The settlement values averaged 157mm for Immediate settlement and 815mm for consolidated settlement. The study provides crucial information about the geotechnical properties of the brackish shoreline of Abonnema, Niger Delta, Nigeria. The results suggest that the area has a high percentage of fine particles, and the clay is cohesive with low shear strength. The bearing capacity values increased towards the bottom medium-coarse sand, and the settlement values were significant. These findings are vital for development planning and the design of suitable structures in the area.

KEYWORDS

Geotechnical properties, brackish shoreline, Atterberg limit, infrastructure development, bearing capacity.

1. INTRODUCTION

The brackish shoreline is a transitional environment developed as a result of the movement of freshwater into marine bays and lagoons, with a reduced concentration of dissolved salts (Krumble and Sloss, 1963). Tidal influences have a great effect on the depositional process in this environment. However, not all shore depositional take place between the tidal limits, that is, shore processes strongly condition some depositions above the tidal limits (Dunar and Rodgers, 1957).

The Niger Delta region in Nigeria is growing quickly, with Abonnema having over 200,000 residents. However, environmental issues such as shoreline erosion, saltwater intrusion into the aquifer, and limited land availability due to the swampy mangrove forest surrounding the community are hindering physical development in the area. To address these issues, land reclamation/sand filling and shoreline protection are urgently needed. However, these solutions cannot be effectively implemented without a detailed understanding of the geodynamics of the area (Morrison, 2017). Abonnema has its fair share of environmental problems. Some of these are coastal/shoreline erosion, saltwater intrusion into the aquifer, and the swampy mangrove forest surrounding the community, thereby limiting land availability for development. This calls for urgent land reclamation/sand filling and shoreline protection. These problems surfaced in the works of Teme (2008) and Abam (2018). These studies have highlighted the environmental and engineering geological problems facing the Niger Delta, with many of these attributed to the nature of the deltaic sediments and prevailing climatic conditions (Akpokodje, 1985).

This paper, therefore, attempts to fill this gap by conducting a detailed engineering geological investigation along the Abonnema shoreline. Specific objectives are to establish the soil stratigraphy up to 30 meters, describe the soil properties, and identify geotechnical problems arising from the geodynamic setting of the region. The findings will be used to inform the design of resilient shoreline protection structures and to guide sustainable development efforts in the area. The paper will contribute to the critical knowledge gaps in the existing literature and, therefore, will add to the broader understanding of the interplay between soil mechanics and environmental constraints in deltaic regions.

The study aims to carry out an engineering geological soil investigation to construct a shoreline protection structure involving the following:

- Determining the soil stratigraphy to a depth of 30m.
- Determining the type, nature, and characteristics of soils underlying the shoreline.
- Determining the relevant soil parameters for the design of shoreline protection.

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- Determining environmental/geotechnical problems as a result of the peculiar geodynamic setting of the environment.
- Suggesting possible solutions to the associated problems.

2. Study Location

Abonnema is located in the Niger Delta area of Nigeria, lying between latitude 4.8° North and longitude 6.8° East. The area is surrounded by mangrove swamps intersected by creeks in the north, east, and south, while to the west is the River Sombreiro. Figure 1 depicts the study location.

Abonnema is geographically the transition of the mangrove zone and is otherwise known as the middle delta of the Niger Delta. The terrain is fundamentally flat, and the mean elevation does not exceed more than 10 meters above sea level at low tide. At high tide, it reduces because of the rise in seawater levels. It is a tidal coastal plain with tidal flats to the fore and swamps inland or towards the hinterland (Frank-Briggs, 1982). Sediments range from fine to coarse-grained sand, fine clayey sand, and peaty deposits within the swamp, as observed during the field studies.

The climate of Abonnema is typical for the coastal climatic zone, fully under the influences of Tropical Maritime Air Mass. This is a well characterized rainfall pattern and occurs well over most parts of the year, peaking at over 600 mm during the wet season. The mean annual temperature is about 27°C, varying by about 2°C. The rainfall is high, above 2,000 mm per year, due to the fact that the area lies close to the equator and falls within the subequatorial climatic belt.

Abonnema's soil profile comprises clays, silt, sands, and gravels with soft mud on the surface and a very high-water table. Geologically, it falls within the Benin Formation (Oyegun, 1999). Poor drainage, due to its low-lying topography coupled with high water table and heavy rainfall, is common. These have been exacerbated by high population growth rates in recent times, which further contribute to wastes generated that, if poorly managed, can contaminate groundwater (Wizor, 2012). The interplay of these environmental, climatic, and geological factors further calls for cautious geotechnical evaluation and sustainable development planning in Abonnema.

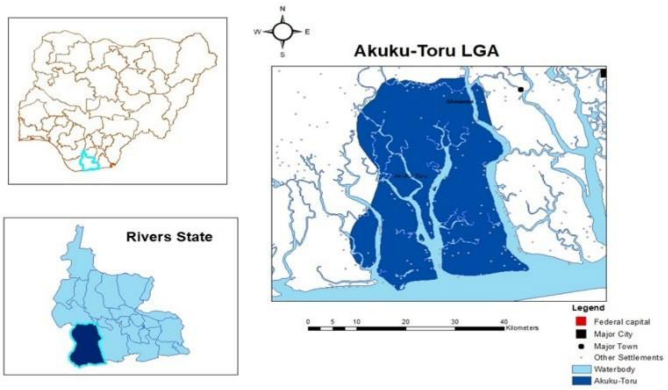

Figure 1: Study Location Map

3. Materials and Methods

The study was conducted along the brackish shoreline of Abonnema, Niger Delta, Nigeria. Soil samples were collected during the dry season to minimize seasonal variations. Five geotechnical boreholes were drilled to a depth of 30 meters, with samples retrieved at regular intervals of 1.0m and at points of noticeable soil changes. Both disturbed and undisturbed samples were collected for laboratory analyses, ensuring comprehensive characterization of soil properties.

3.1 Field Investigations

Field investigations included:

- *Borehole Drilling*: Boreholes were drilled using a light cable percussion rig. Undisturbed samples were collected from cohesive soils for detailed study, while a standard penetration test (SPT) was performed in granular sediments to assess in-situ densities.
- *Static Cone Penetration Test (CPT)*: Resistance to cone penetration was recorded at 20 cm intervals using a hydraulic sounding head equipped with pressure gauges.

3.2 Laboratory Testing

The laboratory analyses focused on determining both index and engineering properties of the soil samples. Key tests performed include:

- *Grain Size Distribution*: Sieve analysis was used to classify soil particle sizes.
- *Atterberg Limits*: Both the Liquide limit, Plastic liquid and Plasticity index were determined.
- *Compaction Tests*: Soil compaction characteristics were assessed to determine optimum moisture content and dry density.
- *Unconfined Compressive Strength (UCS)*: UCS tests evaluated the strength of cohesive soils under axial loads.
- *Oedometer Tests*: One-dimensional consolidation tests provided data on compressibility and consolidation rates.
- *Shear Strength Tests*: Undrained triaxial tests measured cohesion and internal friction angles for cohesive soils.

3.3 Data Analysis and Interpretation

Laboratory tests were conducted in triplicate to ensure reliability, with results averaged and analyzed. Comparative analyses between in-situ and laboratory-derived properties were performed to validate findings. Parameters such as permeability, consolidation coefficients, and bearing capacity values were computed using established geotechnical equations and methodologies. This comprehensive methodology integrates field and laboratory approaches to provide a robust understanding of the geotechnical characteristics of the Abonnema shoreline, facilitating informed recommendations for engineering applications.

4. Results and Discussion

4.1 Lithological Characteristics

The subsurface stratigraphy along the brackish shoreline of Abonnema, as revealed through borehole investigations, demonstrates a stratified sequence of four distinct geological layers: Details depicted in Figure 2.

4.1.1 Peaty Clay Layer

The uppermost layer, approximately 5.0 meters thick, consists of soft, whitish, silty peaty clay. This layer is indicative of high organic content and exhibits low strength and compressibility. Its presence highlights potential challenges for engineering foundations due to high settlement rates.

4.1.2 Silty Fine Sand Layer

Beneath the peaty clay lies a stratum of silty fine sand, extending to depths between 4.5 meters and 9.0 meters. The sand is loose, whitish-grey, and contains minor silt fractions, reflecting moderate drainage potential but limited shear strength, making it prone to instability under load.

4.1.3 Medium-Dense Fine Sand Layer

This layer, roughly 4.0 meters thick, consists of yellowish-brown, angular, silty fine sand. Its moderate density and angular grain structure indicate improved load-bearing capacity compared to the overlying layers, although the presence of silt may still impede drainage under saturation.

4.1.4 Medium to Coarse Sand Layer

Beneath the peaty clay lies a stratum of silty fine sand, extending to depths between 4.5 meters and 9.0 meters. The sand is loose, whitish-grey, and contains minor silt fractions, reflecting moderate drainage potential but limited shear strength, making it prone to instability under load.

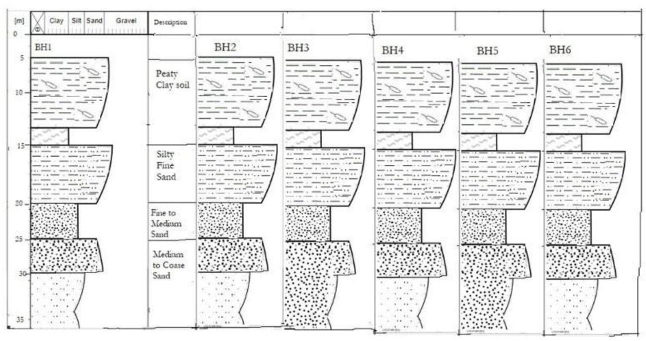

Figure 2: Stratigraphic sequence along the shoreline

4.2 Grain Size and Distribution

The grain size analysis confirms a progression from fine-grained soils at the surface to coarser materials at greater depths, consistent with the lithological stratigraphy. Particle size distribution for each layer is summarized in Table

4.2.1 Peaty Clay

Contains 40–56% clay-sized particles, indicating high plasticity and low permeability.

4.2.2 Silty Fine Sand

Displays a mixture of fine sand (44–61%) and silt (5–16%), reflecting reduced drainage characteristics and moderate strength.

4.2.3 Medium-Dense Fine Sand

Dominated by fine sand particles (47–61%) with minor silt content (17– 22%), providing better stability compared to overlying layers.

4.2.4 Medium to Coarse Sand

Comprises 32–42% coarse sand, with negligible fines (<5%), contributing to excellent drainage and high shear strength.

Although variability within each major soil group is minimal, average values demonstrate consistency in grain size trends and align with field observations. The progression from fine-grained to coarse-grained sediments corroborates depositional processes influenced by tidal actions

Table 1: Summary Particle size Distribution

S/N	No. of Sample	% passing 0.074mm	Gravel	Coarse to medium	Fine sand	Silt	Clay	Soil type
1.	7	66 – 70	0	0-1	15-17	10-26	40-56	Clay
2.	7	12-13	0	0-5	44-61	5-16	2-17	Silty clay
3.	7	6-11	0	1-9	47-61	17-22	01-8	Fine sand
4.	7	0-2	0-2	32-42	13-71	1-3	0	Medium sand
5.	7	0-1	0-4	35-59	17-23	0-2	0	Medium to coarse sand

Source: Analyzed data

4.3 Atterberg Limits and Consistency Indices

The average moisture content of the clay is high (above 35%), and this characteristic's high in-situ moisture content is a good indication of the various Atterberg limits (Adebisi et al., 2019). The plasticity of the soil index ranges from 21.0% to 22.9% with a corresponding liquidity index (LI) of 0.49 to 0.13, respectively. A plot on the Casagrande plasticity chart (Figure 3) shows Organic clay.

Table 2: Atterberg limits of the Various Soil Types

Borehole No.	Depth (m)	Natural Moisture Content (%)	Liquid Limit LL (%)	Plastic Limit PL (%)	Plasticity PL in % LL-PL	Liquidity Index WN-PL PL	Coefficient of Earth Pressure at Rest
1	2.0	36.3	47.0	26.0	21.0	0.49	0.68
	4.0	37.6	47.3	25.8	21.5	0.55	0.70
2	2.0	36.1	47.3	25.4	22.0	0.49	0.68
	4.0	37.9	47.3	24.7	22.4	0.59	0.70
3	2.0	36.1	47.4	25.4	22.0	0.58	0.69
	4.0	37.9	47.1	24.7	22.4	0.59	0.70
4	2.0	36.5	46.9	24.8	22.1	0.53	0.70
	4.0	37.0	47.0	25.2	21.8	0.54	0.67
5	2.0	36.7	46.8	24.7	22.1	0.54	0.68
	4.0	38.8	47.1	24.8	22.3	0.63	0.70

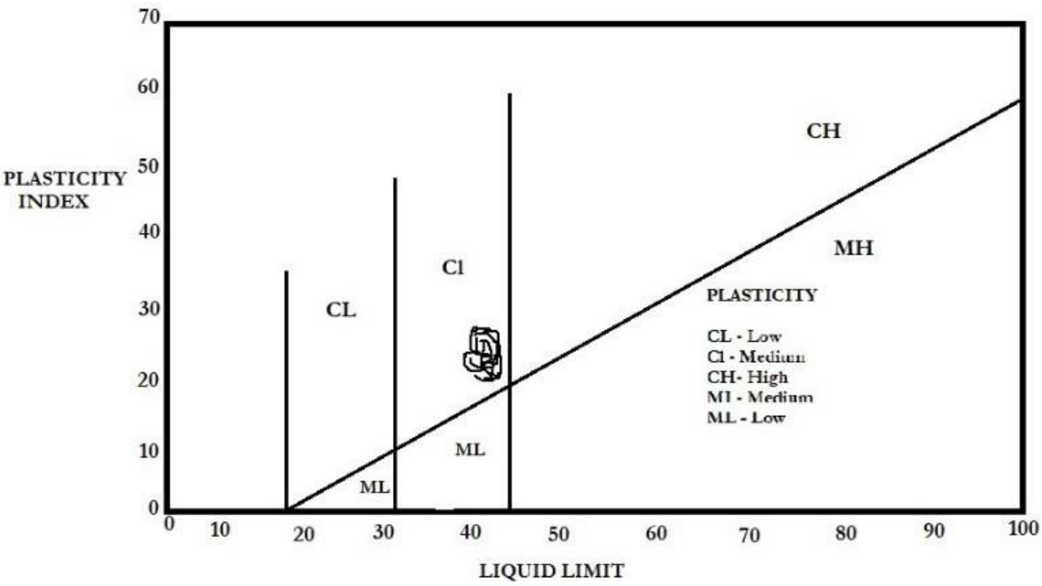

Figure 3: Casagrande Plasticity Chart

4.4 Soil Classification

Table 3: Classification of Soil into Groups Using AASHTO and USCS Scheme

Soil Type	Gravel	Sands			Fine	AASHTO	USCS
		Coarse	Medium	Fine			
		% Retained No 4	% Retained No. 10	% Retained No. 40	% Plastic		
Peaty Clay	0	1	2	16	61	A-7	
Loose Silty Fine Sand	0	2	5	52	16	A-3	SP
Fine Sand (Yellowish Brown)	0	1	6	54	26	A-3	SP
Medium Sand	3	20	57	19	3	A-1-a	SP
Medium Coarse Sand	4	35	49	10	2	A-1-a	SP

Source: Analyzed Data

4.5 Consolidation

One-dimensional consolidation test results obtained from the oedometer offer useful information about the compressibility and consolidation characteristics of soils along the Abonnema shoreline. Calculated values for the coefficient of consolidation (Cv) and the coefficient of compressibility (Mv) at different depths are summarized in Table 4. At 2 meters, the Cv, which ranged from 2.48 m^2/year to 1.85 m^2/year, was measured under an effective pressure of 50 kN/m^2. These values are consistent with those observed at a depth of 4 meters, indicating similar consolidation properties across all tested locations. The results suggest moderate rates of pore water dissipation during consolidation—a typical behavior seen in silty clays and peaty soils. The plot of void ratio versus effective pressure also reveals that the peaty clay exhibits medium compressibility, reflecting significant deformation potential under loading conditions. The findings also highlight the high swelling potential of the soil, attributed to its organic content and fine-grained composition.

Table 4: Results of Consolidation Tests

Borehole No,	Depth	Po KN/M2	Co-efficient of Consolidation Cv (M2/yr)= (m2/yr)	Average Co-efficient Compressibility MV (M2/MN)
1	2.0m	50	2.48	1.689 x 10-4
		100	2.29	1.775 x 10-4
		200	2.08	1.860 x 10-4
		400	1.85	1.955 x 10-4
2	4m	50	2.48	
		100	2.29	1.955 x 10-4
		200	2.08	
		400	1.85	
3.	2.0m	50	2.45	1.652 x 10-4
		100	2.28	1.761 x 10-4
		200	2.05	1,879 x 10-4
		400	1.84	1.980 x 10-4

4.6 Standard Penetration Test (SPT)

The Standard Penetration Test (SPT) results, summarized in Table 5, reveal the following characteristics of the subsurface soil types across the boreholes:

4.6.1 Silty Peaty Clay

The N-values for this layer range from 6 to 9, with an average of 7.6. This indicates very soft soil with low density and minimal shear strength. The silty peaty clay is unsuitable for supporting significant structural loads due to its compressibility and high organic content.

4.6.2 Silty Fine Sand

With N-values ranging from 12 to 14 and an average of 13, this layer represents loose to moderately compacted sand. The presence of silt reduces its drainage capability and increases susceptibility to settlement, making it moderately challenging for foundation applications.

4.6.3 Fine to Medium Sand

This layer exhibits N-values between 17 and 19, with an average of 18, indicating medium-density soil. The improved density and reduced fines content contribute to better load-bearing capacity compared to the overlying layers.

4.6.4 Medium to Coarse Sand

The highest N-values, ranging from 21 to 23, yield an average of 21.8. These values indicate dense, well-compacted sand with excellent shear strength and load-bearing properties. This layer is the most suitable for supporting heavy foundations, with minimal risk of settlement.

Table 5: Field SPT N-values

Soil type	N-value					
	BH 1	BH 2	BH 3	BH 4	BH 5	Average
Silty Peaty clay	9	8	6	8	7	7.6
Silty five sand	12	13	12	14	14	13
Five to medium sand	19	17	17	19	18	18
Medium to coarse sand	21	22	22	21	23	21.8

Source: Field Data

4.7 Bearing Capacity Computations

4.7.1 Based on SPT N-values

The bearing capacity of the various soil layers was computed using the SPT N-values based on the relationship.

$$q_\mu \left(\frac{tons}{sqbt}\right) = 0.22N$$

Where N = SPT Value

But $q_\mu \left(\frac{tons}{sqbt}\right) = 0.1073mpa$

Hence $q_\mu \left(\frac{tons}{sqbt}\right) = (0.22N)(0.1073)mpa$

Using the above relationship and an FS of 2.5, the bearing capacity of the various soil groups is given in Table 6.

Table 6: Average Bearing Capacity values based on SPT N-Value

Soil Group	SPT N-value	Bearing Capacity (Kpa)
Silty Peaty Clay	8	75.154
Silty fine Sand	13	122.751
Fine to Medium Sand	17	160.521
Medium to Coarse Sand	22	207.733

Source: Computed from Survey Data

Other bearing capacity parameters such as undrained cohesion and frictional angle are presented in Table 7

4.7.2 Settlement Computations

Table 7: Result of Undrained Triaxial Compress Test

Borehole No	Depth of Sample (m)	Natural Moisture Content (%)	Unit Weight		Strength Parameters		Shear Modules MNG/M2	Poisson's Ratio
			Bulk Unit	Dry Unit	Undraned Cohesion	Friction		
1	2,0	36.3	14.1	10.1	21	5	4.1	0.41
	4.0	37.6	14.3	10.3	24	3	3.8	0.40
2	2.0	36.1	14.9	10.4	23	5	4.0	0.41
	4.0	37.9	14.2	10,2	24	4	3.9	0.41
3	2.0	37.8	14.1	10.2	22	5	4.1	0.41
	4.0	38.0	13.9	10.1	25	3	3.9	0.40
4	2.0	36.5	14.0	10.3	23	5	4.0	0.41
	4.0	37.0	14.2	10.4	24	4	4.2	0.41
5	2.0	36.7	13.8	10.1	21	6	4.4	0.40
	4.0	38.8	14.1	10,2	23	4	3.8	0.40
6	2.0	37.0	13.9	10.1	23	5	4.3	0.41

Source: Analyzed Data

The immediate settlement of the clay layer was calculated using Skepton and Bjoquin (1987) given as;

$Loed = Mv. d_2. H$

Where Mv = average co-efficient of volume compressibility

$d2$ = average effective vertical stress imposed on the soil by the superstructure = 187.5 KIV/m2 assumed.

H = thickness of a particular layer under consideration. Details of the computation are presented in Table 8

Table 8: Primary settlement values

Borehole No.	Mv (x10-4)	H (m)	Settlement (mm)	Average settlement
1	1.816	4.6	0.157	
2	1.955	4.5	0.165	
3	1.818	4.9	0.167	
4	1.875	5.0	0.176	
5	1.895	3.5	0.122	
Average			0.157	

Source: computed field data

4.7.3 Consolidated Settlement

Using Terzaglu's (1943) classical equation for settlement given as;

$$Sc = \frac{c_c 0}{1+e_0 H_0 . log_{10}(\sum v_0 + \sum v_0)/\sum v_0}$$

Where

Sc = final settlement of layer of thickness Hm

H = thickness of compressible layer beneath formation base

d_{vo} = Vertical stress $\frac{KN}{m^2}$s induced at the centre of the layer by net

foundation pressure$q = \frac{1}{2}(\ )_1(\tau)_1$

$\Delta_0 v$ =Imposed structural load on the ≈ 245mpa (assured)

Cc i = compression index ≈ 0.009 (LL -10)

Table 9: Consolidated Settlement Values

	BH1	BH2	BH3	BH4	BH5
H0	4.6	4.5	4.9	5.0	4.3
$dvo(kPa)$	35	35	35	35	35
cc = $0.009(-10)$	0.333	0.333	0.333	0.333	0.333
$\Delta dv(mPa)$	230	230	230	230	230
Sc (mm)	21.15	21.17	13.72	11.60	09.98
Total settlement $\rho i + Sc$	**21.31**	**21.38**	**13.88**	**11.65**	**10.14**

Source: Computed data.

5. Discussion

The study identifies the shoreline as predominantly characterized by peaty clay, exhibiting medium to low bearing capacity and significant swelling potential. The shoreface zone represents a medium to low bearing capacity, peaty clay deposit with high swelling potential. Such clay is in situ very weak, with high organic content and bulk densities greater than 1000 kg/m^3, confirmed from various standard penetration tests (SPT) using an SPT penetrometer. Essentially, such soils are inherently weak and capable of carrying very light structural loads only.

The undrained triaxial compression tests also show that the peaty clay has an angle of internal friction from 3° to 6° with cohesion values between 21 and 26 kN/m^2, indicating moderate frictional resistance and cohesiveness, which will definitely improve the shear strength of the overlying silty fine sand and the underlying medium to coarse sand layers substantially. The high compressibility of the clay and the low consolidation rate, according to the values specified in Table 9, are key issues regarding the stability of the structure. The obtained immediate settlement value of 16.7 mm designates that the clay is inclined to deform upon loading, developing a high risk for long-term settlement.

The soft peaty clay layer is very susceptible to formation failure due to settlement. This is because the lofty structures and the soil underneath usually have different load-carrying capacities, which extend the shear strength beyond the limit, hence causing extrusions of the soil and increased settlement. Poor bearing in the clay results in an unstable condition at the foundation. Basically, progressive failure tendency demands some mitigations during design and construction to avoid potential disastrous situations.

6. Conclusion

The soils of the Niger Delta present significant geotechnical challenges, including low bearing capacity, high compressibility, and pronounced settlement risks. Addressing these issues requires advanced soil stabilization methods, innovative foundation designs, and tailored engineering solutions that account for the unique characteristics of the region's shoreline. Future research should emphasize adaptive strategies to mitigate environmental and human-induced pressures, ensuring sustainable development in the area.

Recommendations for Future Research

- **Climate Change Impacts**

The effects of rising sea levels and increased storm surges on soil stability and the structural integrity of foundations, particularly in low-lying coastal regions should be examined.

- **Foundation Design Innovations**

The effectiveness of various foundation systems, such as deep pile foundations and raft designs, to develop strategies that minimize settlement and improve load distribution be studied.

- **Soil Stabilization Techniques**

The potential of chemical stabilization methods, like lime or cement treatment, to strengthen peaty clay and reduce its compressibility be studied.

- **Material-Soil Interaction Studies**

Investigation on how peaty clay interacts with different construction materials to recommend optimized techniques for building in challenging soil conditions be carried out.

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