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RESEARCH ARTICLE

GEOTECHNICAL ASSESSMENT AND FOUNDATION DESIGN RECOMMENDATIONS FOR THE PROPOSED ENGINEERING STRUCTURE: A CASE STUDY OF WARRI-SOUTH LOCAL GOVERNMENT AREA, DELTA STATE

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ABSTRACT

The research offers an evaluation of the geotechnical index properties of the sub-soil at the proposed building site in Agbassa Community, Warri South Local Government Area of Delta State, Nigeria. Four boreholes were drilled at the site, each reaching a depth of 10.0 meters. The study area, which spans 100m x 100m, was thoroughly investigated through both field studies and laboratory testing. The results reveal that the sub-soil consists of 3 meters of high plasticity clay with high moisture content, overlain by 4 to 5 meters of silty sand that transitions to fine to coarse sand down to a depth of 10 meters. The sand's textural composition indicates a coefficient of uniformity ranging from 2.01 to 2.04. According to the Unified Soil Classification System, the sand is classified as SM (Silty Sand). The grain size, according to British Standard Sieve Sizes, ranges from 0.06mm to 10mm, showing that the sand is uniformly graded. Further laboratory tests classified the soil as Silty Sand (SM) and the clay as CH under the Unified Soil Classification System. Analysis of geotechnical parameters such as Kv, Cv, Mv, and pressure-depth relationships indicates that the sub-soil is highly compressible with low porosity. The ultimate bearing capacity of the soil ranges from 257.9kN/m² to 341.58 kN/m², with allowable bearing pressures between 85.97kN/m² and 113.86kN/m². Based on these findings, it is recommended to use a long strip foundation for the proposed structure, as it is both adequate and economical. The scope of the work included drilling four boreholes, collecting samples, and assessing the soil's suitability for the intended construction project.

KEYWORDS

Geotechnical indices, Sub soil investigation, Foundation design, Unified Soil Classification System

1. INTRODUCTION

Nigeria has seen a geometric increase in the number of failed structures over the past ten years, including buildings, roads, bridges, and dams. These failures have caused fatalities as well as negative economic effects. The growing number of building collapses in the nation due to inadequate foundation design has made geotechnical research extremely relevant in recent years (Awoyera et al., 2020). This foundational mistake has not spared Delta State (Ashioba and Udom, 2023). From an engineering perspective, wetlands' soils are typically low-bearing-capacity foundation materials with water-saturated voids. These soils can present several significant engineering challenges, including excessive surface and groundwater, poor drainage, high compressibility, low bearing capacity, and differential settlement (Oghenero et al., 2014). Because of their distinct geomorphological characteristics and extensive environmental deposition, quaternary soils, which constitute the basis of the Niger Delta, are vertically and laterally heterogeneous in form and exhibit anisotropic engineering qualities.

According to a group researcher there are a number of reasons why foundations fail, including inadequate knowledge about the subsurface geological elements and soil, bad foundation design, and subpar building materials (Fatoba et al., 2010). These elements, along with the nonlinear behavior of stressed soils and the challenge of accurately calculating soil parameters on the spot, can result in significant losses and structural damage. To mitigate potential environmental impacts, structural failure, or post-construction problems, it is crucial to incorporate subsurface geotechnical data into the design and construction of civil engineering structures (Oghenero et al., 2014; Ngah and Nwankwoala, 2013). This is preferable because of the quickening pace of urbanization, which has led to substantial infrastructure development. In order to produce pertinent data inputs for the design and construction of foundations for planned projects, a geotechnical study of the subsoil state of a site are required (Nwankwoala and Warmate, 2014).

According to civil engineers typically receive assistance in designing the foundations of their constructions when determining the soil competency for foundation studies (Akintorinwa and Adelusi, 2009). This relies on having a significant and detectable contrast between the physical properties of the different subsurface layers. Properties such as velocity, electrical resistivity, density, and acoustic characteristics provide insights into the type and nature of the Earth's materials. Geophysical techniques have been used in foundation studies (Ofomola et al., 2009; Akintorinwa et al., 2010; Akintorinwa and Abiola, 2011; Fatoba et al., 2010; Oyedele et al., 2012; and Coker et al., 2013). A group researcher investigated subsurface competency using geotechnical methods for a proposed structure in the F.C.T., Nigeria 9 (Osisanya et al., 2022). They recommended that the building foundations consider the characteristics

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of the sub-soil at the drilling locations, specifically at depths between 1.0 and 3.0 meters.

According to geotechnical research, clay minerals have a critical role in defining a soil's strength and compressibility (Mehmet and Gurkan, 2007; Rozalina and Yanful, 2012). Because the soil's clay content affects soil cohesion, friction angle, and plasticity index, it plays a major role in determining the soil's competence (Kim et al., 2005). In order to gain a deeper comprehension and more accurate knowledge on the sub surface's strength in relation to foundation building, geotechnical approaches were used in this work. Thus, at university site III, the purpose of this investigation is to furnish sufficient data regarding subsurface competency for pre- and post-foundation studies. Preventive measures are preferable to remedial ones, as the saying goes. Hence, this research aims to assess the geotechnical index properties of the sub-soil at the proposed building in Agbassa Community, Warri South Local Government Area of Delta State, Nigeria. The aim of the research is to determine generally suitable foundation and economic design for the proposed structure and in order to achieve this proper geotechnical soil investigation must be carried out to avoid foundation failure, loss of lives and property.

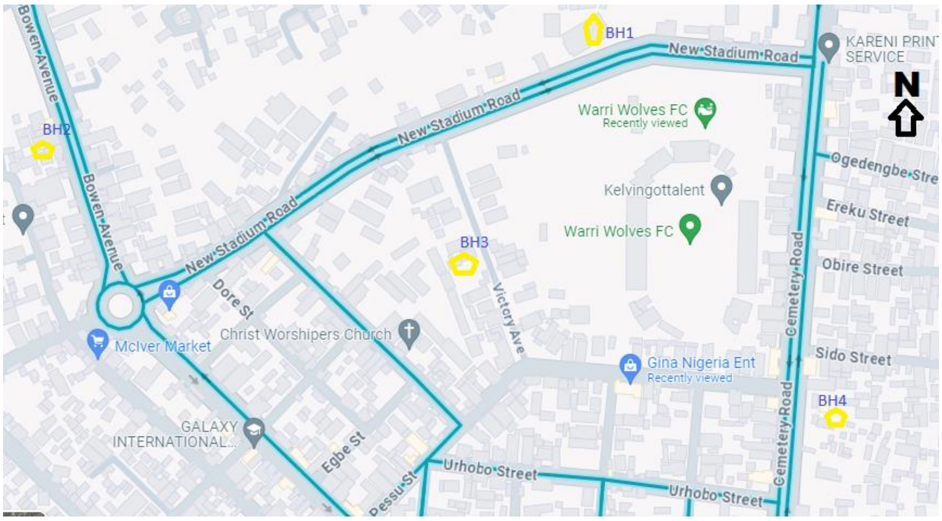

Figure 1: Google Map showing the boring points of the Study Area

2. Description of the Study

Geographically, the research area is situated in Delta State, it lays between latitudes N5° 30′ 49.78″ to N5̊ 30′ 37.25″ and longitudes E5° 45′ 22.01″ to E5̊ 45′ 16.06″ (Table 1, Figure 1). Within the tropical region where the research area is located, there are two distinct seasons: the rainy and the dry. November through March is the dry season, and April through October is the wet season. Most years, there is more than 3000 mm of rainfall, and occasionally, the temperature reaches 28 °C with 80% humidity (Iloeje, 1981). Although human activities like farming, logging, and exploration have significantly changed the environment, which was primarily mangrove swamp forest, grassland has frequently taken its place.

3. Local Geology of the Study

Warri and its environs is part of the Niger Delta basin's Cretaceous to Recent clastic sediment piles, which are made up of the Agbada Formation, the older to younger Benin Formation, the Akata Formation, and occasionally the Somebreiro Warri Deltaic Plain Sands (Allen, 1965; Reyment, 1965; Short and Stauble, 1967). The basement complex, which is the base of the Niger. Delta geologic sequence is unconformable positioned above the Akata Formation. It is roughly 7000 meters thick and Paleocene in age. An alternating succession of deltaic sands and shales, roughly 3700 m thick, makes up the Eocene Agbada Formation, the Niger Delta basin's oil reservoir. Very porous sands and gravels with a few intercalations of clay make up the Oligocene Benin Formation. There are alternate phases of sand and silt/clay in the highest section, which is quaternary in age and ranges in thickness from 40 to 150 meters. The latter is more noticeable as one approaches the coast (Etu-Efeotor and Akpokodje, 1990). Situated in the northern portion of Warri, where it is quite shallow, the Benin Formation is home to the most abundant aquifer in the Niger Delta region, with a varied thickness exceeding 2000 meters. Underlying the research area directly is the Quaternary Somebreiro-Warri Deltaic Plain Sand (Wigwe 1975).

4. Materials and Methods

To accomplish the stated objectives, an experimental approach was employed, necessitating the collection of soil samples and control samples from seven sampling points within three areas of the study site. The following materials were utilized for sample collection: Global Positioning System (GPS) for precise location determination, sample bags for containment, shovels for excavation, marker pens for labelling, and a measuring staff for depth measurement. Disturbed and undisturbed samples were collected with aid of percussion drilling rig. The disturbed samples were collected at a depth of one (1) meters interval while the undisturbed samples were collected at every 2m interval to minimize the influence of organic and biogenic matter on the engineering properties of the soil. This depth selection aimed to capture representative soil characteristics relevant to the study objectives.

Table 1: Sampling Location and GPS Coordinates of the Boring points

Location Name	Boring Points	Latitude (N)	Longitude (E)
New Stadium Area	1	5°30′49.78″	5̊ 45′22.01″
Bowen Avenue	2	5°30′43.81″	5̊ 45′0.14″
Victory Avenue	3	5°30′39.94″	5̊ 45′16.06″
Sido Street	4	5°30′37.25″	5̊ 45′31.32″

After collection, the soil samples were transported to the laboratory for analysis. Several tests were conducted on the soil samples to assess their engineering properties. These tests included: Particle size analysis: Determining the distribution of particle sizes within the soil sample; Specific gravity test: Measuring the density of the soil particles relative to the density of water; Natural moisture content test: Determining the amount of water present in the soil sample in its natural state; Atterberg limit tests: Assessing the consistency and plasticity of the soil through tests for plastic limit, liquid limit, and plasticity index; Compaction test: Evaluating the soil's ability to be compacted and its maximum dry density under controlled conditions; Triaxial tests: Assessing the shear strength and stress-strain behaviour of the soil sample under different confining pressures. These tests provide valuable insights into the engineering properties of the soil, which are essential for various construction and geotechnical applications.

4.1 Atterberg Limits Test

4.1.1 Liquid Limit

Procedure: Fill the cup with soil paste, then create a groove at the center using the standard grooving tool. Raise the cup and drop it from a height of 10 mm using the crank-operated cam. Repeat this process at least three times with the same soil, adjusting the moisture content each time.

4.1.2 Plastic Limit

Procedure: The soil paste is repeated rolling of an elliposoidal- sized soil mass by hand on a non-porous surface. Casagrande defined the plastic limit as the water content at which a thread of soil just crumbles when it is carefully rolled out to a diameter of 3mm (1/8").

4.1.3 Plasticity Index

The plasticity index (PI) of a soil is defined as a measure of its plasticity, representing the range of water contents over which the soil exhibits plastic behavior. It is calculated by subtracting the plastic limit (PL) from the liquid limit (LL), expressed by the formula:

$$P.I = L.L - P.L \quad (1)$$

Where P.I = plasticity index

4.2 Natural Moisture Content

Procedure: Clean, dry, and weigh the container, recording this weight as W1. Ensure the balance is tarred before measuring the weight. Weigh the soil sample in the container and record this as W2. Place the container in the oven for 24 hours, and then record the final constant weight of the container with the dried soil sample as W3.

$$\text{Moisture content} = \frac{w1-w2}{w2-w3} \times \frac{100}{1} \quad (2)$$

Where: W1 = weight of wet soil

W2 = weight of dry soil

W3 = weight of moisture lost

4.3 Particle Size Analysis

Procedure: a sample of the aggregate is sieved through a series of progressively finer sieves to separate the particles by size. The mass or percentage of the sample that passes through each sieve is then measured and used to calculate the uniformity coefficient of the soil samples analysis. The formula is given by:

$$Cu = \frac{D_{60}}{D_{10}} \quad (3)$$

Coefficient of Uniformity (Cu), Cu > 4 indicates a well-graded soil, Cu < 2 indicates a uniform soil and Cu < 4 indicates poorly graded soil (Casagrande, 1948, Aladin, et.al 2024).

4.4 Specific Gravity Determination

Procedure: Collect a representative soil sample and remove any large particles. Weigh a clean, dry container, then fill it with distilled water and record the weight. Add the dried soil sample to the container and record the combined weight of the soil and water. The detailed mathematical calculation process is outlined below:

$$S.G = W_2 - W_1 \quad (4)$$

W1 = weight of bottle

W2 = weight of bottle + soil

4.5 Compaction Test

Procedure: weight the empty mold, Record the molds height and diameter, transfer your soil into the large mixing pan, calculate the amount of water to add to the soil, pour the water into the spray bottle, spray water onto the soil, secure the collar back on the mold.

4.6 Triaxial Test

The soil specimens are placed in a confining cylinder, where they are pressurized to simulate stress conditions and then sheared to failure to determine the shear strength properties of the sample. Most triaxial tests are conducted on high-quality undisturbed specimens.

The most widely used relationship is the Mohr-Coulomb strength theory equation is

$$Ʈ = C + \sigma_n \tan Ø \quad (5)$$

Where Ʈ stand for shear strength, C is cohesion, σ_n is normal stress and Ø is frictional angle

$$\text{Normal stress } (\sigma) = \frac{\sigma1+\sigma3}{2} + \frac{\sigma1-\sigma3}{2} * \cos 2Ø \quad (6)$$

σ_1 and σ_3 is cell pressure

5. Results and Discussion

5.1 Particle Size Distribution

A summary of the particle size determination curve and the Sieve Analysis is shown in the Figure 2 to 5. Sieve Analysis is carried out on the sub-soil (samples) collected from the four (4) boreholes drilled from a depth of 4m to 10m of termination. The grain size ranges from 0.06mm to 10mm according to the British Standard Sieve Sizes. This indicates the presence of Silt, Sand, fine to coarse and a little presence of fine gravel at the depth of termination. The uniformity coefficient (Cu) of the sub-soil ranges from 2.01 to 2.04, which indicates that the grain size is Uniformly Graded. According to the Unified Soil Classification System classified the SAND at the proposed site as SiltySAND (SM).

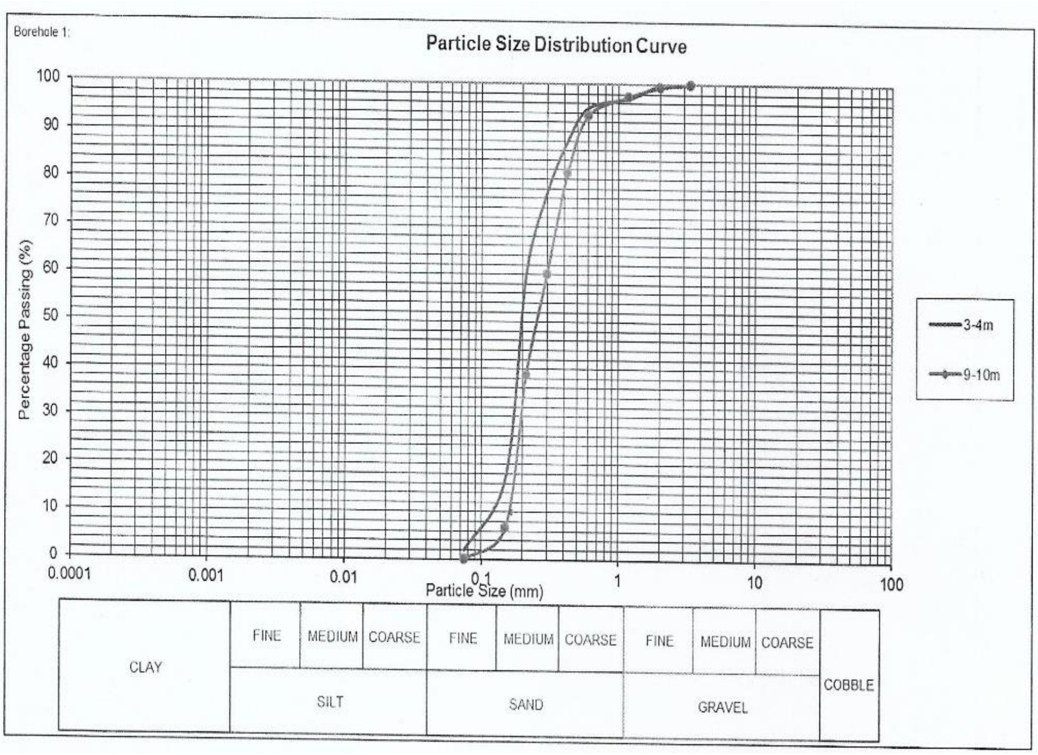

Figure 2: Particle size distribution curve of BH1 at 3-4m/9-10m depth

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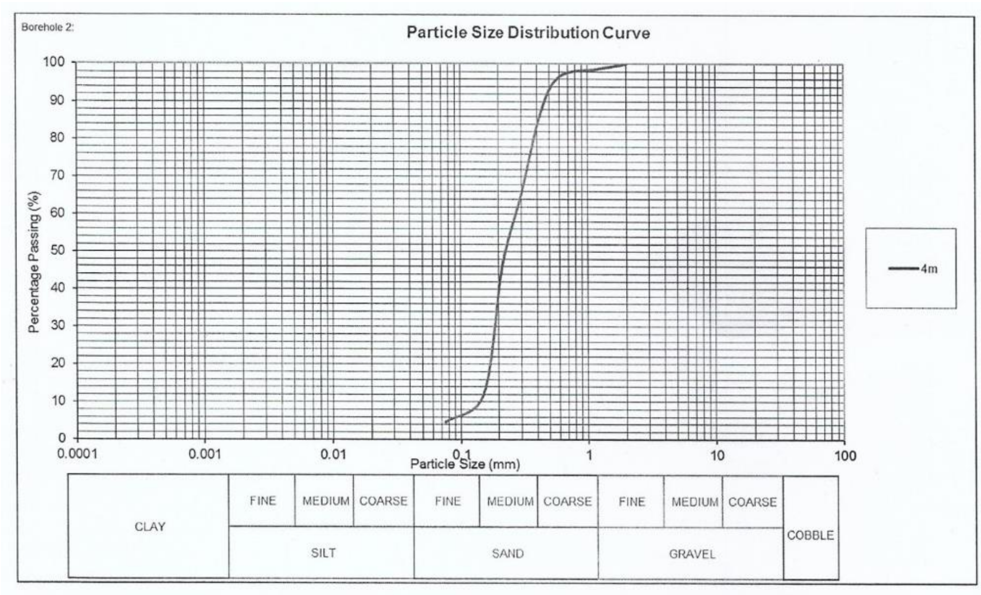

Figure 3: Particle size distribution curve of BH2 at 4m depth

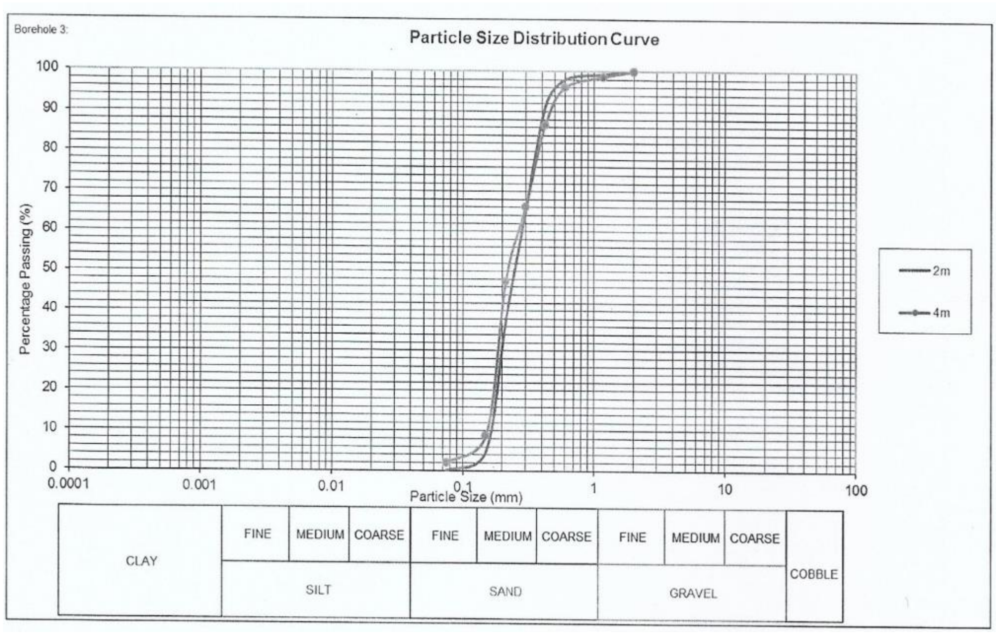

Figure 4: Particle size distribution curve of BH3 at 2m/4m depth

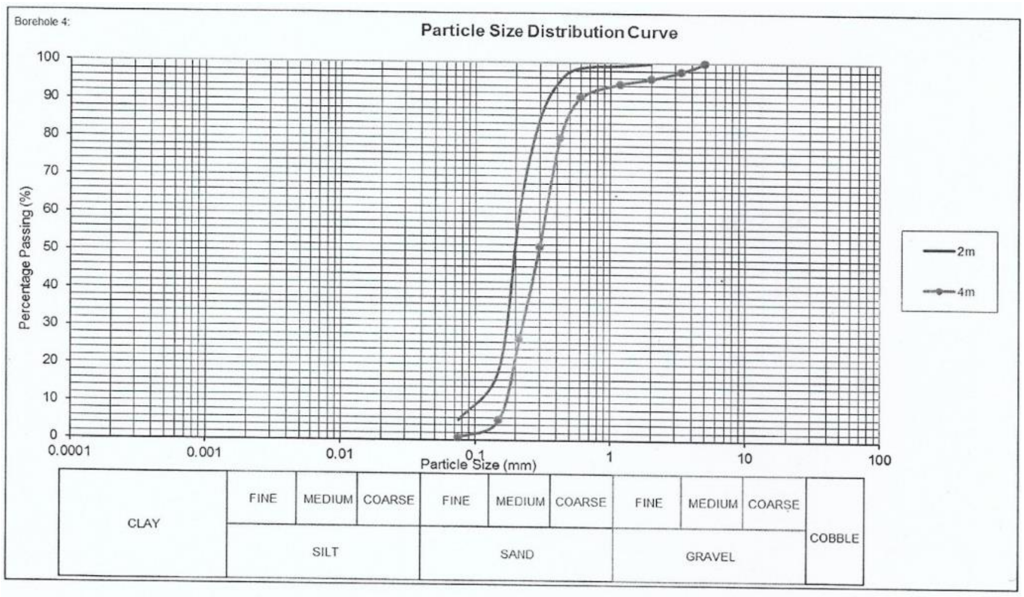

Figure 5: Particle size distribution curve of BH4 at 2m/4m depth

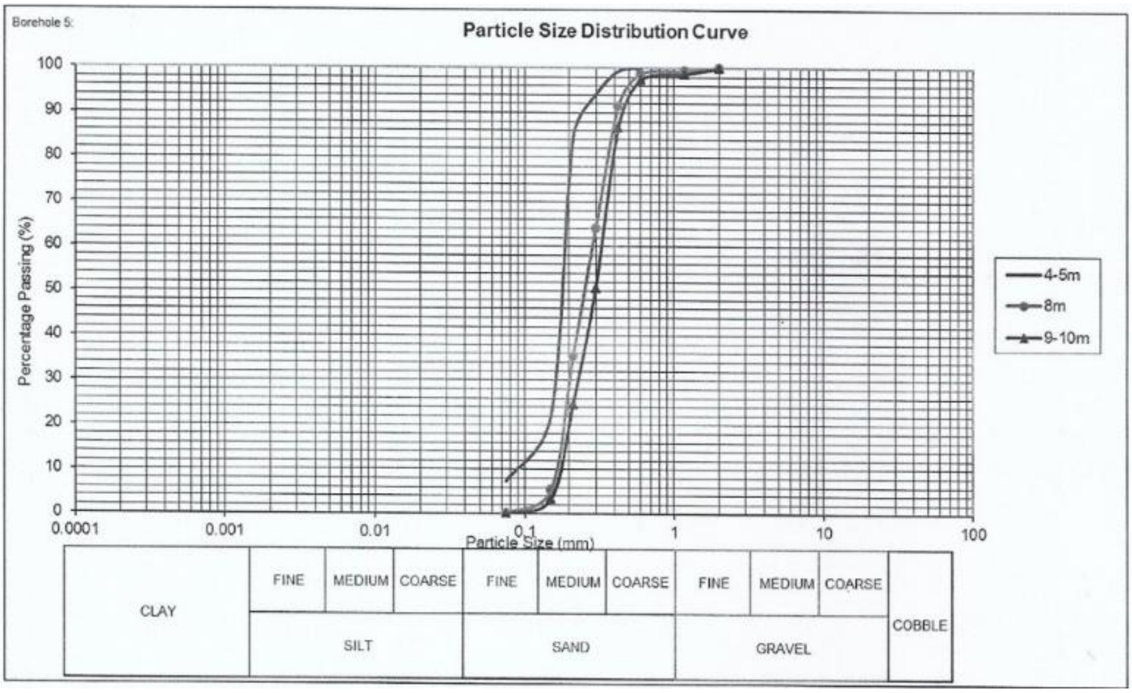

Figure 6: Particle size distribution curve of BH5 at 4-5m/8m/9-10m depth

5.2 Atterberg Limit

The value of Liquid Limit ranges from 59.5% to 92.0% while the value of the Plastic Limit ranges from 21.2% to 28.3%. It indicates that the plasticity of the sub-soil at depth 2m to 3m is extremely high and the moisture content is also very high. The value of plasticity index ranges from 38.3 to 63.7 as the depth increases. It indicates that the sub-soil is extremely plastic. According to the Unified Soil Classification System classified the clay as CH.

5.3 Consolidation Test

A summary of the consolidation test results is shown in the Table 2. The value of pre-consolidation pressure ranges from 115kN/m^2 to 250kN/m^2 while the value of overburden pressure ranges from 22.8kN/m^2 to 63kN/m^2. The value of K_v, C_v, M_v, e ranges from 83.05×10^{-8}cm/s to 3.00×10^{-8}cm/s, 89.75m^2/years to 11.67m^2/years, 0.38m^2/MN to 0.08m^2/MN and 0.864 to 0.469. The value of pressure ranges from 25kN/m^2 to 800kN/m^2. The decrease in K_v, C_v, M_v, void ratio (e) and increase in pressure, depth (m) indicates that the sub-soil has high compressibility and it is impermeable.

Table 2: Summary of the consolidation test results

Parameters / Sampling Location	BH1 (2m)	BH2 (2m)	BH5 (2m)	BH3 (2m)	BH4 (2m)
Initial vio ratio	0.767	0.715	0.749	0.732	0.682
Final void ratio	0.75	0.65	0.68	0.71	0.67
Overcons ratio	2.44	1.83	2.05	1.97	2.3
overbuden pressure (kN/m^2)	28.7	29	29	29	30.5
Bulk density (kN/m^3)	18.5	18.5	18.4	18.7	19.1
Dry density (k/Nm^3)	14.3	14.7	14.6	14.7	15.2
NMC (%)	29.1	25.3	26.2	27.4	25.6
Specific Gravity	2.58	2.58	2.61	2.59	2.61
Preconsolidation Pressure (kN/m^2)	70	54	60	58	70
Cc	0.19	0.16	0.15	0.27	0.15
Cs	0.06	0.04	0.018	0.08	0.05

5.4 e-logP Curve

The e-logP curve revealed normal consolidation and pre-consolidation due to increase in water table and moisture content. The moisture content ranges from 19.2% to 32.3% while the Bulk density ranges from 18.3kN/m^3 to 20.9kN/m^3. It indicates that the water table is high. The specific gravity ranges from 2.59 to 2.68. It indicates the presence of feldspar or kaolinite in the sub-soil.

5.5 Unconsolidation Undrained Triaxial Test

A summary of the undrained triaxial test result is shown in Table 3. The Ultimate bearing of the sub-soil ranges from 257.9kN/m^2 to 341.58kN/m^2 while the allowable bearing pressure ranges from 85.97kN/m^2 to 113.86kN/m^2 using safety factor of 3. According to the undrained shear strength classification of clays classified the shear strength consistency as very stiff and it has low porosity.

Table 3: Summary Result of Undrained Triaxial Test

Borehole	Depth(m)	C_u(kN/m^2)	Ø	q_f(kN/m^2)	q_a(kN/m^2)
1	3 – 4	29	7	295.81	98.60
2	2 – 3	40	3	257.9	85.97
3	2 – 3	40	5	341.58	113.86
4	1 – 2	32	4	261.2	87.07

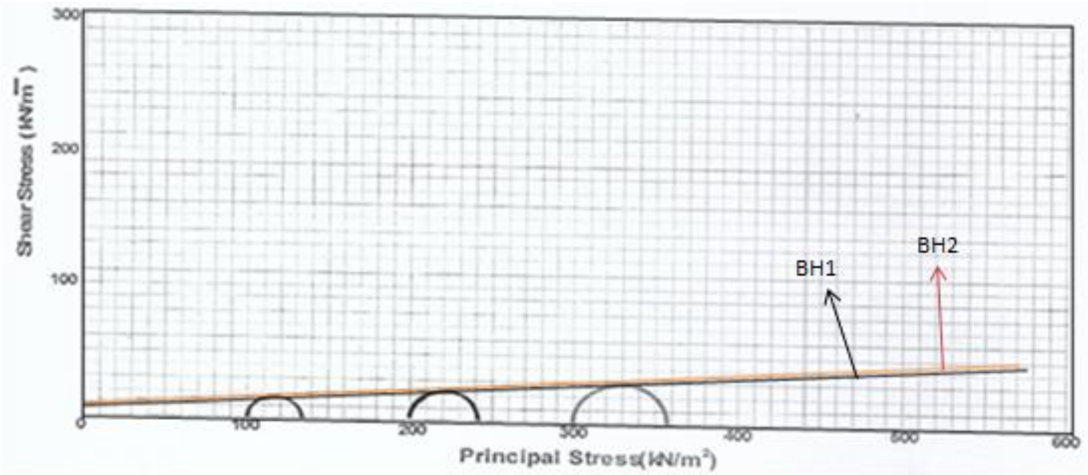

Figure 7: Shear stress against principal stress of BH1 and BH2

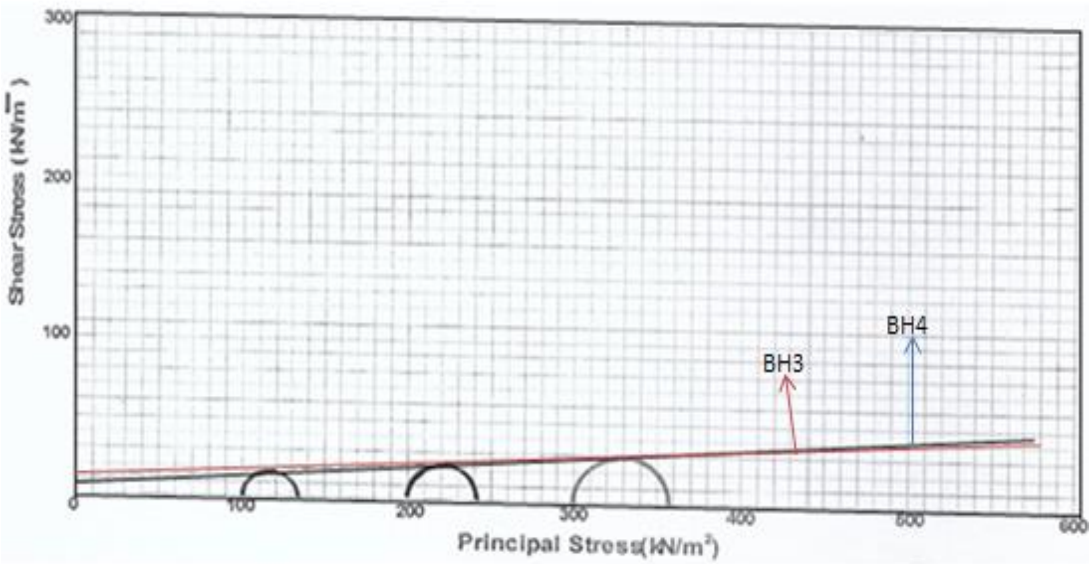

Figure 8: Shear stress against principal stress of BH3 and BH4

6. Conclusion

The geotechnical investigation conducted at the proposed study area in Agbassa Community, Delta State, Nigeria, has provided valuable insights into the sub-soil properties essential for foundation design and construction. The comprehensive analysis of field and laboratory data has revealed significant findings regarding the soil composition, classification, and engineering characteristics. The sub-soil beneath the site consists of a layer of clay with high plasticity and moisture content, transitioning to silty-sand and sand layers at varying depths. Unified Soil Classification System categorizes the soil as SiltySAND (SM) and clay as CH, indicative of its engineering behavior. Key laboratory test results, including Atterberg limits, consolidation tests, and undrained triaxial tests, highlight the high compressibility and impermeability of the sub-soil. The presence of extremely plastic clay and the variation in soil properties with depth necessitate careful consideration in foundation design. Based on the findings, it is recommended to use a long strip foundation, which is deemed adequate and economical for the proposed structure. The ultimate bearing capacity and allowable bearing pressure values obtained from the investigation serve as crucial parameters for the safe and efficient design of the foundation. The scope of work, which involved drilling boreholes, collecting samples, and conducting laboratory tests, has provided comprehensive engineering properties necessary for the project's safety and economic design. Additionally, the investigation extends to assessing sub-soil conditions for other proposed structures in the region, demonstrating its broader applicability and significance. In conclusion, this geotechnical investigation serves as a vital foundation for informed decision-making in the design and construction of the proposed building and other structures in Agbassa Community. The findings and recommendations presented herein aim to ensure the structural integrity, safety, and longevity of the proposed development. Should further inquiries arise or additional assistance be required, we remain at your service to provide expert guidance and support.

Recommendation

Foundation Design: Based on the findings of the geotechnical investigation, it is recommended to employ a long strip foundation for the proposed buiding. This type of foundation is deemed adequate and economical considering the sub-soil properties discovered. Ultimate Bearing Capacity and Allowable Bearing Pressure: The ultimate bearing capacity and allowable bearing pressure values obtained from the investigation are crucial parameters for the safe and efficient design of the foundation. These values should be considered in the structural design process. Sub-Soil Conditions Consideration: The presence of extremely plastic clay and the variation in soil properties with depth necessitate careful consideration in foundation design. Engineers should account for these factors to ensure the stability and durability of the structure.

Broader Applicability

The investigation extends to assessing sub-soil conditions for other proposed structures in the region, demonstrating its broader applicability and significance. The findings can inform future construction projects in the area.

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