

Geotechnical Characterization of Soils in Ahoada Town, Rivers State for Safe Foundation Design and Construction

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Abstract: *A geotechnical investigation was conducted to evaluate the subsurface conditions and assess the suitability of soils for shallow foundation construction in Ahoada town, Rivers State, Nigeria. The study involved field sampling and laboratory testing of soil samples to determine relevant geotechnical parameters such as grain size distribution, Atterberg limits, moisture content, and shear strength characteristics. The geological setting of the area is typical of the Niger Delta sedimentary basin, characterized by alternating layers of sand, silt, and clay deposits. Results show that the near-surface soils consist predominantly of clayey sand and sandy clay layers underlain by more competent sandy strata at greater depths. Results obtained show that the Atterberg limit results reveal that the liquid limit ranges from 53.5% to 97.8%, the plastic limit ranges from 30.1% to 60.0% while the plasticity index values range from 17.1% to 39.5%. The cohesive soils (clays) are highly plastic (CH) in the Unified Soil Classification System (USCS) designation. The natural moisture content ranges from 71.3% to 97.5%. The particle size distribution analysis reveals that the sand is fine to medium to coarse grained and in a medium dense state of compaction and based on its coefficient of uniformity and gradation classifies as poorly graded (SP) by the USCS designation. The moisture content of the sand ranges from 8.9% to 13.0% while the bulk unit weight ranges from 19.6KN/m³ to 20.3 KN/m³. The angle of shearing resistance ranges from 26^o to 33^o. The result of the undrained shear strength of the clay ranges from 16Kpa and 19Kpa. The clay is very soft to soft and exhibit medium to high moisture content. The strength test result indicates a material of low undrained shear strength, the coefficient of consolidation, C_v of the clay soil samples varies between 1.40m²/year and 2.69 m²/year. The coefficient of volume compressibility, M_v, for the same materials varies between 0.215 m²/MN and 0.657 m²/MN, generally indicating clay layers of high to very high compressibility. The high groundwater table and presence of compressible clay layers in the upper strata pose challenges for shallow foundation design. However, with proper foundation design, including soil improvement or adequate footing depth, shallow foundations can be safely adopted in areas with adequate bearing capacity.*

Keywords: geotechnical characterization, groundwater, soil stability, foundation design

INTRODUCTION

Rapid urban development in many parts of the Niger Delta has increased the need for reliable geotechnical investigations prior to construction. Foundation failures in the region are often attributed to inadequate knowledge of subsurface soil conditions. Geotechnical investigations are necessary to determine soil properties, evaluate bearing capacity, and recommend suitable foundation types for structures. Ahoada town, located in Rivers State in the Niger Delta region of Nigeria, is characterized by low-lying floodplain terrain and sedimentary deposits formed by fluvial and deltaic processes. The geology of the region consists mainly of Quaternary alluvial deposits composed of sand, clay, silt, and gravel derived from riverine sedimentation. The terrain of Rivers State is generally dominated by freshwater swamps, mangrove swamps, and coastal sand ridges, with much of the land being less than 20m above sea level and susceptible to seasonal flooding.

Engineering and geological characteristics of soil are critical in guiding the design and construction of foundations. The stability and performance of a structure rely on the underlying soil's capacity to safely and efficiently bear loads. Soil properties influence bearing capacity, settlement behaviour, and overall foundation stability, making their assessment essential for construction of civil engineering structures like building, bridge, highway, railway, runway, embankment etc (Ashioba and Nwankwoala, 2025).

The engineering properties of soil include shear strength, permeability, compressibility, and density, among others. These properties dictate how soil reacts to various loads and environmental conditions. Engineers conduct detailed geotechnical investigations to evaluate these properties and select the most suitable foundation type, whether shallow or deep. (Oke *et al.* 2008).

Soil behavior under loading conditions depends on factors such as composition, moisture content, grain size distribution, and stress history. These properties determine the soils ability to resist deformation, drain water efficiently, and sustain structural loads without excessive movement (Ashioba *et al.*, 2024; Ngah *et al.*, 2013). Several authors have suggested that careful design and construction of civil engineering structures can prevent structural failure as well as environmental or post construction issues (Ashioba and Udom, 2023; Oghenero *et al.*, 2014; Nwankwoala *et al.*, 2014; Ngah *et al.*, 2013). Hence, the objective of this study is to investigate the geotechnical characterization of soils in Ahoada town, Rivers State for construction purposes.

MATERIALS AND METHODS

Description of the Study Area: The study area is found within longitude $6^{\circ} 35^1 E$ and $6^{\circ} 65^1 E$ and latitude $4^{\circ} 75^1 N$ and $5^{\circ} 08^1 N$ (Fig. 1). The study area is in the Niger Delta tropical rain forest vegetation and basically accessible by a good road network. Although there are wooded valleys in the Southeast, the vegetation is mostly open grasslands which are used for grazing and farming. The study area is Ahoada in Ahoada-East local government area characterized by low-lying terrain, dense vegetation, and a network of rivers such as the Orashi and Sombreiro rivers. Stratigraphically, the Niger Delta comprises of the lower marine unit, the Akata Formation, the middle continental unit, the Agbada Formation and the upper continental

sequence, the Benin Formation (Reyment, 1965, Short and Stauble, 1967). The main deposit encountered at the topsoil is organic peaty clay, followed by silty sand/ sandy clay layers and at deeper layers are loose to medium dense sands with clay lenses. The area experiences heavy rainfall and seasonal flooding, which influence groundwater levels and soil moisture conditions. These environmental factors must be considered when designing foundations.

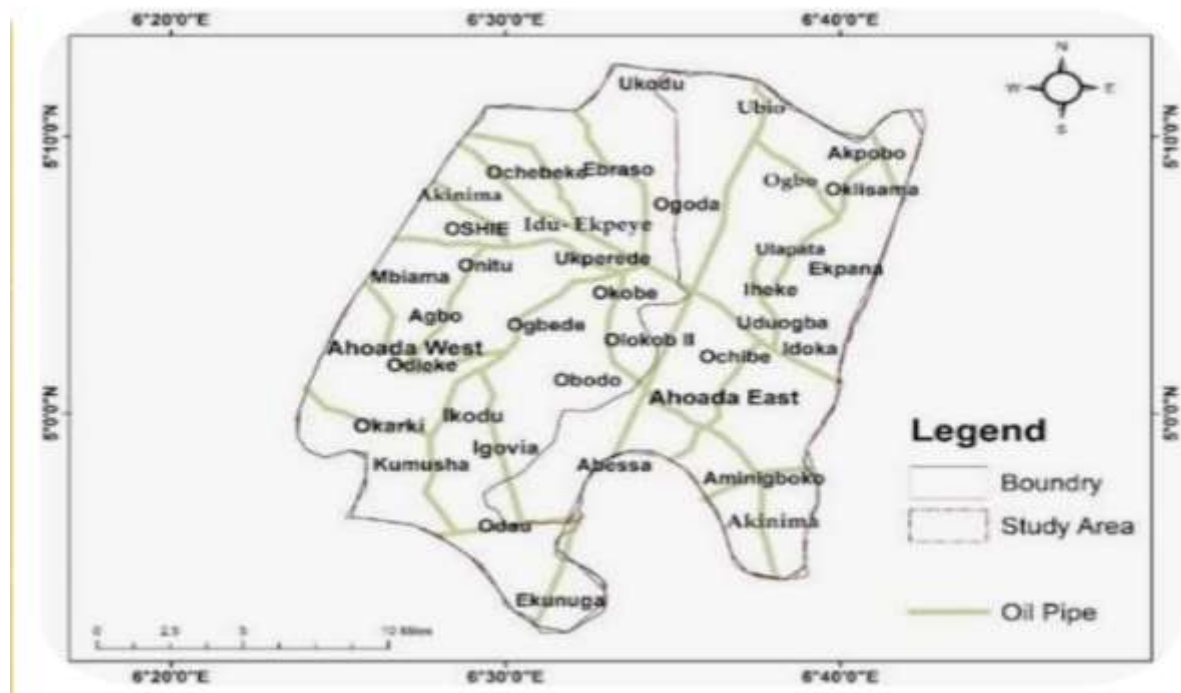


Fig. 1 Map of Ahoada East showing the study location

Sample Collection: The investigation comprised mainly the drilling of two (2) number geotechnical boreholes in Ahoada, Rivers State, with field observations including soil stratification, groundwater conditions, soil consistency and colour and finally the presence of organic matter. The boreholes were drilled using the percussion boring rig. The disturbed samples were taken at regular intervals and at change in soil type. The samples were used for a detailed and systematic description of the soil in each stratum in terms of its visual and tactile properties and for laboratory tests. The soil sampling was carried out in accordance with BS1377, with a minimum requirement set out in ASTM. Field measurements of groundwater showed that groundwater levels stood at 1.0m. The water levels in boreholes are subject to seasonal fluctuations.

Laboratory investigation: A series of classification, strength and compressibility tests were carried out in the laboratory. These tests were performed in accordance with British and ASTM standards. Details of the different tests are given below.

Moisture Content: Moisture content test was carried out in accordance with BS1377, on samples recovered from the boreholes. The moisture content was determined by drying selected

moist/wet soil materials for at least 18 hours to a constant mass in a 110°C drying oven. The difference in mass before and after drying was used as the mass of the water in the test material. The mass of material remaining after drying was used as the mass of the solid particles. The ratio of the mass of water to the measured mass of solid particles was the moisture content of the material.

Atterberg Limits: Atterberg limits were determined on soil specimens with a particle size less than 0.425mm. The Atterberg limit refers to arbitrary defined boundaries between the liquid limit and plastic states (liquid limit, W_L) and between the plastic and the brittle states (plastic limit, W_P) of fine-grained soils. The liquid limit is the water content at which a part of soil placed in a standard cup and cut by a groove of standard dimensions flow together at the base of the groove when the cup is subjected to 25 standard shocks. The one-point liquid test was carried out. Distilled water was added during soil mixing to achieve the required consistency. Plastic limit is the water content at which a soil can no longer be deformed by rolling into 3mm diameter threads without crumbling. The difference between the liquid limit and the plastic limit is the plasticity index, I_P .

Particle Size Analysis: Particle size analyses were performed by means of sieving. Sieving was carried out for particles that would be retained on a 0.075mm sieve, dry sieving was carried out by passing the soil sample over a set of standard sieve sizes and then shakes the entire units for few minutes with sieve shaker (machine).

Particle size is presented on a logarithmic scale so that two soils having the same degree of uniformity are represented by curves of the same shape regardless of their positions on the particle size distribution plot. The general slope of the distribution curve may be described by the coefficient of uniformity C_u , where $C_u = D_{60}/D_{10}$ and the coefficient of curvature C_c , where $C_c = (D_{30})^2 / D_{60} \cdot D_{10}$. D_{60} , D_{30} and D_{10} are effective particle sizes indicating that 60%, 30% and 10% respectively of the particles (by weight) are smaller than the given effective size. Reference test standard, BS1377, Part2, 1990.

Unit Weight: The unit weights were determined from measurement of mass and volume of the soil. The unit weight (KN/m^3) refers to the unit weight of the soil at the sampled water content, The dry unit was determined from the mass of oven-dried soil and the initial volume. . Reference test standard, BS1377, Part2, 1990.

Unconsolidated undrained Triaxial: Unconsolidated undrained triaxial compression tests were performed on cohesive samples, relatively undisturbed samples obtained from the open boreholes, with the objective of determining their undrained strength parameters, in accordance with BS1377, Part2, 1990

Direct Shear Test: The soil specimen is loaded into the shear box which split into two halves along a horizontal plane at its middle. The box is square with 60mm sides and 50mm high. It is made up of brass metal. It is placed inside a larger box-container and mounted on the loading frame. A proving ring is fitted to the upper half of the box to measure the shear force. The proving ring which butts against a fixed support records the shear force as the box moves and the shear displacement is measured with a dial gauge fitted to the container. Another dial gauge

fitted to the top of the pressure pad measures the change in the thickness of the specimen. . Reference test standard, BS1377, Part1-2016.

Oedometer Consolidation: Laboratory consolidation tests were carried out on cohesive soil specimens, relatively undisturbed sample with object of determining the compressibility properties of the soils, in accordance with BS 1377. The plot of void ratio (e) against effective pressure (P) for the samples tested presented in tables 1 and figure 4 together with calculated values of the coefficients of consolidation, (Cv) and coefficient of compressibility (Mv). Test results show that the samples are of predominantly high compressibility.

Soil Stratigraphy: The strata show that the site is predominantly clay both in boreholes BH1 and BH2. In BH1, the strata reveal a formation of peaty clay from top to the depth of 2m and loose fine silty sand from the depth of 3m to 7.0m. Silty clay was observed from depth of 8.0m to 14.0m while at 15.0m was silty sand is greyish in colour. Beneath the silty sand was soft greyish silty peaty clay to the depth of 18.0m. In BH2, peaty clay is observed from ground surface to a depth of 7.0m. Underneath the peaty clay, loose greyish silty fine sand was encountered to a depth of 8.0m. Between 8.0m and 17.0m, another layer of peaty clay is observed. Below 17.0m to the depth of 21.0m, fine sand is encountered. The sand is loose to medium dense in compaction and grey in colour. Beneath the sand stratum to the final 30.0m depth of the investigation, peaty clay is again encountered. The clay is soft in consistency and grey in colour.

RESULTS AND DISCUSSION

Soft Clays: The engineering properties and behaviour of clay are significant due to dominant influence of fine particles. An increase in the liquid limit of clays and silts corresponds to greater compressibility. The engineering properties of soil samples obtained from the laboratory analysis are presented in tables 1-5.

Table 1: Geotechnical properties of soil samples

Soil type	Soil parameters	Min.	Max.	Mean
Clay	Moisture Content (%)	71.3	97.5	84.4
	Bulk unit weight (KN/m ³)	14.1	14.8	14.45
	Dry unit weight (KN/m ³)	7.6	8.9	8.25
	Undrained shear strength (Kpa)	15	18	16.5
	Cohesion, C (KN/m ²)	16	23	19.5
	Angle of shearing resistance (Degree)	3	6	4.5
	Liquid limit (%)	53.5	97.8	75.65
	Plastic limit (%)	30.1	60.0	45.05
	Plasticity Index (%)	17.1	39.5	28.3
	Classification USCS	CH	CH	CH
	Coefficient of consolidation (m ² /Yr.)	1.40	2.69	2.045
	Coefficient of compressible (m ² /MN)	0.215	0.657	0.436
	Poisson's ratio	0.40	0.43	0.42
	Coefficient of earth pressure at rest, Ko	0.81	0.90	0.86

Table 2 :Results of the Atterberg limit test

Location/ Borehole No.	Depth of sample (m)	Moisture content (%)	Liquid Limit (%)	Plastic Limit (%)	Plasticity index (%)	Liquid limit index	Coefficient of Earth pressure at Rest, K_0	Casagrande classification
Ahoada 1	2.0	80.4	80.4	50.1	30.3	0.70	0.84	CH
	8.0	90.2	93.5	56.4	37.0	0.65	0.79	CH
	12.0	89.6	53.5	36.4	17.1	0.75	0.77	CH
2	2.0	97.5	97.8	58.3	39.5	0.83	0.81	CH
	4.0	90.3	94.1	60.0	34.1	0.86	0.84	CH
	6.0	89.7	65.6	30.1	35.5	0.76	0.87	CH
	12.0	80.5	67.1	33.4	33.7	0.73	0.90	CH
	16.0	72.5	69.3	32.8	36.5	0.77	0.81	CH
	22.0	71.3	69.2	37.7	31.5	0.76	0.81	CH
	26.0	79.5	76.9	38.2	38.7	0.81	0.87	CH

Table 3: Results of particle size distribution and drained direct shear test

Borehole No.	Depth of sample (m)	Moisture content (%)	Bulk Unit Wt .KN/m ³	Angle of shearing Resistance (ϕ) Degree	Effective particle size D_{10} (mm)	D30 (mm)	Mean particle size D50	D60 (mm)	Coeff. of uniformity $C_u = D_{60}/D_{10}$	Cc	USCS
1	3.0	12.6	19.8	28	0.022	0.046	0.074	0.085	3.864	1.132	SP
	15.0	18.9	20.1	30	0.031	0.068	0.104	0.105	3.387	1.421	SP
2	8.0	14.2	19.6	31	0.058	0.145	0.170	0.184	3.172	1.970	SP
	18.0	19.2	19.7	33	0.031	0.061	0.162	0.097	3.129	1.237	SP

Table 4: Results of the Undrained Triaxial compression tests

BH No.	Depth (m)	Moisture content (%)	Bulk Unit Wt KN/m ³	Dry Unit Wt. KN/m ³	Undrained Cohesion Cu KN/m ²	Angle of Shearing Resist. (φ) Degree	Shear Modul. MN/m ²	Poisson's Ratio
1	2.0	80.4	14.5	8.7	20	6	7.5	0.40
	8.0	90.2	14.7	8.7	21	5	7.8	0.40
	12.0	89.6	14.8	7.9	18	3	8.7	0.41
2	2.0	97.5	14.1	7.6	16	6	4.7	0.42
	4.0	90.3	14.3	8.0	18	5	4.6	0.43
	6.0	89.7	14.7	8.9	22	4	7.5	0.40
	12.0	80.5	14.8	8.9	23	3	9.7	0.40
	16.0	72.5	14.6	8.6	19	6	8.7	0.41
	22.0	71.3	14.6	8.5	18	6	8.6	0.41
	26.0	79.5	14.7	8.2	20	4	8.8	0.42

Medium dense sand: The sand is fine to medium in grain size, poorly graded, moderately dense, and ranges in colour from grey to brown. The layers exhibit nearly uniform gradation. The ranges of variations in relevant engineering parameters of the sand are shown in table 5.

Table 5: Characteristics values for sand samples

Soil type	Soil Parameters	Min.	Max.	Mean
Sand	Moisture content (%)	12.6	19.2	15.9
	Bulk unit weight (KN/ m ³)	19.6	20.3	19.95
	Effective unit weight (KN/ m ³)	8.31	9.09	8.7
	Poisson's ratio	0.40	0.43	0.42
	Angle of shearing resistance (Degree)	28	33	30.5
	Effective particle size, D ₁₀ mm	0.022	0.058	0.04
	Effective particle size, D ₃₀ mm	0.046	0.145	0.096
	Mean particle size, D ₅₀ mm	0.074	0.170	0.122
	Effective particle size, D ₆₀ mm	0.085	0.184	0.135
	Coefficient of uniformity Cu= D ₆₀ /D ₁₀	3.129	3.864	3.497
	Coefficient of curvature Cc = (D ₃₀) ² /D ₆₀ .D ₁₀	1.132	1.970	1.551
	Classification USCS	SP	SP	SP

The amount of moisture present significantly influences the engineering behaviour of clay soils, as they tend to swell upon absorbing water and contract when it dries out. The results reveal that the moisture content values range between 71.3to 97.5%, which is comparatively high due to sampling during the wet season. Atterberg limit results reveal that the liquid limit ranges from 53.5- 97.8%, the plastic limit ranges from 30.1- 60.0% while the plasticity index

ranges from 17.1- 39.5%, this suggests that the clays exhibit high plasticity (CH) on the bases of unified soil classification system (USCS). The particle size distribution shows that the cohesionless soil samples are mainly fine to medium, moderately dense and poorly graded sand (SP). The cohesive soils consist of highly organic clays and peats, which are very soft and extremely compressible as the values of coefficient of volume compressibility (M_v) vary between 0.215 and 0.657m²/MN.

Conclusion: The geotechnical investigation of Ahoada town indicates that the subsurface soils are typical of Niger Delta deposits consisting of alternating layers of clay, silt, and fine sand. The upper soil layers are generally clayey soil which may exhibit moderate to high compressibility and low bearing capacity. However, deeper sandy layers provide more competent strata capable of supporting structural loads. Although shallow foundations can be adopted in many parts of the area, careful site investigation and proper foundation design are required to mitigate potential problems associated with weak surface soils and high groundwater levels. The findings of this study provide valuable geotechnical information for safe and sustainable infrastructure development in Ahoada town and similar environments within the Niger Delta region. Where weak or highly plastic soils occur, soil improvement techniques such as compaction, replacement with granular materials, or use of raft foundations may be necessary.

Declaration of Conflict of Interest: There is no conflict of interest.

Data Availability: Data are available upon request.

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