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Geotechnical Properties of Soil in the Flood-Prone Okpe Town, Isoko North Local Government Area, Delta State

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Abstract

This research work focused on assessing the geotechnical properties of soil in Okpe Community. Soil samples were collected from five different locations within the community, and at each location three sampling depths (0.3 m, 4 m and 8m) were adopted. Four geotechnical analyses (consistency limits, specific gravity, optimal moisture content "OMC" and maximum dry density "MDD") were carried out on the 15 soil samples, in accordance with ASTM approved guidelines. The consistency limits test results indicated that the topsoil (0.3 m), 4 m and 8 m soils liquid limit values varied from 52.38% -63.42%, 29.07% - 69.69% and 19.83% -28.50%, respectively. Also, the plastic limits values for the topsoil, 4 m and 8 m soils ranged from 20.70% - 26.08%, 16.60% - 32.34%, and 5.74% - 19.73%, respectively. The topsoil, 4 m and 8 m soil samples specific gravity values varied from 2.66 – 2.69, 2.64 – 2.67, and 2.62-2.64n respectively. Likewise, MDD results depicted that its values for the soil samples collected at the topsoil, 4 m and 8 m soil depths ranged from 1.53 g/cm^3-1.59 g/cm^3, 1.59 g/cm^3 - 1.65 g/cm^3 and 1.68 g/cm^3-1.75 g/cm^3, respectively. Similarly, the results revealed that the OMC of the soil samples collected at the topsoil, 4 m and 8 m depths varied from 15.3% to 16.3%, 14.8% - 17.9%, and 13.2% -14.2%, respectively. The findings will contribute to informed decision-making for infrastructure development in flood-prone areas.

1.0. Introduction

Soils are formed mainly from the weathering of rocks and decomposition of organic matters, and they consist of organic and inorganic constituents. Soils play major roles in civil structural development, agricultural production and environmental sustainability. Soil is one of the basic factors to be considered during foundation design and roads construction, also it also aids watershed management and supports ecosystems [1]. Understanding the geotechnical properties of soils is essential for designing and constructing safe and reliable civil engineering structures. The study of soil properties provides valuable information on their physical characteristics, chemical composition, mechanical behavior, and underlying rock formations [2].
The Niger Delta region, including the Okpe community, is characterized mostly by wetlands. Wetlands store a substantial amount of carbon, and the volume, stratigraphy, and properties of peat in these wetland soils influence their carbon storage capacity [3]. However, from a civil engineering perspective, wetland soils often present engineering challenges such as poor bearing capacity, high compressibility, low drainage, and susceptibility to excess surface and groundwater [4].

The stability and performance of civil engineering structures are highly dependent on suitable foundation design, which relies on accurate knowledge of the geotechnical properties of the underlying soils. Adequate data on soil properties are crucial for assessing the suitability of soils for foundations and construction materials [5]. Geotechnical investigations provide essential information for efficient design and construction, reducing complexity and costs associated with heavy structures that exert significant pressure on the soil. The engineering characteristics of the soil, determined through geotechnical examinations, dictate its loading capacity and behavior under stress and strain conditions [6].

To ensure the stability and integrity of civil engineering structures, it is essential to conduct comprehensive geotechnical studies that encompass the topsoil, subsoil, and underlying rock formations. Insufficient information about soil and subsurface materials, poor foundation design, and inadequate building materials have been associated with numerous cases of foundation failure [7]. Therefore, conducting detailed soil explorations and geotechnical evaluations is critical to assess soil suitability and minimize the risk of structural failures during and after construction [8].

This study focuses on investigating the spatial distribution and geotechnical properties of soils in the Okpe community, located within the Isoko region of Delta State, Nigeria. The Isoko region is experiencing significant infrastructural developments driven by educational, hospitality, and tourism sectors, as well as oil exploration and production activities [9]. To facilitate the design and construction of civil engineering structures in the region, it is imperative to gather comprehensive geotechnical data and understand the soil characteristics unique to the area. By evaluating the subsoil conditions and geotechnical properties, this study aims to provide essential insights for foundation design and construction practices, minimizing post-construction issues and ensuring the long-term stability of structures within the Okpe community.

2. Material and Methods

2.1 Description of the Study Area

Okpe community is located in the Isoko region, which is one of the prominent tribes in Nigeria. The Isoko region has a population of approximately 340,994 and covers an area of about 1,181 km^2, as estimated from the Delta State government portal [10]. Geologically, Isoko can be characterized as flat, with wetlands encompassing around 30% of the total area. Okpe community is predominantly covered with wetland and the soils are primarily of the alluvial type. Farming and poor waste management are the major anthropogenic activities that affect soil engineering properties in the region [11].

Okpe climate like its neighboring communities climate is characterized by two distinct seasons - wet and dry seasons. The wet season typically spans from approximately April to October, with an average annual rainfall of 1800 mm, and the region is subjected to very high water tables and flooding in some areas. Conversely, the dry season occurs from November to March, and it is characterized by low water table and high temperature ranging from 26^oC to 35^oC [12,13]. The town experiences seasonal flooding, with approximately half of the town being flooded yearly. Given the presence of two universities and the rapid development in the Isoko region, it is crucial to understand the geotechnical behavior of the soils in flood-prone towns like Okpe. Fig. 1 shows the map of Delta State indicating Isoko land.

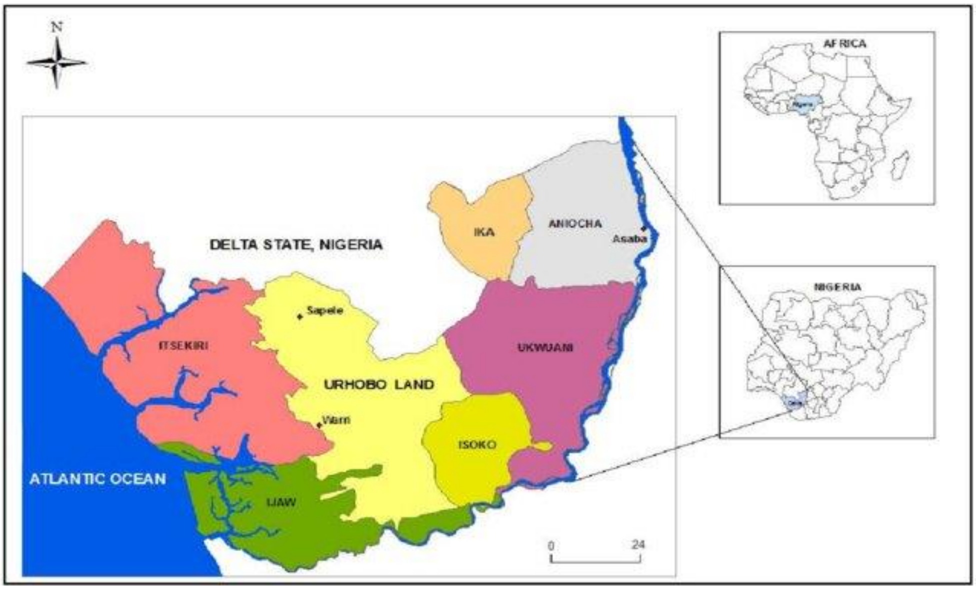

Fig 1. Map of Delta state showing Isoko land
Source: Aziakpono and Ukpebor (2013)

2.2 Sample collection and preparation

Five (5) boreholes were used to obtain soil samples for this study. The boreholes were drilled through manual drilling methods, to a depth of approximately 10 m below the soil surface. Soil samples were taken at an interval of every 4 m, starting from the topsoil (0 – 0.3m); therefore the three soil depths captured were: 0 – 0.3 m (topsoil), 4 m and 8 m. After the sample collections, the disturbed samples collected from the boreholes were coded and taken to the laboratory for geotechnical properties analysis. Fig. 2 shows the borehole drilling and soil samples collection activities.

Figure 2. Sample collection

2.3 Geotechnical properties analysis

2.3.1 Atterberg Limit

The Atterberg limits (liquid limit "LL", plastic limit "PL") of the soil samples were determined in accordance with ASTM D4318 approved procedures [8].

2.3.2 Specific gravity determination

The soil samples' specific gravity values were determined in accordance with ASTM procedures as explained by Akpokodje [1].

2.3.3 Soil compaction determination

Proctor compaction test technique was used to determine the Maximum Dry Density (MDD) and optimal moisture content (OMC) of the soil samples in accordance with ASTM D698-12 standard [14]. The moisture content of the soil was determined gravimetrically as explained by Akpokodje [1].

3. Results and Discussion

3.1 Atterberg Limits

The result of the Atterberg limits of Okpe community soils is presented in Table 1. It can be observed that the liquid limit (LL) and plastic limit (PL) of the soil samples declined with increased soil depth, irrespective of the sampling location. Similar results were obtained by Zolfaghari [15] where the LL and PL varied unevenly across the soil profile. Similarly, Deng [16] observed that the LL and PL of soil samples declined from 62.68% to 30.91%, and 35.93% to 19.43%, respectively, as the soil depth increased from 0.3 m to 9 m.

The presence of a high plasticity index within the 0m-4m depth range implies a low shear strength, making the soil susceptible to sudden and unpredictable structural failures caused by volumetric changes due to moisture infiltration through surface cracks. Moreover, the high liquid limit observed within the same depth range indicates a high compressibility and a significant potential for shrinking and swelling.

Table 1: Result of the Atterberg limits test for Okpe community soils

Location	Depth	LL (%)	PL (%)	PI
1	0.3 m	52.38±1.44	22.99±0.15	29.39±1.12
	4 m	29.07±0.15	17.21±0.75	11.86±0.55
	8 m	19.10±1.8	9.20±0.36	9.90±0.74
2	0 m	59.20±0.37	25.00±0.66	34.20±0.41
	4 m	34.53±1.73	22.40±0.33	12.13±1.40
	8 m	28.50±0.70	14.77±0.58	13.73±0.42
3	0.3 m	63.42±0.70	26.08±0.94	37.34±0.24
	4 m	69.69±0.68	32.34±0.57	37.35±0.28
	8 m	31.95±0.75	19.73±0.54	12.22±0.24
4	0.3 m	55.26±0.73	20.70±0.39	34.56±1.10
	4 m	42.71±1.29	17.45±1.13	25.26±0.32
	8 m	23.08±1.35	10.32±0.71	12.76±0.64
5	0.3 m	57.69±1.24	22.18±1.13	35.510±.94
	4 m	48.21±1.24	16.60±0.89	31.61±0.39
	8 m	19.83±0.70	5.74±0.48	14.09±0.38

3.2 Specific Gravity

The specific gravity values of the soil samples are presented in Table 2. The results revealed that the soil specific gravity values decrease with soil depth. There was wide spatial variation of the specific gravity values across the studied region; as the topsoil samples specific gravity values varied from 2.66 – 2.69, the 4 m sub soil samples values ranged from 2.64 – 2.67, while the 8 m subsoil samples values varied between 2.62 and 2.64. Results obtained in this study were lower than those reported by Obasi [17] for sub soils sampled from Imo state, Eastern Nigeria, where the borrow pits' soil specific gravity values ranged between 2.68 and 2.71. The specific gravity of the soil samples, regardless of the location and sampling depth fell within the standard (2.6 to 2.8) approved by NIS for soils considered suitable for road construction.

Table 2: Specific gravity values at different soil depths and locations

LOCATION	0.3 m	4 m	8 m
1	2.68	2.65	2.62
2	2.69	2.65	2.63
3	2.67	2.67	2.62
4	2.66	2.64	2.63
5	2.66	2.65	2.64

3.3 Optimal Moisture Content

The results of the soil samples OMC are shown in Table 3. It was noted from the results that the OMC of the soil samples collected at the topsoil, 4 m and 8 m depths varied from 15.3% to 16.3%, 14.8% to 17.9%, and 13.2% to 14.2%, respectively. It can be seen from Table 3 that the soil OMC values decreased non-linearly with increased soil depth. Similar results were recorded by Nwadike [18], where the OMC values obtained for sub soil varied widely across the region they investigated.

Table 3: The soil samples optimal moisture content.

DEPTH (m)	L1	L2	L3	L4	L5	Mean
0.3	15.3	15.9	16.2	16.1	16.3	15.96
4	14.8	15.2	17.9	14.9	15.1	14.98
8	13.9	14.0	14.1	15.8	13.2	14.2

3.4. Maximum Dry Density

The maximum dry density results of the soil samples are presented in Table 4. Table 4 revealed that the MDD values for the soil samples collected at the topsoil, 4 m and 8 m soil depths ranged from 1.53 g/cm^3 to 1.59 g/cm^3, 1.59 g/cm^3 to 1.65 g/cm^3 and 1.68 g/cm^3 to 1.75 g/cm^3, respectively. Similar results were obtained by Amadi [8] for a series of sub soil sampled from northern Nigeria. It is observed from the results that the soil's MDD values increased with increase in soil depth, signifying that the soil particle size becomes coarser as the soil profile increases. Fine grained soils tend to have lower MDD values when compared to coarse grained soils [18]. Soil MDD is an essential geotechnical parameter in civil engineering discussion making, as it reflects the strength and permeability status of the soil. Soils with low MDD values tend to have lower strength and higher permeability, which can be linked to larger volume of fines in the soil mass.

Table 4: The soil maximum dry density at various depths

LOCATION	Maximum Dry Density (g/cm^3)		
	0.3 m	4 m	8 m
1	1.54	1.59	1.68
2	1.55	1.64	1.71
3	1.59	1.83	1.75
4	1.63	1.63	1.74
5	1.53	1.65	1.73

4. Conclusion

This research work has provided valuable insights into the geotechnical characteristics of the soil samples collected from five different locations in Okpe Community. The results obtained from the consistency limit test revealed significant variations in plastic limit and liquid limit across different depths. The consistency limits test results indicate varying levels of plasticity within different depth ranges, as the topsoil exhibited higher plasticity when compared to the subsoil. Likewise, the specific gravity values of the soil varied widely across the studied area, with the topsoil having higher specific gravity values when compared to the subsoil.

The maximum dry density results reveal an increase in its value with an increase in the soil depth, indicating that the subsoil is coarser than the topsoil. These findings emphasize the importance of considering the geotechnical properties of the soil in foundation design and construction planning in Okpe Community. Engineers and developers should consider the soil's high plasticity, low shear strength, and compressibility characteristics to mitigate the risk of structural failures and ensure the long-term stability and durability of construction projects. Further research and site-specific investigations are warranted to expand our understanding of the geotechnical behavior of the soil in Okpe Community, which will contribute to more accurate and reliable foundation design practices in the region.

List of abbreviations

LL	Liquid limit
MDD	Maximum dry density
OMC	Optimal moisture content
PI	Plasticity index
PL	Plastic limit

Declarations

Availability of data and material

The data and material used in this study are available upon request from the corresponding author.

Competing interests

The authors declare that they have no competing interests.

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Authors' contributions

Authors 1 and 2 conceived and designed the study; Author 2 collected and analyzed the data; Author 2 drafted the manuscript. All authors read and approved the final version of the manuscript.

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