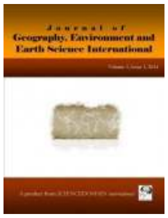

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Subsoil Conditions of Parts of Niger Delta Wetland, Nigeria

P. K. Wokoma[1] and N. E. Ekeocha[1*]

[1]Department of Geology, Faculty of Science, University of Port Harcourt, Port Harcourt, Rivers State, Nigeria.

Authors' contributions

This work was carried out in collaboration between both authors. Author NEE designed the study. Both authors managed the literature searches and data analyses. Author PKW managed the experimental processes and wrote the first draft of the manuscript. Author NEE worked on the final manuscript. Both authors read and approved the final manuscript.

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ABSTRACT

The subsoil conditions of Gbaran North Bank area, parts of the Nigerian wetland were evaluated using both disturbed and undisturbed soils, which were subjected to various laboratory tests adopting the British Standards methods, with the aim of establishing the subsoil conditions of the area as it affects use of the soils for various kinds of construction. The liquid limit recorded values between 37% and 50%, plastic limit range of 11% – 23% and attendant plasticity indices of 20% - 33%. The soils classified as highly plastic on the basis of their plasticity index and showed expansivity range of low – medium, while the swelling type was critical – non-critical. The soils recorded shear strength values of 39 – 42 KN/m^2 with coefficient of consolidation C_v values of 0.4 – 30.5 m^2/yr. The soils from the results showed tendencies towards expansion and therefore pose a problem to construction except precautionary measures are taken to ensure safety and durability of structures.

**Corresponding author: E-mail: nnamdi.ekeocha@uniport.edu.ng;*

Keywords: Subsoil; expansivity; plasticity index; consolidation; swelling; construction; wetland.

1. INTRODUCTION

Wetlands are described as land areas that possess tendencies toward prolonged water logging, periodic expansion and contraction, and generally lack the qualities for use as construction sites due to high moisture content and instability of the soils. The region therefore conforms to the view of [1] that wetlands are low-bearing-capacity foundation materials that have voids that are completely or partly saturated with water.

Soil, in the geotechnical engineering perspective, is the soft unconsolidated material, which overlies the rocks in the outer part of the earth's surface. Its geotechnical properties are ultimately related to the physical conditions, which determine to a large extent, its suitability as a foundation or construction material.

The formation of soil is as a result of cycles of geological processes that take place on the surface of the earth. The cycles consist of weathering or denudation, transportation, deposition, and upheaval [2]. Hence geotechnical characterizations of soils are generally defined from site investigation and laboratory testing.

The evaluation of subsoil conditions provides a guide to knowledge of the geological, geotechnical and hydrogeological conditions that may affect the construction or performance of a civil engineering structure on the soil [3]. Subsurface exploration and laboratory testing therefore become veritable means of ascertaining these conditions in order to achieve success of any structure.

In consideration of the poor nature of soils within the area, i.e. the effect of the incessant flooding cases that ultimately lead to some long-time of water logging, the consequent high levels of moisture in the soil, which has occasioned uncontrolled manner of structural [buildings, roads, etc.] collapse. A number of cases abound that are consistent with [4]

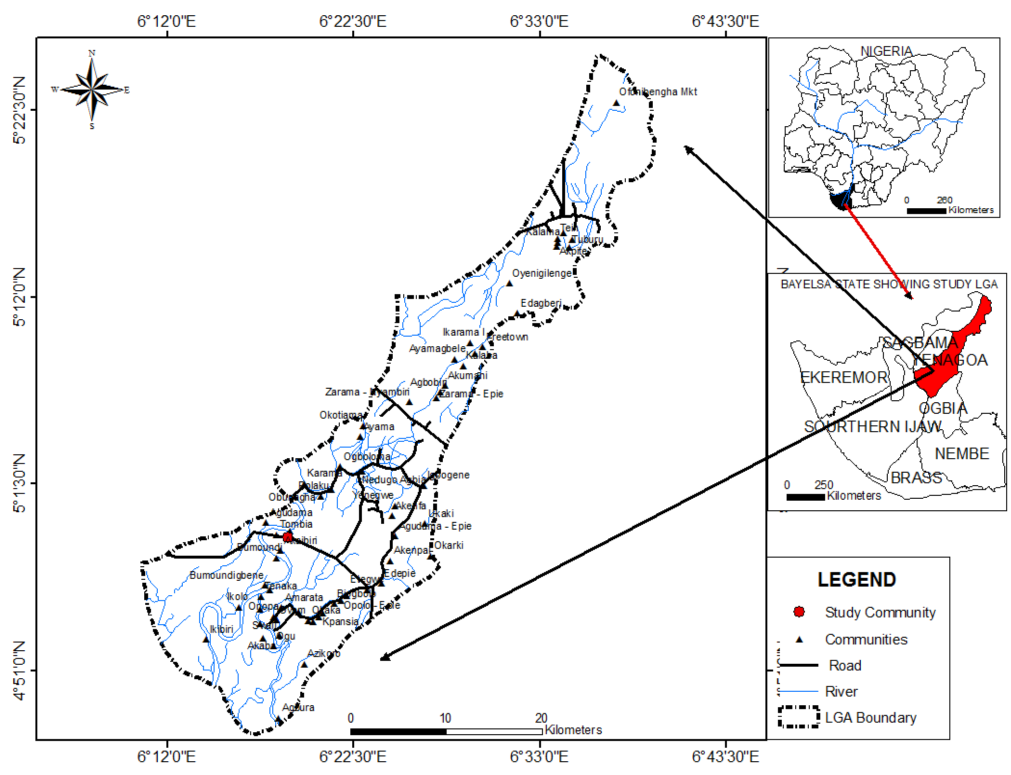


Fig. 1. Map delineating the study community

submission that the natural hazard and general swampiness of the terrain constitute serious concern for civil engineering construction and these include, the widespread pavement failures in the Niger Delta; the reported cases of collapse of residential 6-storey building in 2014, the 21- storey Nigerian Industrial Development Bank building in 2007 both in Lagos and the fly-over bridge in Port Harcourt in 2013. This study is therefore apt in ensuring propriety of construction material and type; and the eventual stability and success of such structures while ensuring safety of life and property on long term basis.

1.1 Location of the Study Area

The study area is located in Gbaran–Ekpeiama Local Government area of Bayelsa State, Nigeria, within the geographical coordinates of between Longitudes $6^0 17' – 6^0 25''$E and Latitude $4^0$55' - $5^0$05'N (Fig. 1).

The area falls within the Niger Delta region of Nigeria, a region that hosts most of the wetland of Nigeria. It comprises of five (5) major geomorphic units namely dry flatland and plains; Sombreiro-Warri deltaic plains with abundant freshwater swamps; freshwater swamps, back swamps, alluvial plains, meander-belt; saltwater mangrove swamps and active/abandoned coastal beaches [4].

1.2 Geology of the Study Area

The Tertiary Niger Delta is a sedimentary structure formed as a complex regressive off lap sequence of clastic sediments ranging in thickness from 9000-12000 m [5]. Starting as a separate depocenter, the Niger Delta has formed a single united system since Miocene.

The Tertiary deltaic complex has been divided into three major facies units based on the dominant environmental influences [6]. These main sedimentary environments are continental, transitional and marine. The base of the stratigraphic sequence is represented by massive marine shales. The middle part of the sequence is represented by interbedded shallow marine fluvial sands, silt and clays which are typical of a paralic setting. The sequence is capped by a section of massive continental sands.

Due to the relative unbroken progradation throughout the Tertiary, these three depositional lithofacies are readily identified despite local facies variations as three regional and diachronous formations ranging from Eocene to Recent in age. The three formations are locally designated, from the bottom, as Akata Formation, Agbada Formation and Benin Formation respectively. Of these three formations, the Agbada Formation constitutes the main reservoir of hydrocarbons in the Niger Delta while the Benin Formation constitutes the groundwater bearing unit within the region. Above the Benin Formation lies the Quaternary deposits, upon which most of the construction is done.

2. METHODOLOGY

Disturbed and undisturbed soil samples were collected and used in carrying out laboratory and insitu tests. Laboratory analyses included index properties, strength and compressibility tests adopting procedures prescribed by the British Standards [7]. The moisture content (BS 1377:4), liquid and plastic limits (BS 1377:2) and linear shrinkage tests were carried out on soil samples collected from depths greater than 3.75m below ground surface. The soil samples were also subjected to bulk density determination, grain size analysis, Proctor compaction test, consolidation (BS 1377:5) and undrained triaxial tests (BS 1377:7). Fig. 2 shows the borehole points on the location map.

3. RESULTS AND DISCUSSION

The soil samples classified as inorganic clays of medium plasticity on the unified soil classification system. The results of the consistency of the soils and the percentage of fines are summarized in Table 1.

The moisture content of a soil, which can be used to determine the volumetric strain of a saturated soil, was observed to be low - medium. It should be noted that the greater amount of water a soil contains, the less the interaction between adjacent particles and the more the soil will behave like a liquid. In other words, shear strength decreases with increasing amount of water contained in a soil. The moisture content of the samples varied in relation with depth in line with [8].

The consistency results indicated that the soils had established a relationship between the studied soils on the basis of swelling potential, and their plasticity index, with a resultant classification of the expansivity of the soils as medium expansivity (Table 2). Also the shrinkage limit of the soils was used to classify the swelling types of the samples mainly as non critical except for sample No 5 that classified as critical (Table 3).

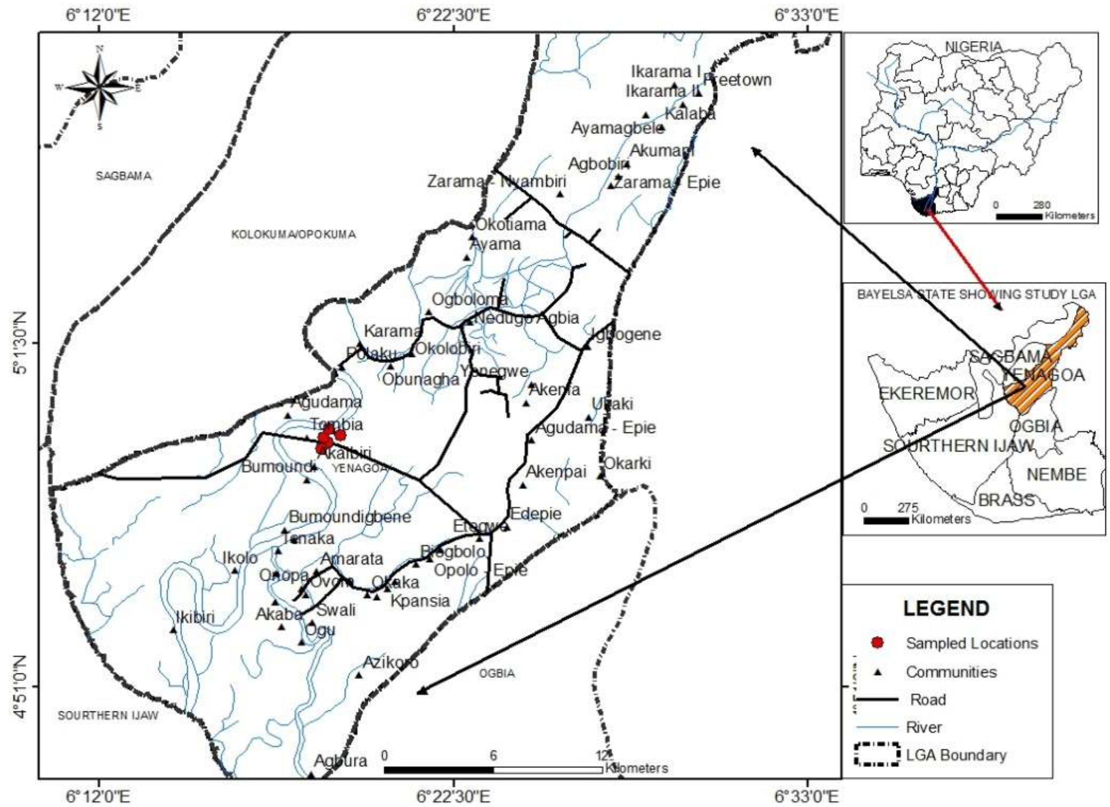


Fig. 2. Location map showing borehole points

Table 1. Results of consistency of the soil samples

Sample no	Liquid limit (%)	Plastic limit (%)	Plasticity index (%)	Moisture content (%)	% Fines	Linear shrinkage (%)
1	48.0	22.6	25.4	22.6	3	27
2	49.7	22.8	26.7	22.8	6	32
3	37.0	16.4	20.6	16.4	2	26
4	48.0	21.6	26.4	21.6	3	17
5	44.1	11.2	32.9	11.2	5	5.3

Table 2. Relation between swelling potential and plasticity index [9]

Swelling potential (%)	Soils expansivity	Plasticity index, %
<1.5	Low	0 – 15
1.5 – 5	Medium	15-35
5 – 25	High	35 – 55
25	Very high	>55

Table 3. Relation between linear shrinkage and swelling types of soils [9]

Swelling type	Shrinkage limit %
Non-critical	12
Marginal	10 -12
Critical	<10

The proportion of fines as derived from the grain size distribution (Table 1) does not agree with the supposition of high amounts of clays. This therefore may be an indication of high presence of organic soils/peat (this study however did not evaluate organic matter content). Critical degree of expansion, which is generally associated with high value of clay content as well as high shrink-swell behavior, in this study could be attributed to the suspected organic soils and or peat. The samples however showed medium swelling tendencies on the basis of liquid limit while on the basis of plasticity index according to (10) (Table 4), the swelling characteristics are high. This further confirms the possible high presence of organic soils or peat.

Table 4. Potential swell based on plasticity [10]

Classification of potential swell	Liquid limit, %	Plasticity index, %
Low	20-35	<15
Medium	35-50	15-25
High	50-70	25-35
Very high	>70	>35

The bulk densities, the dry densities with associated optimum moisture content (Table 5), classify the samples as stiff and hard. The soils recorded higher dry densities that accord them the potentials toward swelling in line with [11], who stated that samples with dry densities greater than 1.76 Mg/m^3 generally possess a high degree of swelling potential. The implication is that the soils will be prone to failure by settlement, with high tendencies toward eventual collapse. This assertion is supported by the general poor nature of the soils in the region.

The test results for the samples are presented in Table 5 while typical e – log p curve is shown in Fig. 3 and typical Mohr circles are shown in Fig. 4.

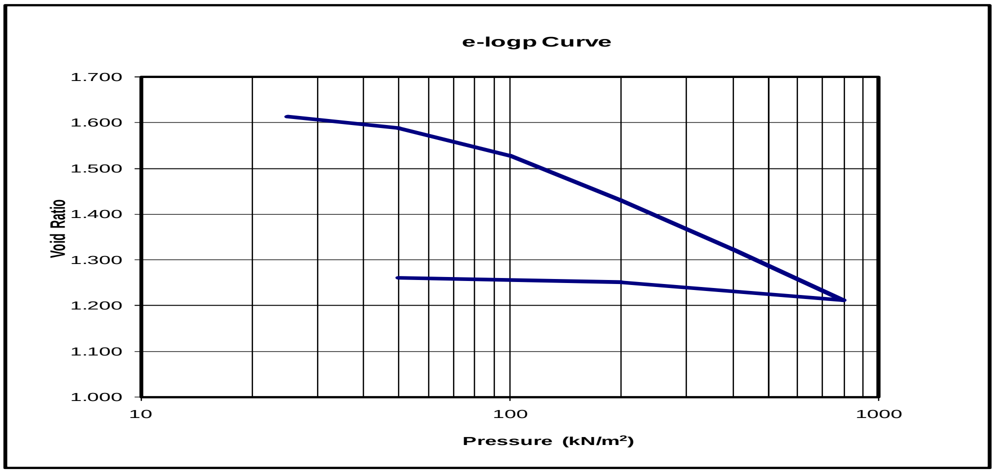
Saturated hydraulic conductivity (K) was another important parameter that was determined. The flow rate of water through soil or aquifer material depends on the magnitude of the hydraulic conductivity value [12,13].

The results obtained are consistent with [14]. The trend of this result agrees with the observed trend of plasticity, suggesting that the samples with highest Cv show greater potentials toward settlement and possible collapse of structures that may be constructed on them. The trend of consolidation characteristics can be defined by the particle size, the type and quantity of clay and or organic matter, the bulk density and hydraulic conductivity. The low consolidation rates show a strong relationship with the rate of drainage and justify the observed undrained triaxial shear strength condition. This inherent unstable condition can be surmounted using engineering solutions, which are very expensive.

Consequent upon the tendency of the soil to swell, it is expected that the bearing capacity will be low but can be improved practically by a layer of compacted sand or gravel as [15] proposed for soft clays. His further test results showed that the influence of the upper soil layer thickness beneath the footing depends mainly on the shear strength parameters and bearing capacity ratio of the layers, the shape and depth of the foundation and the inclination of the load. Where sand overlies clay [16], asserted that punch through may be initiated.

Table 5. Density and strength characteristics of the soil samples

Sample no	Bulk density (Mg/m^3)	Optimum moisture content %	Maximum dry density Mg/m^3	Cv range (m^2/yr)	Mv range (m^2/MN)	K range (cm/sec) $x10^{-8}$	Cu KN/m^2	ϕ_u (^{o})
1	8.1	27.2	6.37	0.4-0.6	0.84-0.12	1.09-0.23	40	6
2	6.5	47.7	4.4	1.3-30.5	0.42-0.06	39.83-0.06	40	5
3	9.3	35.5	6.86	2.8-30.5	0.48-0.07	45.45-0.66	39	4
4	8.3	44.6	5.74	5.6-1.1	0.22-0.09	3.85-0.30	42	4
5	6.9	33.3	4.57	1.05-0.45	1.08-0.13	3.54-0.18	40	6



BH No.	Depth (m)	Pressure range (kPa)	Coefficient of consolidation Cv, (m^2/yr)	Coefficient of compressibilit Mv, (m^2/MN)	Coefficient of permeability K, (cm/sec) x 10^{-8}
1	3.0	0-25	0.4	0.84	1.09
		25-50	0.4	0.39	0.51
		50-100	0.5	0.46	0.73
		100-200	0.8	0.39	0.91
		200-400	0.6	0.22	0.42
		400-800	0.6	0.12	0.23

Fig. 3. Typical e – logp curve

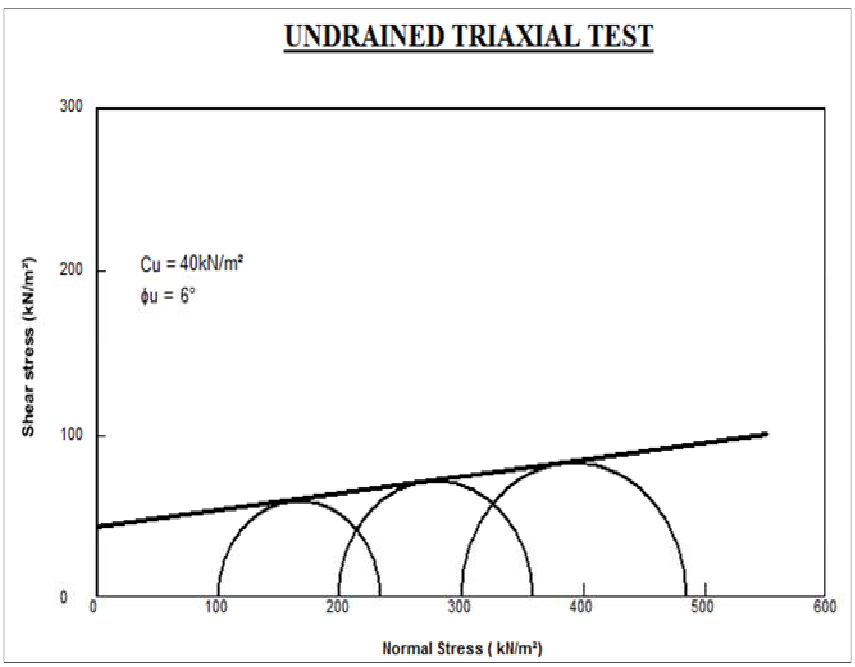


Fig. 4. Typical Mohr circles

4. CONCLUSION

The observed conditions agree with the fact that wetlands are often generally waterlogged and have high tendencies toward flooding particularly during high events of rainfall.

The soils have been established to possess expansive character. Soils that possess this character do not support construction of different structures without improvement. In view of the foregoing, adequate soil improvement must be undertaken in the designing and construction of safe and durable structures in the area.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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