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Geotechnical characteristics of the meander belt soils of Niger Delta in Nigeria

Les caractéristiques de geotechnical des sols de ceinture de méandre de Delta de Niger dans Nigéria

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ABSTRACT
Three main sedimentary environments are distinguishable in the Niger Delta in Nigeria. These are the continental, transitional, and marine environments. The continental environment comprises the upper and lower flood plain environments made up of the braided streams and the meander belt systems. The area enclosed by the Orashi River in the east and the Forcados River and Ase River in the west and the mangrove swamps in the south form the meander belt of the Niger Delta. A significant proportion of the Niger Delta lies within the meander zone where the area is filled with sedimentary sand deposits capped with variable thickness of problematic clays. Many crude oil processing facilities were founded within these soils and some of them have undergone structural damages. Also, several road pavements and embankments have been subjected to the damaging influence of these soils. The disruptive nature of these soils, particularly the upper clay deposits in the area had necessitated the demand for ground investigations to characterize these soils for design purposes. The characterization of the soils was made on the basis of mineralogical characteristics, identification and classification tests and engineering properties. Ground investigations had been conducted in the area using borings with sampling, in-situ tests and laboratory tests to evaluate the engineering properties of the soils. This paper summarizes the findings of the investigations with special attention paid to the engineering behaviour of the clay.

RÉSUMÉ
Trois environnements sédimentaires principaux sont distinguables dans le Delta de Niger dans Nigéria. Ceux-ci sont les environnements continentaux, transitoires et marins. L'environnement continental comprend l'inondation supérieure et plus basse environnements simples ont formé de l'a tressé des ruisseaux et les systèmes de ceinture de méandre. Le secteur enclos par la Rivière de Orashi dans l'est et la Rivière de Forcados et la Rivière de Ase dans l'ouest et les marais de manglier dans le sud forme la ceinture de méandre du Delta de Niger. Une proportion significative des mensonges de Delta de Niger dans la zone de méandre où le secteur est rempli avec les dépôts de sable sédimentaires a plafonné avec l'épaisseur variable d'argiles problématiques. Beaucoup de pétrole de facilités de traitement bruts étaient fondé dans ces sols et certains d'eux ont subi des dommages structuraux. Aussi, plusieurs trottoirs de route et les remblais ont été exposés à l'influence qui endommage de ces sols. La nature perturbatrice de ces sols, particulièrement les dépôts d'argile supérieurs dans le secteur avaient nécessité la demande pour les investigations de sol pour caractériser ces sols pour les buts de conception. La caractérisation des sols a été faite en se basant sur les caractéristiques minéralogiques, en se basant sur les tests d'identification et classification et les propriétés d'ingénierie. Les investigations de sol avaient été dirigées dans le secteur utilisant borings avec essaie, les tests de dans-situ et les tests de laboratoire pour évaluer les propriétés d'ingénierie des sols. Ce papier résume les conclusions des investigations avec l'attention spéciale payée au comportement d'ingénierie de l'argile.

1 INTRODUCTION

About one-third of the 40,000 square kilometers occupied by the Niger Delta in Nigeria lies within the continental sedimentary environment comprising the alluvial valley of the Niger. The environment is made up of braided streams and meander belt systems of the upper deltaic plain of the Niger. This plain extends northwards from the mangrove swamps to the apex of the delta. The northern part of the zone is more susceptible to annual floods while the southern part on the other hand is subjected to considerable tidal influence but less affected by river floods. Most channels in this valley are bordered by natural levees, which are high enough to escape the effects of flooding.

This alluvial valley commonly known as the Meander Belt of the Niger is characterized by an extensive spread of alluvium consisting mostly of sands and clays. A typical stratal sequence of the soils discloses a prevalent deposit of medium to coarse sand capped by problem clays of variable thickness; but found to be thickening southwards.

Several lightly loaded oil processing facility and roads are founded in these clays. A high proportion of these utility structures are seen to experience severe structural damages after few years of their construction. The disruptive nature of these clays generated the need for ground probes to determine their geotechnical properties for design purposes. Numerous ground investigations have been conducted in this area using soil boring with sampling, in-situ tests and laboratory tests to evaluate the index and engineering properties of these clays. Results of the previous ground investigations carried out in fourteen sites within the meander belt were collated for the characterization of the clays based on the mineralogical composition, identification and classification tests and engineering properties.

2 GEOLOGY OF THE AREA

The Niger Embayment developed as a result of subsidence of a part of African Shield during Middle and Upper Cretaceous periods. The Embayment has determined the main course of the Niger Water since Upper Cretaceous period. The main formations have been recognized in the subsurface of the Niger Delta Complex (Short and Stauble 1967). These are Benin, Agbada and Akata Formations. The three formations were laid down under continental, transitional and marine environment.

The area for this investigation falls within the Benin Formation (Short and Stauble). The Benin Formation was laid down in a continental upper deltaic environment.

The present Niger Delta is flanked on either side by higher lying coastal plain, which formed the ancient coastline and consists of Miocene-Pleistocene sediments Consequent on the occurrence of low stands of the sea level, the Niger River System eroded a great part of this coastal plain and the remainder is found as a Coastal Plain Terrace on either side of the present delta. In an intermediate position between the Coastal Plain Terrace another terrace exists, the sub-recent Sombreiro-Warri Terrace of the late Pleistocene age. This sedimentation constituted the ancient Niger Delta. The elevation of this terrace is higher than that of the recent alluvial plain permitting it to remain virtually non-inundated during periods of floods of the Niger.

The alluvial plain consisting of the Meander Belt is a belt of recent Quarternary sedimentation, which reflects reliably the hydrographic trend of the water systems, derived from the Niger and constituted the true present delta.

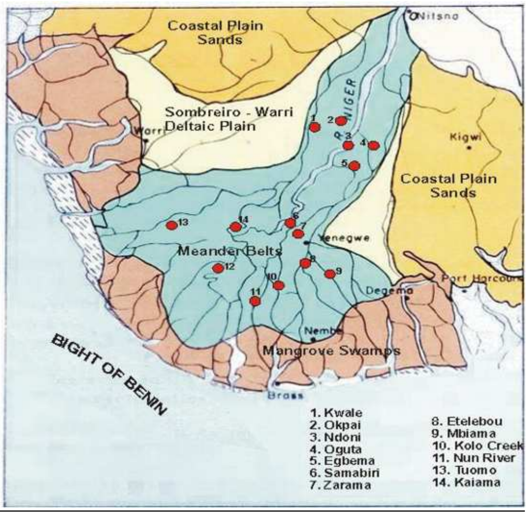


Figure 1. Geological map of the Niger Delta showing locations of past investigations in the area.

3 TYPICAL SOIL PROFILE AND DESCRIPTION

Available data from previous investigations in the area and the inspection of the exposures of the soils at the riverbanks within the area disclosed that the near surface soils are composed mainly of greyish brown clays. The greyish brown colour is attributed to chemical conversion by oxidation and apparent desiccation by surface drying. There is a distinct change in colour from greyish brown to bluish grey from depths varying between 3.0 and 5.0m beneath the ground surface. Remarkable reduction in the strength of the clay is also observed below these depths. This depth of change in the attributes of the clay varies considerably throughout the belt.

It is noteworthy that the strength and stiffness of the clay respond faithfully to the changes in the climatic conditions. Fig 3 shows the contrast in the results obtained in the clay layer from cone soundings conducted in wet and dry seasons in the same site.

Most of the data from the in-situ penetration resistance tests showed that the sand immediately beneath the clay is significantly dense. This notable high resistance shown by the upper portion of the sand deposit is attributable to the densifying effect of the seasonal fluctuations in the ground water levels in the area. However, beneath this top dense few metres, the sand deposit grades into a predominantly medium dense state with few loose bands.

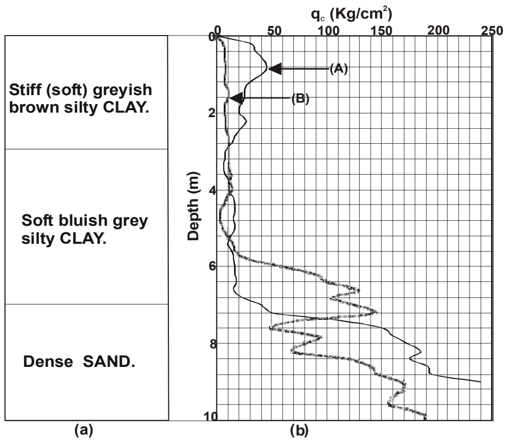


Fig 2. (a) Typical soil profile (b) cone sounding - (A) in dry season (B) in wet season.

3.1 Mineralogy

In order to predict the soil behaviour and also evolve methods to minimize the damaging effects of soil, there was the need to identify the type and amount of the clay minerals in the soil. Soil samples were collected from two locations considered typical of the area; Kwale at the northeast part of the valley and Zarama at the southeast. These two locations are virtually longitudinally opposite each other. The samples were consigned to the Natural History Museum in the United Kingdom for the mineralogical analysis. The Kwale sample was analysed by conventional X ray diffractometry and also subjected to electron microscope scanning. The Zarama sample was analysed fully quantitatively using position sensitive detection X ray diffraction.

It was found that the mineral assemblage in both clay samples was reasonably similar. The dominant minerals are Kaolinite and Smectite with quartz, goethite and mica in little quantities. However, a small quantity of 7A iron-rich clay probably odonite was detected in Kwale clay.

Table 1 Mineralogical Composition of the Clay

Parameter (%)	Zarama	Kwale
Kaolinite	40	60
Smectite	31	30
Quartz	17	trace
Geothite	6	trace
Mica	6	-
Odonite	-	10

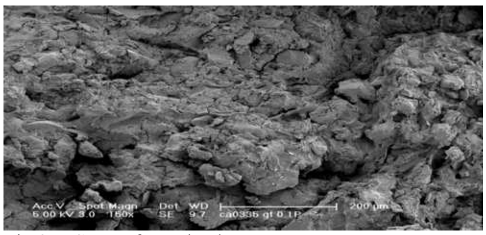


Fig 3a. SEM of Kwale clay at 5.5m.

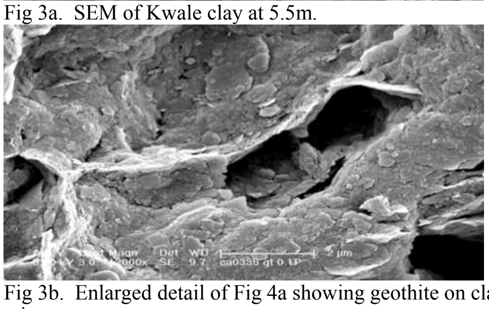


Fig 3b. Enlarged detail of Fig 4a showing geothite on clay and micropore.

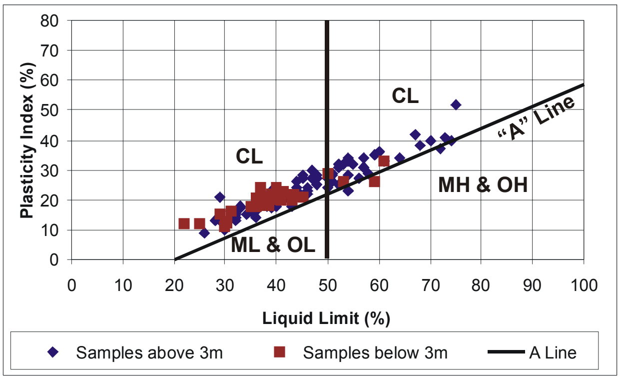
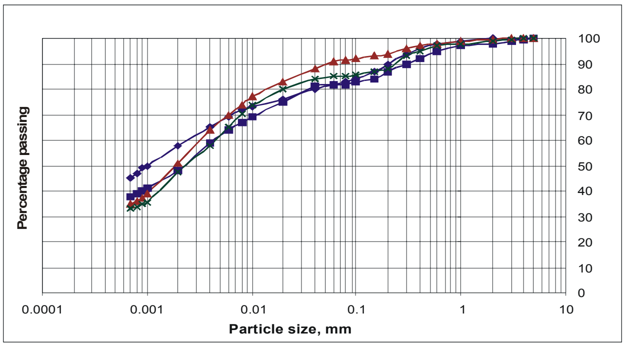
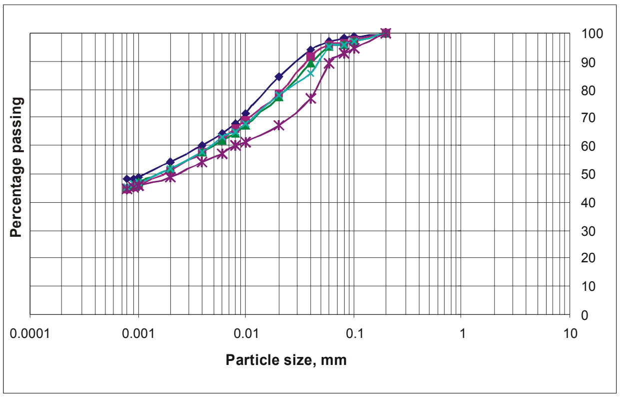


Fig 4. Plasticity of Meander Belt Clay.



(a)



(b)

Fig 5. Grain size distribution (a) Kwale sample (b) Zarama sample.

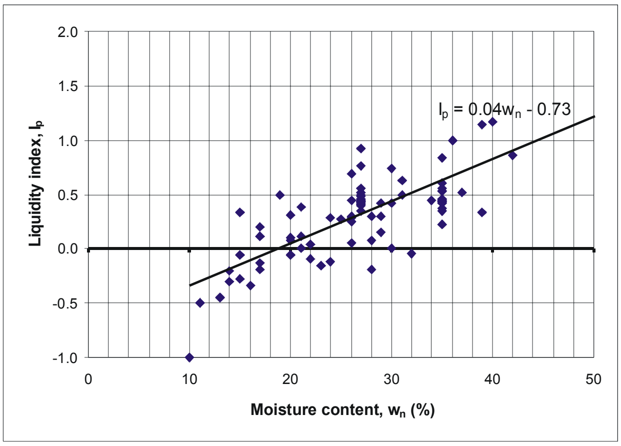


Fig 6. Relationship between liquidity index and moisture content.

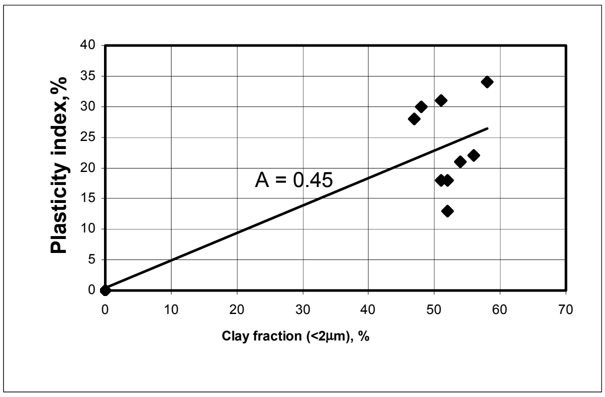


Fig 7. Relationship between plasticity index and clay fraction

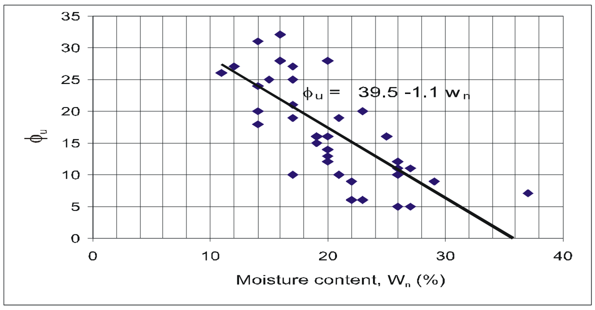


Fig 8. Relationship between undrained angle of shear resistance and moisture content.

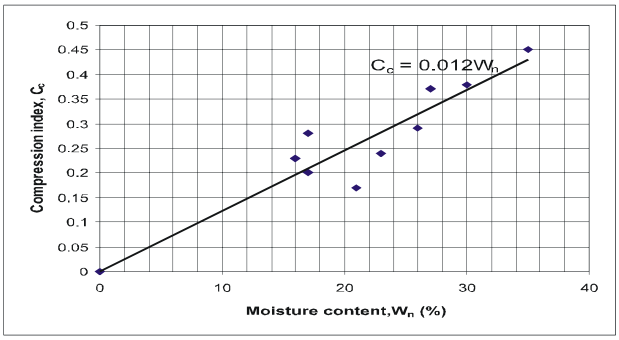


Fig 9. Relationship between compression index and moisture content.

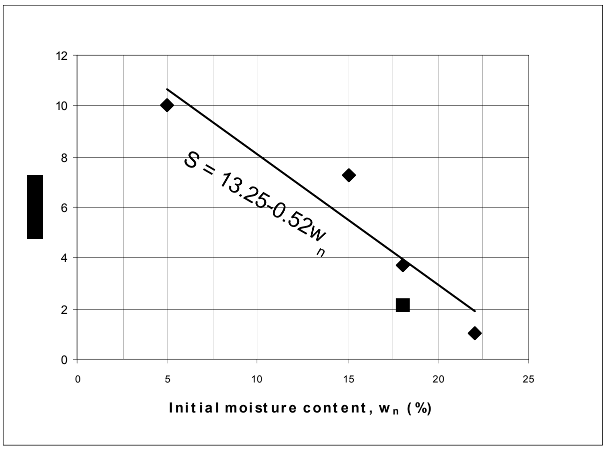


Fig 10. Relationship between percent swell and initial moisture content.

The primary structure macroscopically in this clay is the angular blocky ped structure, which permits movement in the clay, and also allows expansion during wet periods and contraction during dry periods. Table 1 shows the mineralogical compositions of the clay soils from the two sites. Also, the scanning electron micrographs of the soil from Kwale are presented in Fig 4a and 4b.

4. INDEX AND ENGINEERING PROPERTIES

The data obtained from the ground investigations conducted in the area show the natural moisture contents of the upper and lower sublayers of the clay to vary between about 10 and 40% with the plasticity indices covering a similar range. Fig 5 shows the Atterberg limits when plotted on the conventional Plasticity Chart to consistently lie above the A line. The clay samples retrieved from two representative sites reveal the following grain size distribution.

Site	**Particle Size (%)**		
	Clay	**Silt**	**Sand**
Kwale	50 - 55	40 - 42	3 - 10
Zarama	50 - 60	30	10 - 20

The grain size distribution of the clay retrieved from these sites within the valley but several kilometers apart are reasonably similar; although with higher silt content in the Kwale sample and slightly higher sand content in the Zarama sample.

The mineralogical composition of the clay shows kaolinite to be most dominant with smectite (montmorillonite) coming second. The activity of the clay is low as depicted in Fig 8, thus reflecting the dominance of kaolinite. However, with the high clay content in the soil, the moderate proportion of smectite in the composition of the clay and the macroscopic ped structure of the clay, which allows expansion, and shrinkage of the soil, the Meander Belt Clay can be categorized as clay of high swelling potential.

Unconsolidated undrained shear strength parameters of the clay are normally needed for the design of the foundations of the structures. Laboratory triaxial compression tests were used for this purpose. The collated data from these tests showed the clay to exhibit significantly high angles of shear resistance at low natural moisture contents. However, the angle of shear resistance tends to zero at moisture content of about 36% as shown in Fig 9. The saturation moisture content of this clay is found to hover around this value.

The upper 3.0 to 4.0m of the clay is overconsolidated with OCR ranging from 3.0 to 6.0 while the lower 4.0 to 8.0m is lightly oversonsolidated with OCR varying between 1.5 and 2.0. Both sublayers of the clay are moderately compressible. The compression indices of both sublayers are correlated with natural moisture content as shown in Fig 10. With this relationship it becomes possible to estimate the compression indices of the clay from natural moisture content data.

In order to assess the swelling potential of the clay the soils recovered from the two typical sites were compacted at various moisture contents, adopting the British Standard light compactive effort. The compacted soil was immersed in a tank filled with water and allowed to swell under a surcharge pressure of 1.0kPa for five days. It was observed that at this time, the swelling of soil was in effect complete. The relationship between the initial moisture content and swelling potential of the clay is shown in Fig 11. The correlation shows that with the compactive effort used in the test, the swelling potential of the clay could be reduced significantly where the compaction of the clay is carried out at initial moisture contents around 25%.

5. DISCUSSION

The Meander Belt Clay covers most of the upper deltaic plain of the Niger Delta. Several lightly loaded structures including roads are founded within the upper portion of this clay. This soil exhibits high apparent shear strength during dry seasons when most construction works are carried out in the area and expectedly most foundations for the structures are embedded in the clay. The damages undergone by various structures founded in this clay has given it the reputation of "problem soil". The assessment of the available data and the various parametric relationships established it is apparent that the clay is extremely responsive to the climatic changes. This clay is susceptible to volume changes, which are directly related to the changes in the natural moisture content causing it to swell in wet seasons and shrink in dry seasons. From the various correlations obtained in this analysis of the available data, reasonably reliable estimates of the values of the natural moisture content for satisfactory engineering performance of the clay can be made. The relationships deduced from the analysis could be used also in establishing the danger values of the natural moisture content for the various use of the Meander Belt Clay.

6. CONCLUSIONS

A large portion of the upper deltaic plain of the Niger Delta is covered by the Meander Belt Clay. This clay overlies a prevalent deposit of sand. The thickness of this clay varies between about 3.0 and 10.0m. Many of the light loaded structures and road pavements are founded in this material. However, a large proportion of these facility have undergone severe damages attributed to the volume change behaviour of the clay.

This paper has summarized the characteristics and engineering properties of the clay. The characteristics of this soil are largely dependent on the high clay content, the macroscopic blocky ped structure that accommodates expansive and shrinking movements in the soil and the moderate proportion of smectite which is conceded as a mineral susceptible to high volume changes. The Meander Belt Clay is categorized as clay of high swelling potential. The engineering properties of this clay are essentially subjected to the changes in the climatic conditions. To attenuate the problem of the expansive clay it would be desirable to determine the design parameters of the clay at the time of the construction of the proposed structure or during wet seasons when the soil would yield the most pessimistic soil parameters and the design of the foundations should be carried out accordingly.

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REFERENCES

Balasubramaniam, A.S., Bergado, D.T. and Sivandsan C. 1985. *Engineering Behaviour of Soils in South East Asia, Commemorative Vol. Of the South East Asian Geotechnical Society.*

Gidagasu, M.D. 1972. *Mode of Formation and Geotechnical Characteristics of Laterite Materials of Ghana in Relation to Soil Forming Factors. Engineering Geology Vol.6* pp79 – 150.

Lake, L.M. and Simon, N.E. 1969. *Investigations into the Engineering Properties of Chalk at Wetford Theale, Berkshire. Proc. of Conf. On In-situ Investigations in Soils and Rock*s- British Geotechnical Society, London.

Mitchell J. K. 1992. *Fundamentals of Soil Behaviour. John Wiley & Son Inc. New York.*

Short, K.C and Stauble, A.J. 1967. *Outline of Geology of Niger Delta. American Asso. Of Petr. Geologists, Bull. Vol.51*. Pp561 – 779.

Whiteman, Arthur. 1982. Nigeria- Its Petroleum Geology and Potential. Vol.1, Graham and Trotman.