Environmental and geotechnical depiction of foundation soils in deltaic part of Southern Nigeria

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ABSTRACT: The influences of the Meander Belt (MB) and Coastal Plain Sand (CPS) on geotechnical properties of foundation soils have not featured in the engineering geological literature. This study employed moisture content and cohesive strength (C_u), chemistry and clay mineralogy of foundation soils in the two principal sub-environments in Niger Delta of Southern Nigeria. Major oxides were analysed by lithium melaborate and atomic absorption spectrophotometry (AAS). Clay minerals by X-ray diffraction (XRD) technique and scanning electron microscopy (SEM) signals form images for grain interpretation. Disturbed and undisturbed samples were tested for consistency limits and C_u respectively. Kaolinite (18.5%) has higher amounts of Fe_2O_3 (88.3%) and Al_2O_3 (22.7%) in soils from MB area compared to those from the CPS area. Conversely, much higher amount of SiO_2 (83.9%) is recorded in soils from the CPS than those from the MB areas. SEM revealed that quartz grains from the MB range between 5 and 100 µm, while those in the CPS area range between 20 and 100 µm. The foundation soils from MB are low to very high plastic silty clay, while those from the CPS area are silty clay of medium to high plasticity with average C_u of 32.4 and 40.0 kN/m^2 respectively.

1 INTRODUCTION

Abam & George (1997) and Abam & Okogbue (1997) identified the Meander Belt (MB) and Coastal Plain Sand (CPS), which are principal sub-environments in the Niger Delta, Southern part of Nigeria. Soils that underlain the sedimentary environments serve as foundation and construction materials but are usually problematic (Mohamad 1993, Teme 2002).

Osammor (2009) and Adeyemi & Osammor (2000) carried out a comprehensive assessment of foundation soils in the area and obtained a strong correlation between cone resistance and STP number of blows. Tse (2006), Onyebuolise & Akpokodje (2008), Tse & Akpokodje (2010) and Youdeowei & Nwankwoala (2011) evaluated the geotechnical characteristics of the subsoil in the deltaic environment.

However, the general engineering principles governing the design of foundations of structures are quite inadequate for the area underlain by Deltaic soils when considering the role of the principal environments on the stability of foundations.

In this study, the interaction of the major oxides, geochemistry, and clay mineralogy, critical water content and cohesive strength of the soils were considered taking cognizance of the principal environments. This is expected to help in the design of foundations serviceability limit of engineering structures whose failure could lead to a huge loss of human and material resources.

2 SEDIMENTARY GEOLOGY

The area under study (Fig. 1) developed as a result of sediments accumulating in response to rift Atlantic Ocean during the Miocene-Eocene period (Whiteman 1982, Obaje 2019). The geological formations of the Niger Delta are ‘Agbada and Akata’ of Eocene period. Recent in age are a continuation of Imo-shale (Palaeocene) and the Ameki Formation. The topmost and youngest Benin Formation (Miocene-Recent) is the outcropping formation in the Niger Delta.

In geology and soil classification, clay is adjudged to be less than 2 µm irrespective of their mineralogy. Therefore, the ancient sedimentary processes can be related to the properties of clay-sized particles, which govern the engineering performance of soils (Avwenagha et al. 2014).

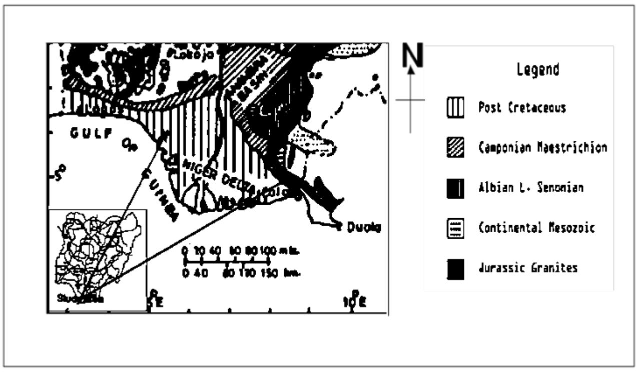

Figure 1. Geological map of Southern Nigeria showing the Niger Delta Complex

3 METHODS OF STUDY

A reconnaissance survey was carried out to delineate areas that fall into the Coastal Plain Sand (CPS) and Meander Belt (MB) zones. Sixty (60) disturbed, and twenty (20) undisturbed sampling was done from isolated pad footings illustrated in Figure 2. B is the width and H is the height of excavation with water table level ranging between 0.5 to 1.2 m below the natural ground level in the study area.

Abundances of major oxides in the sampled soils were determined using X-ray fluorescence (XRF) spectrometric technique under standard analytical conditions.

Qualitative and quantitative estimation of respective clay minerals was determined from the X-ray Diffraction (XRD) pattern of an X-ray machine. Photomicrographs of the soils were obtained from scanning electron microscopy (SEM) along a pattern of parallel lines.

The procedures for the determination of consistency limits, as standardized by the ASTM (1985) designation-2487-92, were such that both liquid limit (LL) and plastic limit (Lp) were determined using air-dried soil samples which have been passed through the British Standard Sieve No. 40 (sieve size 0.425 mm). The difference of which is the plasticity index (IP) employed for plotting on the Casagrande chart.

Triaxial shear strength testing was conducted in accordance with BS 5930 (1981) procedures on undisturbed samples.

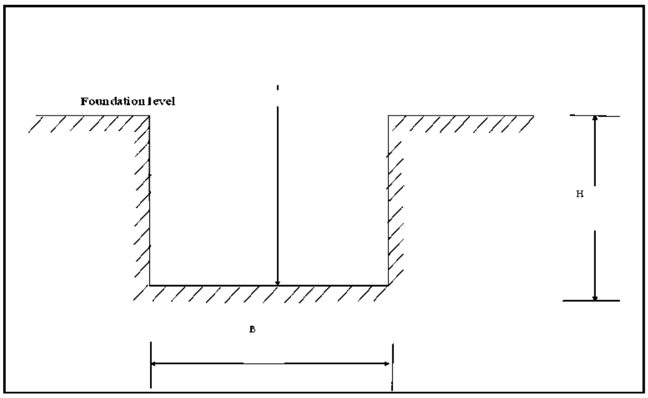

Figure 2. Typical foundation excavation for soil sampling (B – foundation width, H - foundation height. Drawing, not to scale)

Table 1. A summary of the chemical composition of deltaic soils

Environment	Statistics	Amount of oxides percent (%)										
		SiO_2	TiO_2	Al_2O_3	Fe_2O_3	MnO	MgO	CaO	Na_2O	K_2O	P_2O_3	SO_3
Meander Belt	Minimum	35.9	0.0	7.9	1.0	0.006	0.05	0.03	0.05	0.07	0.05	0.03
	Maximum	44.04	21.7	22.7	88.3	0.4	1.4	1.8	0.9	5.0	0.2	5.1
	Mean	60.4	1.4	17.8	6.5	0.2	0.9	0.5	0.7	2.5	0.1	0.3
Coastal plain sand	Minimum	78.6	0.7	8.3	2.5	0.02	0.04	0.02	0.05	0.06	0.01	0.03
	Maximum	83.9	1.2	11.8	3.0	0.3	0.2	0.04	0.07	0.1	0.2	5.1
	Mean	80.5	1.0	10.3	2.8	0.07	0.2	0.03	0.06	0.08	0.1	0.03

Table 2. Amount of clay and non-clay minerals (percent)

Environment	Statistics	Clay minerals percent (%)							Non-clay Minerals	
		Kaolinite	Chlorite	Illite	Anatase	Albite	K-feldspar	Geothite	Quartz	Calcite
Meander Belt	Minimum	7	1	11	1	2	2	2	29	1
	Maximum	32	4	23	3	8	7	7	56	2
	Mean	18.5	2.8	17.4	1.7	5.4	4.3	5.7	40.2	1.1
Coastal plain sand	Minimum	20	-	1	1	1	1	2	60	-
	Maximum	30	-	2	2	1	1	4	75	-
	Mean	28.08	-	1.6	1.2	1.0	1.0	2.8	65.4	-

4 RESULTS AND DISCUSSION

From Table 1 the quantities of the major oxides in the soils from the MB contain much higher amounts of Fe_2O_3 (88.3 %) and Al_2O_3 (22.7 %) than those from the CPS area which contain 3.0 % of Fe_2O_3 and 11.8 % of Al_2O_3.

Conversely, a much higher amount of SiO_2 (83.9 %) is recorded in soils from the CPS as against 44.04 % for those from the MB area. This shows that the iron and aluminium oxides might have been significantly washed off from the CPS than in the MBS soil which resulted in the dominance of SiO_2 in the MBS.

The X-RD patterns analyzed in Figure 3, and quantitative interpretation provided in Table 2. Kaolinite (30 – 32 %) is the most abundant clay mineral in the foundation soils from both environments, while there are more illite (23 %) and chlorite (4 %) in the MB soil than in CPS with 2 % illite without chlorite. In the CPS area, chlorite and calcite are absent with a higher percentage of quartz than the soils from the MB area.

Observation of the scanning electronic microscope (SEM) shown in Figure 4 revealed that quartz grains from the MB range in size between 5 and 100 µm, while those from the CPS area range between 20 and 100µm. The soils generally, contain angular grains of quartz and feldspar with variably rounded to sub-rounded detrital grains of goethite and mica. This is indicative of highly matured and weaning sediments. There are voids between the mineral grains especially those of the CPS area where they are largely unsaturated as calcite and chlorite are absent. Sediments show coated grains of clay matrix quartz overgrown with chlorite. Small quartz grains are more coated than large grains with very fine-grained sandstone consisting of quartz, and feldspars extensively coated with diagenetic clay minerals. These appear to be mostly, kaolinite and chlorite with a lesser amount of illite in the samples from the MB area.

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Soils from the MB environment have slightly higher variation (22.3 %) in plasticity index (I_p) compared to the CPS area which *Ip* of 20.5 % variation. This is consistent with the established distribution and geotechnical properties of Deltaic soils in parts of Southern Nigeria as reported by Okeke & Okogbue (2010).

A maximum C_u of 55 kN/m^2 is recorded for clay from both the CPS and the MB areas. Clays from the MB show much higher C_u variation (48.8 %) than those from CPS areas that show 24.3 %. In general, average C_u values of 32.4 and 40.0 kN/m^2 are recorded for foundation soils from the MB and the CPS areas respectively. On the Casagrande chart (Fig. 5), it can be confirmed that soils from MB are silty clay of low to very high plasticity, while those from the CPS area are silty clay of medium to high plasticity.

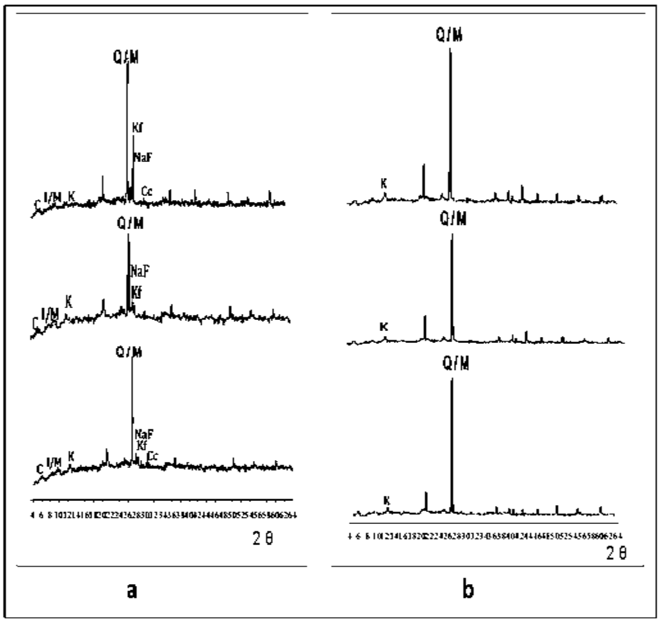

Figure 3. X-ray diffractograms showing traces of kaolinite (K), muscovite (M), illite (I) and chlorite (C) (a – Meander Belt and b – Coastal Plain Sand)

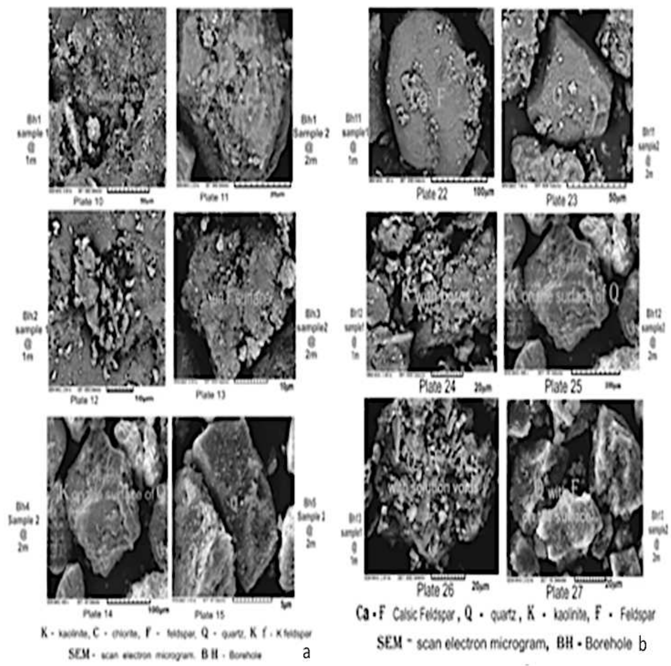

Figure 4. SEM photomicrographs of clay from deltaic sediments (a – Meander Belt, b – Coastal Plain Sand)

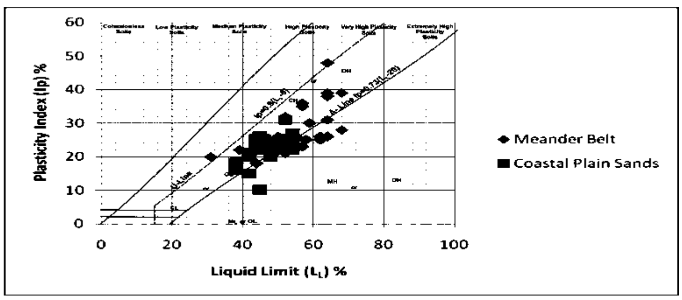

Figure 5. Casagrande chart for soil classification in the Meander Belt and Coastal Plain Sand areas

Table 3. Consistency and cohesive strength of deltaic soils

Environment	Geotechnical Properties	Statistics				
		Minimum	Maximum	Average	Standard deviation	Coefficient of variation (CV) %
Meander Belt	Plasticity Index (Ip) %	20	36	26.4	5.9	22.3
	Undrained Cohesion (Cu) kN/m^2	10	55	32.4	15.8	48.8
Coastal Plain Sands	Plasticity Index (Ip) %	10	31	22.4	4.6	20.5
	Undrained Cohesion (Cu) kN/m^2	24	55	40.0	9.7	24.3

A regression plot between kaolinite and alumina for both deltaic soils is shown in Figure 6. A fairly strong correlation (r ≈ 0.7) exists between kaolinite and alumina from both the MB and CPS areas. This implies that clay mineralogical composition increases with an increase in the chemical composition of the deltaic soils. A regression analysis between C_u and I_p of samples from both the MB soils and CPS areas shown in Figure 8 reveals fairly strong positive correlation (0.54) exists between cohesion and I_P of soils from the CPS area only.
A typical example of such is shown in Figure 8, and it can be observed that this failed portion is at a river across the road. Therefore, due to the weak cohesive strength of the clay, the underlying soil might have been eroded over time, which had threatened the foundation of the ring culverts leading to its eventual collapse.

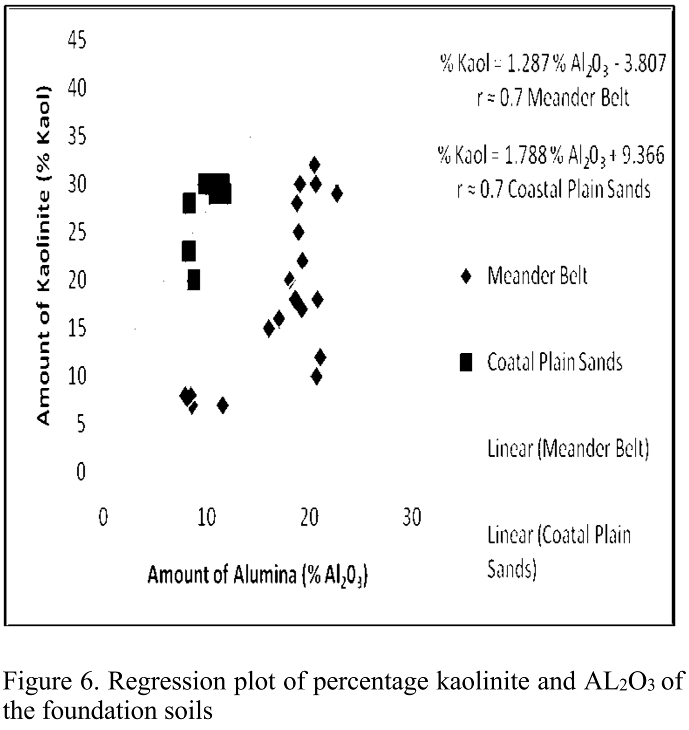

Figure 6. Regression plot of percentage kaolinite and AL_2O_3 of the foundation soils

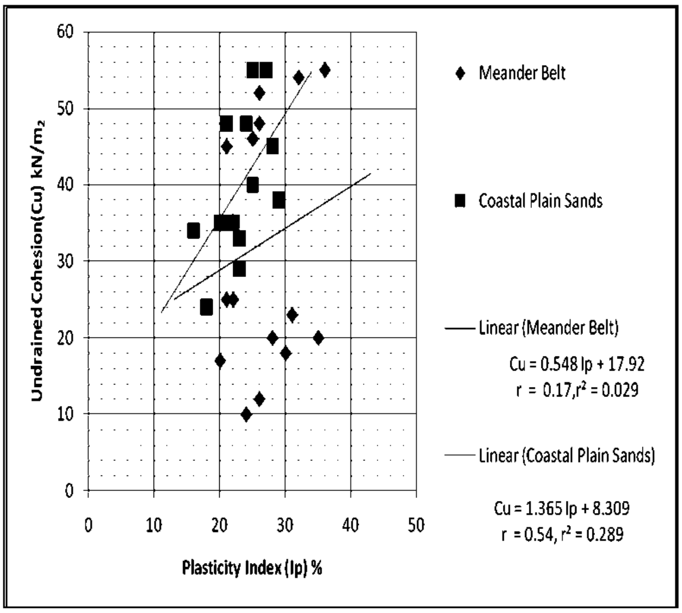

Figure 7. Regression plot of undrained cohesion against plasticity index of the studied soils

Figure 8. Typical pavement failure due poor-quality soil

5 CONCLUSIONS

The Deltaic sediments which underlain both the Meander Belt (MB) and Coastal Plain Sand (CPS) areas of Southern Nigeria serve as foundation materials in the area. Geology revealed that the topmost and youngest soil type is the Miocene – Recent Benin Formation.

Quartz grains from the MB have a wider range in size compared to those in the CPS area. Soils from the MB contain much higher amounts of Fe_2O_3 and Al_2O_3 compared to those from the CPS area. Kaolinite is the most abundant clay mineral present in foundation soils from both environments. Soils from the MB area contain more illite and chlorite soils from the CPS have few amount of illite with no chlorite, which significantly affected the plasticity index and cohesive strength of the soils.

Cognizance of the sub environments and the clay properties that may affect the stability of foundation is required in executing problem-free design and construction in the Niger Delta area.

6 REFERENCES

Abam, T.S.K. & George, E.A.J. 1997. Penetration testing in the highly stratified sediment of the Niger Delta. *Journal of Mining and Geology.* 33(1): 7-14.

Abam, T.S.K. & Okogbue, C.O. 1997. The cone penetrometer and soil Characterization in the Deltas. *Journal of Mining and Geology.* 33(1): 15-24.

Adebisi, N.O. 2010. *Geotechnical properties of foundation soils in the Basement Complex terrain of Southwestern Nigeria*. Unpublished Ph.D. thesis, Department of Geology, University of Ibadan.

Adeyemi G.O. & Osammor, J. 2000. In-situ geotechnical investigation of soils in Southtern Nigeria. *Journal of Mining and Geology*. 37(1): 69-76.

America Society for Testing and Materials (ASTM). 1985. D-2487-92, Classification of soils for engineering purposes. *Annual book of ASTM Standards*. 0408: 395-408.

Avwenagha, E.O. Akpokodje E.G. & Tse, A.C. 2014. Geotechnical Properties of Subsurface Soils in Warri, Western Niger Delta, *Journal of Earth Sciences and Geotechnical Engineering*, Scienpress. 4(1): 89-102.

British Standard BS 5930, (USCS). 1981. Code of Practice for Site Investigation. *British Standard Institution*.

Mohammad A.M. 1993. Geotechnical conditions of the deltaic alluvial plains of Bangladesh and associated problems. *Engineering Geology* 36(1-2): 125-140.

Nwankwoala, H.O. & Oborie, E. 2014. Geo-technical investigation and characterization of sub-soils in Yenagoa, Bayelsa State, Central Niger Delta, Nigeria, Civil and Environmental Research, IISTE. 6(7): 75-83.

Obaje, N.G. 2009. *Geology and mineral resources of Nigeria*. Chapter 8. The Dahomey Basin.Vol. 120 of the series. Lecture notes in Earth Sciences. 103-108.

Okeke, C.O. & Okogbue, C.O. 2010. Distrbution and geotechnical properties of expansive soils in parts of Southern Nigeria. *Journal of Mining and Geology.* 26(1): 13-31.

Onyebuolise, B.C. & Akpokodje, E.G. 2008. Engineering Geological Properties of sub-soils of Yenagoa, Bayelsa State. *Scientia Africana*. **7**(2): 89-99.

Osammor, J. 2009. *Geotechnical characterization of foundation soils of the Delta area.* PhD Thesis, Department of Geology, University of Ibadan.

Teme, S.C. 2002. Geotechnical Consideration on Foundation design in the Niger Delta. *Paper presented at the special technical session, 39th Annual International Conference of the NMGS, PH, Nigeria*, 51p.

Tse, A.C. & Akpokodje, E.G. 2010. Subsurface soil profiles in site investigation for foundation purposes in parts of the Mangrove swamps of the Eastern Niger Delta. *Journal of Mining and Geology*. 46: 79-92.

Whiteman, A. 1982. *Nigeria, its petroleum geology resources.* Vol.2, Graham and Trotman Ltd., London.

Youdeowei, P.O. & Nwankwoala, H.O. 2011. Sub-soil characteristics of Sand deposits in some parts of Bayelsa State. *Journal of Soil Science and Environmental Management.* Vol.2 (2), pp. 34-38.