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Research article

DEPENDENCE OF SHEAR STRENGTH AND COMPRESSIBILITY OF TROPICAL LATERITIC SOILS ON CLAY CONTENT

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ABSTRACT

Laterites are used extensively as construction materials in Nigeria. Particle size distribution of the laterites from the sedimentary basin of Southern Nigeria show that laterites are composed of sands and clays. The dependence of the shear strength and compressibility on their clay content is investigated using field samples of sand and clay mixtures. The results show that the soils cohesion, plasticity index and compressibility index are directly proportional to the clay content, while the friction angle and initial void ratio are inversely proportional to the clay content at the same moisture content.

Keywords: Clay content; sand and clay mixtures; soils cohesion; plasticity index; compressibility index; friction angle; initial void ratio

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INTRODUCTION

According to Tomlinson (1976), Laterite is a ferruginous soil of clayey texture and which has a concretionary appearance. Other workers on laterites are Evans (1910), Woolnough (1927), Du Preez (1949), Maignien (1966), Pullan (1967), Goudie 1973, Adepagba et al (1974), Ola (1975, 1977), Alao (1983) and Otoko (2014). Although most engineering design methods have been developed on ideal soils such as pure sands or pure clays (Tembe et al, 2010), it is very difficult to classify laterites as pure sand or pure clay since it possesses both properties of sand and

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clay. Clay minerals influence soil behavior (Naser Al Shayea 2001). Also clay fraction is crucial in determining its geotechnical characteristic such as strength and compressibility. Mehmet and Gurkan (2007), Rozalina and Yanful (2012), Panagiotopontos et al (1997), Naser Al Shayea (2001), Yongsham and Kwong (2002), Mohammad et al (2011), Shanyong et al (2009), Lius and Roger (2000). Naser Al Shayea (2001) concluded that the soils cohesion is directly proportional to the clay content, while the friction angle is inversely proportional to the clay content. Shanyong et al supports the fact that the clay content influences the stress – strain behaviour of the soils. Kim et al (2005) indicates that apart from the cohesion, the plasticity index and the coefficient of secondary consolidation (creep) are also directly proportional to the clay content while the friction angle and permeability are inversely proportional to the clay content.

This paper presents an investigation to determine the dependence of shear strength and compressibility of tropical lateritic soils on clay content. This knowledge is fundamental in the interpretation of the properties of tropical laterites for engineering design, particularly as they are already being widely used as construction materials.

GEOMORPHOLOGY

The project area of about 36,270 km^2 in Southern Nigeria lies between latitudes $4^0 15'$ and $5^0 47'$N and between longitudes $5^0 22'$ and $7^0 37'$E in the Rivers State. It is low lying, flat and riddled with an intricate system of natural water channels through which the River Niger reaches the sea. The area rises from 2m along the coast to over 60m above sea level farther inland.

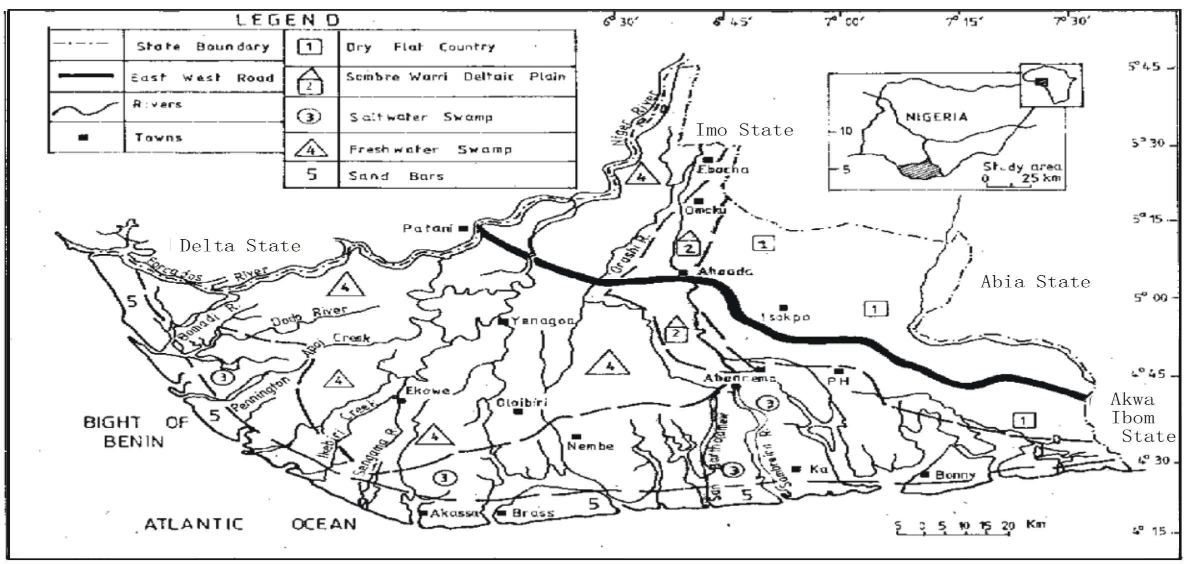


Figure 1: Map of study area (Rivers State) showing geomorphological zones

Five broad geomorphologic zones are recognized (fg.1) in the study area. These are:

1. A dry flat country (DFC), where laterites are abundant.
2. A relatively dry land with abundant swamp units also known as the Sombreiro-warri deltaic plane (SWP) with considerable amount of laterites.
3. A saltwater mangrove swamp area (SWS) with estuaries and creeks. The swamps are thickly vegetated and brackish to saltwater. The widest stretch of the zone occurs in the Port Harcourt – Abonnema axis and are bordered on the landward side by firm sedimentary deposits of the coastal plain Formation (Udo, 1970).

Within these swamps are found a number of fairly high grounds dry throughout the year. On these areas settlements like Abonnema, Buguma, and Tombia (Ofomata, 1975), Bille and Ke are built.

4. A zone of freshwater swamps and alluvial plains (FWS). This zone has high concentrations of silt and alluvium and is highly susceptible to annual inundation by river floods. Large tracts of swamps and many silted flats occur in several areas like Yenagoa, Ekowe, Kolo, and Oboburu.
5. Beaches and bars which are predominantly sandy. On these raised very recent sands are places like Brass, and Akassa.

GEOLOGY OF STUDY AREA

Geologically the study area lies within the Niger Delta; and is part of the Benin formation (Simpson, 1954).

The stratigraphy of the delta consists of three major units, the Akata, the Agbada and the Benin from base to top. The Benin Formation which is extensive in the southern Nigeria sedimentary basin has a variable thickness up to 1,400m (Onyeagocha, 1980). It is predominantly sandy with a few clay and shale intercalations. The sands and poorly cemented sandstones are generally coarse – grained, but commonly very loose and pebbly to fine – grained, with grains sub-angular to well rounded. This materials are believed to be deposited in a continental fluviatile to deltaic environment (Onyeagocha, 1980). Here, the Benin formation is overlain by the coastal plain sands towards the north, Deltaic plain Dunes, abandoned beach ridges, fresh and salt water swamps, meander belts, and alluvium in the south. These range in age from Oligocene to Holocene.

The Benin formation and materials overlying it are covered in places by considerable thicknesses of red earth called laterites composed of iron – stained regoliths (probably limonite and goethite); and these are the materials under study.

FIELD AND LABORATORY PROCEDURE

Undisturbed samples were taken from 12No. 60mx60m test pits with U4 samplers. Bulk samples were also taken. The moisture content of the undisturbed samples were determined in order to ensure that further tests on the samples were within the same natural moisture content range. Particle size distribution and consistency limits were determined on air dried bulk samples according to BS 1377 (1990) specifications.

Further tests on the undisturbed samples were the one dimensional consolidation test and the unconsolidated undrained triaxial compression tests, according to BS 1377 (1990) standard. Samples were selected based on their natural moisture content. In order that moisture content does not significantly affect the results, samples tested had moisture contents within ± 5% of the average natural moisture content. From the test result obtained, strength envelopes and consolidation curves were plotted for determination of the strength parameters (C,Ø) and consolidation parameters (C_c, e_o) respectively.

RESULT AND DISCUSSIONS

Table 1 shows the summary of field and laboratory results, while fig. 2 shows the particle size distribution curves, which indicate that the laterites tested are basically sandy soil with various amounts of clay. The percentage clay content is easily determined from the grading curves following the British classification system BS 1377 (1990). The cohesion and friction angles obtained from the strength envelopes of unconsolidated undrained triaxial compression tests are shown in table 1, while typical Mohr - Coulomb envelope for the soil, is shown in fig. 3. The compression index and final void ratio obtained from the consolidation curves are also show in table 1, while typical consolidation curve for the soil, is shown in fig. 4. Table 1 also shows values of natural moisture content (NMC), liquid limit (LL), plasticity index (PI), specific gravity (SG) and linear shrinkage (LS); and also shows the Cassagrande classification (CC) of all the samples.

Table 1: Laboratory Test Results

Sample	Clay Content (%)	NMC (%)	LL (%)	PI (%)	CC	SG	LS	C (KPa)	Ø°	C_c	e_o
A	31.7	10.1	39.5	26.5	CI	2.69	11.1	80	7	0.30	0.69
B	28.4	10.3	39.1	26.2	CI	2.70	10.8	78	8	0.27	0.71
C	26.3	10.4	38.7	25.4	CI	2.75	10.5	75	10	0.25	0.73
D	24.5	10.0	37.8	24.7	CI	2.78	10.2	70	12	0.22	0.74
E	22.1	9.9	36.6	23.3	CI	2.81	9.7	67	15	0.20	0.76
F	20.3	10.2	35.4	23.1	CI	2.84	10.1	63	15	0.19	0.77
G	18.2	10.1	34.9	22.7	CL	2.86	9.8	60	17	0.19	0.79
H	16.5	10.3	34.5	21.8	CL	2.89	10.0	55	20	0.18	0.80
I	15.1	10.2	33.8	19.4	CL	2.90	9.6	52	22	0.16	0.80
J	14.4	10.0	33.4	17.6	CL	2.91	9.5	48	21	0.15	0.81
K	10.6	10.4	32.9	14.2	CL	2.90	8.8	45	23	0.13	0.83
L	8.2	10.3	32.6	13.5	CL	2.92	9.0	42	25	0.12	0.84

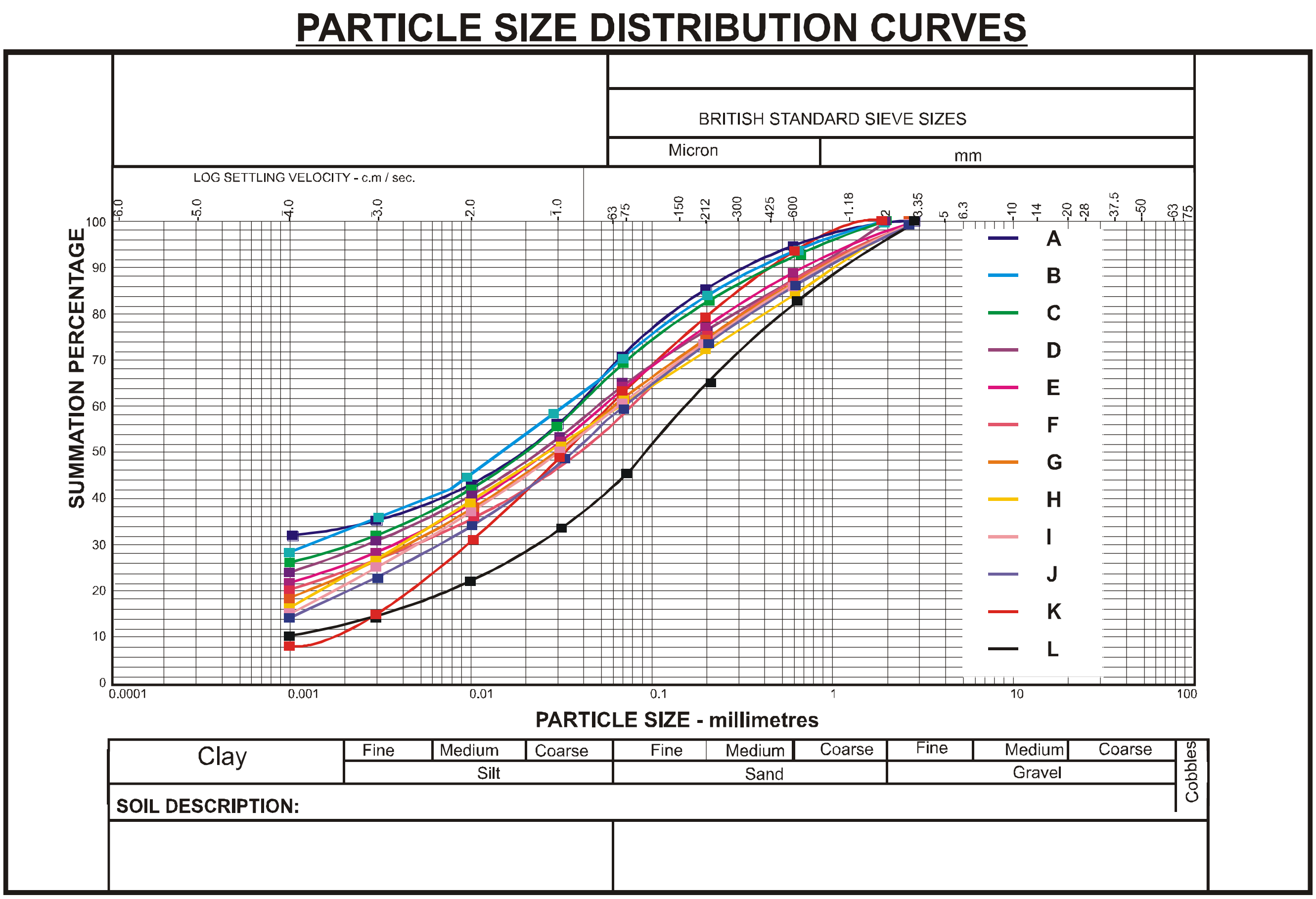
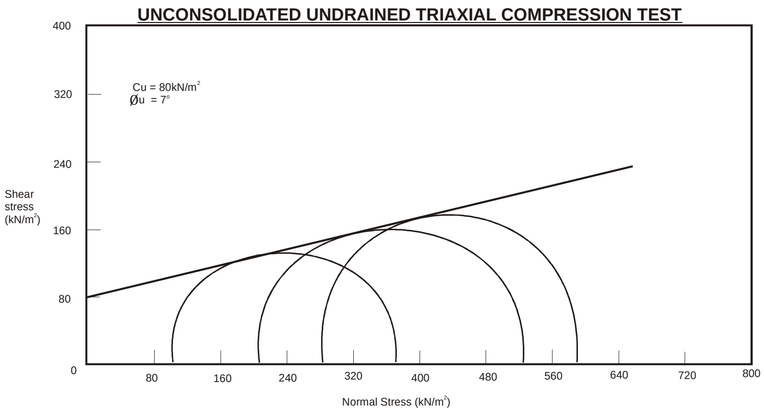


Figure 2: Particle Size Distribution Curves



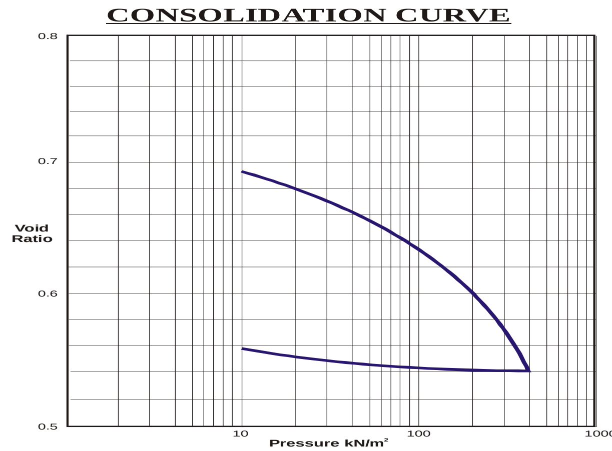
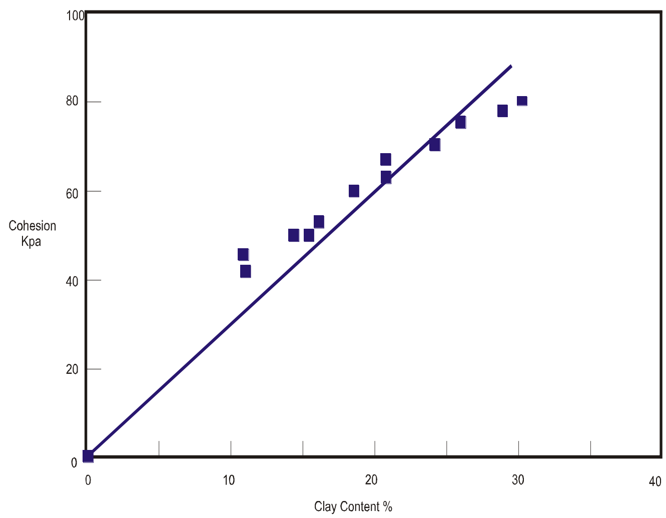


Figure 3: Mohr Circle of Stress

Figure 4: Consolidation curve

DEPENDENCE OF SHEAR STRENGTH ON CLAY CONTENT

It is well known that shear strength is a function of cohesion and friction angle. Therefore, to investigate the dependence of shear strength on clay content, the shear strength parameters (C and Ø) were plotted against the clay content.



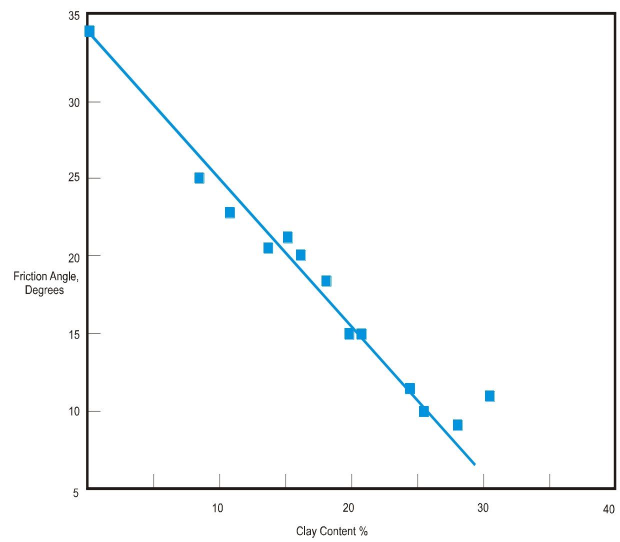


Figure 5: Variation of Clay Content with Cohesion

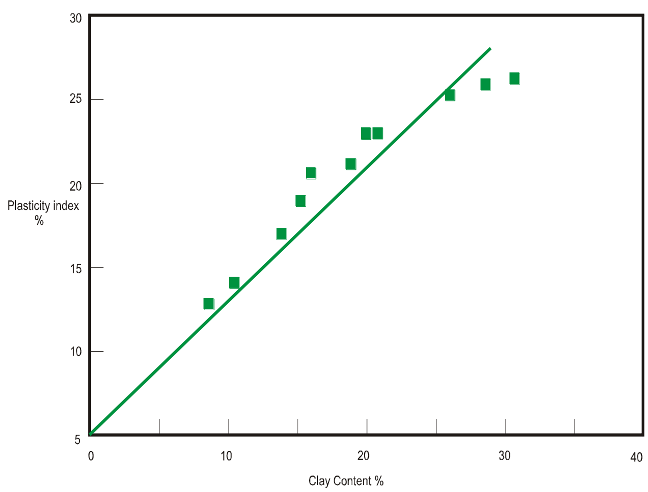
Figure 6: Variation of Clay Content with friction angle

The variation of clay content with cohesion is shown fig 5, indicating that the cohesion is directly proportional to the clay content, which confirms the work of shanyong et al (2009); while fig 6 shows the variation of clay content with friction angle indicating that the friction angle is inversely proportional to the clay content. Similar observations were reported by Al-Shayea (2001), Tiwari and Marui (2005) and Yin (1999). Shanyoug et al (2009) reason that at low clay content the clays reside in largely empty void spaces and have little effect on the entire soil behaviour, as the applied loads are carried by the sand skeleton.

DEPENDENCE OF COMPRESSIBILITY ON CLAY CONTENT

Pure sand does not pose any compressibility problem. The tropical deltaic laterites tested are sandy clays of low and intermediate plasticity. Compressibility is a function of the compressibility index, and a function of the void ratio. Therefore, plasticity index, compression index and void ratio were plotted against clay content in fig 7,8 and 9 respectively.

While fig 7 and fig 8 show that plasticity index and compression index are directly proportional to the clay content, respectively, fig 9 shows that the final void ratio is inversely proportional to the clay content.



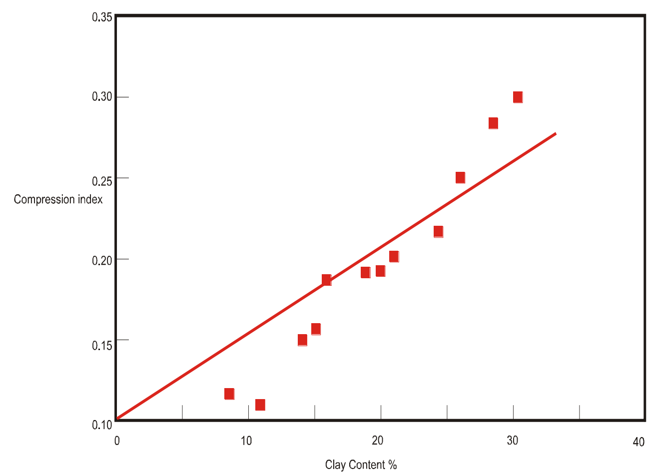


Figure 7: Variation of clay content with compression index

Figure 8: Variation of clay content with plasticity index

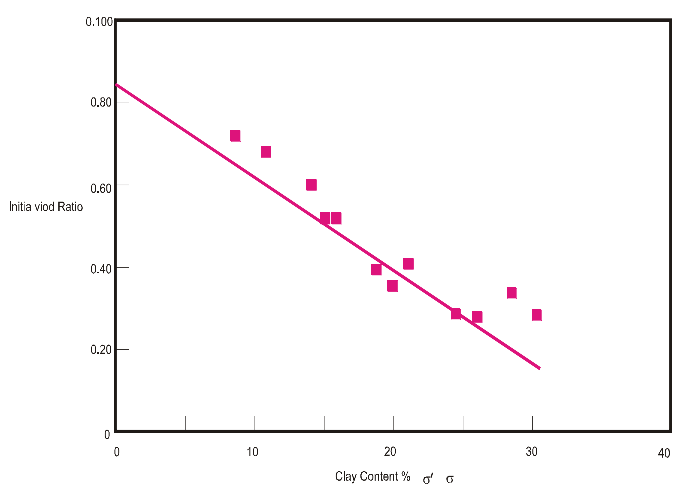


Figure 7: Variation of clay content with initial void ratio

As observed by Shanyoug et al (2009) and Rozalina and Yanful (2012), as the clay content increases the soil becomes more plastic, thus the plasticity index increases, its swelling and shrinkage potential increases also, and so does it's compressibility; while the permeability decreases as a result of the clay occupying the void spaces in the sand, and consolidation time increases.

Coarse soils exhibit very high void ratio while fine soils have very low void ratio. The inverse proportional relationship between final void ratio and clay content shown in fig 9, is because as more clay is added to sand, the sand/ clay mixture tend to behave like fine material, as established by Rozalina and Yatful (2012).

CONCLUSIONS

The following conclusions have been drawn from correlation obtained between the clay content, strength and compressibility with reference to the clay content of the natural soil in the study area.

1) The plasticity index is indirectly proportional to the clay content. This explains why the tropical lateritic soils with lower clay content are better construction materials than the more plastic clays in the riverine swamps of the Niger Delta of Nigeria with higher clay content.

2) Soil cohesion is directly proportional to the clay content, while the friction angle is inversely proportional to the clay content. Foundations on tropical deltaic laterites can comfortably be designed as C – Ø soils, instead of assuming them to be granular soils (Ø soils), which would be unsafe

3) Compressibility also has been shown to be directly proportional to the clay content. While well designed foundations would be stable on tropical laterites, design on the riverine deltaic peaty clays must be done with great caution due to the high clay content of the clays.

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