The Influence of Observed Clay Content on Shear Strength and Compressibility of Residual Sandy Soils

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ABSTRACT

The occurrence and distribution of soils in nature is such that, the various type of soil can be found together. Most of the engineering design methods and parameters of structures on soil have been developed for ideal soils such as pure sands or pure clays; the reality is that these ideal soils are rarely found in nature. In a sand-clay mixture, it is quite difficult to establish the characteristics of the soil since it possesses both the properties of sand and clay. Typical soils encountered in the Voltaian geological formation of Ghana is sand, however, particle size distribution of the Voltaian soils show that the sand occurs with other soil types especially clay. The influence of the clay portion of the soil on the strength and compressibility of the sandy soil has been investigated using field samples of sand and clay mixtures. It was established that, the soils cohesion increase with increasing clay content, the friction angle decreased with increasing clay content at the same moisture content. The compression index increases with the clay content and decreases with the initial void ratio. The plasticity index also increases with clay content.

I.INTRODUCTION

Even though the various constituents of soils (clay, silt, sand and gravel) have different physical and engineering properties when they occur alone, in most natural soils these constituents exist as an inhomogeneous mixture or as banded layers based on their formation processes. It has also been established by Tembe et al (2010) that, the engineering models required for design depend, among other things, on the particle size distribution of the soil in question. However, most of the engineering design methods and parameters have been developed for ideal soils such as pure sands or pure clays (Tembe et al, 2010). In a sand and clay mixture, it is very difficult to classify the soil into as sand or clay since it possesses both properties of sand and clay. It was established by Naser Al Shayea (2001) that clay minerals have a dominating influence on the behavior of the entire soil mass even if they are present only as small fractions of the soil. Also the level of clay fraction in a soil is crucial in determining its geotechnical characteristics such as strength and compressibility. Investigations into the influence of clay content on the engineering properties of sandy soils have been carried out by various researchers in the past using reconstituted sand and clay mixture, Mehmet and Ozden (2007), Rozalina and Yanful (2012), Panagiotoponlos et al (1997), Naser Al Shayea (2001), Shanyoug et al (2009), Mohammad et al (2011), Yongshan and James (2002), Lius and Roger (2000). Naser Al Shayea (2001) concluded that for a clay and sand mixture, the cohesion increases with increasing clay content while the friction angle decreases with increasing clay content. Shanyoug et al (2009) researched into the influence of clay content on the engineering properties of sand and stated that the clay content plays an important role on the mechanical response of soils, especially when the soils are subjected to loading. In general, by increasing clay content, the plasticity and the coefficient of secondary consolidation (creep) increase, while the friction angle and permeability decrease (Kim et al, 2005). Mehmet and Ozden (2007) stated that field observations show that granular soils may contain a considerable amount of clay and/or silt and these fines are expected to influence the engineering behavior of sandy soils.

This paper is based on investigation that were carried out to determine the influence of clay content on the strength and compressibility of sandy soils in the Voltaian formation of Ghana using the clay content in the naturally occurring soil. Field observations show that the predominant soil type of the Voltain formation is mainly sands, however, the sand occurs with different amounts of clay, silt and gravel. The clay is expected to influence the engineering behavior of the sand. Knowledge of the influence of clay content on strength and compressibility parameters of the Voltain sandy soils is fundamental in the interpretation of their properties for engineering design.

II. STUDY AREA

The area selected for the study is located in Brong Ahafo Region of Ghana, about 5km from Atebubu on the Atebubu to Bassa road and lies within the Voltaian Formation. Figure 1 shows a geological map of Ghana indicating the location of the study area. Typical soils found in the Voltaian are residual soils derived from the weathering of the underlying sedimentary rocks. The Voltaian has areas of uniform lithology with interbedding of different lithological units being a common geological feature of the basin (G.O. Kesse, 1985). Major soil types in the area are sand but due to the lithological interbedding the sandy soils occurs with other soil types. The area consists of gently dipping or flat bedded sedimentary rocks that are easily eroded. The result is an almost flat and extensive plain which is between 60m and 150m above sea level towards the south and 180m above sea level towards the north (Dickson and Benneh, 1988). The area falls within the Tropical continental or interior savanna climatic zone. This climate is a modified form of the tropical continental or of the wet-equatorial. The mean annual rainfall is 115 - 125cm and occurs in two seasons from May to June and September to October. The mean monthly temperatures are low, ranging from about 30˚C in March to about 24˚C in August. Relative humidity varies from 90 to 95% in the rainy seasons to 75 to 80% in the dry seasons (Dickson and Benneh, 1988).

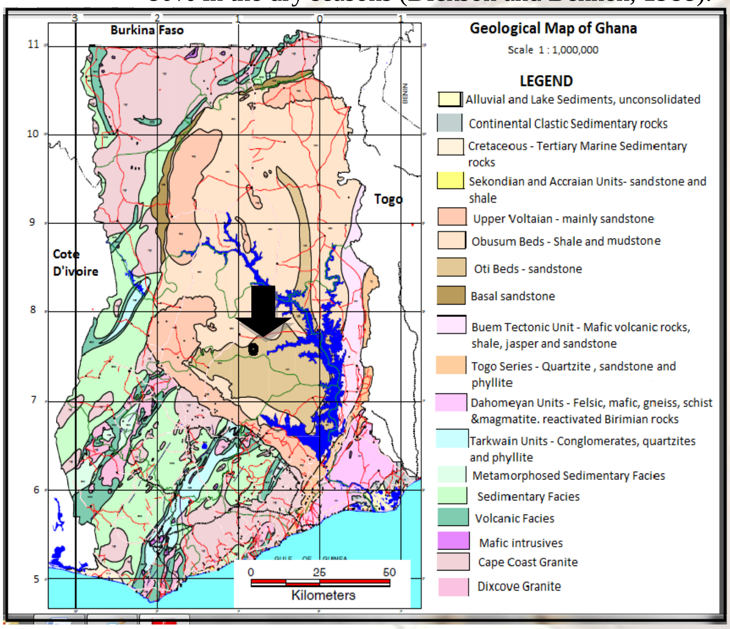

Fig. 1: Geological Map of Ghana showing the Study Area.

III. MATERIALS AND METHODS

The soil samples used for the research were obtained from the study area by excavating test pits at a grid of 50m x 50m. In all 10 test pits were excavated and U100 samples, often called ‘undisturbed’ samples were taken from the more cohesive horizons of each test pit. Small bulk samples were also taken from the same horizon within the test pits.

The U100 samples were extruded and the moisture contents determined so as to ensure that samples selected for further testing were within the same natural moisture content range. Bulk samples were air dried and used to determine the particle size distribution and consistency limits of the soil according to BS 1377 (1990) specifications.

The undisturbed samples were used to determine the strength and compressibility of the soils by conducting the unconsolidated undrained triaxial and one-dimensional consolidation test according to BS 1377(1990) standard. For the triaxial and consolidation tests, samples were selected based on their natural moisture content. All samples tested had moisture contents that were within ±5% of the average natural moisture contents of the samples to ensure that the moisture content does not affect the results significantly. From the test results, Mohr circles of stress were plotted to determine the values of cohesion (C) and the frictional angle (Ø) while the consolidation curves were plotted to determine values of compression index (C_c) and the initial void ratio (e_o).

IV. RESULTS AND DISCUSSIONS

Summary of the laboratory tests results are presented in Table 1 and particle size distribution curves are shown in Figure 2. The curves show that the tested samples were mainly sandy soil with various amounts of clay. The percentage clay in each sample was determined from the grading curves using the British Classification System (BS 5930). Figures 3 and 4 also show typical Mohr circles of stress plotted from unconsolidated undrained test on sample and typical consolidation curve for the same sample. Similar curves plotted for all the samples were used to extrapolate the results in columns 5 to 8 of Table 1. The Plasticity Index (PI) was calculated from the relationship PI = PL – LL where PL is the plastic limit and LL is the liquid limit of the samples obtained from the Atterberg Limits tests.

Table 1: Laboratory Test Results

Sample	**Clay Content (%)**	**NMC (%)**	**PI (%)**	**C (KPa)**	**Ø°**	**C_c**	**e_o**
A	6.8	10.2	12.1	40	28	0.05	0.42
B	7.0	10.0	13.2	66	25	0.05	0.4
C	16.9	9.9	16.7	120	24	1.0	0.38
D	22.3	10.3	18.2	140	20.2	0.12	0.35
E	24.1	10.1	20.3	142	20	0.12	0.34
F	27.0	10.0	22.1	150	17.5	0.12	0.20
G	27.5	10.4	23.2	155	15	0.2	0.19
H	29	10.3	25.0	163	15	0.18	0.15
I	30	10.0	26.6	163	12.6	0.18	0.1
J	31.2	10.2	26.6	165	12.6	0.19	0.1

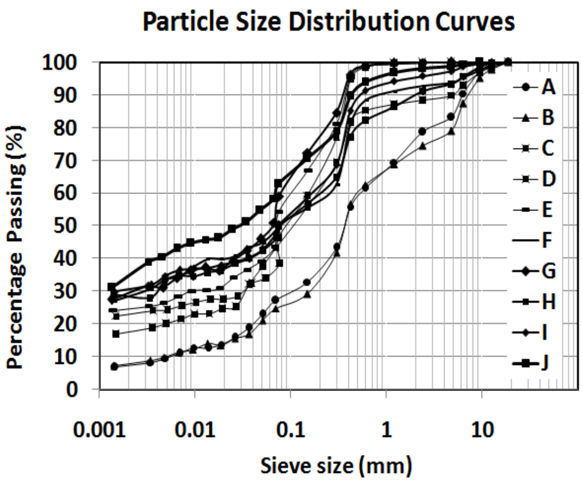

Fig. 2: Particle Size Distribution Curves

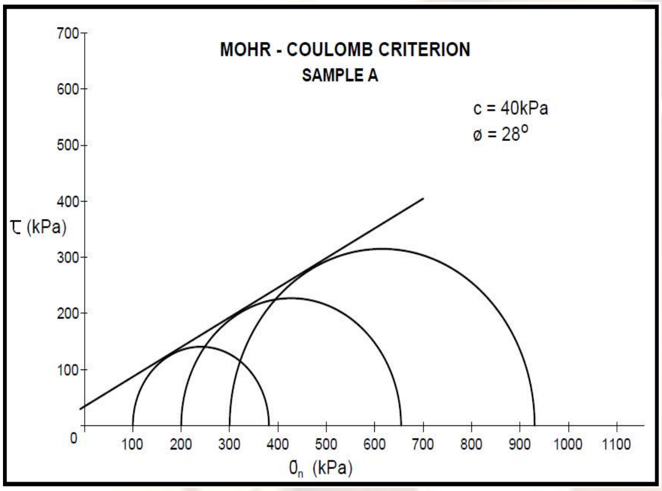

Fig. 3: Mohr Circle of Stress

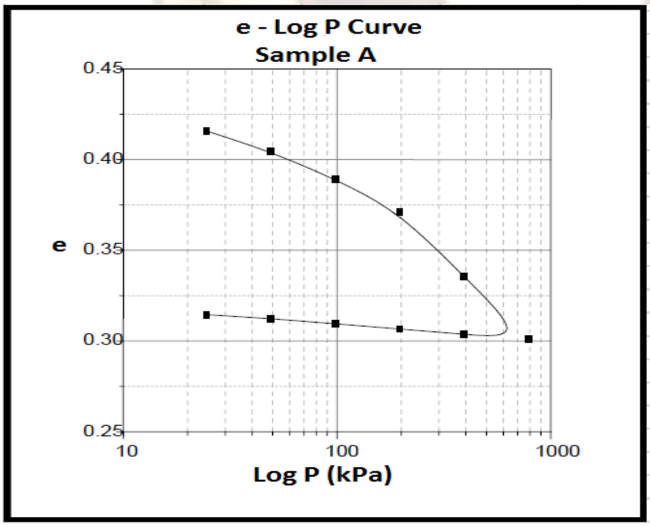

Fig. 4: Consolidation Curve

Clay Content and Shear Strength

The two main parameters that control shear strength of soils are the cohesion and the friction angle. For a sandy soil, the friction angle is expected to be higher than its cohesion and vice versa for clayey soil. In order to establish the relationship between the clay content and the shear strength of the sandy soils, the shear strength parameters (C and Φ) were plotted against the clay content and the graphs were used to determine the correlation between the two parameters.

Figure 5 shows a graph of the clay content and the cohesion, the cohesion increases with increasing clay content. This confirms the laboratory investigations undertaken by Shanyoug et al (2009) which concluded that there is a general increase in cohesion with clay content. As more clay is introduced into the sandy materials, the clay particles fill the void spaces in between the sand particles and begin to induce the sand with interlocking behavior. This explains why clayey sand soils which are expected to exhibit low cohesion have high cohesion values when the clay content increases.

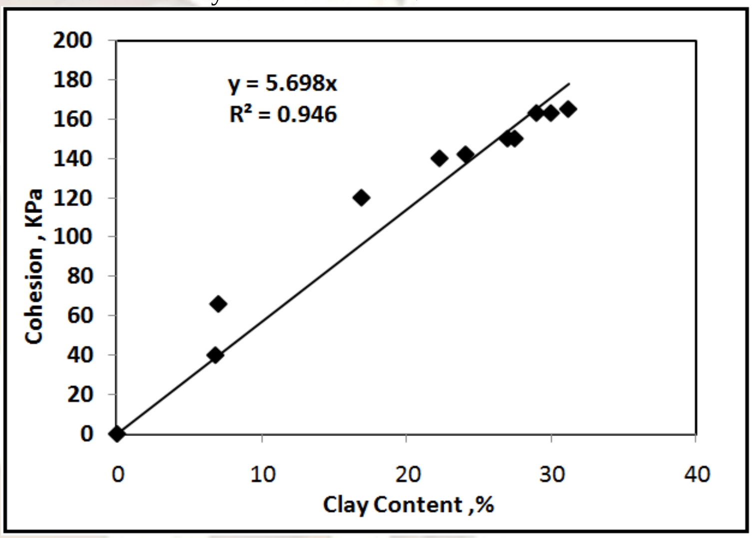

Fig. 5: Variation of Clay Content with Cohesion C

A graph of clay content and friction angle is presented in Figure 6. The graph indicates an inverse relation between the two parameters, the friction angle decrease with increasing clay content in the samples. Similar observations of decreasing friction angle of sandy soils with increasing clay content were reported by Al-Shayea (2001), Tiwari and Marui (2005) and Yin (1999). Shanyoug et al (2009) explain that, at low amounts of fines, most of the fines are occupying the voids between the sand grains. Since the applied loads are carried by the sand skeleton, these fines have little effect on the behavior of the mixtures, as they are just residing in largely empty void spaces.

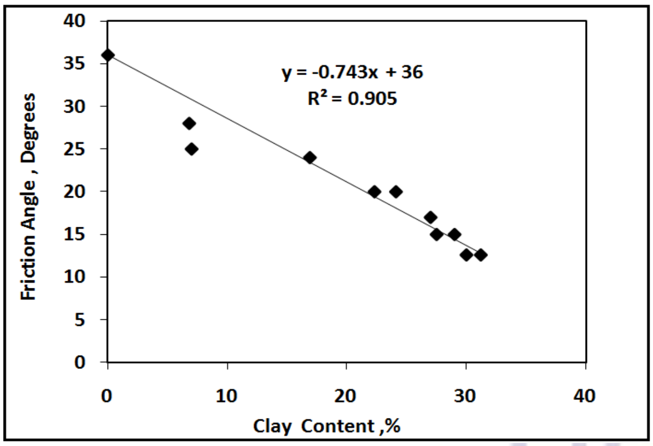

Fig. 6: Variation of Clay Content with Friction Angle

Clay Content and Compressibility Parameters

Generally, granular soils such as sand do not exhibit any compressibility characteristics when subjected to loads, however, when it contains clay minerals, it exhibit some amount of compressibility which can impact on its engineering applications. Compression index is a measure of the settlement that will occur due to a structure placed on the soil. Void ratio is a measure of the volume of voids over volume of solids. These two parameters including the plasticity index were used to establish the influence of clay content on the compressibility of sand. A graph of clay fraction against the Plasticity Index (PI) is presented in Figure 7; the graph shows a linear correlation between the two parameters. The PI increases with increasing clay content. This is due to the fact that plasticity is offered only by the clay fraction with the sand acting as inert filler that does not have any physio-chemical interaction with the clay to affect its plasticity. This phenomenon was also observed by other researchers (Naser Al Shayea, 2001).

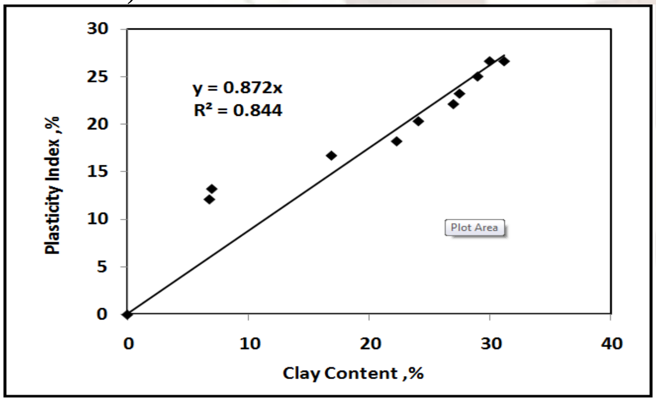

Fig. 7: Variation of Plasticity Index with Clay Content

Figure 8 presents a graph of clay content against the compression index, there is a high correlation between the two parameters, increasing clay content, increases the volume change of the sample when subjected to increasing loads. It was established by Shanyoug et al (2009) and Rozalina and Yanful (2012) that as the clay content increases, the soil becomes more plastic, its swelling and shrinkage potential increases and so does it's compressibility. As the clay content increases, it occupies the void spaces in the sand therefore reducing the permeability; the soil takes longer period to consolidate.

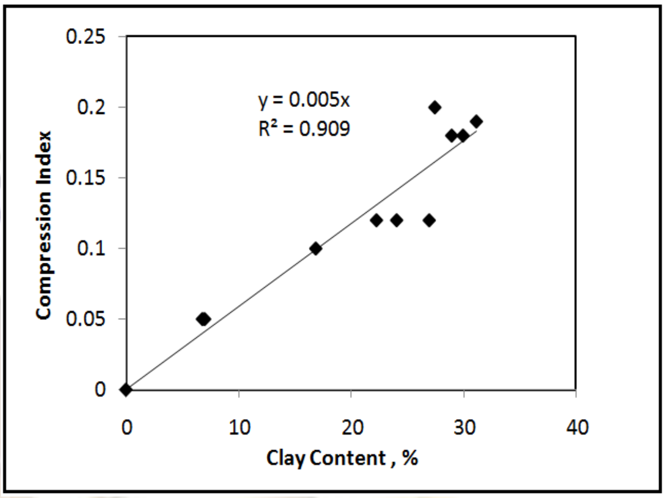

Fig. 8: Variation of Clay Content with Compression Index.

Graph of clay content against initial void ratio is presented on Figure 9; the graph indicates an inverse relationship between the two parameters. Coarse soils exhibit very high void ratio and fine soils have very low void ratio. As the proportion of clay in sand and clay mixture is increased, the mixture begins to behave like a fine material. This relationship between the void ratio and the clay content was established by Rozalina and Yanful (2012). Shanyoug et al (2009) stated that in the consolidation process, the sand and clay mixture is subjected to vertical pressure, the soil particles re-arranged to form a new packing which leads to a reduction in the void spaces between the particles.

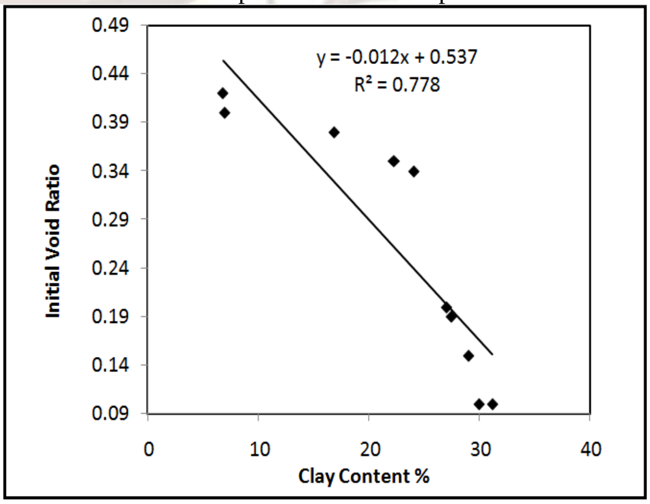

Fig. 9: Variation of Clay Content with Initial Void Ratio

V. CONCLUSIONS

Engineering Implications of the Study

The correlation coefficient from graphs indicates a strong correlation between the clay content and the strength and compressibility parameters. The influence depends on the amount of the clay in the sandy soil. Based on this current study using the clay content as observed in natural samples in the study area, the following conclusions have been drawn.

1. The plasticity index of the soils increase linearly with the amount of clay occurring in the soil. For areas with high clay content the soil becomes highly plastic that can sometimes lead to problems in foundation construction resulting in higher costs.
2. Clay content also increases the cohesion and decreases the friction angle. For such cases, the foundations can be designed as C – Ø soils using the appropriate bearing capacity equations. Assumptions that, the Voltaian soils are mostly sands and foundations designed as granular soils (Ø soils) can lead to catastrophic failures.
3. The compressibility also increases with clay content and different percentage of clay within a site should be analysed to ensure that appropriate designs are done to cater for differential settlements due to the varying clay content.

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