COMPACTION AND CONSOLIDATION CHARACTERISTICS OF A-7-6 SOIL

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ABSTRACT

This study presents an investigation of the compaction and consolidation characteristics of black clay soil, which belongs to A – 7 – 6 soil class. The soil samples were collected at 0.5, 1.0, 1.5 and 2.0 metres from selected active pits of clay deposits in Bako, a village in Gwagwalada Area Council of the Federal Capital Territory, Abuja, Nigeria. Compaction and consolidation characteristics of collected samples under axial and compressive loads were investigated. Maximum dry density and optimum moisture content as well as recompression/compression index were calculated from the compaction and consolidation results respectively. The values of compaction and consolidation characteristics from the experimental results were then compared with those obtained using different empirical correlations from literature. The Liquid limit for samples passing through sieve No 200 (0.075 mm) ranged 64.29 to 81.67 % while plasticity index is 34.29 %. The compression index (*Cc*) values vary slightly with the applied compaction energy levels. The modified energy level recorded the highest *Cc* of 0.2989 which reduces to 0.2823 at the Standard proctor compaction energy level. The West Africa energy level gave a value of 0.227. The lowest value of 0.1531 was obtained for the Reduced standard proctor compaction energy level. The soils recompression index (*Cr*) varies from 0.0529 at the Standard proctor compaction energy level to 0.0229 at the Reduced Standard proctor energy level while its value was maintained at 0.0059 for both the West Africa and Modified energy levels.

Keywords: *Compression Index (C_c), Maximum Dry Density (MDD), Optimum Moisture Content (OMC).Recompression Index (C_r)*

1.0 INTRODUCTION

According to AASHTO method of soil classification, the soil samples obtained from selected pits in Bako, Gwagwalada area of the Federal Capital Territory, Abuja Nigeria was classified as A-7-6, dark grayish coloured clay, using the established results of Atterberg limit test conducted in the Geotechnics department of the Federal University of Technology Minna, Nigeria. In Nigeria, this soil is predominantly found in the North-Eastern part along the Lake Chad basin and partly within the Benue trough (Ola, 1981; NBBRRI, 1983; Osinubi *et al.*, 2009).

This clay type of soil is giving hazardous Problems to engineers. With rapid development in Soil improvement, construction technique and social needs, various constructions of structure are taking place. The possibility of good construction sites to build structures on clay soil is difficult due to its poor strength and deformation characteristics (Fulzele *et al*., 2016). This study discussed clay soil, an **A-7-6** soil by classification, and its compaction and consolidation characteristics.

The compaction and or densification occur as a direct result of the mechanical loading, and are essentially complete at the end of the loading. Volume changes are incurred as a result of reduction in the quantity of air voids; water content remaining constant. Since it is impractical to squeeze out all the air, the as-compacted condition is a partly saturated one.

While compaction is densification, the achievement of high unit weight is not the direct objective. Rather, the intent is to produce a soil structure which will exhibit and retain a requisite level of integrity throughout its designed service life. The properties which must be imparted to the soil vary with the study, but such descriptors as strength, compressibility, and flexibility are commonly involved and this discussion focuses primarily upon the behavior and or characteristics of compacted **A-7-6** soil and its corresponding consolidation characteristics (Altschaeffl *et al.*, 1983).

Consolidation on the other hand is the process that involves a decrease in volume by the expulsion of pore water under long term static loads from a saturated soil without replacement of the pore water by air. This is the process that involves a gradual compression occurring simultaneously with a flow of water out of the soil mass with the gradual transfer of applied pressure from the pore water to the soil mineral skeleton. When a saturated clay-water system is subjected to an external pressure, the pressure applied is initially taken by the water in the pores resulting thereby in an excess pore water pressure. If drainage is permitted, the resulting hydraulic gradients initiate a flow of water out of the clay mass resulting in the compression of the mass thereby transferring a portion of the applied stress to the soil skeleton which in turn causes a reduction in the excess pore pressure. The water that is dissipated in a soil sample when load is applied is called free water (Murthy, 2009).

Casagrande was the first to develop a graphical method of determining the preconsolidation pressure of a clay deposit using a semi-logarithmic graph to evaluate its void ratio and effective stress. The graph consists of a recompression curve with its slope referred as recompression index C_r, and a virgin compression curve whose slope is also known as the compression index C_c. These indices are very essential in the evaluation of the magnitude of consolidation settlement (Casagrande, 1936).

The primary settlement of the clay stratum was determined using equation 1.2.

$$C_c = \frac{\Delta e}{\Delta \log \sigma'} \quad (1.1)$$

Where C_c is the compression index, Δe is the change in void ratio, $\Delta\sigma'$ is the change in effective stress.

$$S = \frac{CcHo}{1+e0} Log \frac{Po+\Delta p}{Po} \quad (1.2)$$

Where S is consolidation settlement, Cc is the compression index, H_0 is clay layer thickness, e_o is the initial void ratio, P_0 is the average effective pressure before the application of new load, Δp is the average pressure increase on the clay layer due to the application of new load.

If the soil has been previously loaded in the past by episodes such as a glacier, embankment, and structure, the C_c term is replaced with the recompression index (C_r) term to compute the anticipated settlement up to the estimated preconsolidation pressure. The C_r and C_c values as obtained from the consolidation test (ASTM D2435) and the void ratio is plot against the introduced pressure in increments on the clay soil sample using logarithmic scale. Figure 1 shows a typical consolidation curve with the various portions of the curve described. The C_r of the consolidation curve is the reloading curve portion while C_c is the virgin portion of the consolidation curve.

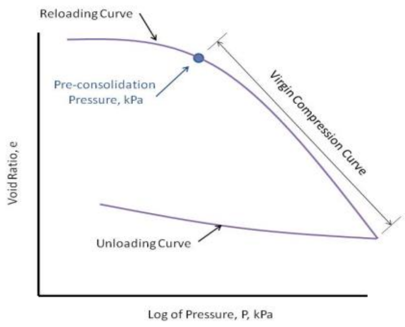

Figure 1.0: Typical consolidation curve (ASTM D2435: 2003).

2.0 METHODOLOGY

2.1 Compaction Characteristics of A-7-6 Soil

Five different compaction energy level tests were conducted on the air dried and pulverized disturbed samples collected at depths 0.5 m to 1.9 m from selected pits in Bako, Gwagwalada area of Abuja in the geotechnics laboratory of the federal university of technology Minna according to part1 of BS 1377 (1990), to determine the optimum moisture content(OMC) and Maximum Dry Density (MDD) determined are represented in figure 2.1 using five different compaction energy levels. The Reduced Standard Proctor Compaction energy level (Daniel and Benson, 1990) which involved the use of 2.5 kg rammer falling through 300 mm height with 15 blows and 3 different layers in a 944 m^3 compaction mould, Standard Proctor energy level (Proctor, 1993) involves the use of 2.5 kg rammer falling through 300 mm height, 25 blows, 3 layers in a 944 m^3 mould, West African Standard compaction energy level (Nigeria General Specification for Road and Bridge Works, 1992) employs the use of 4.5 kg rammer with falling height of 300 mm and 10 blows on each of 5 layers in a 944 m^3 mould, Reduced Modified Standard energy level involved the use of 2.5 kg rammer falling through 300 mm with 10 blows, 5 layers in a 944 m^3 mould and the Modified Compaction energy level that employs the use of 4.5 kg rammer falling through 300 mm height with 25 blows, 5 layers in a 944 m^3 mould.

This research work made use of both the light and heavy compaction procedures so as to obtain a wide range of MDDs and OMCs in order to achieve the aim of this study. The procedures were performed according to part1 of BS 1337:1990. In the light method (2.5 kg rammer method), different amounts of water were added to dry samples in order to cover the required range of water content. The range should provide at least two values either side of the optimum moisture content as described in BS 1377 (1997). The sample was thoroughly mixed and the mixture allowed equilibrating for 24 hours in a sealed container. After equilibration, the sample was placed in a mould in three layers with 10, 15 and 25 blows for the reduced modified, reduced and standard proctor compaction energy levels respectively being applied to each layer from a controlled drop height of 300 mm. The sample was extruded, the top side leveled off and the dimensions and moisture content measured in order to compute the dry density at each moisture content.

In the heavy compaction test (4.5 kg rammer method), the preparation of samples was similar to that of the light method but the compaction is done in five layers, and again 10 and 25 blows, for the West African and Modified standard compaction energy levels respectively, applied per layer from a controlled drop height of 450 mm. In this method the total compactive energy applied is 4.5 times greater than the light procedure. In both methods, each dry density was plotted against the corresponding moisture content and a smooth curve drawn through the points in order to compute the optimum water content (OMC) and maximum dry density (MDD). The dry density (ρ_d in Mg/m^3) corresponding to a certain moisture content (w in %) can be calculated from equation 2.1.

$$\rho_d = \left[\frac{100}{(100+w)}\right] \rho \qquad (2.1)$$

Where ρ is the bulk density of each compacted specimen.

2.2 Consolidation Characteristics of A-7-6 Soil

Consolidation tests were carried out using Wykeham Farrance WF24001 One Dimensional Oedometer apparatus for investigating the consolidation characteristics of the A-7-6 (black cotton) soil in accordance with BS 1377 (1990).

After compaction, using the required energy level and its corresponding Optimum Moisture Content (OMC) established from the various compaction energy levels, the sample was placed in the oedometer apparatus with a transparent cell that encased the consolidation mould of 20 mm and 50mm height and diameter respectively. The mould was then covered with a double drainage porous stone which was always lubricated after each consolidation test to prevent friction. The loading beam and hanger was checked to be balanced without weights. The oedometer cell was then filled with water to ensure that the sample remains fully saturated for tests on fully saturated samples (reconstituted samples). In the case of partly saturated samples (intact samples) the water was added at a specified loading level in order to observe swelling and collapse potentials. Each loading increment was maintained for 24 hours and loads were doubled each day. Seven different loadings were applied for seven consecutive days before unloading for a further 24 hours at the eight day. Readings of time and displacement were recorded during each loading stage of the test according to BS 1377 (1990), this is to obtain required consolidation parameters used in the evaluation of consolidation.

3.0 RESULTS AND DISCUSSION

3.1 PHYSICAL PROPERTIES

Table 3.1: Physical Properties of Clay Soil

Serial No	**Properties**	**Values**
1	Liquid Limit (LL) %	(40-120) %
2	Plastic Limit (PL) %	(20 - 60) %
3	Specific Gravity (G)	2.60 - 2.75
4	Fine (<75)	(70 - 100) %
5	Soil Classification IS 1498-1970	CH or MH Clay/Silt of high plasticity

Study of structures in black cotton soil (Fulzele *et al*., 2016)

Table 3.2: Physical Properties of Study Sample

Serial No	**Properties**	**Values**
1	Liquid Limit (LL) %	64.29 %
2	Plastic Limit (PL) %	34.29 %
3	Specific Gravity (G)	2.60
4	Fine (<75)	81.67 %
5	Soil Classification IS 1498-1970	CH of high plasticity

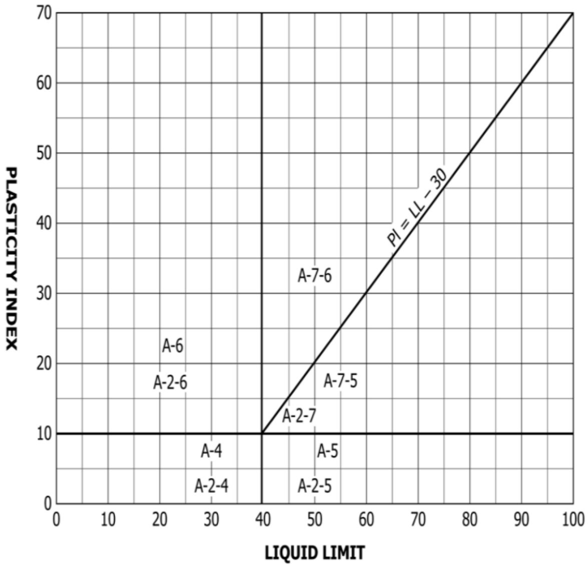

Figure 3.0: Liquid Limit and Plasticity Index flanges for Silt-Clay materials (AASHTO)

The study sample has a Liquid Limit of 64.29 % and Plasticity Index of 34.29 %, using the chart in figure 3, this soil is established to be an A-7-6 clay soil.

3.2 COMPACTION CHARACTERISTICS

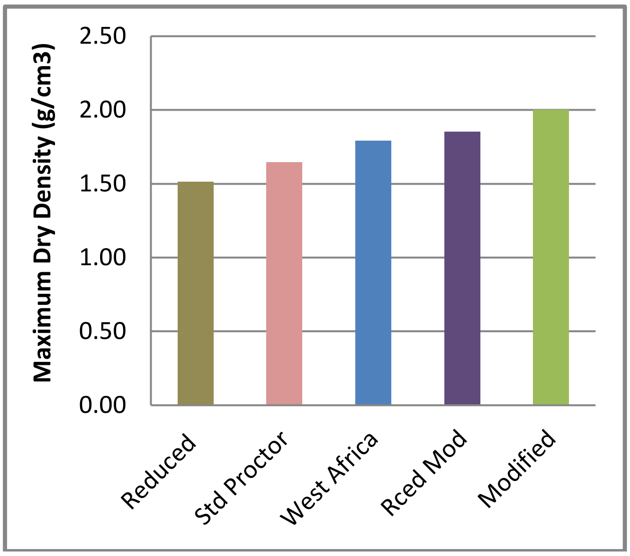

Figure 3.1: Variation in MDD relative to various Compaction Energy Levels

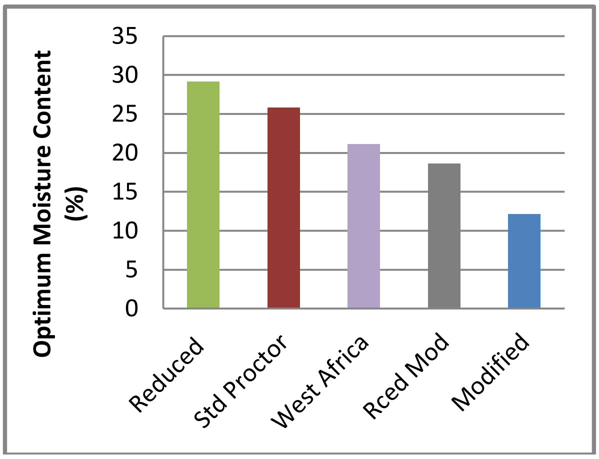

Figure 3.2: Variation in OMC relative to various Compaction Energy Levels

The Maximum Dry Densities (MDDs) and Optimum Moisture Contents (OMCs) obtained from the five different compaction energy levels are as summarized in table 3.1 and shown in figures 3.1 and 3.2 respectively.

Table 3.1: Compaction Characteristics of A-7-6 Soil from Bako, Gwagwalada Abuja

EL	Rcd	Std	W/A	RM	Mod	Rm
MDD (g/cm^3)	1.51	1.65	1.79	1.85	1.99	1.35 - 1.60
OMC (%)	29.2	25.8	21.1	18.6	12.1	20-35

The compaction test results are in consonant with the findings of Lambe (1958), Daniel and Xu (1993), Daniel and Benson (1990), Lare *et al.*, (2014), Sigh et al., and Mada *et al.*, (2013) as the trend indicates that there is an increase in the dry densities from its lowest value at 1.5116 g/cm^3 using the reduced energy level to its highest value at 1.9997 g/cm^3 using the modified compaction energy level as in table 3.1. The MDD values are in reverse order of the optimum moisture content of the test sample as it decreases in value from 29.14 % using the reduced energy level to its minimum value of 12.09 % in the modified energy level.

3.2 CONSOLIDATION CHARACTERISTICS

The various recompression (C_r) and compression (C_c) index results of the consolidation tests conducted on the clay soil sample using four different compaction energy levels are as shown in figures 3.3 and 3.4 respectively. Anaylysis of these results indicates that the West Africa and Modified energy levels have the lowest recompression index of 0.0059 each whereas the highest recompression index was observed to be 0.0529 in the Standard Proctor energy level while the Reduced energy level have an intermediate recompression index of 0.0229. The compression index inturn was observed to increase from 0.1531 at Reduced energy level to 0.2271 at West Africa energy level after which the value decreases from 0.2989 at Modified energy level to 0.2823 at Standard Proctor energy level.

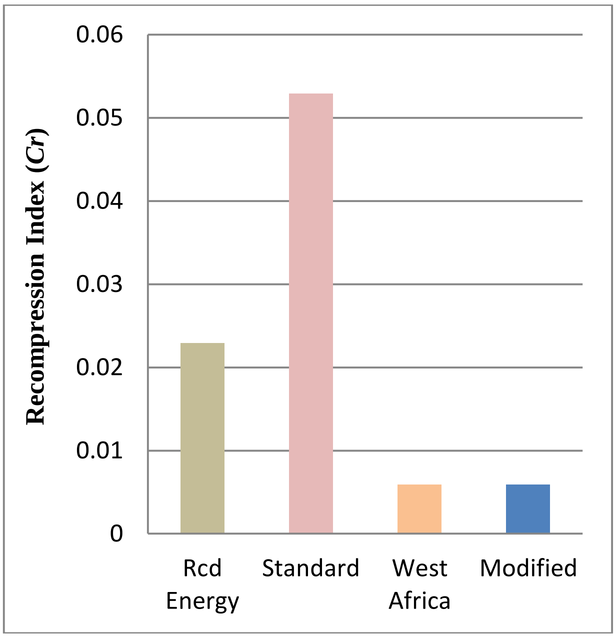

Figure 3.3: Recompression Index (C_r) with different compaction energy levels

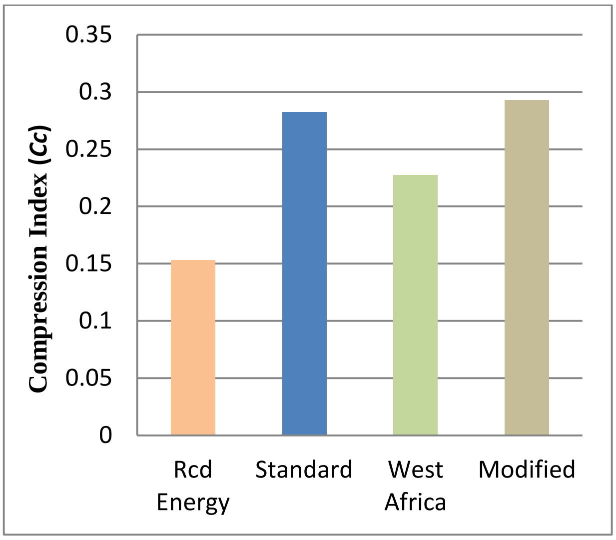

Figure 3.4: Compression Index (C_c) with different compaction energy levels

The varying C_r and C_c values can be attributed to the water absorptive tendencies of the clay soil under 24 hours sustained loading, compaction efforts, saturation and rate/channel of dissipation of water during consolidation before the addiction of further loads.

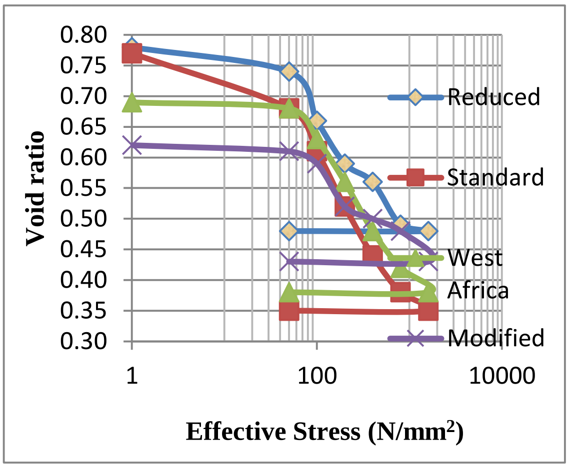

Figure 3.5: Relationship between void ratio and effective stress with varying compaction energy levels

Inferred also from the varying consolidation characteristics (C_r and C_c) with respect to different energy levels are the possibilities of the effects of the various Maximum Dry Densities and Optimum Moisture Contents associated with respective energy levels.

4.0 CONCLUSION

1. The soil sample from selected pits in Bako, Gwagwalada was classified using AASHTO soil classification system as A-7-6 clay soil.
2. The values of Maximum Dry Densities (MDD) for the soil increases from 1.5116 g/cm^3 at the Reduced Standard proctor energy level to its highest value of 1.999 g/cm^3 at the Modified energy level
3. The Optimum Moisture Content (OMC) behaves differently in the reverse order of the MDD as it decreases from 29.14 % at the Reduced energy level to its lowest value of 12.09 % at the Modified energy level
4. The soils recompression index (C_r) varies from 0.0529 at the standard proctor compaction energy level to 0.0229 at the Reduced Standard proctor energy level while its value is maintained at 0.0059 for both the West Africa and Modified energy levels.
5. The compression index (Cc) values vary slightly with the applied compaction energy levels. The modified energy level recorded the highest Cc of 0.2989 which reduces to 0.2823 at the Standard proctor compaction energy level. The West Africa energy level gave a value of 0.227. The lowest value of 0.1531 was obtained for the Reduced standard proctor compaction energy level.

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