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BONE ASH INFLUENCE ON SOIL CONSOLIDATION

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Abstract: Research work on the utilization of bone ash as soil stabilizer revealed that the ash has positive effect on soil strength but no report on it influence on soil settlement. In order for a material to act as stabilizer, its impact on soil settlement characteristics must be investigated. Hence, this research investigated the influence of bone ash stabilizer on the settlement characteristics of soil. Two soil samples were collected from two locations within Ibadan metropolis Nigeria. Bone ash was prepared from calcination of cattle bones at a temperature of 1100°C in electric furnace. After grinding, the ash was added to the collected soil samples in varying proportions by dry weight (3%, 5%, 7%, 10%, 15% and 20%) in order to determine the compressibility behaviour of the soil at different proportions of bone ash. The settlement characteristics investigated were compression index, coefficient of consolidation, pre-consolidation pressure, coefficient of area and volume compressibility and initial void ratio of both control soils and twenty four stabilized soil samples. The result revealed that Soils A and B coefficient of volume and area compressibility, and compressibility index reached their lowest level at 7 and 10% stabilization which is good for engineering. The soils pre-consolidation pressure and coefficient of consolidation reached peak values at 7 and 10% bone ash stabilization. Therefore, addition of about 7 to 10% of bone ash to the soils will reduce their settlement potential and increase their stability.

Keywords: *Consolidation, bone ash, stabilization, Soils, Settlement characteristics*

1.0 Introduction

Soil stabilization involves the use of stabilizing agents (binder materials) to improve its geotechnical properties such as compressibility, strength, permeability and settlement characteristics. The components of stabilization technology include soils and or soil minerals and stabilizing agent or binders (cementitious materials). There are many methods available through which soil at any site could be improved. Soil improvement is frequently termed soil stabilization, which in its broadest sense is alteration of any property of a soil to improve its inherent engineering performance. Soil improvement increases shear strength, reduces permeability, and reduces compressibility (Murthy, 2005). The commonly used soil stabilizers or binders are cement, lime, fly ash and blast furnace slag. Cement is the oldest binding agent since the invention of soil stabilization technology in 1960's. It may be considered as primary stabilizing agent or hydraulic binder because it can be used alone to bring about the stabilizing action required (Sherwood, 1993 & EuroSoilStab, 2002). Lime stabilization may be referred to pozzolanic reaction in which pozzolanic materials react with lime in presence of water to produce cementitious compounds (Sherwood, 1993 & EuroSoilStab, 2002). The effect can be brought by using either quicklime (CaO) or hydrated lime ($Ca(OH)_2$). Slurry lime also can be used in dry soils conditions where water may be required to achieve effective compaction (Hicks, 2002).

Rice husk is an agricultural waste obtained from milling of rice. About 108 tons of rice husks are generated annually in the world. Meanwhile, the ash has been categorized under pozzolana, with about 67-70% silica and about 4.9% and 0.95%, alumina and iron oxides, respectively (Oyetola and Abdullahi, 2006). The silica is substantially contained in amorphous form, which can react with the $Ca(OH)_2$ liberated during the hardening of cement to further form cementations compounds. Rice husk ash (RHA) is a pozzolanic material that could be potentially used in soil stabilization, though it is moderately produced and readily available. Bone ash is the white, powdery ash left from the burning (calcination) of bones. It is primarily composed of calcium phosphate. Bone ash is tricalcium phosphate in the form of hydroxyapatite $Ca_5(OH)(PO_4)_3$. Bone ash is significant because some of its important properties are due to the unique cellular structure of bones that is preserved through calcination. Bone ash has excellent non-wetting properties; it is chemically inert, free of organic matters and has very high heat transfer resistance. Ayininuola and Shogunro (2013) studied the influence of bone ash on shear strength of soil and discovered that bone ash played a fascinating role in increasing its shear strength.

Saha and Pal (2012) carried out laboratory investigations to study the compressibility behavior of soil and fly ash used in successive layers. Pre-consolidation pressure of the soil increased with the use of soil and fly ash in successive layers. Experimental test results showed that fly ash may be an effective stabilizing material to reduce the settlement value during primary and secondary consolidation of soil. Ashwani and Nitish (2013) conducted one-dimensional consolidation tests to study the effect of addition of various percentages of rice husk ash, fly ash and stone dust on compressibility characteristics of highly compressible clay soil. The addition of different waste materials to parent clay significantly improves soil compaction characteristics. Also, the industrial wastes effectively increase one-dimensional stiffness of soil and consequently reduced soil settlement. Saeid *et al.* (2012) presented a series of laboratory tests for investigating the adequacy of fly ash on the compressibility and swelling characteristics of soil. In the research, the compression index, swelling index, and initial void ratio of an unstabilised sample and eight stabilized samples with difference fly ash additives were investigated. The result revealed that fly ash stabilization could reduce the consolidation property and swelling behavior of soil. In addition, increment in the amount of fly ash led to reduction in the initial void ratio of stabilized samples.

Kumar and Sharma (2007) studied the effect of fly ash on consolidation characteristics of expansive and non-expansive clays and concluded that the value of compression index decreased for both expansive and non-expansive clays with increasing in fly ash content. Assessment of the consolidation properties of compacted lateritic soils stabilized with up to 8% tyre ash was carried out by Afolagboye and Talabi (2013) using time dependent one dimensional consolidation test; to enhance the usage of the material in geotechnical engineering. Reduction in both the compression index (C_c) and swell index (C_s) were observed with the increase in tyre ash content irrespective of the moulding water content. Saha and Pal (2012) studied the effect of fly ash on soil settlement and concluded that compressibility of the soil decreased due to the silt size particles of the fly ash used. Their experimental results showed that fly ash may be an effective stabilizing material to reduce soil settlement during primary and secondary consolidation. Also, Ashwani and Nitish (2013) presented their paper in which they conducted one-dimensional consolidation tests to study the effect of addition of various percentages of rice husk ash, fly ash and stone dust on compressibility characteristics of highly compressible clay soil. They concluded that the addition of different waste materials to parent clay resulted in significant improvements in the soil compaction characteristics. Results of their study also showed that the industrial wastes effectively increased one-dimensional stiffness and therefore, reduce settlement. Afolagboye and Talabi (2013) revealed that the coefficient of consolidation (C_v) decreased with the increase in consolidation pressure and increased with the increase in percentage tyre ash content in the three different moulding water contents.

Over the years, bones from cattle have been used for several purposes. Some of these include production of animal feed, gelatin in food industries, pharmaceuticals, photography, and cosmetic manufacturing - and the refining of sugar. Recently, cattle bones have found application in the medical field through their use in the manufacture of surgical implants (Mucalo, 2015). Cattle bones are the source of production of bone ash. Bone ash is grey white in colour. It is primarily composed of calcium phosphate, commonly used in fertilizers, polishing compounds and making ceramics such as bone china. It also has historical uses in the manufacture of baking powders and assay cupels (Wikipedia, 2012). Ayininuola and Shogunro (2013) used bone ash to stabilize soils and the ash played a fascinating role in increasing soil shear strength. This present research was designed to investigate the influence of bone ash on soil settlement characteristics or parameters.

2.0 Materials and Methods

The soil samples used were obtained from two locations the Faculty of Technology University of Ibadan and Alakia, Ibadan, Nigeria and labeled as samples A and B. The two soils were gap-graded but sample B contained more fine particles than sample A. The samples were collected at depth range from 1.5 to 2.0m of laterite horizon being the preferred soil upon which structure foundations are sited. The collected soil samples A and B were air-dried for weeks. The bones used for the production ash were obtained in fresh state from the slaughter house located at Bodija market Ibadan, Nigeria. The first step in the preparation of the bone ash involved burning of the bones in open air that lead to partial combusted of bone chips as shown in Figure 1. The partially combusted bones were broken and carbonized in an electric oven at a temperature of 1100°C for a period of 4 hours. The combusted bones were air cooled, milled and sieved using a sieve of aperture 75μm to obtain the required bone ash of grey whitish material as shown in Figure 2.


Figure 1: Bones undergoing open air burning


Figure 2: Milled bone ash

The percentages of oxides present in the bone ash were measured using Atomic Absorption Spectrophotometer (AAS). Each soil collected were divided into seven soil samples and received one of the following percentages of bone ash 0, 3, 5, 7, 10, 15 and 20%. The samples with 0% bone ash served as controlled samples. The control samples particle sizes were analysed in line with ASTM D422 (2007), liquid and plastic limits carried out in accordance with ASTM D4318 (2010) and also their maximum and optimum moisture content determined as detailed in ASTM D698 (2007).

The one-dimensional consolidation testing procedure was first suggested by Terzaghi. This test is performed in a consolidometer (sometimes referred to as an oedometer). The one dimensional consolidation test was conducted for all the samples. The soil was prepared using the outcome of the compaction test results. The prepared soil specimen was placed inside a metal ring with two porous stones, one at the top of the specimen and another at the bottom. The specimen was 64 mm (2.5 in.) in diameter and 25 mm. (1 in.) thick. The load on the specimen was applied through a lever arm, and compression was measured by a micrometer dial gauge. The specimen was kept under water during the test. Each load usually was kept for 24 hours. The load was doubled, which doubled the pressure on the specimen, and the compression measurement continued. At the end of the test, the dry weight of the test specimen was determined. The detail of the test is covered in ASTM D2435 (2011).

3.0 Results and Discussion

3.1 Soil Classification

The particle size curves of the two soil samples A and B are shown in Figures 3 and 4. The result showed that the two soils were gap-graded but sample B contains more fine particles than A. The two soil samples A and B were classified in accordance with the American Association of State Highway and Transportation Official (AASHTO). The parameters used were the particle size distribution results, plastic and liquid limits with the plasticity index. Soil sample A is A-7-6 soil i.e. a clayey soil. Also, soil sample B is clay sample classified as A-7-6. The compaction test was carried out in order to know the optimum moisture content (OMC) and maximum dry density (MDD) of samples A and B and also of all other soil samples mixed with bone ash. The results were used for the preparation of soil samples for oedometer test.

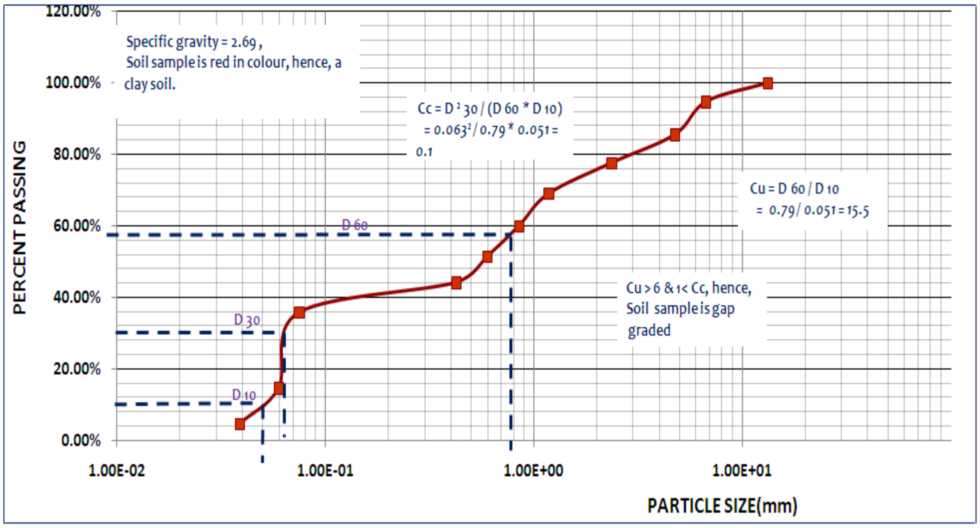


Figure 3: Particle Size Distribution Curve for Sample A

3.2 Soil Consolidation

The oedometer test was conducted for control and stabilised soil samples of soils A and B. Sample A at 0% stabilisation, the test results obtained from the oedometer test were summarised in Table 1. The initial data of the prepared soil specimen before the commencement of the oedometer test were as density of water, initial moisture content, dimension and specific gravity of the specimen and ring dimeter. The data obtained after the completion of the oedometer test were specimen wet and dry weight, final moisture content and final moisture content of the specimen. The data obtained were used to estimate change in height of specimen after the test, specimen void ratio before and after the test, its degree of saturation and dry density.

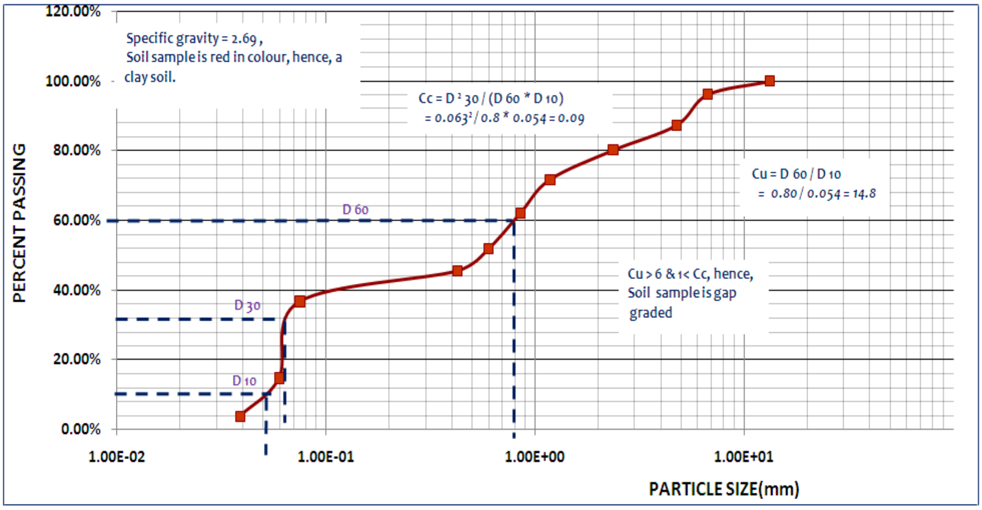


Figure 4: Particle Size Distribution Curve for Sample B

3.3 Determination of Consolidation Parameters

Using the data obtained in the above section and Table 1, the following steps were followed in order to obtain all the consolidation parameters. This method used was proposed by Casagrande and Fadum (1940). The first step carried out was to plot graph of compression dial reading versus the logarithm of time (Figure 5). Referring to the curves in Figure 5, the intersection formed by the final straight line produced backward and the tangent to the curve at the point of inflection is the 100 percent primary consolidation point and was designated as D_{100}. The dial reading at zero primary consolidation D_o was obtained by selecting any two points on the parabolic portion of the curve where times were in the ratio of 1: 4 (t_1 and t_2 in the Figure 5). The difference in dial readings between these two points is equal to the difference between the first point and the dial reading which corresponds to zero primary consolidation. For example, in Figure 5, two points A and B whose times were 10 and 2.5 minutes respectively, were marked on the curve. Let z be the ordinate difference between the two points. A point C is marked vertically over B such that BC = z. Then the point C corresponds to zero primary consolidation, D_o. The interval between 0 and 100% consolidation is divided into equal intervals of percent consolidation. Since it has been found that the laboratory that the theoretical curves have better correspondence at the central portion, the value of coefficient of consolidation, C_v was computed by taking the time t and time factor T at 50 percent consolidation.

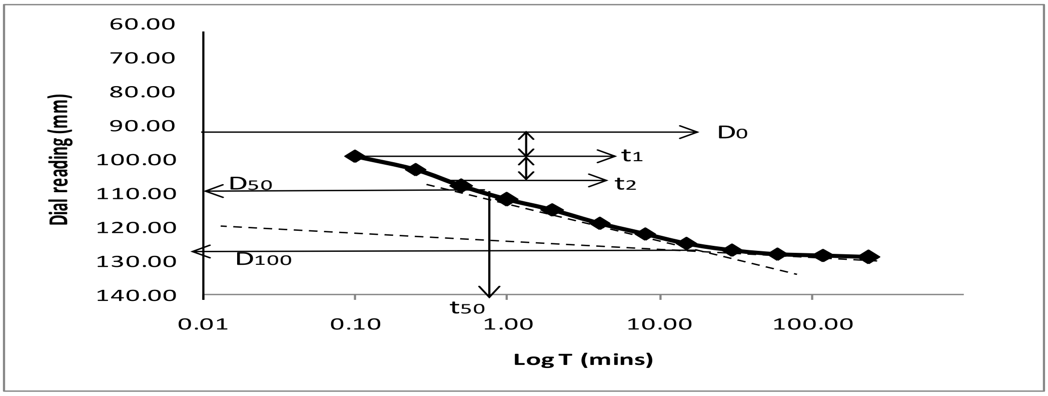
Table 1: Oedometer test results for Sample A at 0% stabilisation

Time	Deformations (mm)				
(mins)	at P= 14 kN	at P = 28 kN	at P = 56 kN	at P = 112 kN	at P = 224 kN
0.00	0.00	129.50	149.00	166.00	196.00
0.10	99.00	135.00	153.00	175.00	215.00
0.25	103.00	141.00	157.00	184.00	226.00
0.50	108.00	143.00	159.00	186.00	229.00
1.00	112.00	144.00	160.00	188.00	231.00
2.00	115.00	145.00	160.50	189.00	232.50
4.00	119.00	145.50	161.00	190.00	234.00
8.00	122.00	146.00	162.00	191.50	235.00
15.00	125.00	147.00	163.00	193.00	235.50
30.00	127.00	147.50	164.00	193.50	236.00
60.00	128.00	148.50	165.00	194.00	237.00
120.00	128.50	149.00	165.50	195.00	237.50
240.00	129.00	149.50	166.00	196.00	238.00

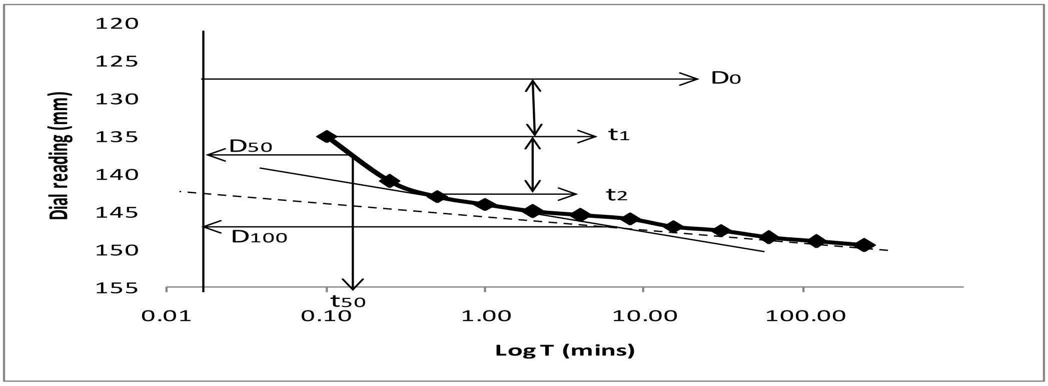
Where P is the external applied load on the oedometer specimen

From the plots (Figure 5), the values of D_o, D_{50} and D_{100} were taken. Other calculations were done as shown in Table 2. The C_v for sample A at 0% stabilization ranged from 0.32 to 1.21 cm^2/min i.e. highest C_v value obtained as 1.21 cm^2/min. From the values of the void ratio obtained in Table 1, the graph of e against log P was plotted as shown in Figure 6. From the graph, the pre-consolidation pressure, P_c, coefficient of area a_v and volume compressibility m_v were calculated. The method involves locating the point of maximum curvature on the e-log p curve in Figure 6. From point B, a tangent was drawn to the curve and an horizontal line was also constructed. The angle between these two lines was bisected. The abscissa of the point of intersection of this bisector with the upward extension of the inclined straight part corresponds to the pre-consolidation pressure P_c.

The procedure illustrated above was followed to obtain the consolidation parameters for soil A at different percentages of bone ash stabilization. Also, the same format was also used for soil sample B at different percentages of bone ash stabilization. The summary of results obtained is shown in Table 3.

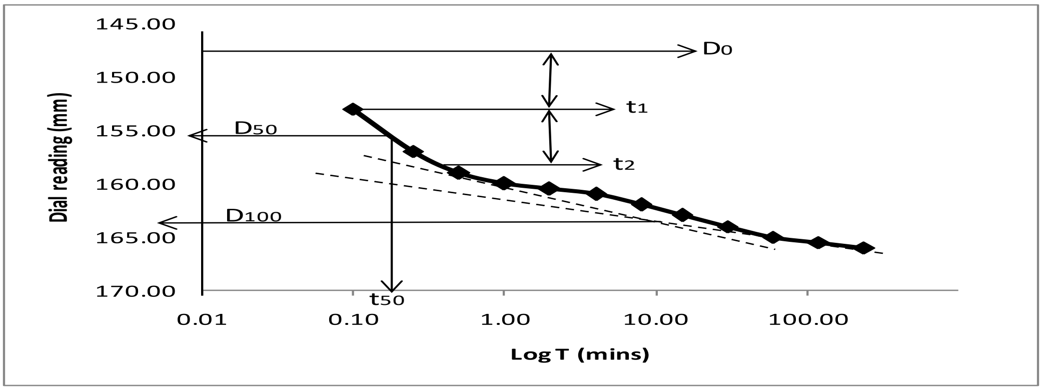


(a) When P = 32kN

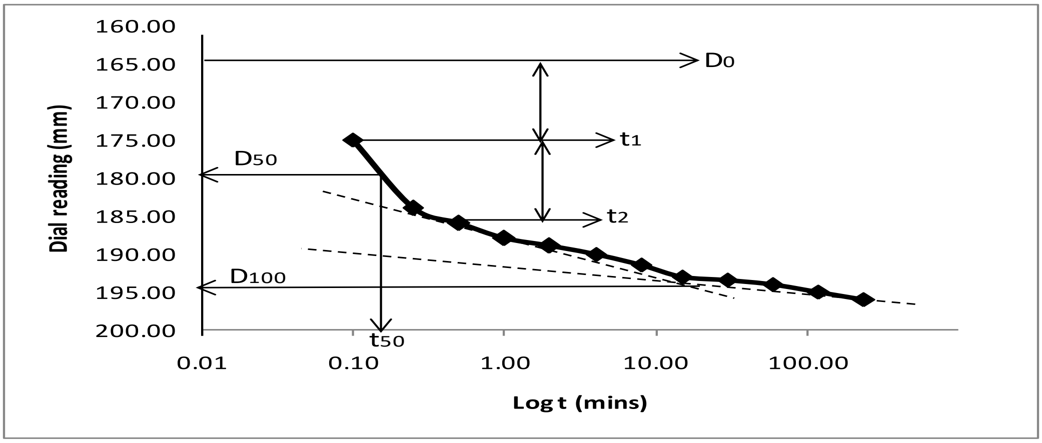


(b) When P = 64kN

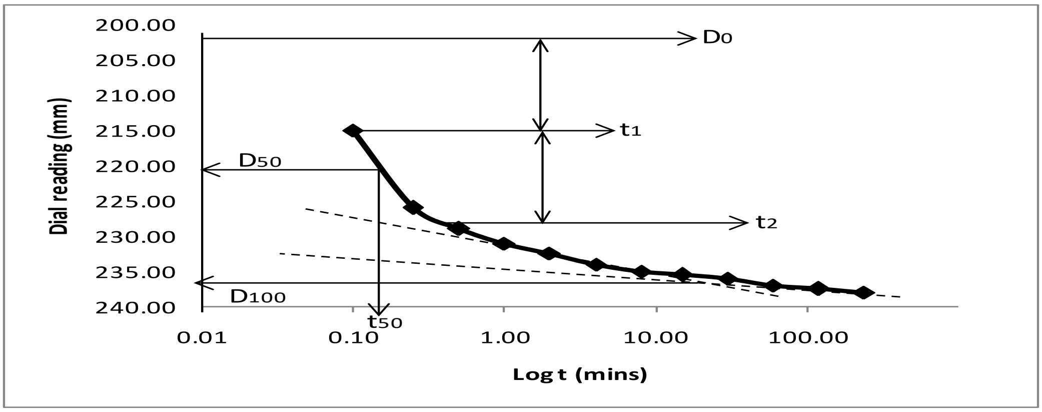
Figure 5: Graph showing dial reading vs log. time for each loading for the oedometer test.



(c) When P = 128 kN



(d) When P = 256 kN



(e) When P = 512 kN

Figure 5 (cont'): Graph showing dial reading vs log. time for each loading for the oedometer test.

Table 2: Analysis of Dial reading vs Log. time plot data

Pressure (kN/m^2)	T_{50} (min)	D_0	D_{100}	D_{50}	ΔH	$\sum\Delta H$	H	C_v	H_v	e
0							2.2			
32	0.73	94	127.2	110.6	0.033	0.033	2.17	0.32	0.94	0.767
64	0.15	127.5	147	137.3	0.02	0.053	2.15	1.51	0.92	0.751
128	0.2	147.6	163.8	155.7	0.016	0.069	2.13	1.12	0.91	0.738
256	0.18	164.5	194.5	179.5	0.03	0.099	2.1	1.21	0.88	0.714
512	0.15	202	236.5	219.3	0.035	0.133	2.07	1.4	0.84	0.686

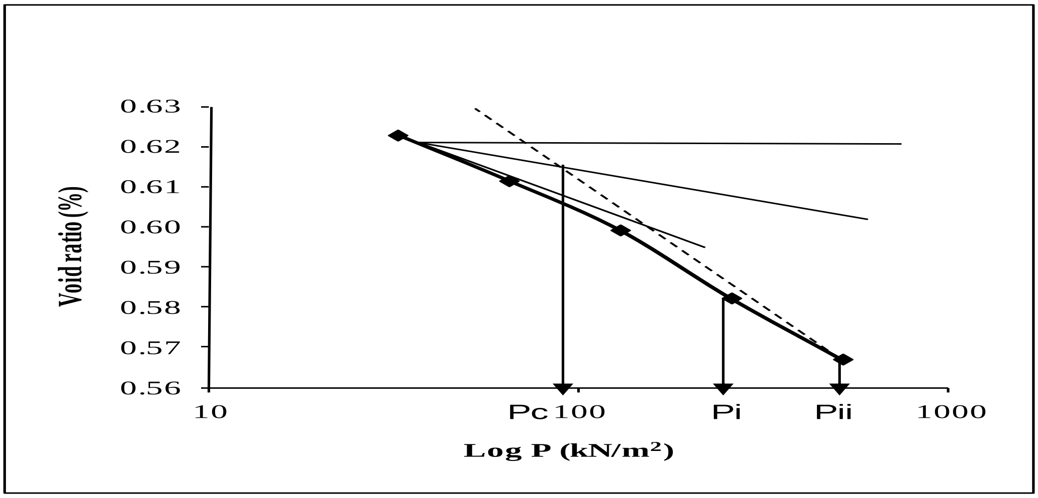


Figure 6: Graph showing e-logP plot

3.4 *Chemical Analysis of Bone Ash*

The result of the chemical analysis test of the bone ash is presented below in Table 4. It shows the major chemical compounds in the bone ash with their level of abundance rated in percentages. The results revealed that the bone ash contained calcium oxide (CaO) and phosphate (P_2O_5) as the major oxides. The bone ash contains some of the elements (oxides) found in pozzolana. However, the total percentage of iron oxide, silicon oxide and aluminum oxide is less than the minimum of 70% specified by pozzolanas (ASTM C618, 2005). ASTM C 618 (2005) defined pozzolana as siliceous or siliceous and aluminous materials which in themselves have little or no cementitious properties but in finely divided form and in the presence of moisture, they react with calcium hydroxide at ordinary temperatures to form compounds possessing cementitious properties. The CaO presents in the bone ash are capable of making ash a pozzolana in the presence of water. The P_2O_5 has the potential to act as a binding agent to cement particles of soil together and increase stability.

3.5 Influence of Bone Ash on the Soils Settlement Parameters

The value of compression index C_c of sample A at 0% stabilization was calculated as $9.3x10^{-2}$. This property declined until the percentage of bone ash reached 7% and was $3.3x10^{-2}$. The value started to appreciate and reached $5.0x10^{-2}$ at 20%. Sample B compression index reached the least value of $3.7x10^{-2}$ at 7% stabilization and further increased to $4.7x10^{-2}$ at 20% stabilization as shown in Figure 7. The behavior observed may be due to the partial replacement of the plastic soil particles with bone ash fines, an abrasive non-plastic material with reduction in clay content. The plasticity of a soil is controlled by the amount of clay fraction in it; it decreases as the amount of clay fractions decreases (Arora, 2008).

Table 3: Summary of Settlement Parameters.

Sample	**Bone Ash** (%)	**Pc (kN/m^2)**	**C_c x10^{-2}**	**C_v (cm^2/min)**	**a_vx10^{-5} (m^2/kN)**	**m_v x10^{-5} (m^3/kN)**	**e_o**
A	0	99	9.3	1.21	10.9	6.1	0.79
	3	105	5.6	1.27	6.6	3.8	0.75
	5	110	5.3	1.45	6.3	3.7	0.72
	7	120	3.3	1.56	3.9	2.3	0.69
	10	96	3.9	1.39	4.7	2.8	0.67
	15	95	4.3	1.39	5.1	3.1	0.64
	20	90	5.0	1.24	5.9	3.6	0.63
B	0	80	6.0	0.95	7.0	3.6	0.96
	3	82	5.3	1.02	6.3	3.3	0.91
	5	99	4.7	1.11	5.5	2.9	0.89
	7	110	4.0	1.25	4.7	2.6	0.83
	10	130	3.7	1.39	4.3	2.4	0.81
	15	100	4.1	1.17	4.8	2.7	0.79
	20	88	4.7	1.11	5.5	3.1	0.77

Table 4: Chemical Composition of Bone Ash

Oxide	% Composition
Calcium Oxide (CaO)	48.21
Phosphate (P_2O_5)	37.77
Magnesium oxide (MgO)	1.29
Silicon Oxide (SiO_2)	0.12
Iron Oxide (Fe_2O_3)	0.09
Aluminium Oxide (Al_2O_3)	0.08
Moisture	0.15
Loss on ignition	0.21

The coefficient of volume compressibility m_v of soil A at 0% stabilization was estimated as $6.1x10^{-5}m^3/kN$ and reduced to $3.6x10^{-5}m^3/kN$ at 20 % stabilization. Similar trend was observed when soil B was stabilized with bone ash as shown in Figure 8. At 7% and 10% bone ash stabilization, soils A and B experienced least coefficient of volume compressibility of 3.9 and 4.3 $6x10^{-5}m^3/kN$ respectively. Afolagboye and Talabi (2013) used tire ash to stabilize clay and confirmed that the soil m_v decreased with increasing in tire ash content. Soil A void ratio e_o at 0% stabilization was calculated to be 0.79, the void ratio reduced as the percentage of bone ash increased to 20% stabilization. Soil B experienced similar relationship as shown in the Figure 9.

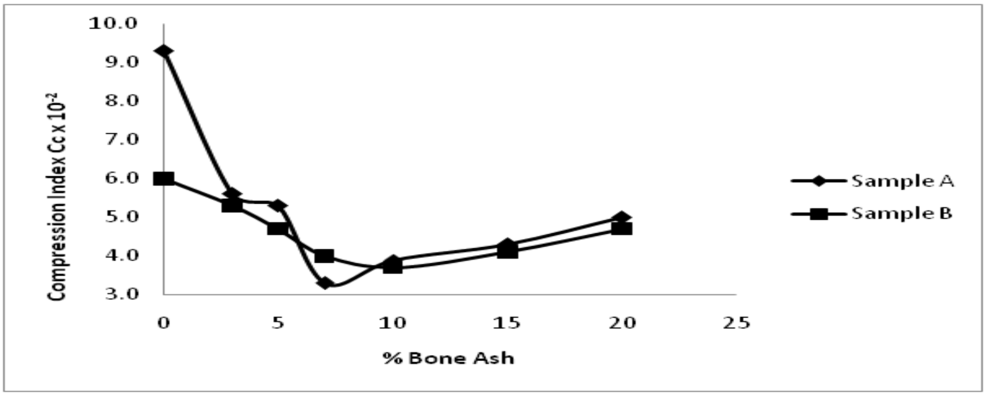


Figure 7: Influence of bone ash stabilization on compression index (C_c)

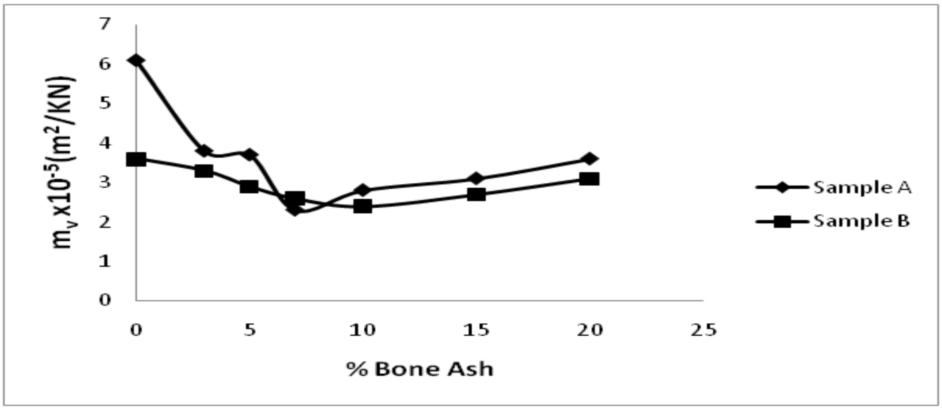


Figure 8: Influence of Bone Ash on Coefficient of Volume Compressibility (m_v) of soil

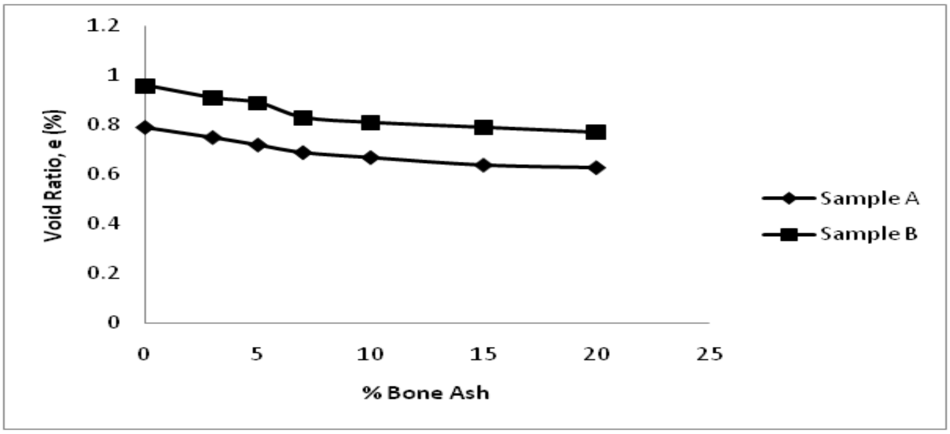


Figure 9: Influence of bone ash on void ratio (%) of soil

Soil A pre-consolidation pressure P_c at 0% stabilization was determined from e-logP curve to be 99 kN/m^2, this value increased as the bone ash percentage increased from 3% (105kN/m^2) to the peak value at 7% stabilization (120kN/m^2). It later decreased to 90kN/m^2 at 20% stabilization. Likewise, sample B experienced similar pattern but attained highest P_c of 130kN/m^2 at 10% stabilization as shown in Figure 10. Using Casagrande logarithm of time method, Soil A coefficient of consolidation C_v at 0% stabilization was determined from dial reading versus log time curve and ranged from 0.32 - 1.21cm^2/min. The value increased as the bone ash percentage increased from 3% (0.51-1.27cm^2/min) to 7% (0.76 – 1.56cm^2/min). It later decreased to 0.73- 1.39cm^2/min at 10% to 0.67 – 1.24 cm^2/min at 20% stabilization. Sample B experienced similar trend and attained highest C_v of 1.39cm^2/min at 10% stabilization.

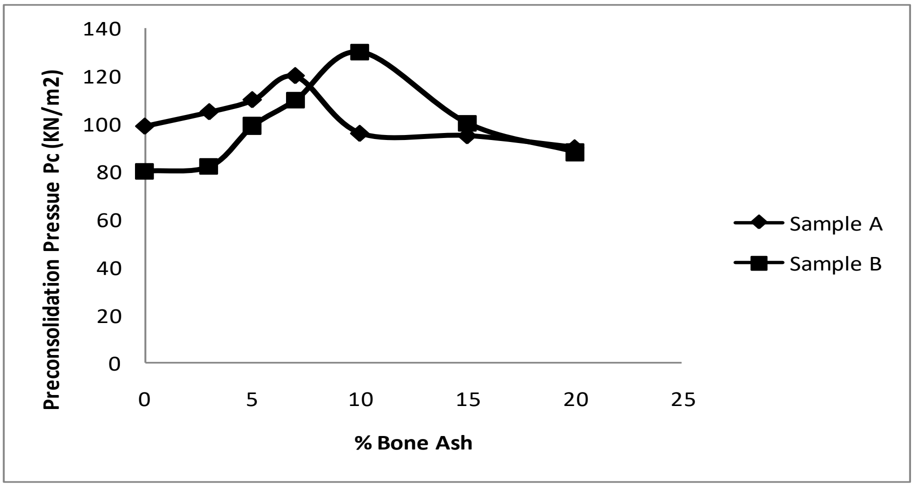


Figure 10: Influence of bone ash stabilization on pre-consolidation pressure (kN/m^2)

Figure 11: Influence of bone ash stabilization on coefficient of consolidation (C_v) cm^2/min

4.0 Conclusions

The study revealed the influence of bone ash on the consolidation parameters of two soils. The two soils were classified according to AASHTO standard as A-7-6 soils which represent clay samples with more than 35% passing the No 200 sieve. Also, the Atterberg limits results showed that both samples A and B possess high plasticity index. Soils A and B coefficient of volume and area compressibility, and compressibility index values reached the lowest value at 7 and 10% bone ash stabilization. The soils pre-consolidation pressure and coefficient of consolidation reached peak values at 7 and 10%

bone ash stabilization. Therefore, addition of 7 to 10% of bone ash to the soils will reduce their settlement potential.

5.0 Acknowledgements

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References

Afolagboye, O. L., and Talabi, A. O. (2013), *Consolidation properties of compacted lateritic soil stabilized with tyre ash.* Journal of Engineering and Manufacturing Technology 1: 36-44.

Arora K. R. (2008). Soil Mechanics and Foundation Engineering. Standard. Publishers Distributors, Delhi, pp.118.

Ashwani, J. And Nitish, P. (2013) *Consolidation characteristics of highly plastic clay stabilised with rice husk ash*. International Journal of Soft Computing and Engineering (IJSCE) 2 (6): 413-418.

ASTM C 618 (2015) American Society for Testing and Materials, ASTM C 618: Standard Test Method for coal fly ash and raw or calcined natural pozzolan for use in concrete. ASTM International.

ASTM D 422 (2007) American Society for Testing and Materials. ASTM D 422: Standard Test Method for Particle Size Analysis of Soils. ASTM International.

ASTM D 698 (2007) American Society for Testing and Materials. ASTM D 698: Standard Test Methods for Laboratory Compaction Characteristics of Soil. ASTM International.

ASTM D 4318 (2010) American Society for Testing and Materials (2010). ASTM D 4318: Standard Test Method for Liquid limit, Plastic and Plasticity Index of soils. ASTM International.

ASTM D 2435 (2011) American Society for Testing and Materials. ASTM D 2435 : Standard Test Methods for One-Dimensional Consolidation, ASTM International.

Ayininuola, G.M,. and Sogunro, A.O. (2013) *Bone ash Impact on Soil Shear Strength*. International Journal of Environmental, Earth Science and Engineering, World Academy of Science and Technology 7, (11): 330 – 334.

Casagrande, A. and Fadum, R.E. (1940). Notes on Soil Testing for Engineering Purposes. Harvard Soil Mechanics, Series No. 8, Cambridge, Mass.

EuroSoilStab. (2002), Development of Design and Construction Methods to Stabilize Soft Organic Soils: Design Guide for soft soil stabilization. CT97-0351, European Commission, Industrial and Materials Technologies Programme (Rite-EuRam III) Bryssel.

Hicks, R. (2002). Alaska Soil Stabilization Design Guide.

Kumar, B. R. P. and Sharma, R. S. (2007). *Volume change behaviour of fly ash- stabilized clays*. Journal of Materials in Civil Engineering, ASCE, 19(1): 67 – 74.

Mucalo, M. (2015). Hydroxyapatite (HAp) for Biomedical Applications, Technology & Engineering. Woodhead Publishing: Cambridge, UK.

Murthy, V.N.S. (2005). Geotechnical Engineering: Advanced Principles and Practice of Soil Mechanics and Foundation Engineering, Fifth Edition.

Oyetola, E.B.and Abdullahi, M., (2006). *The Use of Rice Husk Ash in Low-Cost Sandcrete Block Production, Leonardo*. Electronic Journal of Practice and Technologies 8: 58-70.

Saeid, A., Amin, C., and Hamid. N., (2012). *Laboratory Investigation on the Effect of Fly Ash on the Compressibility of Soil*. International Conference on Civil and Architectural applications (ICCAA'2012) December 18-19, 2012.

Saha, S.and Pal, S.K. (2012). *Compressibility behavior of soil and fly ashused in successive layers*, EJGE 17 (T): 2659–2670. 1996.

Sherwood, P. (1993). *Soil Stabilization with Cement and Lime. State of the Art Review*. London: Transport Research Laboratory, HMSO.