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Comparative Study of the Effectiveness of Lime and Cement Stabilization of Lateritic Clay Soil from Ofunmwengbe in Okada Town, Edo State, Nigeria

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ABSTRACT

The effect of lime and cement addition on the properties of clay soil from Ofunmwengbe in Okada town, Edo State, Nigeria was studied using varying percentages of lime and cement up to 9%. The results obtained, indicate that the plasticity index decreased from 71% at 0% lime and cement content to 17% and 30% respectively at 9% lime and cement content. The treated clay soil was tested for California bearing ratio (CBR) for both unsoaked samples (treated sample not immersed in water) and soaked sample (treated sample immersed in water for twenty four (24) hours). The California bearing ratio increased from 6% and 0.67% for unsoaked and soaked samples of the natural clay soil to peak values of 14% and 18% for unsoaked and soaked samples at 5% lime content and also to 9% and 10% for unsoaked and soaked samples at 7% cement content. There was also an increase in the unconfined compressive strength (UCS) to a peak value of 3.5 kN/mm^2 at 5% lime and 2.25 kN/mm^2 at 7% cement contents respectively as against 0.33 kN/mm^2 for the natural soil. Thus, 5% lime and 7% cement content were recommended for the stabilization of clay soil for both base and sub-base courses in road construction.

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1. INTRODUCTION

Road maintenance and total replacement of existing pavements involve huge budget and any approach that can reduce construction cost and at the same time increase life cycle of pavements will be helpful for efficient road construction and maintenance. Nigerian highways fail due to poor geotechnical properties of the underlying soils which constitute the base or sub grade material for the entire road configuration (Amu et al., 2010; Owamah et al., 2017).

Clay soils are soils which are composed of very fine particles usually silicates of aluminum and or iron and magnesium. Clay soil absorbs water slowly and retains it for a long time. The need for improvement of the engineering properties of soil has been a paramount concern to transportation and geotechnical Engineers and it has existed as long as construction has existed (Caterpillar, 2006; Amadi, 2014).

The ability to blend the naturally abundant lateritic soil with some chemical reagent to give it better engineering properties in both strength and waterproofing has been of great importance to the transportation engineers (Amu et al., 2010). Soil stabilization has come of age and reached a new level of acceptance in the geotechnical and construction communities (Schaefer, 1997). It is the alteration of the property of a locally available soil to improve its engineering properties such as strength, stiffness, compressibility, permeability, workability and sensitivity (Cuisinier et al., 2011; Harichane et al., 2011; Onyelowe, 2016). Soil stabilization has been useful in building of roads, earth dams and embankment, erosion control (Amu et al., 2011; Saeid et al., 2012; Karthik et al., 2014; Ali et al., 2016). The two general methods of stabilization are mechanical and chemical stabilization. Mechanical stabilization involves compacting the soil to affect its resistance, compressibility, permeability and porosity using rollers, plate compactors, tempers etc (Afolayan, 2017). Chemical soil stabilization depends mainly on chemical reactions between chemical additives and soil particles which then produce a strong network that bind the soil grains to achieve the desired effect (Shakeel, 2016).

A lot of researchers have concentrated their efforts on soil stabilization through the utilization of a range of additives including lime, cement, cassava peel ash (CPA), iron ore tailings, rice husk ash, fly ash, industrial waste products, waterborne polymer, potassium nitrate, calcium chloride, silica fume, phosphoric acid and emulsified asphalt and they found out that there were improvements on the soil properties after treatment with the various additives (Basma and Tuncer, 1991; Sherwood, 1993; Miller and Azad 2000; EuroSoilStab, 2002; Said and Taib, 2009; Laxmikant et al., 2011; Seyed et al., 2011; Amin, 2012; Armin and Behzah, 2013; Yilmaz and Ozaydin , 2013; Afeez et al., 2015; Akinwumi and Aidomojie, 2015; Fattah et al., 2015; Osinubi et al., 2015; , Afolayan, 2017; Anil and Ahsan, 2017; Fabiano et al., 2017).

2. MATERIALS AND METHODS

2.1. Materials

The clay soil sample used for this study was obtained from Ofunmwengbe area in Okada town of Edo state. The clay sample was obtained with the help of shovel and packed in sack bags for easy transportation to the laboratory. In this research, quick lime and ordinary Portland cement (OPC) were used as the stabilizing agents. The major chemical constituent of the lime is calcium oxide (CaO) while the main compounds in OPC are tricalcium silicate ($3CaO.SiO_2$), dicalcium silicate ($2CaO.SiO_2$), tricalcium aluminate ($3CaO.Al_2O_3$), and tetracalcium aluminoferrite ($4CaO.Al_2O_3.F_2O_3$), (Sam et al., 2013; Ali et al., 2016). Dangote brand, grade 42.5 of OPC was used for this study.

2.2. Methods

The experimental tests were carried out in accordance to BS 1377, (BS 1990), and consist the following phases:

1. Preliminary laboratory tests that included moisture content, specific gravity, Atterberg limits, grain size analysis, California bearing ratio (unsoaked and soaked for 24 hours), unconfined compression tests and standard Proctor compaction tests to establish the moisture-density relationships of the unstabilized soil

2. Atterberg limits, California bearing ratio and unconfined compression tests on the soil sample mixed with various percentages (3%, 5%, 7% and 9%) of lime and cement. The CBR for both natural and stabilized soaked and unsoaked samples for the varying percentages of the additives

was tested. The soaked samples were obtained by immersing the unsoaked samples in water for twenty four (24) hours before testing for CBR. All the laboratory tests were carried out in Civil Engineering geotechnical laboratory, Faculty of Engineering, University of Benin, Benin City, Edo State, Nigeria.

3. RESULTS AND DISCUSSION

3.1. Soil Characterization

The properties of the soil sample before being treated with additives (lime and cement) are presented in Table 1. The specific gravity of the soil as shown in Table 1 was within the range (2.6 – 2.7) stipulated for natural aggregates by the Federal Ministry of Works and Housing (1997) for road works. The sieve analysis carried out on the soil sample was used for the soil sample classification in accordance to AASHTO (1986) classification. The AASHTO classification was done using percentage passing sieve 75 µm, liquid limit, and plasticity index of the natural soil. The classification revealed the soil to be A-7-6(clay soil). The plasticity index of A-7-6 subgroup is greater than liquid limit minus 30 (AASHTO 1986). The natural moisture content of the soil as shown in Table 1 falls within the range of 18.20% to 28.30% given by Layade and Ogunkoya (2018) for clayey soil. The Atterberg limit (liquid limit, plastic limit and plasticity index), group index, unconfined compressive strength and the California bearing ratio of the natural soil as shown in Table 1, showed that there is need for the soil to be treated for it to be adequate as base and sub grade material for road construction. The liquid limit of the natural soil falls within the range of greater than 90%, as revealed by Whitlow, (1995) for extremely high plasticity index. This makes the soil to have low workability. Also the plasticity index (71%) of the natural soil was very high compare to 55% maximum value stipulated by Nigerian General Specifications for highways (FMWH, 1997), while the CBR values of the natural soil didn't meet the minimum requirement of 10%, 30%, and 80% (for soaked and unsoaked) used for sub-grade, sub-base, and base materials as stipulated by the Nigerian Federal Ministry of Works & Housing (FMWH, 1997). The Federal Ministry of Works and Housing, (1997) also specified OMC less than 18% for both sub-base and sub-grade materials while according to Bello et al. (2007), samples characterized with high value of maximum dry density and low optimum moisture content is best suitable as sub-base and sub-grade materials. The unconfined compressive strength of the natural soil as shown in Table 1, didn't meet the requirement revealed by Das (2009) for soil with medium unconfined compressive strength classification.

Table 1: Properties of the soil before stabilization

Characteristics	Description
Natural moisture content (%)	24
Percentage passing 75 µm B.S sieve (%)	96
Liquid limit (%)	93
Plastic limit (%)	22
Plasticity index (%)	71
Group index	20
AASHTO classification	A-7-6
Maximum dry density (kg/m^3)	1340
Optimum moisture content (%)	29
Unconfined Compressive Strength (kN/mm^2)	0.33
California bearing ratio (unsoaked) (%)	6.20
California bearing ratio (soaked) (%)	0.70
Specific gravity	2.70

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3.2. Effect of Lime and Cement on Atterberg Limits

The liquid limit decreased from a value of 93% (at 0% lime) to 65% (at 9% lime) while the plastic limit increased from a value of 22% (at 0% lime) to 55% (at 7% lime) as shown in Table 2. The plasticity index decreased from a value of 71% (at 0% lime) to 17% (at 9% lime) as shown in Table 2. Also, the liquid limit decreased from a value of 93% (at 0% cement) to 59% at 3% cement as shown in Table 3. The plastic limit increased from a value of 22% at (0% cement) to 32% at 5% cement while the plasticity index decreased from a value of 71% at 0% cement to 30% at 9% cement as shown in Table 3. The decrease in liquid limits, increase in plastic limits and decrease in plasticity indexes of the soil is due to ions in the additives which in turn leads to decrease in the volumetric changes (Muzahimand and Abdelmadjid, 2008; Fattah et al., 2013). Neither lime nor cement addition met the minimum requirement of liquid limit and plasticity index as stipulated by Federal ministry of Works & Housing (FMW&H, 1997).

Table 2: Results of Atterberg limits with varying percentages of lime

Lime content (%)	0	3	5	7	9
Liquid limit (%)	93	82	72	85	65
Plastic limit (%)	22	43	47	55	48
Plasticity index (%)	71	39	25	30	17

Table 3: Results of Atterberg limits with varying percentages of cement

Cement content (%)	0	3	5	7	9
Liquid limit (%)	93	59	64	62	62
Plastic limit (%)	22	24	32	22	32
Plasticity index (%)	71	35	32	40	30

3.3. Effect of Lime and Cement on Compaction

The maximum dry density (MDD) were constant from 0% lime to 7% lime with a value of 1340 kg/m^3 and then dropped to 1320 kg/m^3 at 9% lime, while the optimum moisture content (OMC) decreased as well. However, MDD increased from 1340 kg/m^3 (0% cement) to 1420 kg/m^3 (9% cement) for cement stabilization as shown in Table 4. The increase in MDD with cement can be linked to the additional water needed to enable the pozzolanic soil-additives reactions necessary for the stabilization process. This increases the additive particles that were ready to perform the exchange of cations with the soil particles, thereby filling up the voids spaces and densely packing the soil particles together therefore leading to greater strength (Sherwood, 1993; Amu et al., 2011).

Table 4: Variation of MDD and OMC with Lime and Cement content

Lime/Cement content (%)	Lime		Cement	
	OMC (%)	MDD (kg/m^3)	OMC	MDD (kg/m^3)
0	29	1340	29	1340
3	25	1340	11	1380
5	24	1340	29	1280
7	28	1340	30	1300
9	28	1320	21	1420

3.4. Effect of Lime and Cement on California Bearing Ratio (CBR)

The variation of CBR values with increase in percentages of lime and cement from 0% to 9% are shown in Table 5 and Table 6 respectively. The tests were carried out on both for soaked (for 24 hours) and unsoaked sample. The addition of lime and cement to the soil showed a remarkable improvement in the CBR compared to values of 6% for unsoaked and 0.70% for soaked samples recorded for the natural soil as shown in Tables 5 and 6. The CBR increased upon treatment to a peak value of 14% (for unsoaked) and to 18% (for soaked) at 5% lime. It also increased to a peak value of 9% (for unsoaked) and to 10% (for soaked) at 7% cement content respectively. The considerable increase in strength with lime and cement is due to the binding action of high percentage of cement, causing a considerable increase in the cohesion of the clay particles within the soil sample (Joel and Joseph, 2015). The opinion of Watson (1994) revealed that lime will only be effective with materials which contain enough clay for a positive reaction to take place

Table 5: CBR results for soaked and unsoaked for lime stabilization

Lime content (%)	0	3	5	7	9
CBR (%) for unsoaked	6	12	14	7	7
CBR (%) for soaked	0.7	3	18	14	17

Table 6: CBR results for soaked and unsoaked for cement stabilization

Cement content (%)	0	3	5	7	9
CBR (%) for unsoaked	6	6	5	9	9
CBR (%) for soaked	0.7	8	3	10	4

3.5. Effect of Lime and Cement on Unconfined Compressive Strength (UCS)

The unconfined compressive strength test is the most common method of evaluating the strength of the stabilized soil. The variation of UCS with increase in lime and cement from 0% to 9% is shown Table 7. There was a great improvement in the UCS with addition of lime and cement to the natural soil when compared with the low UCS value of 0.33 kN/mm^2 of the natural soil. The UCS value increased to a peak value of 3.50 kN/mm^2, at 5% lime content and to 2.25 kN/mm^2 at 7% cement content and dropped slightly to a 1.50 kN/mm^2 at 9% lime content and to 1.20 kN/mm^2, at 9% cement content respectively. The increase in strength was due to the binders which had cementitious properties solidifying the soil matrix thereby increasing the strength values of the clayey soil samples (Owamah et al., 2017) and this is also similar to those reported by Amu et al. (2011) and Ogunribido, (2012).

Table 7: Variation of UCS with lime and cement contents

Lime/Cement content (%)	One day unconfined compressive strength (kN/m^2)	
	Lime	Cement
0	0.33	0.33
3	1.20	0.85
5	3.50	1.50
7	2.20	2.25
9	1.50	1.20

4. CONCLUSIONS

The following conclusions were drawn from the study:

i. The clay soil from Ofunmwengbe in Okada Town of Edo State was classified to be an A-7-6 (clay soil) in accordance with AASHTO (1986) classification system and with a Group index of 20-which implied it as poor soil.
ii. The Atterberg's limit tests showed that the addition of both lime and cement reduced the plasticity indices of the sample which are indicators of soil improvement.
iii. At varying percentages of lime and cement contents, there was improvement in the CBR and UCS values, compared to that of the natural soil.
iv. Lime (5%) and cement (7%) can effectively be used for the stabilization of clay soil.

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6. CONFLICT OF INTEREST

There is no conflict of interest associated with this work.

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