International Journal of Earth, Energy and Environmental Sciences
ISSN: 2517-942X
Vol:9, No:10, 2015

Stabilization of Clay Soil Using A-3 Soil

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***Abstract*—**A clay soil classified as A-7-6 and CH soil according to AASHTO and unified soil classification system respectively, was stabilized using A-3 soil (AASHTO soil classification system). The clay soil was replaced with 0%, 10%, 20%, to 100% A-3 soil, compacted at both British Standard Light (BSL) and British Standard Heavy (BSH) compaction energy levels and using Unconfined Compressive Strength (UCS) as evaluation criteria. The Maximum Dry Density (MDD) of the treated soils at both the BSL and BSH compaction energy levels showed increase from 0% to 40% A-3 soil replacement after which the values reduced to 100% replacement. The trend of the Optimum Moisture Content (OMC) with varied A-3 soil replacement was similar to that of MDD but in a reversed order. The OMC reduced from 0% to 40% A-3 soil replacement after which the values increased to 100% replacement. This trend was attributed to the observed reduction in void ratio from 0% to 40% replacement after which the void ratio increased to 100% replacement. The maximum UCS for the soil at varied A-3 soil replacement increased from 272 and 770 kN/m^2 for BSL and BSH compaction energy level at 0% replacement to 295 and 795 kN/m^2 for BSL and BSH compaction energy level respectively at 10% replacement after which the values reduced to 22 and 60 kN/m^2 for BSL and BSH compaction energy level respectively at 70% replacement. Beyond 70% replacement, the mixtures could not be moulded for UCS test.

***Keywords*—**A-3 soil, clay soil, pozzolanic action, stabilization.

I. Introduction

CLAY soils exist in different parts of the world and can cause serious damage to civil engineering infrastructures ranging from building structures to road structures [1]. The common clay minerals available are kaolinite, illite and montmorilonite. These clay soils in its in-situ form can exist as expansive clays or soft clays. These two processes are caused by the non availability or availability of water to the in-situ clay soil deposit. Expansive clay soils are common in semi-arid regions where availability of ground water is minimal and conditions are suitable for the formation of clay minerals such as montmorilonite [2]-[4]). Soft clay soil deposits are common in rain forest areas where ground water is always available to the clay soil deposit. Clay is a material with low strength and markedly affected by water but it can be relatively strong in dry condition [5]. If water is added to clay, it will behave as plastic or flow like liquid. Soft clay normally has very high percentage of clay fraction. Because of its low permeability, dissipation of excess pore pressure is slow.

A-3 soils subgroup in American Association of State Highway and Transportation Officers (AASHTO) [6] soil classification system is placed in a lone column without subdivisions like A-1 and A-2. A-3 soils are uniformly fine and non plastic sand which make its use in any component of road structure to be very minimal and almost completely neglected in AASHTO [6] soil classification scheme. It is therefore pertinent to put this class of soil into any possible engineering use.

Soil stabilization is a technique introduced many years ago with the main purpose to render the soils capable of meeting the requirements of the specific engineering projects [7]. The commonly used stabilizers include ordinary Portland cement (OPC) and lime, with their stabilization mechanisms being relatively well understood [8]-[10].

Cong et al. [11] studied cement stabilization of clay soils with the mixture of sodium silicate and composite promoter. The authors realized that the supplementary cementing materials performed effective pozzolanic actions and improved the mechanical properties of cement stabilized clay soils. These soil stabilizing chemicals are either expensive or difficult to source in large quantity, hence the need to use sharp sand as alternative. Muazu [12] studied the stabilization of fine lateritic soils using river sand. The sand was mixed at 0%, 2%, to 8% by weight of the dried lateritic soil. The Maximum Dry Densities were found to increase continuously from 1.920 at 0% sand content to 1.980g/cm^3 at 8% sand content. The Optimum Moisture Content (OMC) decreased from 29% at 0% sand content to 25% at 8% sand content. The author did not consider the compaction characteristics beyond 8% sand content. Joel and Agbede [13] studied the effect of lime on sand stabilization of Igumale shale. The authors replaced the shale with 0%, 10%, 20% to 50% sand by weight of the Igumale shale. The mixture was further admixed with 0%, 2%, 4% to 14% lime by weight of the Igumale shale. The result showed that, at 0% lime, the MDD of Igumale shale increased from 1.51 g/cm^3 at 0% sand to 1.69 g/cm^3 at 50% sand content. Similarly, at 0% lime, the UCS increased from 360 kN/m^2 at 0% sand to maximum of 440 kN/m^2 at 20% sand content after which the value decreased to 178 kN/m^2 at 50% sand content. The author did not consider the geotechnical properties beyond 50% sand content. This work is therefore aimed at replacing A-3 soil (obtained from river sand) with clay soil from 0% to 100% in order to stabilize the clay soil.

II. Materials and Methodology

A. Material

The materials used for this study include clay soil collected from Niger State Polytechnic, Zungeru, Niger State. The clay soil was collected at a depth of between 1.0 to 1.5m. The disturbed clay soil was prepared according to the method highlighted in part 1 of B. S. 1377 [14].

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The A-3 soil was obtained by sieving air-dried river sand through sieve 0.425mm BS sieve. The mixture of clay soil and A-3 soil was prepared according to the method highlighted in B. S. 1924 [15].

B. Method of Experimentation

The clay soil was replaced with A-3 soil at 0%, 10%, 20% to 100% A-3 soil content. Meanwhile, index property tests were carried out on the natural clay soil and the A-3 soil. All the mixtures formed were compacted at standard proctor compaction and modified standard compaction energy levels to obtain the optimum moisture contents (OMC) and the maximum dry densities (MDD). For each of the two compaction energy levels, each mixture was moulded for unconfined compression strength test (UCS) at varied moisture contents to obtain the optimum moisture content that will give the maximum UCS. The maximum UCS for each of the mixtures was recorded and the values used to obtain the optimum A-3 soil content that gives the highest UCS value. The OMC that gives the highest UCS value will then be compared with the OMC that gives the MDD for each of the compaction energy levels.

III. Result and Discussion

A. Index Properties

The results of the index properties of the clay soil and the A-3 soil are shown on the Table I.

TABLE I
INDEX PROPERTIES OF NATURAL CLAY SOIL AND THE A-3 SOIL

Property	Clay Soil	A-3 soil
Natural moisture content (%)	14.4	9.8
% passing BS No. 200 sieve (%)	83.2	4.0
Liquid Limit (%)	59.3	28.8
Plastic Limit (%)	26.8	NP
Plasticity Index (%)	32.5	NP
Group Index	19.9	0
AASHTO Classification	A-7-6	A-3
USCS Classification	CH	SP
Specific gravity	2.42	2.60
MDD, (BSL Energy Level) g/cm^3	1.723	1.627
MDD, (BSH Energy Level) g/cm^3	1.800	1.661
OMC, (BSL Energy Level) %	22.8	18.7
OMC, (BSH Energy Level) %	20.0	20.1
Max. UCS, BSL Energy Level (kN/m2)	295	-
Max. UCS, BSH Energy Level	795	-

The summary of the index properties of the clay soil and the A-3 soil shows that they fall under A-7-6 and A-3 sub-group respectively according to AASHTO [6] soil classification system. The soils fall under CH and SP respectively according to unified soil classification system.

The grain size analysis of all the mixtures is shown in Fig. 1. The grain size analysis curves showed that the natural clay soil is well graded. This trend decreases as more clay was replaced with A-3 soil.

At 50% A-3 soil replacement, the grain size analysis of the mixtures becomes more of uniformly graded than the well graded nature at 0% A-3 soil replacement. The mixture becomes more uniformly graded as the mixture tends to 100% A-3 soil replacement.

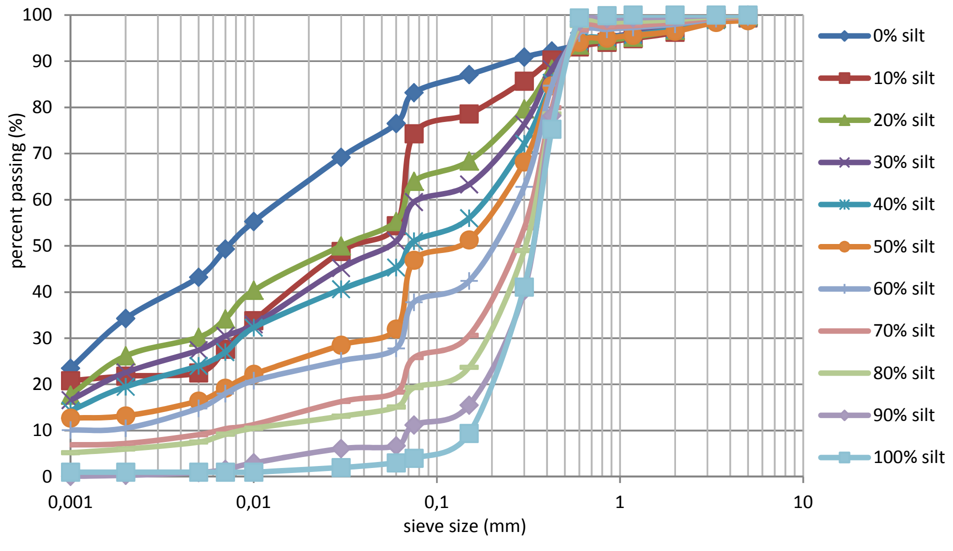

Fig. 1 Grain size analysis of the clay soil at varied A-3 soil replacement

From the index properties on Table I, the clay soil cannot be used for any component of a road structure, and therefore, it will require stabilization to increase its strength and durability. The uniformly graded nature of the mixtures at 50% A-3 soil replacement and above can result in to more void ratio in the mixtures.

B. Void Ratio of Compacted Soil Mixtures

The variation of the void ratio of the mixtures with the percentage A-3 soil replacement is shown on Table II. The void ratio was calculated from formula given by equation 1 where G_s is the specific gravity of the soil solids, ρ_w is the density of water and ρ_d is the maximum dry densities.

$$e = \frac{\rho_w G_s - \rho_d}{\rho_d} \quad (1)$$

TABLE II
CHANGE IN VOID RATIO WITH PERCENT A-3 SOIL REPLACEMENT AT BSL AND BSH ENERGY LEVEL

Silt Replacement (%)	Specific gravity of the mixtures	Void ratio (BSL)	Void ratio (BSH)
0	2.42	0.40	0.34
10	2.46	0.40	0.31
20	2.51	0.38	0.32
30	2.47	0.34	0.25
40	2.44	0.24	0.23
50	2.58	0.32	0.31
60	2.62	0.38	0.33
70	2.63	0.39	0.34
80	2.66	0.50	0.41
90	2.64	0.54	0.51
100	2.60	0.60	0.57

The void ratios reduces from 0% A-3 soil replacement to 40% A-3 soil replacement for both the BSL and BSH compaction energy levels after which the values increased to 100% A-3 soil replacement. This trend is in agreement with the grain size analysis of the mixtures which shows uniformity after 40% silt replacement.

C. Compaction Characteristics

The result of the variation of MDD with percentage A-3 soil at both the BSL and BSH compaction energy level is shown in Fig. 1. The result at BSL energy level showed increase in MDD from 1.723 g/cm^3 at 0% A-3 soil content to 1.962 g/cm^3 at 40% A-3 soil replacement. The value reduced to 1.627 g/cm^3 at 100% A-3 soil content replacement. The trend is similar for BSH compaction energy level where the MDD increased from 1.800 g/cm^3 at 0% A-3 soil replacement to 1.978 g/cm^3 at 40% A-3 soil replacement after which the value reduced to 1.661 g/cm^3 at 100% A-3 soil replacement.

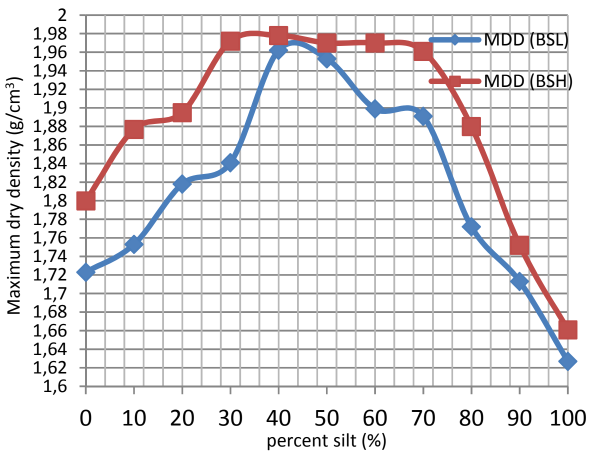

Fig. 2 Variation of MDD with percent A-3 soil at BSL and BSH compaction energy level

This trend is in close agreement with the findings of [13] which recorded increase in MDD from 0% sand replacement to 50% sand replacement at 0% lime. This trend resulted from the grain size analysis of the mixtures which tend towards uniform gradation at A-3 soil replacement beyond 40%. This has caused the compacted soil mass to have increased void ratio as shown in Table II which leads to lower dry densities beyond this A-3 soil replacement level. The minimum void ratio was recorded at 40% A-3 soil replacement which consequently gave the highest MDD.

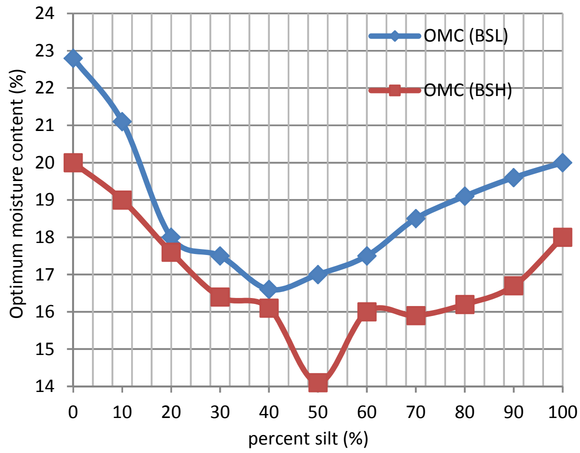

Fig. 3 Variation of OMC with percentage A-3 soil at BSL and BSH compaction energy level

The trend of the OMC is similar to that of the MDD but occurred in a reverse order. The OMC at BSL compaction energy level decreased from 22.8% at 0% A-3 soil replacement to 16.6% at 40% A-3 soil replacement after which the values increased to 20% at 100% A-3 soil replacement. This trend is similar to that of BSH energy level where the OMC reduced from 20% at 0% A-3 soil replacement to 14.1% at 50% A-3 soil replacement after which the values increased to 20.1%. This trend resulted from initial reduction in void ratio from 0% A-3 soil replacement to 40% A-3 soil replacement which allowed smaller pores in a compacted mass for water to occupy. Beyond this A-3 soil replacement, the void and hence the pore spaces began to increase which resulted in to more pore spaces for water to occupy in a compacted mix. The end result is the increase in OMC with more A-3 soil replacement.

D. Unconfined Compressive Strength (UCS)

The variation of maximum UCS with A-3 soil replacement for BSL and BSH compaction energy levels is shown on Fig. 4.

The values at BSL compaction energy level increased from 272 kN/m^2 at 0% A-3 soil replacement to 295 kN/m^2 at 10% A-3 soil replacement after which the values reduced to 22 kN/m^2 at 70% A-3 soil replacement. Beyond 70% A-3 soil replacement, the soil mixture could not be moulded for UCS testing.

At BSH compaction energy level, the UCS values increased from 770 kN/m^2 at 0% A-3 soil replacement to 795 kN/m^2 at 10% A-3 soil replacement after which the values decreased to 60 kN/m^2 at 70% A-3 soil replacement. Beyond 70% A-3 soil replacement, the soil mixtures cannot be moulded for UCS testing. This trend is slightly different from that of [13] which observed maximum UCS at 20% sand content. The A-3 soil used in this study is quite different from the sandy soil used by [13]. The trend observed for UCS at both the BSL and BSH compaction energy level in this study must have resulted from the combined effort of the cohesion of the clay soil and the grading caused by the mixture of the sandy particles in the clay soil coupled with the inert particles of the A-3 soil. Therefore, the 10% A-3 soil replacement is probably the mixture that gave high cohesion and the most suitable grading to give the maximum UCS at both the two compaction efforts.

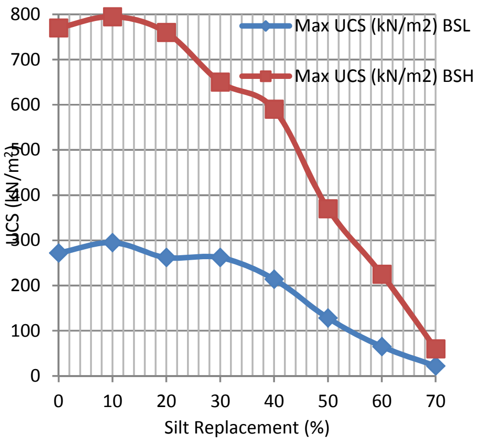

Fig. 4 Variation of UCS with A-3 soil content at BSL and BSH compaction energy level

E. Optimum Moisture Content that Gave Highest UCS

The OMC obtained from the compaction tests were found to vary from the OMC that gave the maximum UCS, (Fig. 5). The trend is similar to that of the OMC obtained from compaction test.

The general trend of the OMC for maximum UCS reduced from 0% A-3 soil replacement to between 30 to 40% A-3 soil replacement after which the values increased to 100% A-3 soil replacement. The variation of OMC for compaction and OMC for maximum UCS at 10% A-3 soil replacement is 7%. Therefore, to achieve the maximum UCS of clay soil replaced with 10% A-3 soil, the OMC of the compaction must be reduced by 7%.

IV. Conclusion and Recommendations

A. Conclusion

The clay soil used for this study classified under A-7-6 while the silt soil classified under A-3 soil according to [6] soil classification system.

The MDD of the clay soil, stabilized with various percentages of A-3 soil at both the BSL and BSH compaction energy levels increased. At BSL compaction energy level, the values increased from 1.723 at 0% A-3 soil replacement to 1.962 g/cm^3 at 40% replacement, while at BSH compaction energy level, the values increased from 1.800 at 0% replacement to 1.978 g/cm^3 at 40% replacement. After 40% replacement, the values decreased to 1.627 and 1.661 g/cm^3 for BSL and BSH compaction energy levels respectively, at 100% A-3 soil replacement. This trend was attributed to the reduction in void from 0% A-3 soil replacement to 40% A-3 soil replacement after which the values increased to 100% A-3 soil replacement.

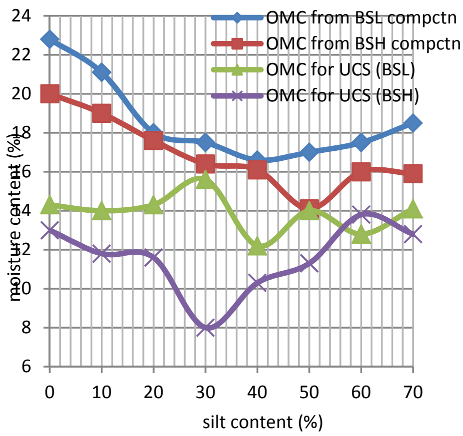

Fig. 5 Variation of OMC for maximum UCS with A-3 soil content at BSL and BSH Energy

The trend of the OMC is similar but in reversed order. At BSL compaction energy level, the OMC of the soil mixture decreased from 22.8% at 0% A-3 soil replacement to 16.6% at 40% replacement, while at BSH compaction energy level, the OMC values decreased from 20.0 % at 0% replacement to 14.1% at 40% replacement. After 40% replacement, the OMC values increased to 18.5 and 14.1% for BSL and BSH compaction energy levels respectively at 100% A-3 soil replacement.

Increase in the maximum UCS for the stabilized clay soil was also observed. At BSL compaction energy level, the UCS values increased from 272 kN/m^2 at 0% A-3 soil replacement to 295 kN/m^2 at 10% replacement, while at BSH compaction energy level, the UCS values increased from 770 kN/m^2 at 0% replacement to 795 kN/m^2 at 10% replacement. After 10% replacement, the values reduced to 22 and 60 kN/m^2 for BSL and BSH compaction energy levels respectively, at 70% A-3 soil replacement.

The optimum moisture content that gave the highest UCS at 10% A-3 soil replacement was observed to be a value 7.0% below the compaction OMC.

B. Recommendations

It is recommended that a clay soil of high plasticity should be replaced with 10% of A-3 soil in order to achieve the maximum UCS.

The mixture should be moulded with water content 7% less than the OMC of the mixture obtained from laboratory compaction test.

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