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Effects of cow dung ash and calcium hydroxide on geotechnical properties of expansive and loose soil

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Abstract

The study is an investigation into the effects of CDA and Ca $(OH)_2$ on geotechnical properties of expansive (Sample A) and loose soil (Sample B). The experiments were designed to study the effects of adding CDA in various percentages by weight (5%, 15% and 15%) of dry soil with 5% constant Ca $(OH)_2$, which produces pozzolanic reactions in soil samples.

Sample A was collected at Moniya, Ibadan, Sample B from The polytechnic, Ibadan and, cow dung was obtained from a farm settlement at Ilora, Oyo State, the dung was air dried and then calcined at 500 ^{0}C – 600 ^{0}C, after which it was sieved using 600μm sieve. The samples were subjected to the following laboratory tests; Natural moisture content, Particle (grain) size analysis, Atterberg limit test, Compaction test, California bearing ratio (CBR) test. The NMC test shows that sample A retains more water than sample B given by the values 26% and 6% respectively, the particle size analysis results showed that sample A has highest percentage of clay passing sieve no. 200 (75μm) i.e. 62.86%, while sample B has 7.27%, this indicates that sample A with high silt clay content are susceptible to volume changes when wet. The liquid limit and plasticity index for sample A is 49% and 28% respectively while sample B is a cohesionless soil. This shows that sample A has high clay content and its load bearing capacity could be reduced when wet. The AASHTO system classified sample A as A-7-6, and sample B as A-3. This shows sample A is fair to poor while sample B is excellent to good. The maximum dry densities ranged from 1.61mg/m3 to 1.87mg/m^3 and Optimum moisture contents range from 19.2% to 16.36% respectively. The CBR value of sample A as to the varying percentage are 2.07%, 10.62% (0% CDA & 5% $Ca(OH)_2$) , 12.69%, 16.77%, 31.41% while CBR value of sample B are thus: 32.7%, 27.06% (0% CDA & 5% $Ca(OH)_2$), 12.09%, 16.2%, 16.74%. It was then observed that CDA at 15% and Ca(OH)2 at 5% is the optimum for expansive soils while adding CDA and Ca(OH)2 to loose soil will increase the OMC and thus reduce its engineering properties.

Keywords: Cow Dung Ash (CDA); Calcium Hydroxide; Pozzolanic activity; Stabilization; CBR

1. Introduction

Virtually all structures in Civil Engineering, regardless of their sizes have contacts with soil through foundation (Subgrade for road, etc.). Foundation is a very essential element in our world today. This foundation sits on our very own earth crust which the expansive and loose soil is part of. Sometimes, soils on which foundation rests may be problematic.

Engineers in developing countries are faced with the challenges of locating suitable soil, i.e. for use as sub-base in engineering road construction. Improvement of soil engineering properties is an inevitable necessity, when the structures are founded on a problematic soil. Expansive, collapsible, liquefiable, soluble, dispersive, silty fine sands, and highly organic weak soils are the most serious kinds of problematic soils.

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Cow dung is basically the end product of herbivorous matter which is acted upon by symbiotic bacteria residing within the animal's rumen (Ojedokun et al, 2014). Cow dung ash is one of the biomass wastages. Burning cow dung as fuel, generates energy and results in the waste product cow dung ash. It contains approximately 60% silica and other elements. Even though silica can be obtained from various agro wastes, an attempt has been made to get higher amount of silica from cow dung ash by chemical processing method, for potential applications. Transparent, glassy nature and an airborne property of pure silica could be obtained from cow dung ash (G. Sivakumar, and K. Amutha, 2012). Cow dung was habitually used in concrete and so one may suppose there were particular benefits in its inclusion. Recent publications suggest that dung may improve workability and durability or may act as an additional binder. Knowledge has also been lost as to whether fresh, old or weathered dung was used. Since there is no historic reference to the dung being old or weathered, it is conceivable that this is a recent invention resulting from modern attitudes toward odour and hygiene.

Calcium hydroxide (traditionally called slaked lime) is an inorganic compound with the chemical formula $Ca(OH)_2$. It is a colorless crystal or white powder and is obtained when quicklime (calcium oxide) is mixed, or slaked with water. Hydrated lime can considerably increase the load carrying capacity of clay-containing soils. They do this by reacting with finely divided silica and alumina to produce calcium silicates and aluminates, forming pozzolans which possess cementing properties (https://en.wikipedia.org/wiki/Calcium_oxide).

2. Material and methods

2.1. Soil sample

2.1.1. Expansive soil (sample A)

35 kg of representative soil was collected at a borrowed pit at Fasola – Apapa Road, Moniya, Oyo State, Nigeria; with sample depth ranging from 0.5-1m; Sample was collected using a shovel, soil sample was labeled for easy identification. The soil sample employed in this work is a disturbed sample due to mechanical actions.

2.1.2. Loose soil (sample B)

35 kg of representative soil was collected at The Polytechnic Ibadan (South Campus), Oyo State, Nigeria; with sample depth of above 0.2m; Sample was collected using a shovel, soil sample was labeled for easy identification. The soil sample employed in this work is a disturbed sample due to mechanical actions.

2.2. Processing of Cow Dung Ash

The cow dung was obtained from a farm settlement at Ilora, Oyo State, the dung was air dried and then calcined at 500 ^{o}C – 600 ^{o}C, a grey mass of cow dung ash was obtained after which it was sieved using 600μm sieve. The oxide composition of CDA is shown in Table 1.

2.3. Calcium Hydroxide

Calcium Hydroxide was obtained from the reaction of calcium carbide and water to produce Acetylene (C_2H_2), Heat and $Ca(OH)_2$. It was then air dried.

Table 1 Oxide composition of CDA

Constituents	Composition (%)
Silicon (mg/Kg)	38.0
Aluminum (mg/Kg)	3.9
Iron (mg/Kg)	2.5
Calcium (mg/Kg)	23.8
Magnesium (mg/Kg)	3.0

2.4. Laboratory Tests

2.4.1. Preliminary/ Classification Test

The tests carried out includes

Natural water content determination

This test was performed to determine the moisture content of soils which is expressed in percentage. It is the ratio of mass of "pore" or "free" water in a given mass of soil to the mass of the dry soil solids. The test was carried out according to the standard test method for laboratory determination of water (moisture) content of soil, BS 1377-2, 1990. Equipment used were weighing balance, moisture cans, drying oven set at 110 °C, hand gloves etc.

Particle Size Analysis

This was done to analyse the soil particles according to their aggregate. Soil sample was poured into the Riffle box with the intention of getting an appreciable sample that would contain all particles present in the soil (a small sample that would contain different sizes of particles present in the soil. A handful of sample was collected into the crucible and kept in the oven at a temperature of 105 ^{o}C for 24 hours so as to remove moisture content in the soil sample. The sample was weighed with the aid of weighing balance (weight of sample before sieving). Consequently, wet sieving was carried out on the sample. The sample was poured/soaked in a tray filled with water and was stirred, washed, sieved with sieve No.200 (75µm) under tap until water became clean. This was done to remove clay/silt particles finer than sieve No.200. The particles retained in the sieve were collected into the crucible and oven dried for 24 hours to expel moisture content in preparatory for dry sieving. Dry sieving was accomplished by passing/pouring the particles through assemblage of sieves of various sizes. These sieves were shaken for some time so that each sieve could retain particles not finer than the sieve and weight of particles retained in each determined, from where percentage retained and percentage passing were deduced.

Atterberg's limit

This was done to determine the liquid limit, plastic limit, Plasticity index and Shrinkage limit of soil. An appreciable sample of laterite soil was poured in a mortal and was ground with a rubber-headed pestle and also sieved using sieve No.36 (425µm) to separate the pebbles from the fines (pulverization process). Water was added to the fines on a wide glass, mixed thoroughly with the aid of spatula to obtain a paste that was subsequently wrapped with/in polythene nylon, and kept in a crucible for 24 hours so as to allow the paste to swell to its maximum capacity. Consequent upon this, water was added to the paste and mixed thoroughly with spatula. The paste was now placed in a brass cup on the Liquid limit device and levelled to a maximum depth. A long narrow cut (groove) was made along symmetrical axis on the cup. The cup was made to fall on a hard rubber base by turning the handle on the device. The number of blows that closed the groove was first noted between the ranges of 40 – 50 blows. At this point, a small sample or paste was collected along the symmetrical axis on the cup and kept in a can from where weights of wet sample and dry sample were determined to the moisture content. More water was added and the number of blows that closed the groove was noted at ranges of 30 – 40 blows, 25 – 30 blows, 15 – 25 blows and 10 – 15 blows respectively, and samples were collected to determine their moisture contents. The more the volume of water added, the lesser the number of blows that would close the groove. The sample for shrinkage limit was collected when 18 – 22 blows closed the groove. The sample was used to fill shrinkage limit mould of 12.7cm long and kept in the oven for 24 hours so as to determine linear shrinkage in percentage.

$$\text{Linear shrinkage} = \frac{(p - p')100}{p'}$$

Where;
P = Original length of mould
P' = New length of sample after oven drying.

A thread of about 3mm was made from the paste after being left for a while and kept in a can so as to determine moisture content (Plastic limit of the sample).

2.4.2. Engineering Test

Engineering tests carried out on the samples includes;

Compaction Test

The compaction test used for this research was carried out in accordance with the Standard Test Methods for Laboratory Compaction Characteristics of Soil Using Standard Effort. This was carried out to determine the Optimum Moisture Content (OMC) and Maximum Dry Density (MDD). Weights of cylindrical moulds were determined using weighing balance. The sample of laterite was divided into four different portions of about 6kg each. 100ml of water was added to the first portion and mixed thoroughly. Some parts of it were kept in two separate cans to determine weight of wet sample and weight of dry sample after spending 24 hours in the oven in order to know its moisture content. The first layer of a 5- layer cylindrical mould was filled with the sample and rammed 27 times with the aid of 4.5kg rammer. The same was done on the rest layers and rammed 27 times each. The weight of compacted wet sample was determined using weighing balance and wet density calculated thereof as shown in below. The same procedures were followed for remaining three portions but with increment of 100ml of water on each portion from the first 100ml. That is, 200ml, 300ml, 400ml of water respectively.

$$\%\ \text{MOISTURE} = \frac{\text{WEIGHT OF MOISTURE}}{\text{WEIGHT OF DRY SAMPLE}} \text{X } 100$$

$$\text{DRY DENSITY} = \frac{\text{WET DENSITY X } 100}{\%\ \text{MOISTURE CONTENT} + 100}$$

California bearing ratio (CBR)

This was carried out to estimate the bearing capacity of the soil using the California Bearing Ratio (CBR) Machine. The dry soil mixed with the CDA and $Ca(OH)_2$, water was added based on the determined OMC and was placed on the California Bearing Ratio (CBR) machine. The proofing ring gauge and plunger penetration gauge were set at zero. Immediately the plunger penetration made a contact with the soil, the gauges started working simultaneously and, the readings were taken on the proofing ring gauge at every 25 division on the plunger penetration gauge. The first 10 readings were referred to as first pointer and the 10th reading being the correct reading was adopted and multiplied with a multiplication factor of 0.18 while the last 10 readings were referred to as second pointer, and so also, the 20th reading was adopted and multiplied with a multiplication factor of 0.12. The test was done on both top and bottom of the compacted wet soil. The higher of the two values was chosen as actual CBR. The average of the top and bottom was however the final actual CBR.

3. Results and discussion

3.1. Natural Moisture Content

Sample A retains more water than sample B given by the values 26% and 6% respectively. This shows that sample A contains more silty clay than sample B.

3.2. Particle Size Analysis

The particle size distribution analysis shows not only the range of particle sizes present in a soil but also the type of distribution of various size particles.

According to clause 6201 of Federal Ministry of Works and Housing (F.M.W & H) Specification Requirement, for a sample to be used as both subgrade/fill and base, the percentage by weight passing the No.200 sieve (75μm) shall be less than but not greater than 35%.

Sequel to the above, the sample A is not a good sample because percentages by weight passing sieve No. 200 exceed 35% requirement, while sample B is good sample because it does not exceed 35% requirement.

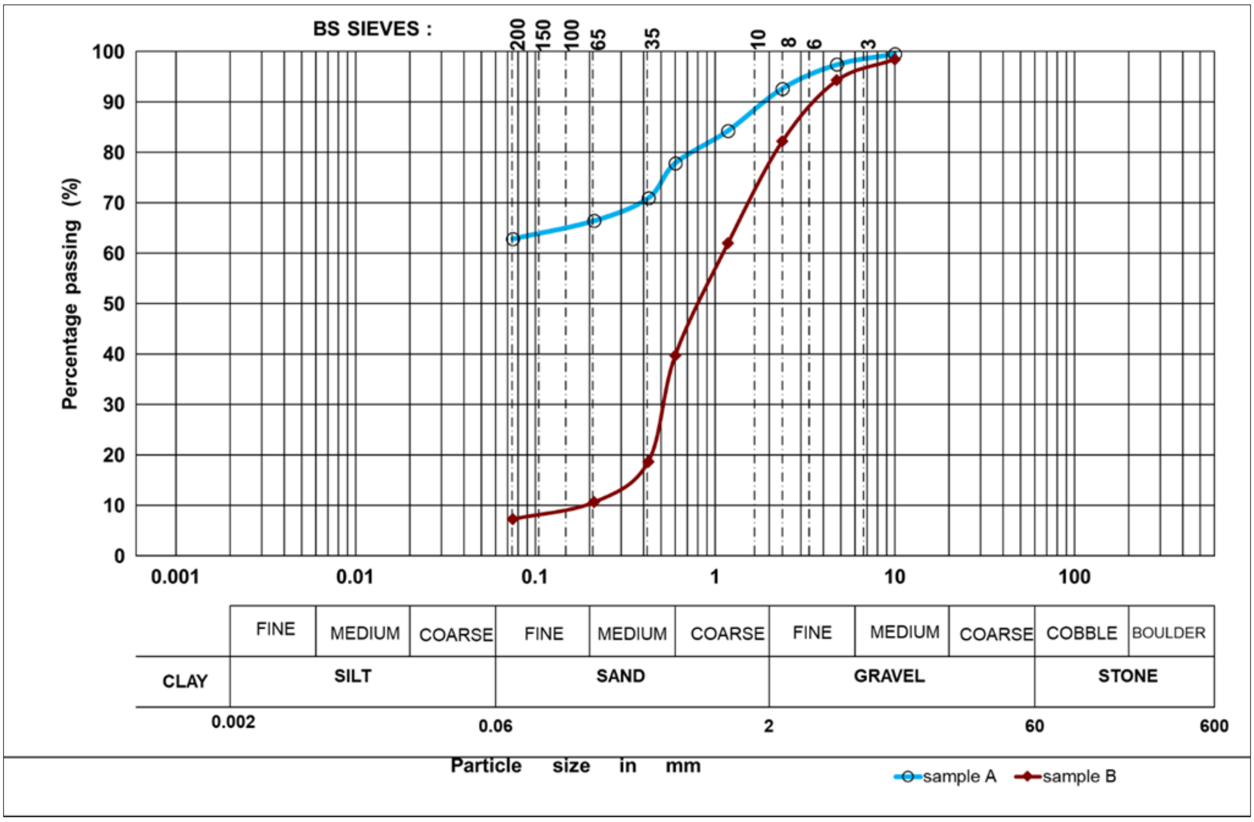

Figure 1 Particle size curve for sample A and B

3.3. Atterberg's limit

It is obvious from the results that sample A absorbs more water and swells on drying which is evident in the result of Linear Shrinkage and Plasticity index. It can be said to be more clayey/plastic than sample B.

According to Federal Ministry of Works and Housing (F.M.W & H) Specification Requirement in clauses 6201 and 6252, material passing the 425μm sieve shall have a liquid limit of not more than 35% and a Plastic Index (P.I) of not more than 12% as determined by American Society for Testing Materials Method.

In view of the above, sample B is fit to be used in constructions where necessary since its Liquid limits and Plastic Index values do not exceed the stipulated values of 35% and 12% respectively. Sample A is not a suitable sample for subgrade, since it shows Liquid Limit and Plastic Index of 48% and 25% which do not fall within the stipulated values of 35% and 12% for Liquid Limit and Plastic Index respectively.

3.4. Compaction Test

From the results obtained from the Compaction test, Table 2, sample B, has higher MDDs which is 1.87mg/m^3 while sample A has lower MDD which is 1.61mg/m^3. For Optimum Moisture Content (OMC), sample A has higher OMC which is 19.2% while samples B has OMCs of 16.36%. Because of the disparities in Optimum Moisture Contents of the samples, sample B is better, because its exhibit lower OMCs of 16.36% compared to 19.2% OMC for sample A. Sample A has affinity to absorb more water and swell on drying which is not healthy for Civil Engineering works.

Table 2 Summary of compaction test carried out on the samples

Sample	MDD (Lbs/cu.pt.)	OMC (%)
Sample A (no additives)	1.61	19.2
Sample B (no additives)	1.87	16.36

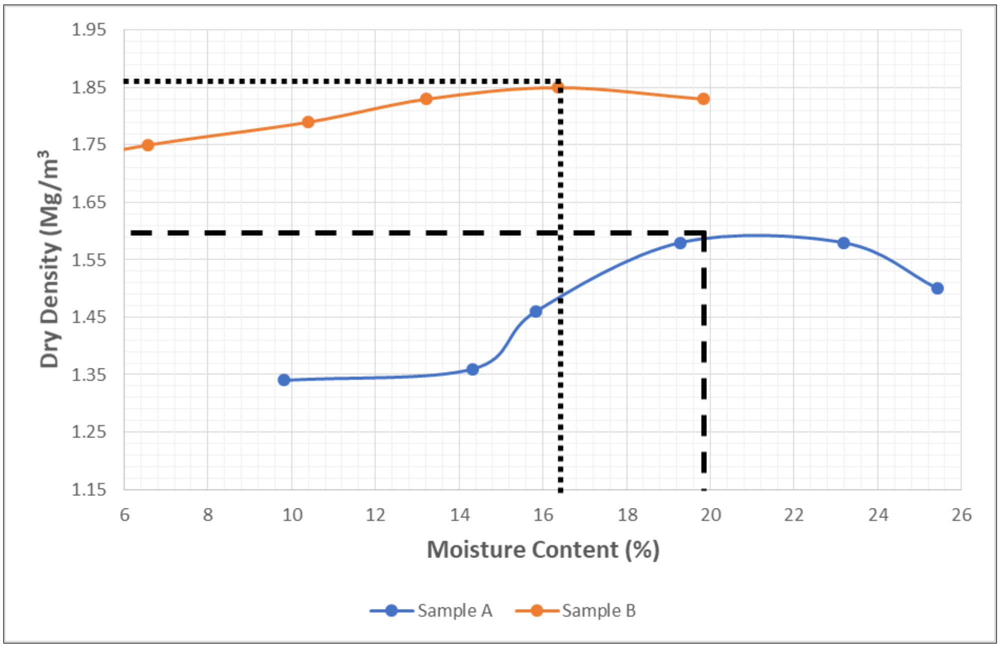

Figure 2 MDD and OMC graph of the two soil samples

3.5. California bearing ratio (CBR)

The results of California bearing ratio test; Table 3, revealed that sample A as to the varying percentage are 2.07%, 10.62% (0% CDA & 5% $Ca(OH)_2$) , 12.69%, 16.77%, 31.41% while sample B has a CBR value of 32.7%, 27.06% (0% CDA & 5% $Ca(OH)_2$), 12.09%, 16.2%, 16.74%.

CBR values of sample A increased significantly on the addition of CDA and $Ca(OH)_2$, and sample B decreased on the addition of the additives as shown in Fig 2.

This increase in strength can be attributed to;

- Presence of Silica in the additives
- Formation of cementitious compound
- Reduction in the swell potential and the fineness ratio
- Increase in sample workability, density and stiffness

This drop in the CBR values may be due to the increase in the fineness of the sample which occurs due to partial replacement of the soil samples with the additives reduces the coarse content. In natural state, water still percolates to the interstitial spaces of the soil thereby weakening them. However, it is reduced in stabilized soil states as CDA and $Ca(OH)_2$ additive has effectively bonded the soil particles to form a closely packed mass that resists and inhibits water ingress into the soil mass. It can also be noticed that the CBR value of sample B is extremely low compared to those of samples A, this can explain its non-plasticity in the liquid limit test.

Table 3 Summary of the California Bearing test (Unsoaked CBR (%)) for the two samples

	Sample A	**Sample B**
0% Ca(OH)2 0% CDA	2.07	32.7
5% Ca(OH)2 0% CDA	10.62	27.06
5% Ca(OH)2 5% CDA	12.69	12.09
5% Ca(OH)2 10% CDA	16.77	16.2
5% Ca(OH)2 15% CDA	31.41	16.74

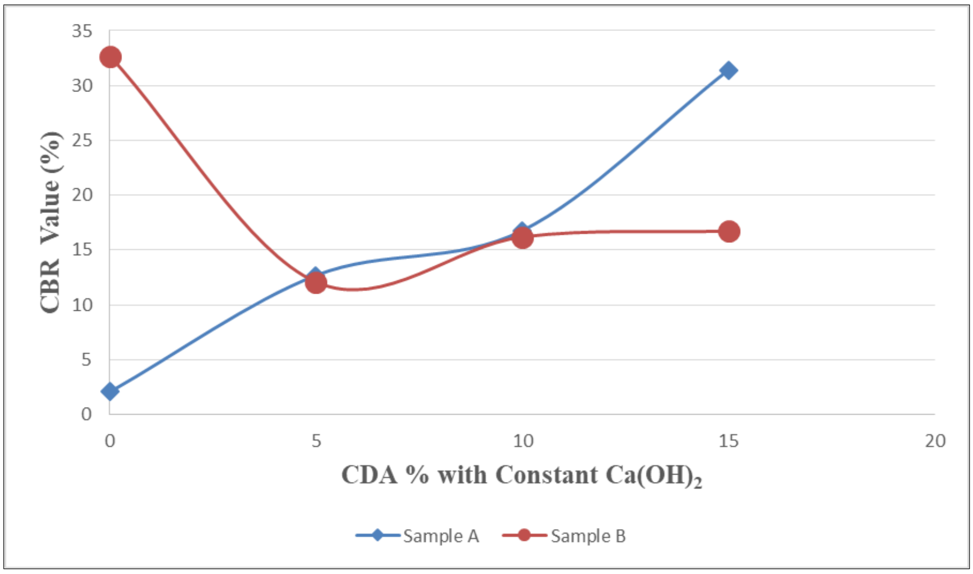

Figure 3 Variation of Unsoaked CBR with additive content for the two soil samples

4. Conclusion

A comprehensive investigation into the effects of CDA and $Ca(OH)_2$ on geotechnical properties of expansive (Sample A) and loose soil (Sample B) has been carried out. Based on the investigations of the study, the following conclusions can be drawn;

- There was an effective improvement in the CBR values as the addition of CDA and $Ca(OH)_2$ varies for the sample A.
- There was no effective improvement in the CBR values as the addition of CDA and $Ca(OH)_2$ varies for the sample B.
- CDA and $Ca(OH)_2$ can be used to stabilize expansive soil, while it is less effective for loose soil.

Recommendation

Based on the investigations of the study, the following recommendations are proffered;

- There is need to investigate further on the effect of increment of CDA and $Ca(OH)_2$ on different soil samples to determine its optimum yield/performance. 15% CDA gives the highest value of CBR value for sample A for this research.
- Cost of preparation of cow dung ash (CDA) can be reduced by the fabrication of a local kiln for calcination of burnt cow dung to be used as stabilizer for construction.

Compliance with ethical standards

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Disclosure of conflict of interest

All authors collaborated to carry out the research work. Author RSB and OAG designed and supervised the study and also drafted the manuscript while author ATO carried out the field study, laboratory as well as statistical analysis. The literature search was carried out by author OGF. The final manuscript was read and approved by all authors.

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