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Research Paper

Potential of Eggshell Powder as Replacement for Cement in Soil Stabilization

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ABSTRACT
Cement stabilized soil is used for rehabilitation projects, however due to the hazards, energy consumption and cost associated with the production and use of cement, a cheaper alternative with similar chemical property which is eggshell powder is sought as replacement for cement in soil stabilization.
Two types of tests: preliminary and mechanical tests were carried out on the both when stabilized with cement, stabilized with eggshell powder and when it is not. Preliminary tests were conducted on natural soil while mechanical tests (Compaction and California Bearing Ratio) were conducted on stabilized soil. The soil was stabilized with cement at 5%, 10%, 15%, 20% and 25% also with eggshell powder at the same percentage. The results of mechanical tests indicate that eggshell powder has stabilizing potentials for soil.
KEY WORDS: Eggshell powder, cement and stabilization

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I. INTRODUCTION

Where a poor soil is encountered, it is evident that a probable solution be sought for in the options of available alternatives. The options may include leaving the poor soil for a new site, excavation to deep foundation level, removal of the poor soil and subsequent replacement with a more suitable one, or treating the poor soil to improve its properties, otherwise known as soil stabilization.

Soil stabilization is a general term for any physical, chemical, mechanical, biological or combined method of changing a natural soil to meet an engineering purpose. Improvements include increasing the weight bearing capabilities, tensile strength and controlling the shrink-swell properties of the soil. Stabilization of soil to obtain the desired properties would be the most probable solution in situations where suitable alternative sites are not available and cost of borrow material is high. Soil stabilization can be accomplished by several methods. All these methods fall into two broad categories (FM5-410, 2012)namely;

Mechanical-stabilization
Under this category, soil stabilization can be achieved through physical process by altering the physical nature of native soil particles by either induced vibration or compaction or by incorporating other physical properties such as barriers and nailing.

Chemical-stabilization
Under this category, soil stabilization depends mainly on chemical reactions between stabilizer (cementitious material) and soil minerals (pozzolanic materials) to achieve the desired effect. A chemical stabilization method is the fundamental of this review and, therefore, throughout the rest of this report, the term soil stabilization will mean chemical stabilization.

Through soil stabilization, unbound materials can be stabilized with cementitious materials (cement, lime, fly ash, bitumen or combination of these). The stabilized soil materials have a higher strength, lower permeability and lower compressibility than the native soil(Keller Inc, 2011). The method can be achieved in two ways, namely: in situ stabilization and ex-situ stabilization.

Soil stabilization aims at improving soil strength and increasing resistance to softeningby water through bonding the soil particles together, water proofing the particles orcombination of the two (Sherwood, 1993). These may involve increasing the soil density, increase in cohesion, frictional resistance and reduction of plasticity index. Researchers all over the world have studied various materials that can be used in conjunction with soil to improve soil properties. Of all the various studies conducted around the world, the most commonly used and effective stabilizer for lateritic soil was found to be cement.

The manufacture of cement requires quarrying to mine for ingredients and subjecting the ingredients in a kiln to about 2,700 degrees Fahrenheit of heat, the cost of cement and the energy required to produce it coupled with the environmental hazard associated with the production of cement gives rise to this study which is an attempt to replace cement with egg shell powder without compromising on the strength.

Eggshell are agricultural wastes which when subjected to adequate preservation could be suitable for soil stabilization because of their calcium based chemical composition(M. & M., 2007). About $7x10^7$metric tons of eggs are produced in the world yearly, 192640 metric tons of eggs are produced in Nigeria and 12.5% of 192640 metric tons are produced by the local hens. Eggshell, preferably the chicken eggshell perceived as a waste material could be annexed for use as a replacement for soil stabilizer like cement since they both share similar chemical composition(Arias & Fernandez, 2001)

Eggshells in the construction industry can replace 10-30% of cement in a mix and can also improve the properties of concrete such as durability and creep(Romanoff, A.L., A.J. Romanoff, 1949). So many researches were made suing egg shell ash to check its effect on stabilizing agents like lime cement, common salt, bamboo leaf ash etc. and these yielded positive results(Arias & Fernandez, 2001).

Eggshell powder is an ideal material to replace cement in the stabilization process due to its similar chemical composition. The chief ingredient in eggshell powder is calcium carbonate which makes it similar to cement. Eggshells are disposed from hotels, restaurants etc. in huge quantities and they are currently facing disposal problems. Use of eggshell powder in soil stabilizers reduce the disposal problems associated with egg shells generations. Moreover, powdering of eggshell can be done easily. Eggshell powder generation does not involve the generation of $CO_{2,}$ as in the case of cement where heating is done up to 2,700 degrees Fahrenheit. Hence use of eggshell powder in soil stabilization, will make the overall stabilization process economical, sustainable and eco-friendly.

An Eggshell is the outer covering of a hard-shelled egg and of some forms of eggs with soft outer coats. There are a large variety of styles and shapes of eggs. Some of them have gelatinous or skin-like coverings; others have hard eggshells as in the case of insects and other arthropods. Fish and amphibians generally lay eggs which are surrounded by the extra-embryonic membranes but do not develop a shell, hard or soft, around these membranes.

The bird egg is a fertilized gamete located on the yolk surface and surrounded by albumen, or egg white. The albumen in turn is surrounded by two shell membranes (inner and outer membranes) and then the eggshell. The chicken eggshell is 95-97%(Hunton, 2005) calcium carbonate crystals, which are stabilized by a protein matrix (Arias & Fernandez, 2001). Without the protein, the crystal structure would be too brittle to keep its form and the organic matrix is thought to have a role in deposition of calcium during the mineralization process (Lavelin, Meiri, & Pines, 2000). Eggshell formation requires gram amounts of calcium being deposited within hours, which must be supplied via the hen’s diet.

Eggshell Production

The US food industry generates 150,000 tons of shell waste a year. The disposal methods for waste eggshells are 26.6% as fertilizer, 21.1% as animal feed ingredients, 26.3% discarded in municipal dumps, and 25.9% used in other ways. But eggshell don’t necessarily have to be discarded at all. They consist of calcium carbonate, along with small amounts of protein and other organic compounds as they are even the cheapest sources of calcium.

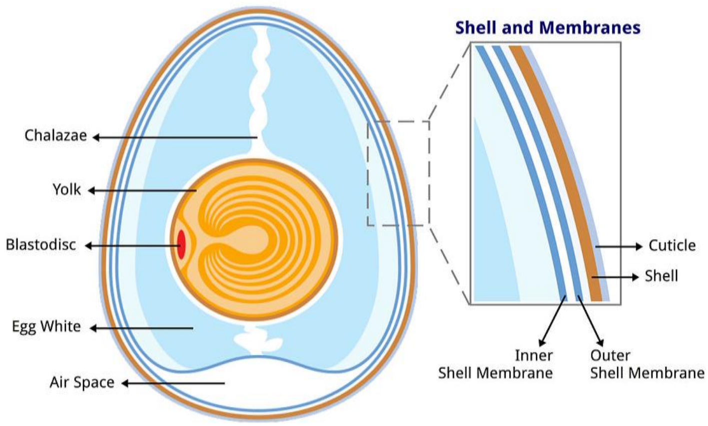

Figure 1 Bird eggs

II. MATERIALS AND METHODS

2.1 Collection of Samples

Laterite

The sample was gotten from the laterite excavated from a construction site and was taken to laboratory for soil classification tests.

Cement

The cement used was ordinary Portland cement (NIS 444, 2003) bought from cement depot at Ilorin, Nigeria.

Eggshell Powder

Eggshells were sourced for locally and were grinded cleaned and the powder was made and preserved by me with help from my colleagues.

Water

Uncontaminated tap water was used to perform the different experiments.

2.2Preliminary Tests

Preliminary tests were carried out in accordance with ASTM standard (ASTM, 2006). (specific gravity, sieve analysis, water content determination, Atterberg limit)

Specific Gravity Determination

Purpose: This test is performed to determine the specific gravity of soil by using a pycnometer. Specific gravity is the ratio of the mass of unit volume of soil at a stated temperature to the mass of same volume of gas-free distilled water at a stated temperature.

Sieve Analysis

Purpose: This test is performed to determine the percentage of different grain sizes contained within a soil. The mechanical or sieve analysis is performed to determine the distribution of the coarser, larger-sized particles, and the hydrometer method is used to determine the distribution of finer particles.

Water content Determination

Purpose: This test was performed to determine the water (moisture) content of soils. The water content is a ratio, expressed as a percentage, of the mass of “pore” or “free” water in a given mass of soil to the mass of the dry soil solids.

Atternerg’s Limits

Significance: To classify fine-grained soils, the liquid and plastic limits are commonly used. The Atterberg limits are based on the moisture content of the soil. The plastic limit is the moisture content that defines where the soil changes from a plastic to a viscous fluid state. A wide variety of soil engineering properties have been correlated to the liquid and plastic limits, and these Atterberg limits are also used to classify a fine-grained soil according to the Unified Soil Classification system or AASHTO system. The liquid limit and the plastic limit of the soil sample is gotten from the test procedures and the values are used to calculate the plasticity index of the soil sample by using the formula Plasticity index (PI) = Liquid limit (LL) – Plastic limit (PL).

2.3 Mechanical Tests

Compaction Test

Significance: Mechanical compaction is one of the most common and cost effective means of soil stabilization. An extremely important task of geotechnical engineers is the performance and analysis of field control tests to assure that compacted fields met the design specifications. Design specifications usually state the required density (as a percentage of the “maximum” density measured in a standard laboratory test), and the water content. In general, most engineering properties, such as the strength, stiffness, resistance to shrinkage and imperviousness of the soil, will improve by increasing the soil density. The optimum water content is the water content that results in the greatest density for a specified compactive effort. Compacting at water content higher than (wet of) the optimum water content results in a relatively dispersed soil structure meaning weaker, more ductile, softer, more susceptible to shrinking than soil compacted dry of optimum to the same density. The soil compacted lower than (dry of) the optimum water content typically results in flocculated soil structure (random particle orientation) that has the opposite characteristics of the soil compacted wet of the optimum water content to the same density.

California Bearing Ratio (CBR)

California Bearing Ratio (CBR) test was developed by the California Division of Highway as a method of classifying and evaluating soil subgrade and base course materials forflexible pavements.CBR test, an empirical test, has been used to determine the material properties for pavement design. Empirical tests measure the strength of the material and are not a true representation of resilient modulus. It is a penetration test wherein a standard piston, having an area of 3 in^2 (or 50 mm diameter), is used to penetrate the soil at a standard rate of 1.25 mm/minute. The pressure up to a penetration of 12.5 mm and its ratio to the bearing value of a standard crushed rock is termed as the CBR.

In most cases, CBR decreases as the penetration increases. The ratio at 2.5 mm penetration is used as the CBR. In some cases, the value at 5 mm may be greater than that at 2.5 mm. If this occurs, the ratio at 5 mm is used. The CBR is the measure of resistance of a material to penetration of a standard plunger under controlled density and moisture conditions. The test procedure is to be strictly adhered if high degree of reproductibility is desired. The test may be conducted in re-moulded or undisturbed specimen in the laboratory. The test is simple and has been extensively investigated for field correlations of flexible pavement thickness requirement.

Test Procedure

The laboratory CBR aparatus consists of a mould with 150 mm diameter with a base plate and a collar, a loading frame and dial guages for measuring the penetration values and the expansion on soaking.

The specimen in the mould was saoked in water for 4 days and the swelling and water absorption values was noted. The surcharge weight was placed on top the specimen in the mould and the assembly was placed under the plunger of the loading frame.

Load was applied on the sample by a standard plunger with a diameter of 50 mm at the rate of 1.25 mm/minute. A load penetration curve was was drawn. The load values on standard crushed stones are 1370 kg and 2055 kg at 2.5 mm and 5.0 mm penetrations respectively.

CBR value is expressed as a percentage of the actual load causing the penetrations of 2.5 mm or 5.0 mm to the standard loads mentioned above, therefore:

CBR = load carried by specimen / load carried by standard specimen x 100

Two values of CBR was obtained (at 2.5 and at 5.0 mm penetrations). If the value at 2.5 mm is greater than that at 5.0 mm penetration, the former is adopted. If the CBR value at 5.0 mm penetration is higher than that at 2.5 mm, then the test was repeated for checking. If the check test again gives similar results, then the higher value obtained at 5.0 mm penetration was reported as the CBR value. The average CBR value of three test specimens was reported as the CBR value of the sample.

III. RESULTS AND DISCUSSION

3.1 Specific Gravity

A – Weight of measuring cylinder + Specimen + Water

B – Weight of Specimen

C – Weight of measuring cylinder + Water

Specific gravity = $\frac{B}{B+C-A}$

B = 528.5g, A = 1770.5g, C = 1471.5g

Specific gravity = $\frac{528.5g}{528.5g+1471.5g-1770.5g} = \frac{528.5g}{229.5g}$ = 2.3

3.2 Sieve Analysis

The coefficient of uniformity and coefficient of curvature were obtained from the sieve analysis test to be 5.379 and 0.911 respectively (Figure2) which indicates that the soil is a poorly graded soil according to Unified Soil Classification for fine aggregates. With a PI of 10.6, LL of less than 40, and less than 35% passing the 0.075 sieve and less than 51% passing both sieves 0.425mm and 2mm, the soil falls under the classification of A-2-6 group according to AASHTO, and its general rating as a subgrade is excellent to good. The specific gravity was derived from the specific gravity test (section 3.1) and the plasticity index was gotten from the difference between the plastic and liquid limit gotten from the Atterberg limit test (Tables 1and 2).

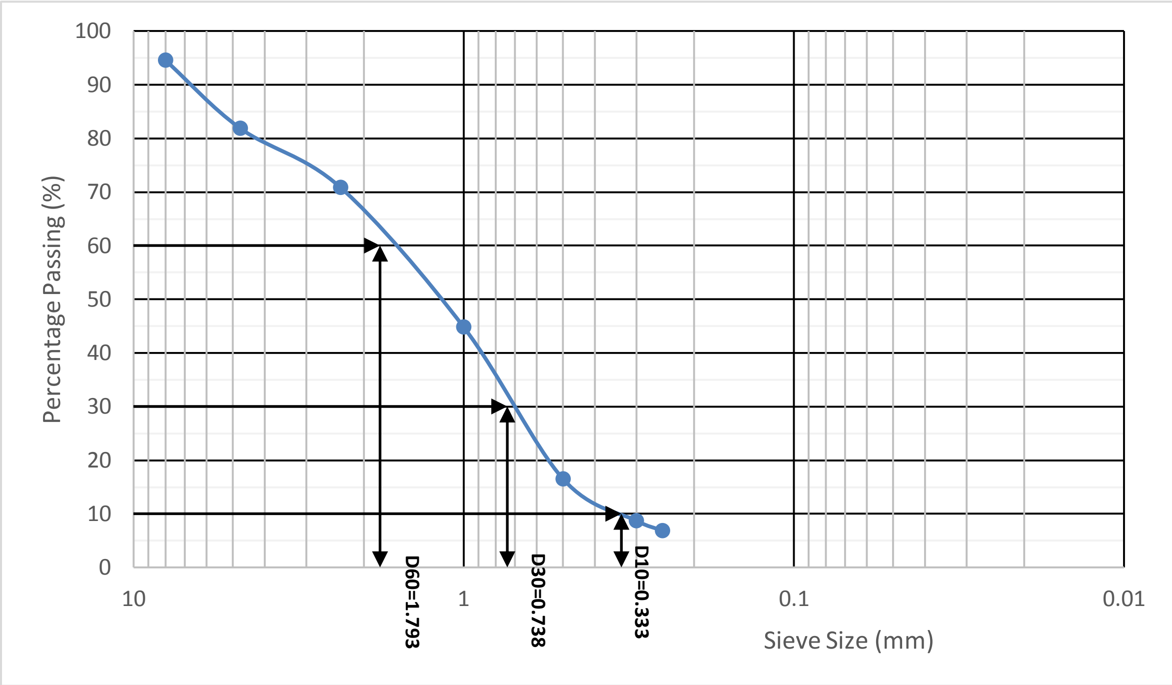

Figure 2 Particle size distribution curve

Coefficient of uniformity, $C_u = \frac{D60}{D10} = \frac{1.793}{0.333} = 5.379$

Coefficient of curvature, $C_C = \frac{D30\hat{}2}{D10*D60} = \frac{0.738\hat{}2}{0.333*1.993} = 0.911$

3.3 Natural Moisture Content

$W (\%) = \frac{M_3 - M_2}{M_2 - M_1} * 100\%$

Where M_1 = Mass of empty moisture can

M_2 = Mass of oven dried soil + moisture can

M_3 = Mass of moist soil + moisture can

Table 1 Table of natural moisture content data

Moisture cans	M_1 (g)	M_2 (g)	M_3 (g)	W (%)
F0	25.0	127.0	137.5	$\frac{10.5}{102} * 100\% = 10.29$
Y2	23.5	121.5	132.0	$\frac{10.5}{98} * 100\% = 10.71$
R1	24.5	113.0	122.5	$\frac{9.5}{89} * 100\% = 10.93$
U1	24.0	118.5	128.5	$\frac{10}{94.5} 100\% = 10.58$

Average moisture content $= \frac{F0+Y2+R1+U1}{4} = \frac{10.29+10.71+10.73+10.58}{4} = \frac{42.31}{4} = 10.58\%$

Liquid Limit

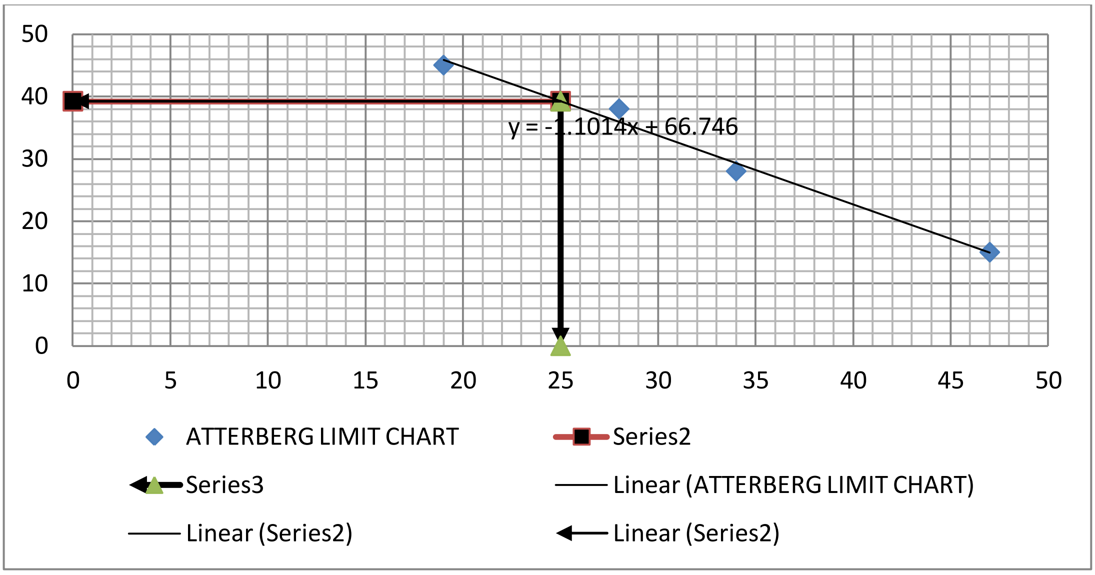

Figure 3 Liquid Limit Chart

Hence liquid limit is 39.21%

Plastic Limit

Table 2 Table of plastic limit data

Can no	1	2	3	4
Weight of wet soil + can (g)	33.5	31.5	32.5	33.0
Weight of dry soil + can (g)	32.0	30.0	30.5	31.0
Weight of empty can (g)	25.5	24.0	24.5	24.5
Weight of dry soil (g)	6.5	5.5	6.0	6.5
Weight of moisture (g)	1.5	1.5	2.0	2.0
Water content (%)	23.08	27.27	33.33	30.77

Average moisture content= (23.08+36.36+33.33+36.36)/4 = 28.61%
Plastic limit is 28.61%
Plasticity index = LL – PL = 39.21-28.61 = 10.6

3.4 **Compaction Test**

From the compaction curve in Figures 4-13, the results of the maximum dry density and optimum moisture content are given as follows;

1. 0% Stabilization: MDD = 1.78g/cm^3, OMC = 16.78%
2. 5% Cement Stabilization: MDD = 1.76g/cm^3, OMC = 16.5%
3. 10% Cement Stabilization: MDD = 1.724g/cm^3, OMC = 14%
4. 15% Cement Stabilization: MDD = 1.76g/cm^3, OMC = 15.9%
5. 20% Cement Stabilization: MDD = 1.78g/cm^3, OMC = 14.4%
6. 25% Cement Stabilization: MDD = 1.78g/cm^3, OMC = 17.8%
7. 5% ESP Stabilization: MDD = 1.76g/cm^3, OMC = 16.5%
8. 10% ESP Stabilization: MDD = 1.78g/cm^3, OMC = 15.8%
9. 15% ESP Stabilization: MDD = 1.8g/cm^3, OMC = 14%
10. 20% ESP Stabilization: MDD = 1.84g/cm^3, OMC = 12.4%

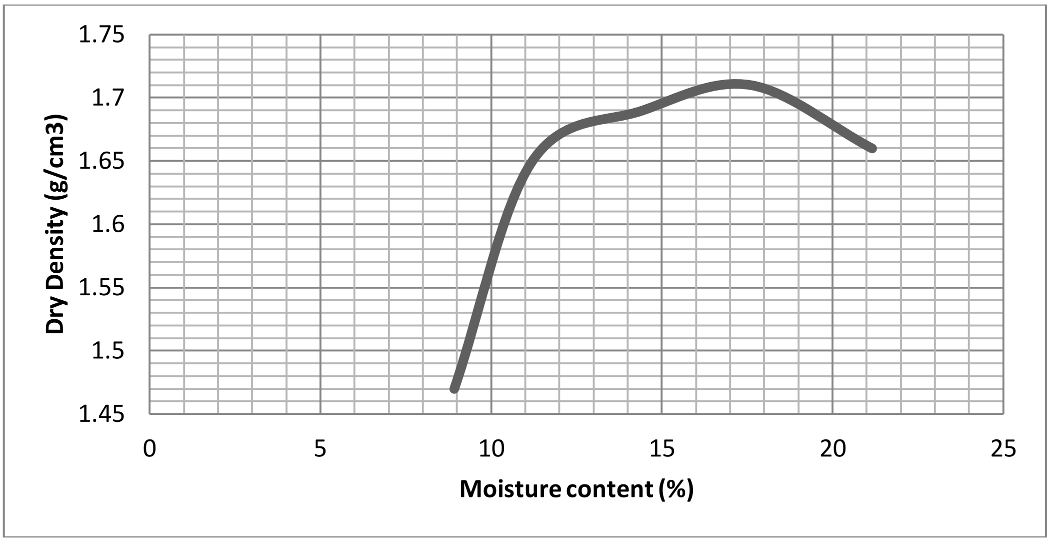

Figure 4 Graph for Compaction Test at 0% stabilization

From the graph; MDD = 1.71g/cm^3, OMC = 16.78%

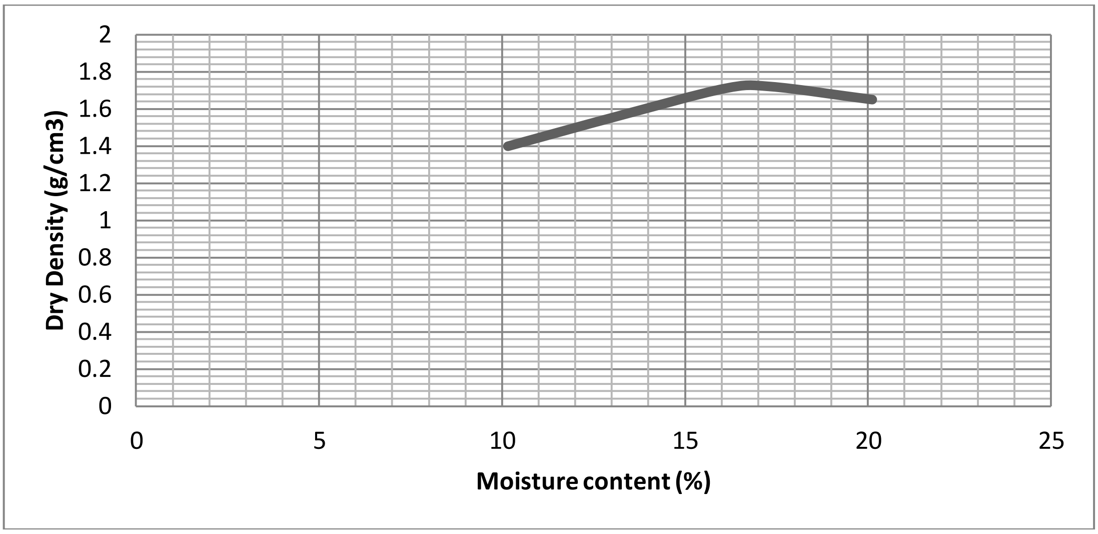

Figure 5 – Graph for Compaction Test at 5% cement stabilization

From the graph above; MDD = 1.72g/cm^3,OMC = 16.5%

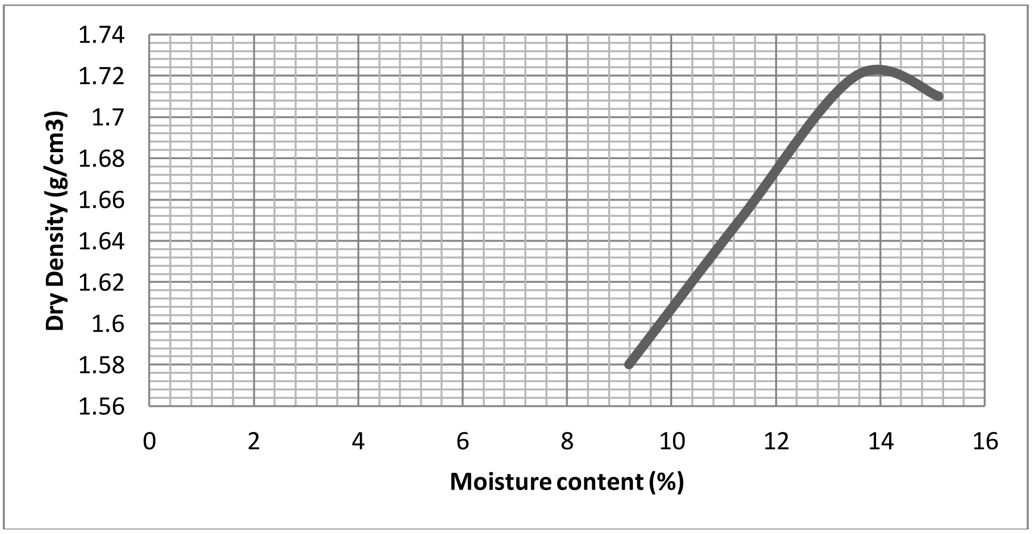

Figure 6– Graph for Compaction Test at 10% cement stabilization

From the graph ; MDD = 1.724g/cm^3,OMC = 14

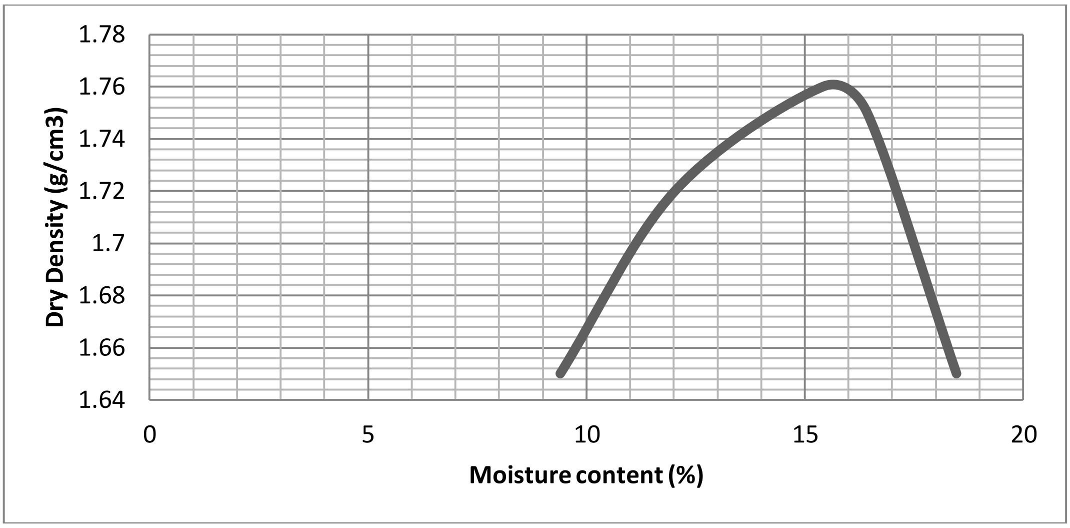

Figure 7 Graph for Compaction Test at 15% cement stabilization
From the graph;MDD = 1.76g/cm^3,OMC = 15.6%

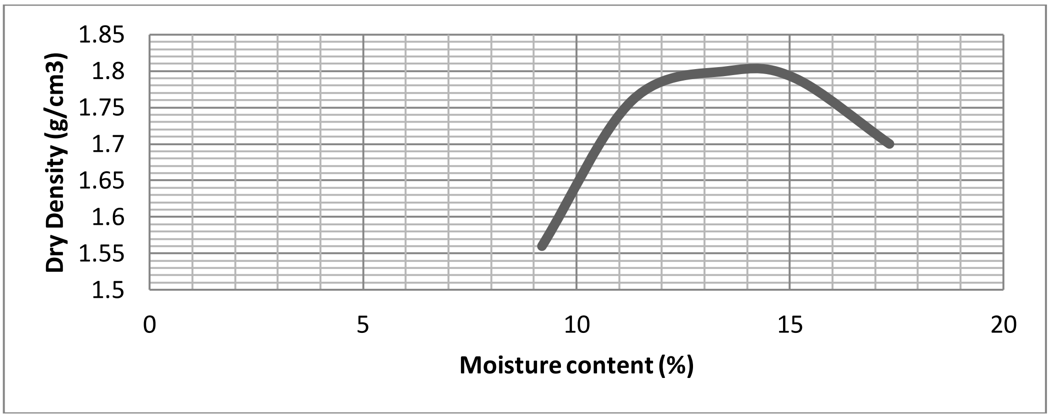

Figure 8 Graph for Compaction Test at 20% cement stabilization
From the graph ; MDD = 1.8g/cm^3,OMC = 14.4%

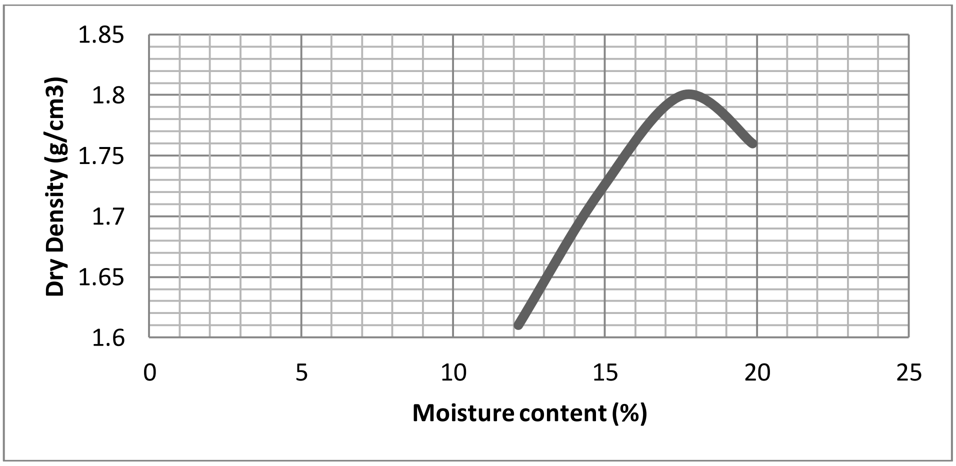

Figure 9 Graph for Compaction Test at 25% cement stabilization
From the graph; MDD =1.8 g/cm^3 ,OMC = 17.8%

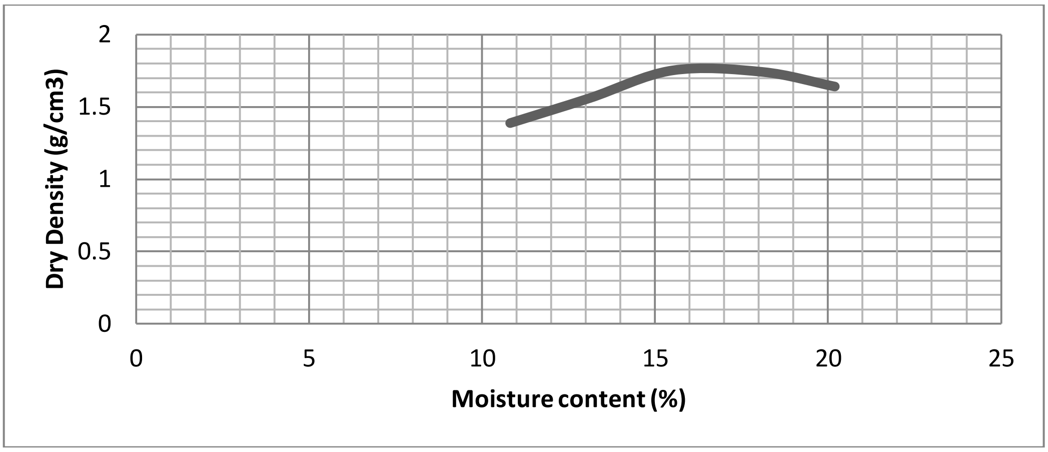

Figure 10 Graph for Compaction Test at 5% ESP stabilization

From the graph; MDD = 1.76g/cm^3 ,OMC = 16.5%

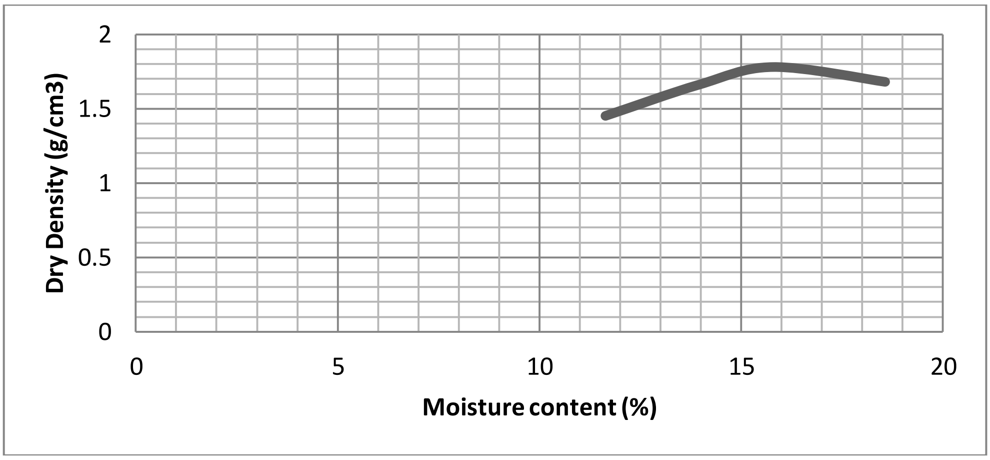

Figure 11 Graph for compaction test at 10% ESP powder

From the graph; MDD = 1.78g/cm^3,OMC = 15.8%

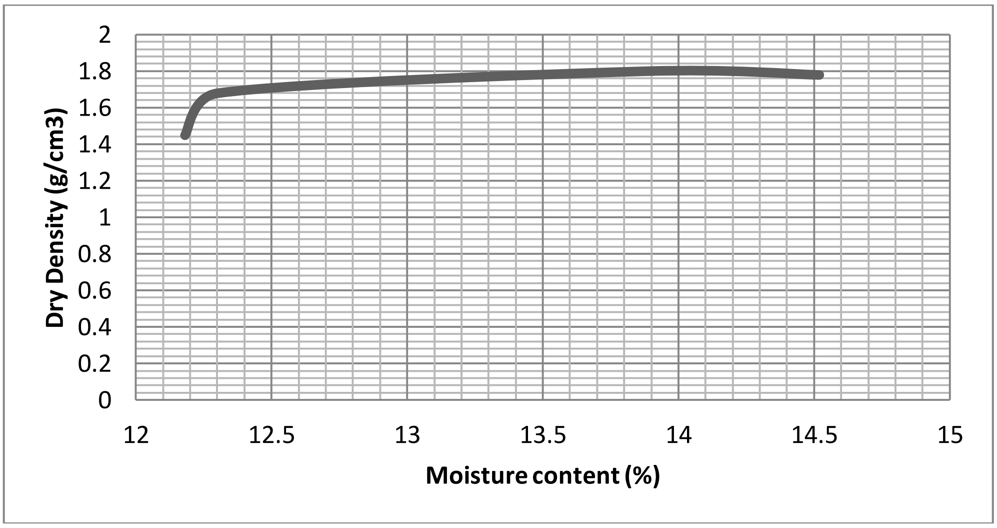

Figure 12 Graph for Compaction Test at 15% ESP stabilization

From the grap ;MDD = 1.8g/cm^3, OMC = 14%

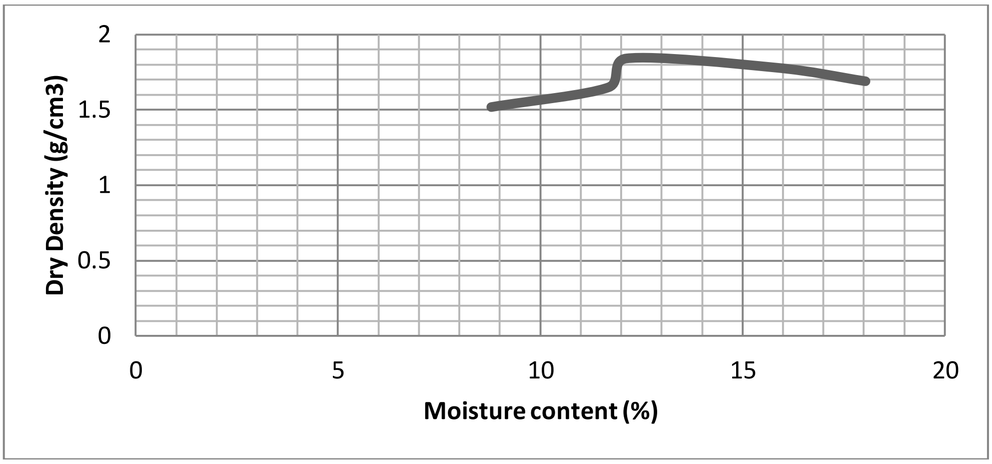

Figure 13 Graph for Compaction Test at 20% ESP stabilization

From the graph; MDD = 1.84g/cm^3,OMC = 12.4%

3.5 **Californian Bearing Ratio data and analysis**

California Bearing Ratio Test

The results of the California bearing ratio calculated are as follows inTables 3-5;

(i) 0% Stabilization: CBR= 28.84%.

(ii) 20% Cement Stabilized: CBR= 90.74%.

(iii) 20% ESP Stabilized: CBR= 67.46%.

Table 3 Table of California bearing ratio at 0% stabilization

Soil description: Reddish lateritic soil				
Penetration (mm)	Force on plunger (kg)	Reading x 0.032 x 2.931	Force on plunger (kg)	Reading x 0.032 x 2.931
0.25	8	0.750336	5	0.46896
0.5	11	1.031712	8	0.750336
0.75	13	1.219296	10.5	0.984816
1	14	1.313088	11	1.031712
1.5	16	1.500672	18.5	1.735152
2	21	1.969632	26.5	2.485488
2.5	25	2.3448	33	3.095136
3	30.5	2.860656	40	3.75168
4	44	4.126848	52.5	4.92408
5	60.5	5.674416	63.5	5.955792
6	72.5	6.79992	73.5	6.893712
7	83	7.784736	83	7.784736
8	95	8.91024	91	8.535072
9	104.5	9.801264	98.5	9.238512
10	113	10.5985	104.5	9.801264

Top Penetration
CBR at 2.5mm penetration = (2.3448/13.44) * 100 = 17.49%
CBR at 5.0mm penetration = (5.674416/20.16) * 100 = 28.15%
Bottom Penetration
CBR at 2.5mm penetration = (3.095136/13.44) * 100 = 23.03%
CBR at 5.0mm penetration = (5.955792/20.16) * 100 = 29.54%
The highest CBR values are 28.15% and 29.54%
Hence, CBR = (28.14 + 29.54)/2 = 28.84%

Table 4 able of California bearing ratio at 20% cement stabilization

Soil description: Reddish lateritic soil + 20% cement				
Penetration (mm)	Force on plunger (kg)	Reading x 0.032 x 2.931	Force on plunger (kg)	Reading x 0.032 x 2.931
0.25	34	3.188928	19	1.782048
0.5	48	4.502016	28	2.626176
0.75	53	4.970976	48	4.502016
1	58	5.439936	68	6.377856
1.5	66	6.190272	188	17.632896
2	74	6.940608	154	14.443968
2.5	84	7.878528	172	16.132224
3	94	8.816448	188	17.632896
3.5	101	9.472992	203	19.039776
4	110	10.31712	218	20.446656
4.5	123	11.53642	225	21.1032
5	132	12.38054	223	20.915616
6	152	14.25638	248	23.260416
7	166	15.56947	251	23.541792
8	182	17.07014	257	24.104544
9	198	18.57082	259	24.292128
10	211	19.79011	256	24.010752

Top penetration
CBR at 2.5mm penetration = (7.878528/13.44) * 100 = 58.62%
CBR at 5.0mm penetration = (12.38054/20.16) * 100 = 61.41%
Bottom penetration
CBR at 2.5mm penetration = (16.132224/13.44) * 100 = 120%
CBR at 5.0mm penetration = (20.915616/20.16) * 100 = 103.8%
The highest CBR values are 120% and 61.41%
Hence, CBR = (120+61.41)/2 = 90.71%

Table 5 Table of California bearing ratio at 20% eggshell powder stabilization

Soil description: Reddish lateritic soil + 20% eggshell powder				
Penetration (mm)	Force on plunger (kg)	Reading x 0.032 x 2.931	Force on plunger (kg)	Reading x 0.032 x 2.931
0.25	26	2.43859	19	1.78205
0.5	38	3.56410	29	2.71997
0.75	45	4.22064	32	3.00134
1	50	4.68960	54	5.06477
1.5	62	5.81510	79	7.40957
2	69	6.47162	98	9.19162
2.5	89	8.34749	104	9.75437
3	107	10.0357	111	10.4109
3.5	115	10.7861	124	11.6302
4	126	11.8178	139	13.0371
5	134	12.5681	153	14.3502
6	141	13.2247	168	15.7571
7	152	14.2564	171	16.0384
8	164	15.3819	193	18.1019
9	170	15.9446	201	18.8522
10	183	17.1639	204	19.1336

Top penetration

CBR at 2.5mm penetration = (8.34749/13.44) * 100 = 62.11%

CBR at 5.0mm penetration = (12.5681/20.16) * 100 = 62.34%

Bottom penetration

CBR at 2.5mm penetration = (16.132224/13.44) * 100 = 72.58%

CBR at 5.0mm penetration = (14.3502/20.16) * 100 = 71.18%

The highest CBR values are 62.34% and 72.58%

Hence, CBR = (62.34+72.58)/2 = 67.46%

IV. CONCLUSION

After a thorough investigations with the results obtained from tests conducted on the performance characteristics of laterite soils stabilized with Eggshell Powder as Replacement for Cement the following conclusion can be drawn.

1. The soil is **well graded**
2. 20% eggshell powder stabilization gave the best compaction result because it has the highest value of maximum dry density and the lowest optimum moisture content.
3. The CBR value at 20% eggshell stabilization is 67.46% which is optimum
4. Stabilizing the soil with eggshell powder improves the maximum dry density and optimum moisture content more than stabilizing with cement. However, even though the CBR value increased when the soil was stabilized with eggshell powder, cement stabilization still gave a higher CBR value.
5. The results observed from the tests indicate that eggshell powder has soil stabilizing potential.

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