Journal of Applied Sciences

ISSN 1812-5654

Journal of Applied Sciences 5 (8): 1474-1478, 2005
ISSN 1812-5654

Effect of Eggshell Powder on the Stabilizing Potential of Lime on an Expansive Clay Soil

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Abstract: This research was meant to study the effect of Eggshell Powder (ESP) on the stabilizing potential of lime on an expansive clay soil. Tests were carried out to determine the optimal quantity of lime and the optimal percentage of lime-ESP combination; the optimal quantity of lime was gradually replaced with suitable amount of eggshell powder. The lime stabilized and lime-ESP stabilized mixtures were subjected to engineering tests. The optimal percentage of lime-ESP combination was attained at a 4% ESP + 3% lime, which served as a control. Results of the Maximum Dry Density (MDD), California Bearing Ratio (CBR), unconfined compression test and Undrained triaxial shear strength test all indicated that lime stabilization at 7% is better than the combination of 4% ESP + 3% lime.

Key words: Eggshell powder, stabilization, lime, clay soil

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, redesigning the structure for the poor condition or treating the poor soil to improve its properties, otherwise known as stabilization[1]. Stabilization of soil to obtain the desired properties would be the most probable solution in situations where suitable alternative sites are not available, where land disputes are likely to occur over relocation and cost of borrow material is high.

Expansive soil, mostly clay often requires treatment by stabilization. They are characterized by the phenomenon of swelling when wet; this makes them highly problematic as foundation soils.

Stabilization is aimed at improving the engineering properties of soil, which may involve increasing the soil density, increase in cohesion, frictional resistance and reduction of plasticity index. Some of the materials that have been used in soil stabilization include lime, cement, fly ash etc. They have been used solely and in combinations with other stabilizing materials to effect a chemical change in the soil. Previous researches have revealed that soil could be stabilized effectively using lime, cement, lime and cement, lime and fly ash combined together in proportion by mass or by weight[2].

Eggshell Powder (ESP) has not being in use as a stabilizing material and it could be a good replacement for industrial lime, since its chemical composition is similar to that of lime. Chicken eggshell is a waste material from domestic sources such as poultries, hatcheries, homes and fast food joints. This amounts to environmental pollution. Eggshell waste falls within the category of waste food, they are materials from the preparation of foods and drinks, if subjected to adequate scrutiny, they could be suitable for soil stabilization[3].

The deplorable state of Nigerian economy has brought about inflation, resulting in a continuous rise in prices of materials. The use of lime for stabilization is therefore becoming expensive requiring an economical replacement. Literature has shown that eggshell primarily contains lime, calcium and protein[4]. It has being in use as a source of lime in agriculture, which confirms that lime is present in considerable amount in eggshell. Now, the question is: should we continue to buy lime at a high cost when we can get a cheap replacement in eggshells?

Subsequent findings revealed that ESP was used for stabilization of a cohesionless soil in Japan[3]. This study is thus directed towards identifying eggshell powder as an effective stabilizing agent by replacing a certain percentage of the lime in the stabilized soil with ESP. Since the quantity of eggshell that may be required for stabilization of a large area may not be met, it is suggested that the ESP be used as a supplement in lime stabilization.

In a well-organized environment, disposal of waste poses a great problem, as regards where and how to

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effectively dispose the waste product without any adverse effect on the society. Specifically, the disposal of eggshell and hatchery waste is reported to be a great difficulty in the United Kingdom, the estimated quantity of eggshell waste to be disposed each year is between 10,000-11,000 tons in UK[4]. Thus, an estimate of about 5,000-6,000 tons could also be expected in Nigeria annually, therefore, in the absence of an effective waste disposal policy, the utilization of eggshell for soil improvement, either for agriculture or engineering purposes will be a welcome development.

Clay: This is a fine soil with particle sizes less than 0.002 mm. They are typically flaky in shape and this account for their usually very large surface area[5]. Clay exhibits plasticity and is cohesive. The behaviour of clay is best studied by identification and analysis of the various clay minerals and the structure assumed.

The analysis of clay minerals is for the study of the shrinkage and swelling behaviour otherwise known as activity, as clay finds its applications surprisingly in the manufacture of edible materials. Kaolinite, a clay mineral, is the main ingredient in kaopectate, a remedy for stomach upset[3]. This application proves that clay popularly believed to be a non-useful; almost unitilizable material is relevant for some other tasks. Montmorillonite is one of the most interesting clay minerals; it is better known as expansive clay or swelling clay. If water is added to the montmorillonite, the water molecules are adsorbed into the spaces between silicates layers.

Adsorption results in large increase in volume, sometimes up to several hundred percent. The pressure generated can be up to 50,000 kg m^{-2}. This is sufficient to lift a good-sized building[3]. If a building is erected on expansive clay that subsequently gets wet, a portion of the building will be shoved upward. In all likelihood, the building will break. Some people think that expansive soils have caused more damages than earthquakes and landslides combined together[6].

On the other hand, swelling clay can be put to use. Montmorillonite mixed with water can be pumped into fractured rock or concrete, when the water is adsorbed, swelling clay expands to fill and seal the rock. The technique is particularly useful where dam have been built against fractured bedrock. Sealing the crack with expansive clays ensures that water will stay in the reservoir behind the dam[7].

Eggshell Powder: Eggshell consists of several mutually growing layers of $CaCO_3$, the innermost layer-maxillary layer (=100 μm) grows on the outermost egg membrane and creates the base on which palisade layer constitutes the thickest part (=200 μ) of the eggshell. The top layer is a vertical layer (=5.8 μ) covered by the organic cuticle[2]. Table 1 shows the mineral composition of eggshell.

Tocan[4] stated that eggshell primarily contains calcium, magnesium carbonate (lime) and protein. He however evaluated the quantity of the lime in eggshell waste to be as almost the same as ground chalk or limestone tonne for tonne. Eggshell waste does have a theoretical value either as an animal feed or as a fertilizer or lime substitute. In many other countries, it is the accepted practice for eggshell to be dried and use as a source of calcium in animal feeds. The quality of lime in eggshell waste is influenced greatly by the extent of exposure to sunlight, raw water and harsh weather conditions. Froning and Bergquist[8] specified that eggshell waste should be ground not more than 2 days after recovery from source to prevent depletion of lime content.

The physical nature of the shell waste and the foul rotten egg odours produced when the material degrades, reduce the lime value and renders the waste difficult to recycle to land[4]. Ideally, the waste should be dried at source, transported to a site where it would be finely ground immediately and used as source of lime to agriculture and for other applications. In order to maximize the recycling opportunities for eggshells, Froning and Bergquist[8] recommended that eggshell waste should be incinerated independently of other wastes so that the calcium/magnesium content of the shell will be converted into calcium/magnesium oxide (quicklime) and the resultant burnt lime could be used as a liming agent.

Stabilization: Stabilization is the alteration of foundation soils to conform to desired characteristics or the improvement of a less stable soil in both strength and durability[5]. Many soils are subject to differential expansion and shrinkage when they undergo changes in moisture content. Many soil also move and rut when subjected to moving wheel loads. It is therefore usually necessary to stabilize them to reduce the volume changes and strengthen them to the point where they can carry the imposed load, even when they are saturated[9].

Earlier, soil improvement has being in the qualitative sense only, but more recently, it has also become associated with quantitative values of strength and durability, which are related to performance. These quantitative values include compressive strength, shearing strength, load bearing quality, adsorption softening and reduction in strength etc. The investigation of soil condition on site will indicate whether stabilization is needed or not and tests may be necessary to determine which of the several techniques may be feasible and economical.

In the broadest sense, stabilization refers to any treatment of soil, which renders it more stable. The type and degree of stabilization is a function of availability, cost and the intending use of the stabilized soil mixture. This makes for the effective utilization of local materials with a view towards lowering cost[10].

In combination with compaction, soil stabilization with lime involves a chemical process where the soil is improved with the addition of lime. In this context the most troublesome soils are the clays and silty clays. Unless stabilized, these soils usually become very soft when water is introduced. Lime in its hydrated form Ca (OH_2), will rapidly cause cation exchange and flocculation/agglomeration, provided it is intimately mixed with soil[9].

Croft *et al.*[3] concluded that the primary effect of small lime additions (2–8%) is to reduce significantly the liquid limit, plasticity index, optimum dry density, swell and to increase the optimum moisture content and strength of expansive clays. Peurifoy and Ledbetter[9] stated that lime can be added and the soils mixed and compacted, initially drying the soil and them flocculating it. Several days to weeks later, the soil can be remixed and compacted to form a dense stabilized layer that will continue to gain strength for many years. This research was carried out to study the effect of eggshell powder on the stabilizing potential of lime on an expansive clay soil.

MATERIALS AND METHODS

This study was conducted between April 2001 and April 2002 in the Transportation Engineering Laboratory of Civil Engineering Department, Obafemi Awolowo University, Ile-Ife, Osun State, Nigeria.

The samples were collected from a section in the central area of Gbogan Township about 5 km from Gbogan-Iwo road at a depth of about 1.8 m. The area of collection was also located at 25 km from Ile-Ife town, Nigeria. The soil samples obtained were mainly dark, chocolate brown and very clayey. The lime used for this work is a whitish one meant for water treatment and was collected from the water treatment plant at Opa Dam on the University campus. The chemical formula is Ca $(OH)_2$ and is named hydrated lime. Chicken eggshells were collected from two burger (Bread and Egg) sellers at Awolowo hall bus stop on OAU campus. The average quantity of eggshells per day amounts to four creates such that at the end of one month, there was about 100 kg of eggshell powder, which is equivalent to the weight of two bags of cement. The eggshell waste was dried before grinding. The finely ground material was sieve using a 75 μm BS sieve and the portion passing the sieve was used. The sieve was chosen in order to achieve a uniform powdery form since chemical reaction takes place faster and more effectively with larger surface areas.

Tests were carried out first on the natural soil without any additive to ascertain the PI, such that the effect of the additives could easily be measured from their PI values when mixed with natural soil. Since the research is directed towards the measurement of the effect of ESP on lime-stabilized clay, the optimal percentage of lime was determined before the addition of ESP.

The quantity of lime added was calculated by 200 g weight of natural soil specified for the test in BS1377 so that the total weight (lime + soil) still equals 200 g. The optimal percentage of lime-ESP combination was obtained from the PI of the samples with varying proportions. The sample was prepared by weighing the quantities of additives required for each batch and first mixing thoroughly before adding water.

The effect of eggshell powder on the soil was assessed by comparing the Plasticity Index (PI) value of soil earlier stabilized with an optimal percentage of lime and the value when a certain percentage of the optimal lime was replaced by eggshell. The best result was the one with the lowest PI. Tests were carried out on the samples, first to determine the optimal quantity of lime and subsequently the optimal of ESP-lime combination by varying the proportion by weight.

The optimal percentage of lime was gradually reduced and complemented with suitable percentages of ESP in the following ratios: 6% lime + 1% ESP, 5% lime + 2% ESP, 4% lime + 3% ESP, 3% lime + 4% ESP, 2% lime + 5% ESP and 1% lime + 6% ESP. For each variation, Atterbrg's limit tests (liquid and plastic limit) were carried out to determine the optimal lime-ESP combination.

The effects of ESP on lime-stabilized soil were assessed further by subjecting the natural soil, the natural soil plus lime and the natural soil plus optimal lime-ESP mixture to general classification and laboratory strength tests which includes:

- Compaction Test (standard proctor)
- California Bearing Ratio Test (soaked and unsoaked)
- Unconfined Compression Test (cured and uncured)
- Undrained Triaxial Test

RESULTS AND DISCUSSION

The natural moisture content of the soil was 6.28%. This value is minimal and does not have much effect on the engineering and main tests. The specific gravity of the soil was found to be 2.68, which is within the range for

Table 1: Results of the particle size distribution

Components	Proportion (%)
Sand	35.0
Silt	36.0
Clay	29.0
Passing #200 sieve	70.4
Activity	1.86

Table 2: Atterberg's limit for lime stabilization

% Lime by weight	LL (%)	PL (%)	PI (%)
0	56.0	18.4	38.0
3	48.5	31.2	17.3
4	49.2	32.5	16.7
5	50.8	37.5	13.3
6	50.0	37.0	13.0
7	47.7	36.9	10.8
8	49.9	37.4	12.3

LL - Liquid Limit, PL - Plastic Limit PI - Plasticity Index

Table 3: Atterberg's limit tests for ESP-Lime stabilization

% Lime by weight	% ESP by weight	LL (%)	PL (%)	PI (%)
1	6	57.5	27.8	29.7
2	5	61.5	35.4	26.1
3	4	52.8	37.6	15.2
4	3	53.1	35.0	18.1
5	2	53.2	34.1	19.1
6	1	52.8	37.1	15.7

LL - Liquid Limit, PL - Plastic Limit, PI - Plasticity Index

Table 4: Results of maximum dry density and optimum moisture content

% Additive by weight	MDD (kg m^{-3})	OMC (%)
0% Lime	1508.0	21.20
7% Lime	1484.0	22.75
3% Lime + 4% ESP	1473.0	23.80

Maximum Dry Density – MDD, Optimum Moisture Content - OMC

silts and silty soil according to ASTM. Results of the particle size distribution indicated that the soil is well graded with component proportions of sand, silt and clay in 35.0, 36.0 and 29.0%, respectively (Table 1).

The plasticity index of the natural soil was 38.0% with a liquid limit of 56.0% and plastic limit of 18.4%, indicating that the clay is of high plasticity (Table 2). It is generally believed that high plasticity is an indicator for swelling potential, clay is susceptible to large volume changes if the PI is greater than or equal to 30%[3].

The effect of the additives on the natural soil as earlier stated was measured by the changes in the plasticity indices of the samples. The addition of lime at 7% reduced the PI from 38.0% to the smallest value of 10.8%, indicating the optimal mixture of lime. The PI of lime however increased further with the addition of 8% lime, this is due to the extra water required by the excess lime which makes the soil to swell (Table 2).

The addition of the combination of ESP + lime resulted in a higher PI of 29.7% than the 10.8% value obtained for the optimal mixture of lime. The values however reduced with subsequent reduction of ESP in the mixture (Table 3). An optimal mixture was achieved at 3% lime + 4% ESP combination. The PI at the optimal mixture was 15.2%, indicating that the addition of ESP has a positive effect on the PI when compared with the PI of sample with 3% lime and 0% ESP, but was not as affective at the optimal mixture of lime.

Compaction test: The natural soil sample had a maximum dry density of 1508.0 kg m^{-3} and optimum moisture content of 21.2%, the addition of 7% lime reduced the maximum dry density to 1484.0 kg m^{-3} and increased the optimum moisture content to 22.75%, while the addition of 3% lime + 4% ESP lowered the maximum dry density further to 1473.0 kg m^{-3} and increases the optimum moisture content to 23.8% (Table 4).

Generally, the higher the MDD, the better the soil for construction works, but for expansive soil, a higher MDD usually indicates a high swelling potential. This shows that the sample mix of 3% lime + 4% ESP shows little tendency for swelling as compared with the other two samples.

Also, the lower the OMC, the better the soil. This implies that the sample stabilized with 3% lime + 4% ESP is better than stabilization with only 7% lime.

California Bearing Ratio (CBR) test: The CBR of a soil is an indefinable index of its strength, which for a given soil, is dependent upon the conditions of the materials at the time of testing. This means that the soil needs to be tested in a condition that is critical to its design.

At any given moisture content, the CBR of a soil will increase if its dry density is increased, i.e., if the air content of the soil is decreased. Thus, a design dry density should be selected which corresponds to the minimum state of compaction expected in the field at the time of construction. The unsoaked CBR value for the clay soil was found to be 4.8%, which is a poor rated sub grade. Addition of 7% lime increased the unsoaked CBR value to 45.5%; while 3% lime + 4% ESP reduced CBR to 4.1% which is rated a relatively poor sub grade (Table 5).

Unconfined compression test: For the uncured samples, the undrained shear strength of the clay soil was 59.64 kn m^{-2}; the addition of 7% lime raised this value to 187.25 kn m^{-2}. The addition of 3% lime + 4% ESP reduced this strength to 93.5 kn m^{-2} (Table 6).

For the cured samples, the undrained shear strength of the soil was found to be 14.27 kn m^{-2}, while the addition of 7% lime increased shear strength to 50.23 kn m^{-2}. It could be seen that the addition of 7% lime still gave the best overall result (Table 6).

The extra strength displayed by the lime mixture is due to the binding action that lime has with fine soil particles. The measured strength is not used for design

Table 5: CBR values for soaked and unsoaked conditions

% Additive by weight	Soaked (CBR %)	Unsoaked (CBR %)
0%	4.4	4.8
3% Lime + 4% ESP	15.5	4.1
7% Lime	11.8	45.5

California Bearing Ratio - CBR

Table 6: Unconfined compression values for cured and uncured conditions

% Additive by weight	Cured (kn m^{-2})	Uncured (kn m^{-2})
0%	14.27	59.64
3% Lime + 4% ESP	35.40	93.50
7% Lime	50.23	187.25

Table 7: Undrained triaxial shear strength for cured and uncured conditions

% Additive by weight	Cohesion © (kn m^{-2})	Internal friction
0%	49.0	20.0
3% Lime + 4% ESP	73.0	19.8
7% Lime	125.0	19.0

purposes; rather, the unconfined compressive strength data are principally significant for control purposes[4].

Undrained triaxial shear strength test: It could be seen that addition of 7% lime raised the value of cohesion C, from 49.0 to 125.0 kn m^{-2} while the angle of internal friction was reduced from 20.0 to 19.0. The addition of 3% lime + 4 % ESP however reduced the cohesion from 125.0 to 73.0 kn m^{-2} (Table 7). These values of cohesion and angle of internal friction were read from the plots of the Mohr's circles for the additive.

From the results obtained and from cogent cross examination of the behaviour of ESP-lime sample with that of 7% lime which is the control for this research, it could be concluded that lime has exhibited its superior potency over (ESP) as a stabilizing agent in all ramifications of engineering properties except for the MDD and OMC where ESP proved better.

It could be seen that ESP cannot successfully replace lime as a material for effective stabilization unless some further researches are conducted. However ESP could be used for stabilization of soil where very high subgrade performance is not necessary. Consequently, the low effect of the 4% ESP + 3% lime could be attributed to the presence of eggshell membrane that contains collagen - an organic compound which reduced the binding effect of calcium and potassium that could have increased the cohesion and internal angle of friction of the soil considerably.

ACKNOWLEDGMENTS

The authors hereby appreciate Eyitope, the wife of the corresponding author and children, Inioluwa and Oreoluwa for the spiritual and moral supports during the preparations for this study and also the members of staff in the Department of Civil Engineering, Obafemi Awolowo University, Ile-Ife, Nigeria.

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