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Stabilizing Potential of Cement and Fly Ash Mixture on Expansive Clay Soil

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Abstract: Soil treatment or stabilization is highly recognized by geologist and engineers as a very important process in improving the performance of weak or marginal soils and make them perform better as highway materials. This study was an investigation of the potential of stabilizing an expansive clay soil with the combination of cement and fly ash. The expansive clay soil samples were first subjected general classification tests where three classes of samples evolved; 12% cement optimal mix, 9% cement plus 3% fly ash optimal mix and the 0% (unstabilized) natural clay soil sample. The three different classes of samples were then subjected to engineering tests; Maximum Dry Densities (MDD), Optimum Moisture Contents (OMC), California Bearing Ratio (CBR), Unconfined Compression and the Undrained Triaxial test. The results showed that the soil sample stabilized with a mixture of 9% cement plus 3% fly ash is better with respect to MDD, OMC, Bearing Capacity and Shearing Resistance, when compared with sample stabilized with 12% cement plus 0% fly ash. This shows that the addition of a certain percentage of fly ash will improve the stabilizing potential of cement on an expansive clay soil.

Key words: Stabilizing potential, cement, fly ash, expansive clay

INTRODUCTION

Soils are very important raw materials for construction work, since virtually all civil engineering construction works involve soil. In most cases, poor soil posses a challenge to the designing engineer and as a way out, he might try to change the design to suit the soil type, improve the soil mass or better still, abandon the site for a better one.

Craig[1] states that if a poor soil can not be removed, then its engineering behaviour or properties can be enhanced by suitable method of ground treatment, while Bell[2] states that the treatment of such soils can be done by preventing ingress of groundwater flow or removing it from the site in question, or by improving soil strength on the other hand through a mechanical medium or chemical medium.

This study deals with stabilization of expansive clay soil, which has the tendency to swell when its moisture content is increased. Soil with this characteristics mostly contains clay minerals especially montmorillonite (smecite). Generally, the kaolinite group are non-expansive, while the mica group, which includes illites and vermiculites can be expansive but does not pose significant problems.

According to Braja[3], the major problems associated with expansive soils, particularly the montmorillonites, are the volume changes. One method of controlling the volume changes will be to stabilize the clay with admixture that will prevent the volume change, or by adequately modifying the volume change characteristics of the clay soil.

Lime, cement, pozzolans fly ash, blast furnace slag, expanded shale and potassium), can be relatively used in stabilizing expansive high plastic clayey soils to relatively shallow depths under footings and slabs for industrial plant bases.

Stabilization of expansive clay can be effectively carried out with the use of admixtures, generally known as chemical stabilization medium; other methods through a mechanical medium are also reliable, but are not as viable as the chemical method.

Expansive clay: Some types of clay show a remarked increase or decrease in volume as the water content is increased or decreased. This property is caused by the presence of clay minerals such as kaolinite, illites and montmorillonite. Clays exhibiting these characteristics are called expansive clays. It is very important to note that soils in this conditions do cause ground movement and are potential cause of settlement, which eventually cause damages to engineering construction due to high compressibility, unsuitably consistency index, low permeability and its swelling and shrinkage effects. These

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make them generally unsuitable for the construction of sensitive projects and structures.

According to Bell[2], the various clay groups have different swelling potentials, generally, kaolinite has the smallest swelling capacity of the clay minerals, illite may swell up to 15% but intermixed illite and montmorillonite may swell some 60-100%. Most of these clays are found in certain areas of the Southern and Western parts of Nigeria.

Cement: Cement performs the role of a binder material which binds other constituents such as water, cement and gravel in concrete production, sandcrete block, screeding, plastering, general masonry work and in soil stabilization. In fine-grained clay soils a pozzolanic reaction occurs between the calcium hydroxide released from cement during hydration, the soil alumina and silica, which is an important aspect of the soil stabilization process. The permeability of cement-stabilized material is greatly reduced and the result is a moisture-resistant material that is highly durable and resistant to leaching over a long time. Cement may be used successfully in stabilizing granular and fine-grained soil as well as aggregates materials due to the presence of calcium hydroxide (lime).

Wilmot and Vorobieff[4] stated that during the process of stabilization, the calcium hydroxide produced would react to modify the clay particles (secondary segmentation). Cements have a two-stage reaction process similar to that of lime, the first commences within minutes of mixing with water (hydration) and the secondary cementation occurs as the free-lime is diffused through the soil matrix.

Cement generally acts on clay minerals to reduce the liquid limit, plasticity-index, potential volume change, increase in shrinkage limit and the shear strength of the soil mass[5].

According to Catton[6], cement stabilized materials generally fall into two classes:

- Soil cement
- Cement modified soil

Fly ash: Fly ash is a fine power like mineral that comes in two grades, Class C and F. According to Catton[6], Class C fly ash contains high lime content, whereas class F has low to midrange lime content. Both are produced with consistent, quality-control standards. Under a microscope, fly ash particles look like tiny ball bearings and are so small that they can be shifted through screens with more than 100,000 openings per square inch. Another type of ash gotten from coal combustion is Bottom ash, which is a coarse to fine-grain sand-like material, which also has the basic properties of a fly ash but has low calcium content.

The chemical composition of fly ash depends largely on its geological and geographic factors related to coal mines (Table 1).

The mineral content of Fly ash as determined by coal combustion by-product utilization manual, are characterized by Quartz, Mullite, Hematite, Magnetite and glass content (Glass content helps to enhance reactivity property of fly ash).

Lime reactivity of fly ash is characterized by its fineness, as fineness increases, its lime reactivity increases. Lime reactivity of fly ash increases when it is grinded very well. Lime reactivity of Indian Fly ash generally varies from 35 to 65 kg cm^{-2}.

Soil stabilization: Soil stabilization consists of increasing the soil density, adding inert materials to increase the apparent cohesion and or its frictional resistance and by lowering its water table[2]. Johnson *et al.*[7] also defined soil stabilization as the alteration of the physical and chemical properties of a soil mass to conform to desired characteristics or the improvement of a less stable soil in both strength and durability.

In this study, cement and fly ash will be extensively used in the stabilization of the soil sample (expansive clay), which is a process of chemical stabilization.

Most materials used for construction purposes most often, do not meet standards both in the performance-based tests conducted in the laboratory and large-scale field tests. Since many of these traditional materials design criteria are empirical and inappropriately increased, therefore more emphasis are needed for the development of mechanistic evaluation tests and techniques for stabilizing these materials; hence soil stabilization is very important in geological and transportation engineering works.

Chemical stabilization involves the use of chemicals and emulsions to aid or modify the behaviour of the soil mass, in most cases, it makes the mass water repellents and with very low permeability tendency. Binder materials are used for the purpose of binding the particles together

Table 1: The chemical composition of fly ash by percentage of weight

Constituents	Weight (%)
Loss on ignition	1-16
SiO_2	45-65
Al_2O_3	12-30
Fe_2O_3	2-14
CaO	1-4
MgO	0.5-2.5
Alkalies	0.1-3.0
SO_3	0.2-1.25

as a coherent mass in the construction and maintenance of transportation facilities, road and dam embankments and for retaining structures. Chemical stabilization can also be done through the process of grouting, which is the injection under pressure of fine viscous liquid into the pure and cavity of the soil mass. Chemical stabilization can aid in dust control in unpaved roads and highways construction, they are very effective for water erosion control, fixation and in leaching control of waste and recycled materials.

Some of the chemicals used in stabilizing soils include cement, lime (with or without pozzolans), chlorides (NaCl, $CaCl_2$), sodium silicate, bituminous materials, aniline, vinsol resil, stabinol, molasses, lignin sulfonate, calcium acrylate and organic compounds, which act as very good additives and binder materials.

For the purpose of this study, chemical medium of stabilization shall be used in stabilizing an expansive clay soil using cement and fly ash. The aims of this study were to investigate the effect of the addition of fly ash on the stabilizing potential of cement on an expansive clay soil and to determine if the combination of fly ash plus cement on the expansive clay soil can effectively replace the use of a large quantity of cement necessary for stabilization and still obtain a better result.

MATERIALS AND METHODS

This study was carried out between July 2003 and March 2004 in the Transportation Laboratory, Department of Civil Engineering, Obafemi Awolowo University, Ile-Ife in Osun state, Nigeria.

Materials used are: Ordinary Portland cement, Expansive clay soil sample, Fly ash, Water (fit for drinking).

The soil sample for this study is a natural clay soil, obtained form Ipetumodu, a community in Osun State, Nigeria. Lying between longitude 4°25 and 4°45′E latitude 7°45 and 7°40′N of the Green Witch Meridian. The soil could be described as a hard-undulated grayish clay soil. The cement used is the Ordinary Portland cement, Elephant brand obtained locally, while the fly was obtained from the Running Shield of the Nigeria Railway Cooperation at Ebute Metta, Lagos State. It was sourced as a residue, of the steam engine of a train head. The fly ash is a grayish solid to powdery particles.

Classification and soil engineering tests were performed on the samples. It should be noted that the percentage of (cement only) added by weight for the Atterberg's limit tests varied as 0, 2, 4, to 12% while the fly ash was gradually introduced from to replace cement in 1, 2, 3, to 11%. Soil engineering strength tests were performed in order to determine the engineering properties of the soil type such as the shearing strength, maximum dry density, bearing capacity under an imposed load and also its rate of settlement. The major soil strength tests performed were: Compaction, California Bearing Ratio (CBR), Unconfined Compression and Undrained Triaxial Shear Strength tests. The experiments for the entire test were all according to the British Standard for testing engineering materials. Based on the results of the Atterberg's limit, the cement for stabilization was added by weight to the soil in 0 and 12% and the effect of the fly ash was determined in the proportion of 9% cement + 3% fly ash by weight.

RESULTS

The natural moisture content of the soil was 9.64%. The specific gravity of the soil was found to be 2.78, which is within the range given by Braja[8] for an expansive clayey soil, such as Illite (2.8), Montmorillonite (2.65-2.80) and Vermiculite (2.6-2.9).

The hydrometer analysis was conducted using the oven-dried particles passing the 75 μm sieve. The grading analysis of the sample showed that it is mainly composed of sand with 60.40% passing No. 200 sieve (Table 2). It could therefore be classified be as a well-graded fine grain soil[9].

The Atterberg's limit is made up of both the liquid limit and the plastic limit; the difference of these two limits gives Plasticity Index of the soil sample (PI). According to Whitlow[9], the plasticity of a fine soil has an important effect on such engineering properties such as compressibility of the soil and its shear strength.

The Liquid Limit (LL) and the Plastic Limit (PL) of the natural soil sample are 58.70 and 16.48%, respectively and its Plasticity Index (PI) is 42.22% (Table 3). This shows that the soil is highly plastic in nature. Whitlow[9] states that if the L.L of a soil sample is less than 35% it is a low plasticity soil, between 50 and 70% is a high plasticity soil, between 70 and 90% is a very high plastic soil, while greater than 90% is an extremely high plastic soil.

The addition of cement by weight reduced the plasticity index of the expansive clay soil sample from 58.70 to 17.17%, at 12% (Table 3) which is the optimal mixture of cement with the clay soil, the plasticity index started increasing again with further addition of cement resulting in additional water requirement of cement, this will make the soil to swell and in the process increasing its liquid limit again.

For the various percentages of fly ash varied with reduction in the optimal value of cement, the mixture of 9% of cement plus 3% of fly ash gave the best result,

Table 2: Important parameters from the grading analysis of the soil sample

Soil component	Amount (%)
Gravel	5.02
Sand	34.58
Silt	28.41
Clay	31.99
Percentage passing 200 sieve	60.40

Table 3: Atterberg's limit values for cement stabilized soil samples

Cement by weight (%)	LL (%)	PL (%)	PI (%)
0	58.70	16.48	42.22
2	56.80	20.28	36.52
4	56.60	23.16	33.44
6	54.40	24.03	29.37
8	51.40	25.37	26.37
10	47.85	29.32	18.53
12	47.30	30.13	17.17
14	47.80	28.11	19.69
16	48.00	27.50	20.50

LL: Liquid Limit, PL: Plastic Limit, Plasticity Index (PI)

although other result gave favourable results when compared with those for cement additions only. The clay soil sample used for this project work has a low PL of 17%, high LL of 49% and PI of 42.22%, when stabilized with 9% of cement plus 3% of fly ash, the PI of the soil sample was reduced from 42.22 to 17.95%, (Table 3 and 4) which gave a good optimal mix for a stabilizer of high plastic clay soil.

When stabilized with 12% of LL of the clay soil was reduced from 58.70 to 43.30% and also the PL was increased from 16.48 to 30.13% and the PI of the stabilized sample became 17.17% (Table 3).

Braja[2] stated that the cement requirement for effective stabilization of A-6 and A-7 soil type and CL, CH soil type is between 10 to 14% by weight and for A-4 to A-5 (CL, ML and MH) soil type requires between 8 to 12%. Bell[1] also gave a similar range for the percentage requirement of cement. This indicated that the 12% cement by weight that effectively reduced the PI of the natural clay soil sample from 42.22 to 17.17% is the optimal mix of cement for the effective stabilization of the high plastic (expansive) clay soil. The addition of 9% of cement plus 3% of fly-ash, successfully reduced the PI of the soil sample from 42.22 to 17.95%, (Table 3 and 4) therefore 9% of cement plus 3% of fly-ash is adopted as the optimal mix of cement plus fly ash, for this clay soil sample.

The fly ash was able to react with cement to stabilize the soil because; fly ash is a pozzolan, which reacts with Calcium oxide (CaO) and water to form cementations material with cement. However, only small percentage of it is Free lime, this makes it a suitable stabilizing material for high plastic clay soil.

Table 4: Atterberg's limit values for cement-fly ash stabilized soil samples

Cement by weight (%)	Fly ash by weight (%)	LL (%)	PL (%)	PI (%)
11	1	49.2	29.92	19.28
10	2	48.00	28.37	19.63
9	3	47.00	29.05	17.95
8	4	48.60	27.36	21.95
7	5	50.80	27.10	23.70
6	6	54.00	26.54	27.46
5	7	55.07	25.67	29.40
4	8	55.50	23.66	31.84
3	9	56.00	22.42	33.58
2	10	56.40	21.47	34.93
1	11	57.80	19.43	38.37

LL: Liquid limit, PL: Plastic limit, PI: Plasticity index

DISCUSSION

It could be seen that the natural clay soil sample has a maximum dry density of 1641 kg m^{-3} and optimum moisture content of 17%, the addition of 12% cement by weight reduced the maximum dry density to 1601 kg m^{-3} and increases the optimum moisture content to 19% and finally, the addition of 9% of cement plus 3% of fly ash gave a maximum dry density of 1604 kg m^{-3} and optimum moisture content of 16% (Table 5).

With 9% cement plus 3% fly ash, the MDD slightly increased by 3 kg m^{-3} above that of the 12% cement and also the OMC decreased 3% below that of 12% cement.

The results obtained from all the samples indicated that the samples have highest CBR value at 2.5 mm penetration, for the 0% mix (unstabilized) soil sample. The average unsoaked CBR value is 2.92%, but when soaked for 72 h, it reduced to 1.49% (Table 6). This is an indication that the sample is a poorly drained heavy clay soil, with high plasticity index.

The addition of 12% cement raised the average CBR value to 9.71 and 21.53% for the unsoaked and soaked samples, respectively (Table 6). Soaking produced a 93% gain in strength, indicating that clay soils stabilized with cement become non-plastic and gain strength with curing time.

The addition of 9% cement plus 3% fly ash however produced a strength increase in the CBR values of the soil to 15.86 and 18.70% for the unsoaked and soaked samples, respectively (Table 6) .

It could be seen that the uncured sample has the lowest compressive strength of 78.84 kn m^{-2} for the 0% unstabilized sample and 1471.46 kn m^{-2} for the cured sample. The sample stabilized with the 12% cement produced an uncured strength of 166.88 kn m^{-2} and 1603.67 kn m^{-2} when cured; this shows that strength increases with curing time (Table 7).

The sample stabilized with 9% cement plus 3% fly ash, produced the best and the highest compressive

Table 5: Compaction test results for stabilized soil samples

Types of additive (%)	MDD (kg m^{-3})	OMC (%)
0% No additive	1641	17
12% Cement	1601	19
9% Cement + 3% Fly ash	1604	16

MDD: Maximum Dry Density, OMC: Optimum Moisture Content

Table 6: California Bearing Ratio test results for stabilized soil samples

Types of additive (%)	Average penetration (mm)	Average unsoaked CBR (%)	Actual soaked CBR (%)	Actual unsoaked CBR (%)	Actual soaked CBR (%)
0%	2.50	2.92	1.49		
No additive				2.92	1.47
	5.00	1.83	0.30		
12%	2.50	9.71	21.53		
Cement				9.71	21.53
	5.00	8.32	8.64		
9% Cement	2.50	15.86	18.70		
+				15.8	18.70
3% Fly ash	5.00	13.45	14.06		

Table 7: Unconfined compression test results for stabilized soil samples

Types of additive (%)	Type of specimen	Applied axial load (N)	Compression stress (kn m^{-2})	Cohesion (kn m^{-2})
0%	Uncured	90	78.84	39.42
No additive	Cured	1620	1471.46	735.73
12%	Uncured	190	166.88	83.44
Cement	Cured	1830	1603.67	801.84
9% Cement +	Uncured	332	291.61	145.81
3% Fly ash	Cured	2000	1756.13	878.07

strength resistance, it has a shearing resistance of 291.61 kn m^{-2}, for the uncured sample and 1756.13 kn m^{-2} for the cured sample (Table 7).

The Unconsolidated Undrained Triaxal Tests were performed on sample with 12% cement stabilization, sample with the 9% cement plus 3% fly ash stabilization and the unstabilized soil sample.

When the three samples were subjected to a total normal stress of 200 kn m^{-2}, analysis showed that the maximum yield or shearing stress of the unstabilized natural clay was 113 kn m^{-2}, the sample stabilized with 12% cement gave 271 kn m^{-2} while the sample stabilized with 9% cement plus 3% fly ash gave 236 kn m^{-2} (Table 8).

The replacement of 3% cement with fly ash in a mixture of 9% cement plus 3% fly ash improved the stabilizing potentials of the samples better than using 12% cement only for stabilizing the sample. This shows that fly ash improves the stabilizing potential of cement on an expansive clay soil and that it is possible to obtain a better stabilizing potential of an expansive clay soil by replacing a certain portion of the cement needed for stabilization with fly ash.

Table 8: Shear strengths results for stabilized soil samples

Type of additive (%)	Total normal stress (kn m^{-2})	Cohesion (C) (kn m^{-2})	Angle of internal (ϕ°)	Shear strength (kn m^{-2})
0% No additive	200	66.00	20.00	113
12% Cement	200	190.00	21.80	271
9% Cement + 3% Fly ash	200	150.00	24.00	239

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