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Improving the Characteristics of Expansive Subgrade Soils Using Lime and Fly Ash

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Abstract: ***This paper investigates the improvements in the properties of expansive soils, as road subgrade stabilized with lime and fly ash in varying percentages. Laboratory tests were undertaken to study the swelling and strength characteristics of expansive soils stabilized with lime, fly ash and a combination of both. Lime and fly ash were added separately to expansive soil at ranges 0-15% and 0-40%, respectively. Index property, compaction, California Bearing Ratio (CBR), Unconfined Compression Strength (UCS), free swell and swelling pressure tests were performed on natural and treated soil samples. For the investigated admixture lime-fly ash; the amount of lime added 5% and 8% combined with the fly ash content 0%, 5% and 10%. Comparing the results obtained of the natural and treated samples, the CBR and UCS of lime-fly ash treated samples increased significantly, coupled with the swelling reduction, depending on additive content. It could be concluded that stabilization of expansive subgrade soils by lime-fly ash admixture is successful and more economical.***

Keywords: Strength, swelling, stabilization, lime-fly ash**.**

1. Introduction

Expansive soils are those clay soils which exhibited significant volume changes as results of soil moisture variation. This type of soil, upon wetting and drying, causes severe damages to pavement constructed on such soil. Generally pavements on expansive subgrade soils show early distresses causing the premature failures of the pavement structure. Expansive soils usually have undesirable engineering properties, such as low bearing capacity, coupled with low stability and excessive swelling. The nature of these soils creating serious problems to the civil engineering structures particularly road pavements constructed on them. Many researchers are doing extensive studies on this problem and its remedial measures. Among various methods for the solutions to the problems posed by expansive soils, the stabilization of such soils is the best practical option. In general soil stabilization seems to be an effective alternative for improving soil properties. Chemical admixtures are most widely and commonly used practice for stabilization of expansive soils, [1]. As reported by many researchers that lime and fly ash were successfully used for stabilizing expansive soils, [2]-[5]. The purpose of this experimental study is to investigate the improvements in strength characteristics and swelling behavior of expansive soils by using lime and fly ash stabilizers.

2. Literature Review

Soil stabilization is the process of creating or improving certain desired properties in a weak soil such as expansive clay so as to render it stable and useful for a specific purpose. [6] stated that the improvements in engineering properties caused by stabilization can include the following: increases in soil strength (shearing resistance), stiffness (resistance to deformation) and durability (wear resistance), reductions in swelling potential of wet clay soils and other desirable characteristics. There are many techniques for soil stabilization classified into two groups, mechanical or chemical stabilization. Mechanical or granular stabilization is accomplished by mixing or blending soils to obtain a material meeting the required specifications. Chemical stabilization involves mixing or injecting the soil with chemically active compounds such as Portland cement, lime, fly ash, calcium or sodium chloride or with bitumen materials. For successful soil stabilizer applications it is imperative to understand the mechanism of stabilization of additive, [7].

Lime is widely used additive to improve the properties of expansive soils. Lime in the form of quicklime (calcium oxide – CaO), hydrated lime (calcium hydroxide – $Ca[OH]_2$), or lime slurry can be used to stabilize clay soils. Quicklime is manufactured by chemically transforming calcium carbonate (limestone – $CaCO_3$) into calcium oxide. Hydrated lime is created when quicklime chemically reacts with water, [8]. Lime stabilization creates long-lasting changes in clay characteristics. When lime is admixed with moist clay, a number of reactions take place including cation exchange, pozzolanic reaction and carbonation, [9]. The cation exchange is responsible for aggregation of the soil particles leading to early strength development. The pozzolanic reaction takes place slowly and is responsible for late strength development.

The properties of soil-lime mixtures are dependent on many variables such as soil type, lime type, lime percentage and curing conditions (time, temperature, and moisture), [3]. He observed that lime reduces plasticity index and makes the soil more workable. He demonstrated that the reaction between lime and soil causes an alternation of the moisture-density relationship that is soil dependent and is also dependent on amount of lime added,. He found that the compaction curve peaks at a higher value of density and a lower moisture content with lime than without.

[10] evaluated three different Virginia soils. 3% to 5% hydrated lime was added and significantly improved the soaked CBR from less than 5% to near 100%. According to

[11] the strength of soils are affected by mineralogical constituents and surrounding environment. The optimum amount of lime for maximum strength gain in stabilizing soil with lime is 4 to 6% for Kaolinite, about 8% for illite and montmorillonite. The addition of lime reduces the swelling characteristics of stabilized clayey soil, [12]. They observed a reduction in swelling pressure from 250 kPa to 0 by addition of 6% lime to Oman expansive soil. They also observed reduction in swell percent from 9.5 to 0 with 6% lime. As reported by [13] the swelling pressure of highly plastic clay 2600 KPa was reduced to 1700 KPa with 10% hydrated lime (immediately) and was further reduced to 0 KPa with 28 days of cure at only 4% hydrated lime.

Fly ash, as waste material is a byproduct that comes from burning of coal used for electrical energy generation. Fly ashes are readily available, cheaper and environmental friendly. In Sudan, only small percentage of fly ash is used in construction industry, while the rest is dumped which causes serious problems to the accessible environment. Fly ash is classified into two classes, F and C, based on the chemical composition of the fly ash. Class F fly ash is produced from burning anthracite and bituminous coals and contains small amount of lime (CaO). This fly ash has siliceous and aluminous materials (pozzolans), which possess little or no cementitious value but in the presence of moisture, chemically react with lime at ordinary temperature to form cementitious compounds, [14]. Class C fly ash is normally produced from lignite and sub-bituminous coals, and usually contains significant amount of lime along with pozzolanic materials, [15]. It is always encouraged to use fly ash for stabilization where easily and economically available.

When fly ash is added to an expansive soil reduces its plasticity, activity and swelling potential owing to a cation exchange process (immediate reaction). The stable exchangeable cations provided by fly ash, such as Ca^{2+}, Al^{3+}, and Fe^{3+} promote flocculation of the clay particles. Furthermore, the time-dependent cementation process (pozzolanic reaction) results in cemented compounds characterized by high strength and low volume change, [16]. He reported reductions in free swell index by 60% and 63% for two expansive soils A and B respectively with 15% class C fly ash. As observed by [17] that the percentage reduction in swelling potential of expansive soil composed of 85% Na-bentonite and 15% kaolinite was 52.6% and 58.3% by treating with 25% of fly ash-1 and fly ash-2 (both class-C), respectively. [18] found a reduction of 65% in swelling potential by addition of 20% fly ash was nearly same as that by 8% lime. [16] reported decrease in swelling pressure from 120 kPa to 90 kPa of expansive soil A and from 160 kPa to 105 kPa of expansive soil B by treating with 12% fly ash. Both soils possessed high plasticity and were classified as CH. [19] found that the peak strength attained by fine fly ash mixture was 25% more when compared to coarse fly ash.

[20] observed that the improved CBR value is due to addition of lime and fly ash as admixtures to the expansive soil. It also reduces the hydraulic conductivity of expansive soil. In combination, the admixtures are beneficial for lower plasticity and higher silt content soils. In terms of material cost, the use of less costly fly ash can reduce the required amount of lime.

3. Materials and methodology

The experimental work was undertaken to achieve the objectives of the study. Laboratory tests were conducted on natural soil and after treatment with lime and fly ash.

3.1 Materials Used

The materials used for the laboratory testing include the expansive soil, lime and fly ash. These materials were collected from different regions in Sudan.

3.1.1 Soil

The soil sample used for the study was collected from Madani in Gezira state from open excavation at 1.0m depth below the ground surface. Before testing, the soil was air dried and then allowed to pass through 4.75mm sieve. Soil passing through 425 microns sieve was used for consistency tests. The characteristics of the soil used are summarized in Table 1.

Table 1: Characteristics of the natural soil sample

Property	*Value*
Grain size distribution:	
Clay	65
Silt	22
Fine sand	13
Consistency limits:	
Liquid limit (%)	69
Plastic limit (%)	34
Plasticity index (%)	35
Specific gravity	2.68
Soil classification	CH
Compaction characteristics:	
Optimum moisture content (%)	24
Maximum dry density (KN/m^3)	14.6
Strength:	
Soaked CBR (%)	2.6
Unsoaked CBR (%)	25
Unconfined compression strength (KN/m^2)	400
Swelling:	
Free swell (%)	195
Swelling pressure (KN/m^2)	167

3.1.2 Fly ash

The fly ash used in this study was obtained from the burning coal of Kenana Sugar Factory in central Sudan. The grade of this fly ash is "F" grade and the chemical compositions are given below in Table 2.

Table 2: Chemical compositions of the fly ash sample

Chemical component	*Percentage*
Silica ($Si\ O_2$)	52.5
Alumina (Al_2O_3)	24.2
Calcium oxide (CaO)	6.5
Ferric oxide ($Fe_2\ O_3$)	3.5
Magnesium oxide (MgO)	1.5
Sodium oxide (Na_2O)	0.3
Potassium oxide (K_2O)	0.2
Loss of ignition	11.3

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3.1.3 Lime

The lime used in this study is a high quality hydrated lime, produced locally and satisfies the general requirements for construction purposes. The basic constituents of lime are shown in Table 3.

Table 3: Chemical composition of hydrated lime used

Chemical composition	*Percentage*
Calcium hydroxide ($Ca(OH)_2$)	65
Active Calcium oxide (CaO)	48
Silica (Si O_2)	5.2
Alumina & Iron (Al_2O_3 & Fe_2O_3)	0.7
Magnesium oxide (MgO)	1.5
Calcium carbonate (Ca CO_3)	3.5

3.2 Methodology

Index tests include Atterberg limits tests, specific gravity and grain size analysis. Index property tests of the soil stabilized with lime and fly ash in varying percentages of lime 3%, 5%, 8%, 12% and 15% and fly ash content 5%, 10%, 15%, 20%, 25%, 30% and 40% were performed.

Modified compaction, California Bearing Ratio (CBR) and unconfined compression strength (UCS) tests on molded cylindrical sample of 152mm diameter and 126mm height were carried out on the soil untreated and treated with three different fly ash contents (0%, 5% and 10%); having every time 5% or 8% lime. The CBR tests were performed as unsoaked and soaked for 4 days. For the measurements of CBR and UCS, three identical compacted soil samples at Optimum Moisture Content (OMC) and Maximum Dry Density (MDD) were prepared. The first sample was subjected directly to the CBR penetration test (unsoaked CBR) and the second was subjected to soaking condition before transferred to the CBR penetration machine to measure the soaked CBR. The third sample was used for the UCS test.

Free swell and swelling pressure tests were conducted on the natural soil and treated with three different fly ash contents (0%, 5% and 10%); having every time 5% or 8% lime. The free swell test was performed by pouring 10cm^3 of soil passing 425μm sieve into a graduated cylinder glass jar of 100ml capacity filled with water. The swollen volume of the soil was observed after 24 hours. The free swell index is expressed as a percentage increase in the volume to the original volume of the soil. The swelling pressure was measured in the conventional oedometer cell performed on compacted soil samples at OMC and MDD. The soil was initially allowed to swell under a seating pressure of 1psi (≈ 6.9 KPa) and after reaching a peak swelling value, it was then compressed by adding weights. The weights were added each day to retain back the expanded sample to the started dial gauge reading. The pressure compressed the expanded sample to its original volume was considered as the swelling pressure.

4. Results and Discussion

The results of the index property tests (grain size analysis and Atterberg's limits tests), the strength tests (compaction, California bearing ratio and unconfined compression strength tests) as well as swelling tests (free swell and swelling pressure tests) are hereby discussed.

4.1. Effect of additives on plasticity

The results of the Plasticity index for the natural and lime-fly ash-stabilized clay are shown in Figure 1. The measured values of the liquid limit and the plastic limit for the natural soil are 69% and 34% respectively. Thus, the plasticity index is 35% and the soil is classified as clay of high plasticity. Figure 1 shows that the addition of lime and fly ash to the soil reduces its plasticity index steadily. In the plot of Figure 1, a significant reduction in plasticity index can be observed as the percent of lime and fly ash increases. The soil classification changed from high plasticity clay (CH) to ML with the addition of 3% lime and 10% fly ash. Moreover the high plastic clay became non-plastic with the addition of 5% lime and 10% fly ash instate of 8% lime. This fact indicates that the use of less costly fly ash can reduce the required amount of lime.

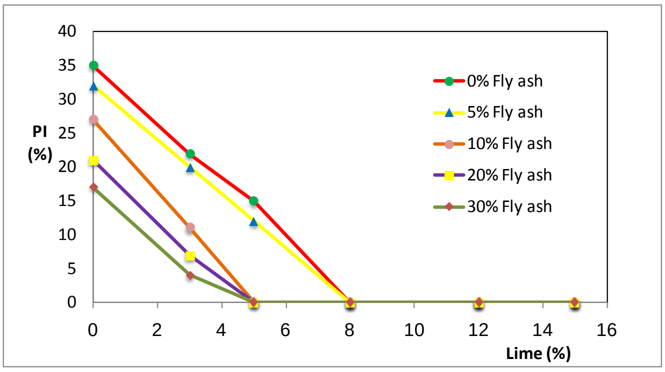

Figure 1: Plasticity Index Variation with Lime-Fly Ash admixture

4.2. Effect of additives on swelling behavior

4.2.1 Free swell index

The free swell of the natural soil was found to be 195% (see Figure 2). This value indicates that the soil is classified as highly expansive clay. The variation of free swell index with percentages of fly ash for lime-stabilized clay is illustrated in Figure 2.

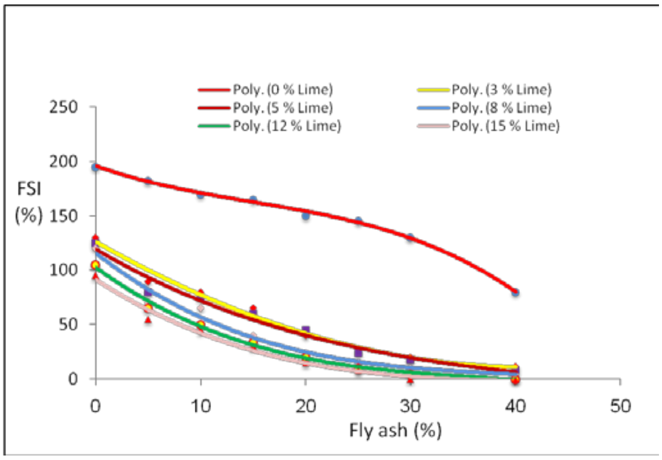

Figure 2: Free Swell Index versus Fly Ash for clay-lime mixtures

It is seen that with increasing percentage of fly ash, the FSI decreases non-linearly. By addition of small percentage of lime the decrease in FSI is significant. The FSI value of untreated soil is around 195%, which reduces to around 80% by addition of 40% fly ash only. When lime added with fly ash there will be more reduction in FSI. It can be observed from figure that the optimum content of lime-fly ash admixture at 8% lime with 20% fly ash will reduce the FSI from 195% to around 20% i.e. a reduction of about 175% of untreated swell value.

4.2.2 Swelling pressure

The swelling pressure of the natural soil is 167 KPa. It is observed that the swelling pressure is reduced from 167 KPa to 0 KPa at 8% lime only or at 5% lime combined with 5% fly ash. This significant reduction in swelling pressure occurred by addition of lime only or by using lime-fly ash. Comparing the two options, lime-fly ash admixture is preferred to be used because of its low cost.

4.3. Effect of additives on strength properties

4.3.1 Compaction characteristics

The results of the compaction test showing the maximum dry density (MDD) and the optimum moisture content of the natural and lime-fly ash-stabilized clay are shown in Figure 3. As seen in figure, the MDD increases with increasing lime content from 5 to 8%, while a reduction in the MDD was observed when fly ash increases from 0 to 10%. Knowing that compaction of soil involves the packing of the soil particles such that its voids are reduced to the minimum. Thus an increment in MDD occurs at the minimum lime-fly ash content (i.e. 8% lime only), while a reduction in the MDD at the maximum lime-fly ash content of 5% lime and 10% fly ash. This result indicates that the lime-fly ash content in the soil-lime-fly ash mixture was in excess of the amount needed to improve the gradation of the soil. Also, Figure 3 reveals that optimum moisture content required to achieve the MDD increases with the addition of lime. It can be seen that the optimum moisture content at 5% lime with 10% fly ash combination content was greater than OMC required at 5% lime with 5% fly ash and 8% lime with 5% fly ash and 8% lime only. The maximum OMC was recorded at the combination of 5% lime and 10% fly ash content. This increase in the OMC observed with the addition of lime-fly ash is caused hydration reactions between the cations of the clay particles and the lime-fly ash.

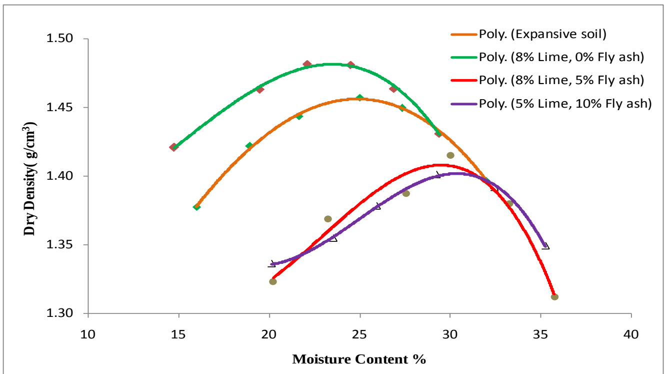

Figure 3: Variation of compaction characteristics (MDD and OMC) with Lime-Fly ash

4.3.2 CBR

The influence of lime-fly ash stabilized clay on CBR is shown in Figure 4. The unsoaked CBR values increase from 25% (untreated) to 70% with 8% lime only. Addition of fly ash led to decreased CBR. The plot in Figure 4 clearly demonstrated that cured strength increases in soaked CBR from 2.6% (untreated) to 151% with 8% lime only. This is considered to be extremely effective and necessary process to provide good subgrade. This result verified the presence of pozzolanic material responsible for the strength gain. While reduction in the CBR was observed at lime-fly ash of 5% lime and 10% fly ash. This reduction in the CBR might be due to the excess lime-fly ash in the clay not required for the early strength gain as a result of flocculation.

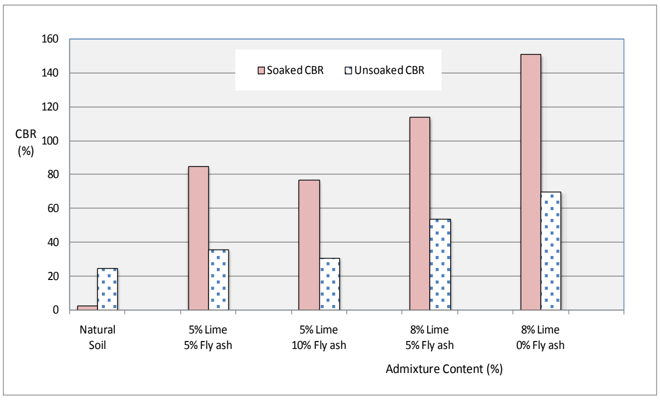

Figure 4: California Bearing Ration (CBR) versus lime-fly ash admixture

4.3.3 Unconfined compressive strength

The unconfined compressive strength variation with lime-fly ash additive is graphically presented as shown in Figure 5. It is observed that lime stabilization demonstrated very significant unconfined compressive strength gains. The increment of strength depends on the amount of lime added. When 8% lime added to the expansive soil studied, the unconfined compression strength increases from 400 KPa (untreated) to 1872 KPa. But using lime-fly ash content at 8% lime with fly ash 5% combination reduced the Unconfined Compressive Strength value to 1720 KPa. This may be fly ash added more fine to the soil leading to reduction in strength.

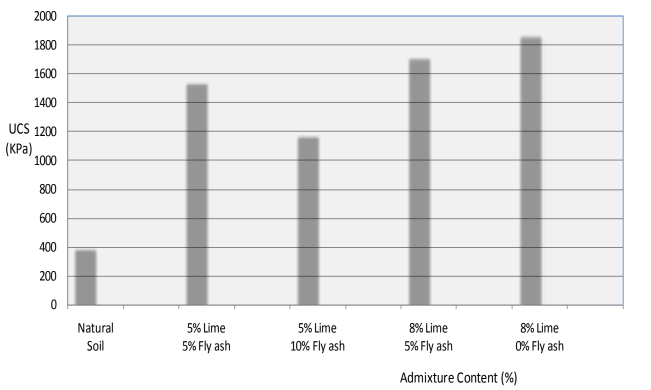

Figure 5: Influence of fly ash admixture on Unconfined Compression Strength (UCS) of the soil.

5. Conclusions

An extensive laboratory testing program was carried out to investigate the influence of using lime, fly ash and lime-fly ash admixtures on the characteristics of expansive subgrade soils. The observations and conclusions can be summarized as follows:

- The results show that lime and fly ash played an important role in improving the strength characteristics and swelling behavior of expansive soil.
- Addition of lime significantly improved consistency, swelling and strength properties of the expansive soil. However, the presence of fly ash fundamental to further improve the soil behavior, due essentially to the occurrence of a larger amount of time-dependent pozzolanic reactions. Moreover it is always encouraged to use fly ash for stabilization where easily and economically available.
- Some factors such as curing and compaction parameters have considerable effect on strength measured by the CBR and unconfined compression strength of the treated soil with time and have to be taken in account when executing earth work with such materials.
- Based on the tests results, it can be stated that, as the percentage of lime-fly ash increases the swelling decreases and the strength increases and the optimum lime-fly ash content at 8% lime with 10% fly ash.
- On the basis of economic considerations, use of good quality fly ash alone is recommended for treatment of clays with low to medium expansiveness. Whereas, for treating highly expansive clays, a combination of fly ash with small percentage of lime is recommended, so it is valuable option in Sudan to use lime-fly ash as a stabilizer.
- Immediate effects of lime in soil can promote reduction in plasticity, reduced moisture retention and improve compaction characteristics resulting in strength gains and swelling reduction.
- It has been found that the quantity of lime-fly ash needed to effectively treat a soil to develop increased strength and reduced swelling varies with the type of clay mineral present.

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