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Use of Lime Piles as an Alternative Method for Stabilisation of Road Embankments

J. R. Nakyeyune[1], S. Bamwesigye[2], S. Jjuuko[3], D. Kalumba[4]

[1]Uganda Christian University, Uganda, jossieritah@gmail.com
[2]Uganda Christian University, Uganda, bamwestephen@gmail.com
[3]Uganda Christian University, Uganda, sjjuuko1@gmail.com
[4]University of Cape Town, South Africa, denis.kalumba@uct.ac.za

Abstract

The durability and performance of an embankment depends on its stability. Several options are available for controlling stability and settlement problems associated with embankment slopes. One of them involves using stabilising agents which are suitable for the existing embankment. This research focused on improving the engineering properties of clay soil insitu by using lime pile technique. The clay soil was obtained from a failed embankment along Kamwenge – Fort portal road, chainage 18 + 900. Preliminary tests were carried out to determine if the soil required stabilisation. It had a high liquid limit of 58.6%, plastic limit 26.5% and plasticity index of 32.1. It was classified as CH using the Unified Soil Classification System. Various tests were carried out, for curing days of 14, 21 and 28, to investigate the effect on the engineering properties of the soil. Results showed an increase in Maximum Dry Density, shear strength and a decrease in Optimum Moisture Content and plasticity index hence improved soil properties for embankment slope stability.

Keywords: *Embankment, Slope stability, Lime piles, Soil improvement*

1 Introduction

Failure of embankments is mainly due to clay soil associated with high organic matter, low bearing capacity and high compressibility that exists in unconsolidated condition leading to excessive settlement. Various options are proposed for embankment slope stability including; re-gradation of slope material to a more suitable angle, removing all slumped and unstable materials, benching slopes, constructing berms of soil/gravel at the toe of the cut, provision of appropriate vegetation on the slope (including fast growing shrubs), drainage measures to intercept surface and seepage water and lead it away from the slope, repairs to the damaged road section and also reconstruction of the concrete lined side drain. However, all these don't change the soil properties for a long lasting solution to the problem. Stabilisation techniques, on the other side, increase the shear strength of the soil. It involves the use of various stabilising agents. This paper investigated the use of lime piles to stabilize an embankment slope.

According to Kennedy et al. (1987), the geotechnical behavior of lime treated soils depend on their physical and chemical properties which is related to soils formation conditions and the mineralogical compositions of the matrix.

2 Lime Stabilisation

2.1 Definition

Lime stabilisation is one of the commonest and most economical techniques of soil stabilisation. This technique is unique in that, lime reacts with the soil forming a two material system. This technique may be applied for heavy wet clays during construction of road sub bases by providing a stable working platform. Many significant engineering properties are improved with lime treatment and they include; increase in soil bearing capacity, reduction in shrinkage properties of the soil, reduction in plastic index, reduction in soil compressibility and immobilization of heavy metals. There are three main common types of lime which include quick lime, hydrated lime and slurry lime. Lime has been used as deep stabilizer in several countries for example Sweden, Japan, USA among others and the stabilisation techniques include;

- Lime slurry pressure injections
- Lime columns
- Lime piles

Lime stabilisation is suitable for soils having plasticity index above 10 (Christopher et al., 2006)

2.2 Lime Piles

These are basically holes augured in the ground filled with lime. These use a mechanism of cation exchange in their work. Ingles and Metcalf (1972) showed one method of lime pile construction, in which a hollow tube is pushed into the soil to the required depth of pile and quicklime is forced into the tube under pressure as it is withdrawn. The other method is auguring holes in the ground and filling them with lime and compacting in layers for stabilization.

2.3 Mechanism of Lime Pile Stabilisation

Mechanism of stabilisation proposed by several authors include pile expansion and clay hydration.

Lime Pile Expansion: Quicklime in the piles reacts with the water in the in-situ soils, drawing excess water from neighborhood of the piles. This leads the piles to expand due to reaction, causing lateral consolidation of the nearby clay. According to authors that proposed the mechanism, using lime piles improves the bearing capacity and settlement characteristics of soft ground. $CaO + H_2O \rightarrow Ca(OH)_2$

Clay Hydration: The migration of calcium ions from the pile into the surrounding clay is aided by soil moisture. For the clay-lime reaction to take place, clay must be in a highly alkaline condition at a minimum pH of 12.4. Clay particles have negatively charged surface absorb positively charged calcium ions forming a slaked lime.

3 Material and Methods

3.1 Clay Soil

Clay soil was sampled along Kamwenge - Fort portal road at km 189 + 900. This was carried out using axel, spade and sacks at a depth of 1 m from the ground within the road shoulders. Several tests were undertaken out on the neat sample and lime pile treated samples to evaluate the effect of lime piles on the engineering properties. Table 1 shows the chemical composition of the obtained soil sample. The main component was Silica (SiO_2) at 55.65 %. Table 2 shows the index test values of the clay soil.

Table 1. Chemical composition of the obtained clay soil

Parameter	**Composition (%)**
Alumina AI2O3	20.16
Calcium Oxide CaO	0.59
Iron Oxide Fe2O3	7.47
Magnesium Oxide MgO	0.73
Manganese Oxide MnO3	0.97
Silica SiO2	55.65

Table 2. Soil classification properties.

Parameters	**Values**	
Liquid Limit (%)	58.6	
Plastic Limit (%)	26.5	
Plastic Index (%)	32.1	
	Sieve No.	
Percentage Retained (%)	200	17.4
	40	80.7
	10	1.9

The soil was classified using the Unified Soil Classification System. From the sieve analysis test, 17.4% of the soil sample was retained on sieve No. 200 (75µm) which was less than 30% but greater than 15% as sand dominated more than gravel. Thus the soil was classified as CH, which is inorganic fat clay with sand.

3.2 Lime

Hydrated lime, Figure 1, was obtained by slaking quick lime with water. Hydrated lime was used as a chemical stabilizer to modify the properties of the soil and was bought from a hydrated lime dealer.

3.3 Sample Preparation

Using an evaporating dish, stove and digital weighing balance, the sample from 1 meter deep was measured and evaporated until no moisture was indicated on glass plate cover. The evaporated soil sample was left to cool and weighed again. The difference in weight was noted as weight of in-situ moisture content.

The extracted soil was air dried and then mechanically ground into a pulverized form. It was then mixed with water equal to the amount of the in-situ moisture. The prepared wet soil was placed in an airtight polythene bag for 24 hour to attain uniform moisture distribution and prevent moisture loss.

The wet soil was then compacted with the modified rammer in four equal layers in the test tank (1000mm*1000mm) to a predetermined in situ bulk density using core cutter and water content values to simulate the natural field conditions of the sample.

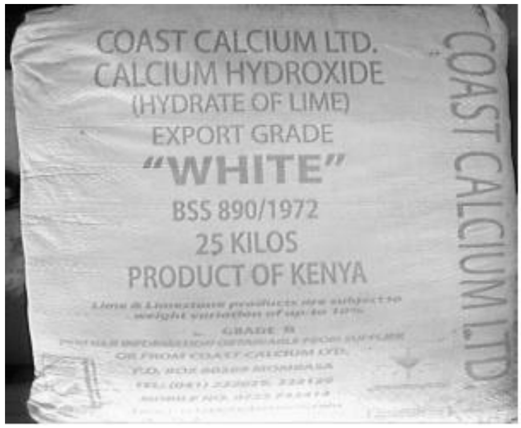

Figure 1. Hydraulic lime used

Table 3. Physical properties of the soil in the test tank.

Properties	Value
In-situ water content (%)	11.54
In-situ bulky density(kg/m3)	1650
Dimension of compacted soil in the test tank(m)	H=350mm, B=1000mm, W=1000mm
Volume of soil in the test tank(m3)	0.35
Mass of the soil compacted in the test tank(kg)	577.5
Volume of the lime pile in each hole(m3)	0.00275
Mass of the lime in the hole(kg)	4.54

3.4 Lime Pile Installation

This was done in the laboratory, Figure 2, involving the installation of nine piles in the compacted soil block. Each of these piles were 100mm in diameter and 350mm height. It was done using a hollow polyvinyl chloride (PVC) pipe that had openings at both ends. The PVC pipe had internal diameter of 100mm so as to aid the penetration into the soil block and create the hole without interfering with the properties of the compacted soil block. Each drilled hole was filled with hydrated lime of uniform mass applied in three equal layers and lightly compacted to form the lime piles. The piles were spaced at 180mm center to center.

The setup was then covered with synthetic fabric and then after lake sand on top to facilitate the physicochemical reactions between lime and the clayey material. This also helped to minimize sudden lateral expansion of the lime piles. The lime and soil block absorbed water and calcium and magnesium ions were diffused in each pile. The soil block was left to cure for a period of 14, 21 and 28 days

Figure 2. Equipment used during installation of lime piles in the test tank.

3.5 Sample Extraction

The sample was extracted between the lime piles using extrusion devices at different curing periods. During the sample extraction, the soil specimens were handled carefully and extracted at slow rate to prevent disturbance, openings or voids, loss of water content and cracking in the samples. The samples were immediately kept in air tight polythene bags after extrusion before conducting different tests.

3.6 Laboratory

Different laboratory tests were carried out on the lime treated samples including classification tests, compaction tests and strength tests. The tests were carried out in reference with BS 1377.

4 Results and Analysis

4.1 Effect of Lime Piles on Atterberg Limits

Figure 3 shows the variation of the liquid and plastic limits of the soil sample due to the lime piles for the different curing days that is 0, 14, 21 and 28 days. The neat soil sample was found to have a liquid limit of 58.6% which consequently reduced by 5.1%, 4.9%, and 2.7%. The plastic limit of the neat sample was found to be 26.5% which decreased with increase in curing days by 10.2%, 7.1% and 3.6%. These variations were because of reaction formed calcium silicate hydrates of high surface area and crystallized calcium aluminate hydrate which are larger than the initial particle size of soil sample. The increase of particle sizes continuously in the soil block consequently reduced the fines thus reducing liquid and plastic limits.

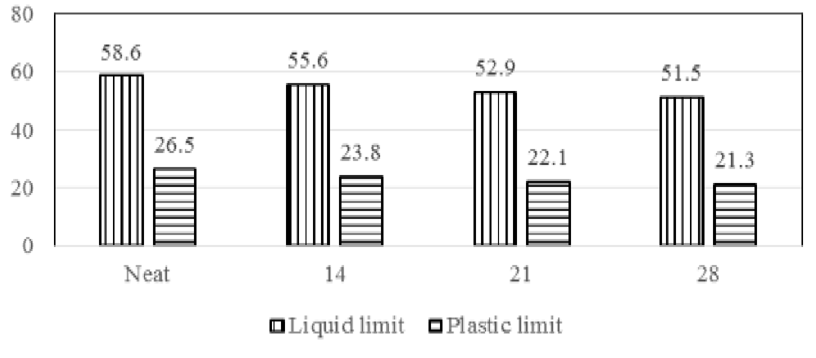

Figure 3. A graph of liquid limit and plastic limit against curing days

4.2 Effect of Lime Piles on Compaction Parameters

Figure 4 shows the variation of maximum dry density (MDD) and optimum moisture content (OMC) with curing days. The maximum dry density of neat soil sample was 1.801kg/m^3. It increased by 22.2%, 27.3% and 7.8% for 14, 21 and 28 days of curing. The maximum dry density increased with increase in curing days due to the increase in bond strength in the flocculation and agglomeration in soil block resulting from the physicochemical reaction hence causing mineralogy changes. The reactions formed calcium silicate hydrates of high surface area and crystallized calcium aluminate hydrate of high strength and larger than initial particle size of soil sample. This reduced the amount of fines in the soil block which consequently increased the maximum dry density as the curing days increased.

There was a decrease in the optimum moisture content in the soil block as the curing days increased. This was caused by flocculation and increased surface area of soil particles which increased the volume of voids in the soil while reducing amount of fines that absorb moisture. And also the increase in hydroxyl ions in the surrounding soil mass which decreased the affinity of surface of clay particles to water consequently decreasing water demand thus reducing optimum moisture content from 13.4% for the neat sample by 9.7%, 3.3% and 10.2% within the 14, 21 and 28 days.

4.3 Effect of Lime Piles on the Shear Strength Parameters

The neat sample gave initial shear strength parameters of cohesion of 19 kPa and angle of internal friction of 13°. The migration and diffusion of calcium ions from the lime piles caused pozzolanic reaction, altering the mineralogy and physicochemical properties of the soil. With the use of lime piles which dehydrated surrounding soil mass under evaporation caused by increased temperature and also reduced percentage of fines by agglomeration forming high strength crystallized with increased soil particle sizes. This significantly increased the soil cohesion by 20.8%, 4.0% and 7.4% within 14, 21 and 28 days. The angle of internal friction increased by 7.7%, 12.5% and finally 11.1% with in 14, 21 and 28 days of curing. Figure 5 shows the variation of shear strength parameters with curing days.

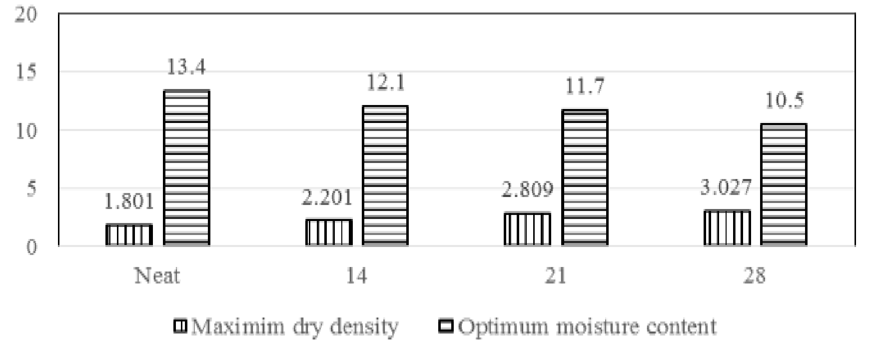

Figure 4. A graph of MDD and OMC against curing days

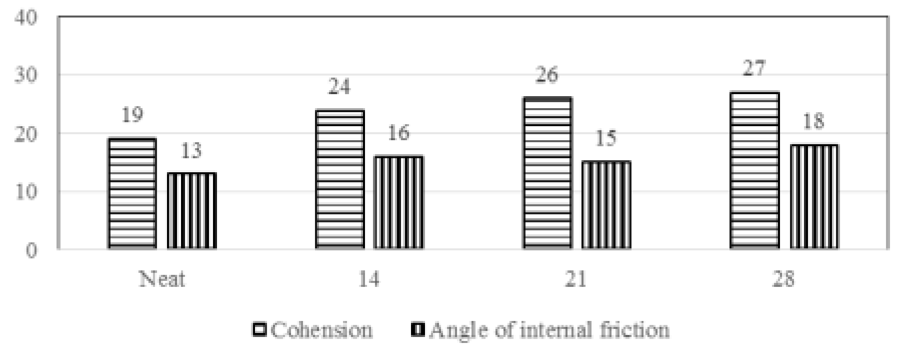

Figure 5. A graph of Cohesion and Angle of internal friction against curing days

5 Conclusion

There was signified reduction of water permeability in the soil which also increased the stability of the soil to be used for road embankment. The water required to achieve maximum compaction was reduced however water content for ion migration was increased which required attention. There was increase in cohesive strength between the stabilised soil particles which also contributed to the stability of the embankment. The internal angle of friction of soil particles increased which reduced the ability to slide off on the road section.

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