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Comparative Study on Some Chemical and Mechanical Stabilizations of Expansive Soils

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Abstract: This paper studies the differences between effects of chemical and mechanical stabilizations on the engineering properties of expansive soil. Undisturbed soil samples were collected form Abu-Gameem in South Sudan. The soil sample was very high expansive in accordance to the primary test conducted. Laboratory tests were undertaken to study the effect of chemical and mechanical additives individually on soil properties. Atterberg's limits, compaction, California bearing ratio, free swell and swelling pressure tests were conducted on natural and treated soil. Quicklime was used as chemical stabilizer agent, while fine sand was used as mechanical. The lime was collected from Sabol industrial area in south of Khartoum while the sand was obtained from Omdurman in Sudan. The soil was first treated by quicklime contents as 3%, 5% and 7% by weight. Then separately was treated by fine sand contents as 5%, 10% 15% by weight. Comparing the results obtained from chemical and mechanical stabilizations, it can be reported that both of them are effective in improving the engineering properties of expansive soils. Notwithstanding, chemical stabilization improved the soil with less contents of additive. Addition of only 3% quicklime reduced soil plasticity from 45% to a suitable value (18%) while addition of 15% fine sand reduced soil plasticity to 24%. Addition of quicklime resulted in reduction of free swell index almost 4 times of its initial value, whereas slight reduction was observed when fine sand used. Significant improvement on the swelling pressure was obtained when using lime. But, the compaction characteristics were improved further when fine sand used. It could be concluded that based on the result of this study, chemical stabilization is more effective than mechanical. However, a combination of them can be used for further investigations.

Keywords*: Expansive soil, Soil stabilization, Swelling, Quicklime, Fine sand.*

1. INTRODUCTION

Soil stabilization refers to alter, modify or improve weak engineering properties of soil, so as to meet a certain engineering requirements. Expansive soils are likely low strength and density on wetting as a result of soil swelling. These soils are especially troublesome as pavement subgrades and unsuitable for construction of embankments, buildings or other light structures in their natural state. Expansive soil is a soil that prone to large volume changes that are directly related to changes in water content. However, expansive soil remains stable if their moisture content remains so. Moisture differential a long seasons affect lightly loaded foundations on expansive soil. Such foundations are subjected into two movement components upon moisture differential, heave and shrinkage. Heave occurs due to wetting, while shrinkage is upon drying. Differential heave may be caused by non-uniform changes in moisture content and variation in thickness and composition of the expansive foundation soil. Expansive soil imbibes water during fall season which result in a dramatic heave, minimize shear strength and tend to be compressible. Swelling soil, upon wetting and drying causes severe damages to pavement constructed on it. Generally pavements on expansive subgrade soil show early distresses causing premature failures. Expansive soils usually have undesirable engineering properties, such as low strength (CBR less than 2% in general), coupled with low stability and extreme swelling. The nature of these soils creating serious problems to the engineering structures particularly roads constructed over them, [1].

Soil stabilization using additives is a suitable option among various methods of solutions for the problems caused by expansive soil. Among various methods of soil treatment the use local available additives for soil stabilization seems to be the most economical treatment method, [1].

2. LITRATURE REVIEW

As an alternative or supplement to construction on expansive soil, it may be desirable and economical to either modify the properties of the soil to reduce its expansion potential or to remove it and replace with non-expansive soil. Various techniques have been used to modify the characteristics of the soil that can be categorized into soil removal and replacement with suitable soil or soil stabilization by admixtures.

2.1 Removal and Replacement

In this method, the expansive soil is excavated to an appropriate depth to minimize heave to an appropriate amount, and then appropriately treated and compacted fill is placed to bring the soil up to grade level. Appropriate soil testing and analyses should be conducted to design the removal and evaluate the expected potential heave after the removal and replacement process. The design depth of removal and replacement must take into account the predicted heave. Depth governed by weight needed to prevent uplift and mitigate differential movement. Chen, F. H [2] Suggests a minimum of 1 to 1.3 m. Removal and replacement does not need special equipment for construction, [4] but in condition of filling materials must be imported from far distance, cost considerations will be significant.

2.2 Soil Stabilization

Soil stabilization is the process of improving the engineering properties in a weak soil such as expansive clay so as to render it stable and useful as engineering material. Improvements in engineering properties caused by stabilization are meant to 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 [3].

2.2.1 Mechanical Stabilization

Mechanical stabilization or blending soil is to mix the expansive soil with imported non-expansive soil up to an appropriate modification of soil properties. A trial of laboratory testing is required to insure the specific admixture properties. Mechanical stabilization includes:

• Use of improved subgrade layer: The improved subgrade is usually a non-expansive soil of acceptable strength and low permeability. This has an advantage of reducing the sub-base thickness and protecting the subgrade from moisture changes. Kenyan Road Design Manual [5] recommended a minimum thickness of 30 cm for the improved subgrade or capping layer.

• Surcharging Expansive Soils: It is well known that placing a substantial thickness of non-swelling material over expansive clays reduces heave. Kenyan Road Design Manual [5] recommends that the total thickness of pavement plus the improved subgrade to be at least 60cm. This approach is not effective over soils of high swelling potential.

• Using Sand Trenches: The function of a vertical sand trench is to act as a water balance reservoir. The predominant pavement distress was found to depend on the moisture conditions of the subsoil. For dry subsoil shrinkage cracks provide good passage for free water resulting in differential volume change in the soil beneath the pavement. In such case water proofing membrane must be installed along the trench and then backfilling is required with bituminous sealing along the trench surface.

2.2.2 Chemical Stabilization

According to Nelson et al [4], admixtures that are available for stabilization of expansive soil may be divided into two groups. These include traditional stabilizers such as lime, Portland cement, and fly ash, and nontraditional stabilizers agents such as potassium compounds, sulfonated oils, ammonium chloride, and others. The traditional stabilizers rely mainly on calcium exchange and pozzolanic reactions to effect treatment. The nontraditional agents rely on various proprietary and chemical reactions [4]. Some stabilizers agents does not perform any chemical reactions such as sand, steel slug etc. Based on this reactions, stabilization can be divided into chemical and mechanical stabilizations.

Chemical stabilization or chemical admixtures are known through their chemical reactions and cation exchange that modify the clay mineral structure. Chemical stabilizers with their introduced groups (traditional and non-traditional) are commonly used across the world. Petry and Little [6] grouped the various stabilizers into three categories:

- Traditional stabilizers: lime, cement, etc.
- By-product stabilizers: cement/lime kiln dust, fly ash, etc.
- Non-traditional stabilizers: sulfonated oils, potassium compounds, ammonium compounds, polymers, etc.

Lime Stabilization

Lime stabilization has been used successfully on many projects to minimize swelling and improve soil plasticity and workability. Generally, from 3 to 8% of lime is added to the soil, [7]. The primary reactions in the lime reaction include cation exchange, flocculation-agglomeration, lime carbonation, and pozzolanic reaction, [8]. The strength characteristics of a lime-stabilized soil depends primarily on soil type, lime type, lime percentage, and curing conditions such as time and temperature. Lime is not an effective treatment for all types of soils. Some soil components such as sulfates, organics, and phosphates can cause reactions that can have serious adverse effects, [4].

Table 1 lists several types of lime used as additives. Quicklime is manufactured by chemically transforming calcium carbonate ($CaCO_3$) into calcium oxide (CaO) by heating. Quicklime will react with water to form hydrated lime. Either quicklime or hydrated lime can be used as an agent for soil stabilization. If quicklime is used, the first water that is introduced will be used in the chemical reaction to form hydrated lime, which then reacts with the soil. Caution must be exercised when using quicklime. It can cause serious burns to skin and eyes if personnel come into contact with it. Modern spreading equipment can reduce the potential safety hazards associated with using quicklime.

Most lime used for soil stabilization is “high calcium” lime, which contains 5% or less magnesium oxide or hydroxide, [9]. However, sometimes dolomitic lime, which contains 35 to 46% magnesium oxide or hydroxide can be used, [4]. Dolomitic lime can also perform well when used for soil treatment, but the magnesium fraction of the lime requires more time to react than calcium does. The type of lime that is used can influence the strength of the treated soil. Dolomitic lime generally will be more effective in increasing strength. But in this study quicklime was used to study it is influence in soil properties.

Table 1. Lime materials used in soil treatment, [4]

Type of lime	Formula
Quick lime	CaO
Hydrated lime	$Ca(OH)_2$
Dolomitic lime	CaO • MgO
Normal hydrated or monohydrated dolomitic lime	$Ca(OH)_2$ • MgO
Pressure hydrated or dehydrated dolomitic lime	$Ca(OH)_2$ • $Mg(OH)_2$

Mohammed [10] reported that the lime-clay reaction takes place in two stages:

• The first stage is cation exchange reaction whereas the sodium cations have exchange with calcium cations. This will reduce the clay particles water absorption capacity and thus reduce swelling potential.

• The second stage happened after complete of the stage one. At this stage the lime reacts with the clay particles and produce cementitous material which produce the clay particles. The lime-clay reaction depends on the soil mineralogy. The lime is more reactive with montmorillonitic clays less with illite and far less than carollite.

Elsharief et al [11] studied lime stabilization of tropical soils from Sudan for road construction. They studied the effects of hydrated lime on the engineering properties for three tropical clays, two highly plastic potentially expansive soils and one red tropical lateritic soil. Elsharief et al [11] reported that lime efficiently reduces the plasticity of the three soils and that for the same increment of lime content the reduction in plasticity is higher for montmorillonitic clays compared to kaolinitic clays. The addition of lime to the three soils increased their maximum dry densities and reduced their optimum moisture content, [11].

3. MATERIALS AND METHODS

Experimental work was undertaken to achieve the objectives of the study. Laboratory tests were conducted on the natural soil and the soil after treatment by quicklime and then by fine sand.

3.1 Materials Used

The materials collected for testing were expansive soil, quicklime and fine sand.

3.1.1 Soil

The soil used for this study was collected from Abu-Gameem in South Sudan from pore hole of depth of 0.5 to 1.0 m 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 2.

Table 2. Characteristics of natural soil sample

Property	Value
Liquid limit (%)	69
Plastic limit (%)	24
Plasticity Index (%)	45
Optimum moisture content (%)	24
Maximum dry density (gm/cm^3)	1.499
CBR (%)	1.6
Free swell index (%)	105
Swelling pressure (Kpa)	280

3.1.2 Lime

The lime used for this study is high quality quicklime obtained from Safola industrial area in south of Khartoum. The quicklime produced in local kilns and satisfies the general requirements for construction purposes. The basic chemical properties of quicklime are provided in Table 3.

Table 3. basic chemical properties of quicklime

Chemical Formula	CaO
Molar Mass	56.0774 gm/mol
Appearance	White to pale yellow/ brown powder
Density	3.34 gm/cm^3
Melting point	2613^{o}C
Boiling point	2850^{o}C
Solubility in water	React to form calcium hydroxide
Acidity	12.8
Hazard	Danger

3.1.3 Sand

The sand used is natural red fine sand obtained from Omdurman town. Physical properties of fine sand are shown in Table 4.

Table 4. Physical properties of fine sand [12]

Coefficient of uniformity	11
Coefficient of curvature	2.00
Effective grain size D_{10} (mm)	0.18
Medium grain size D_{50} (mm)	0.27
Moisture content (%)	6
Maximum void ratio	0.94
Minimum void ratio	0.70
Specific gravity	2.4
Fraction angle	30

3.2 Laboratory Testing

Atterberg's limits test using Cassagrand's device was performed on natural soil and stabilized soil by varying percentages of quicklime (3%, 5% and 7%). Then the test performed on soil stabilized with varying percentages of fine sand (5%, 10% and 15%).

Compaction and CBR tests were conducted on the untreated and treated soil with quicklime and fine sand on the same percentages used for consistency tests. Standard test were conducted to find compaction characteristics. The CBR tests were performed as soaked 4 days for each sample. The soil samples were compacted at optimum moisture content (OMC) and maximum dry density (MDD) for CBR test.

Free swell and swelling pressure tests were conducted on the natural and treated soils by quicklime contents (3%, 5% and 7%). And then treated by fine sand content (5%, 10% and 15%). The free swell test was performed by pouring 10 cm^3 of soil passing 425μm sieve into a graduated cylinder glass jar of 100 ml 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 Odometer cell performed on compacted soil samples at OMC and MDD. Swelling pressure is equivalent to the pressure which must be applied to prevent any volume change in the soil sample when free water is fed into it until saturation.

The soil was initially allowed to swell under a seating pressure of 1psi (≈ 7 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 consistency limits tests, strength tests (compaction, California bearing ratio tests) as well as swelling tests (free swell and swelling pressure tests) performed for natural and treated soils are hereby discussed.

4.1 Tests Result

Tables 5 and 6 present the test results that conducted in the laboratory for the soil treated by different contents of quicklime and the soil treated by different contents of fine sand respectively.

Table 5. Characteristics of treated soil with different contents of quicklime.

Property	Value		
	3%	5%	7%
Liquid limit (%)	54	53	54
Plastic limit (%)	39	38	42
Plasticity Index (%)	16	15	13
OMC (%)	18	24	24
MDD (gm/cm^3)	1.490	1.509	1.489
CBR (%)	44	72	78
Free swell index (%)	51	35	23
Swelling pressure (Kpa)	180	50	20

Table 6. Characteristics of treated soil with different contents of fine sand

Property	Value		
	5%	10%	15%
Liquid limit (%)	49	41	43
Plastic limit (%)	18	16	20
Plasticity Index (%)	31	25	23
OMC (%)	19	18	17
MDD (gm/cm^3)	1.63	1.66	1.71
CBR (%)	2	3	4
Free swell index (%)	91	89	80
Swelling pressure (Kpa)	270	240	195

4.2 Effect of Additives on Soil Plasticity

The plasticity index values for natural soil and quicklime-stabilized soil as well as fine sand-stabilized soil are presented in Figure 1. Measured values of liquid limit and plastic limit for natural soil are 69% and 24% respectively. So the plasticity index for natural soil calculated 45%. Accordingly, the soil is classified as high plasticity clay. The plot of figure 1 shows that addition of quicklime to soil resulted in massive reduction of soil plasticity while addition of fine sand only to the soil resulted in very slight reduction of soil plasticity even when more contents of fine sand used. Moreover, addition of 7% of quicklime reduced the soil plasticity (PI from 45% to 13%). Accordingly the lime-stabilized soil can be classified as non-plastic soil. So it is clearly observed from the plot of figure that the use of quicklime as stabilizer agent is more effective than the use of fine sand to improve soil plasticity.

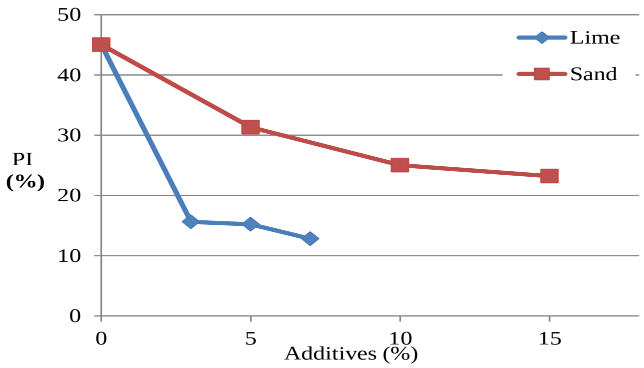

Fig. 1. Quicklime and sand contents on soil versus plasticity index.

4.3 Effect of Additives on Swelling Potential

4.3.1 Free Swell Index

The free swell measured for natural soil as 105% as shown in figure 2. This value indicates the soil can be classified as high expansive clay. The use of additives to stabilize the soil resulted in reduction of free swell. But it is clearly observed that quicklime is more effective. As presented in figure 2, 7% of quicklime resulted in almost 80% reduction of the free swell.

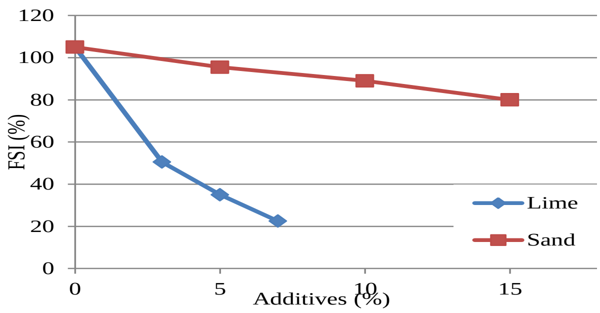

Fig. 2. Additives contents on soil versus free swell index.

4.3.2 Swelling Pressure

Swelling pressure measurement of the untreated soil reached 313 Kpa which indicates that the studied soil is high swelling clay. Effect of quicklime on swelling pressure reduction is clearly observed in the plot of figure 3. Addition of 5% of quicklime resulted in reduction on swelling pressure to almost 20% of its initial value. Addition of lime beyond that amount turned the soil to almost non-swelling soil. On the other hand, the use of fine sand reduced the swelling pressure slightly despite more contents used as shown in figure 3.

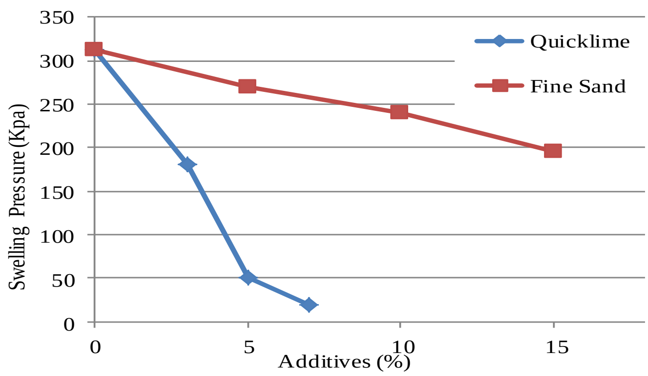

Fig. 3. Lime and sand contents on soil versus swelling pressure.

4.4 Effect of Additives on Strength Properties

4.4.1 Compaction Characteristics

Compaction characteristics (optimum moisture content (OMC) and maximum dry density (MDD)) of the treated and untreated soil are shown in figure 4. An Improvement on compaction characteristics (increase in MDD and decrease in OMC) can be observes when additives used as shown in the plot of figure 4. 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. As known that sand particles align themselves filling voids, MDD was obtained greater when the soil stabilized with sand further than stabilized with lime as shown in figure 4. Nevertheless, improvement in OMC occurs further when lime used particularly when 3% of quicklime used as depicted in the figure. Generally increment in MDD and reduction in OMC are improvements of compaction characteristics of soil.

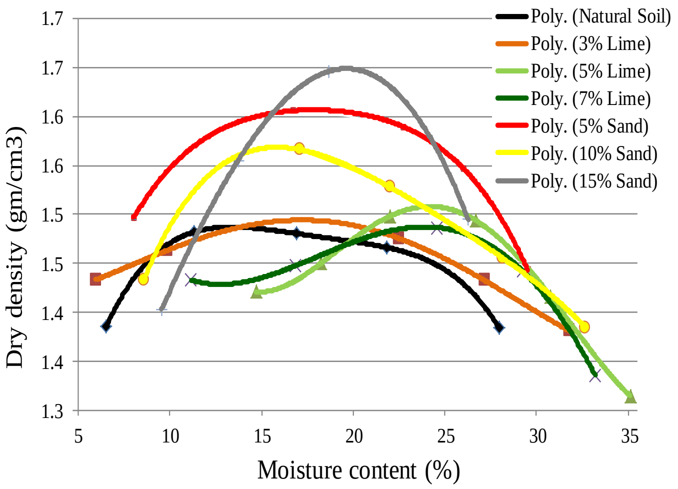

Fig. 4. Effect of additives on compaction characteristics of soil.

4.4.2 CBR

Effect of additives on CBR is shown in figure 5. The natural soil CBR measured only 1.6% which indicates the soil is very weak and could not be used as embankment. The CBR increased to 44% when 3% of quicklime added to the soil as shown in figure 5. More increment in CBR observed when further quicklime added to the soil up to nearly 80% when 7% of quicklime added. Such great increment in CBR may be due to the hardening of lime in the CBR testing mold. Addition of fine sand to the soil resulted in low improvement in CBR as shown in figure 5. Even 15% of fine sand increased the CBR to 3.5% only. This humble improvement may refer to the use of fine sand instead of course sand.

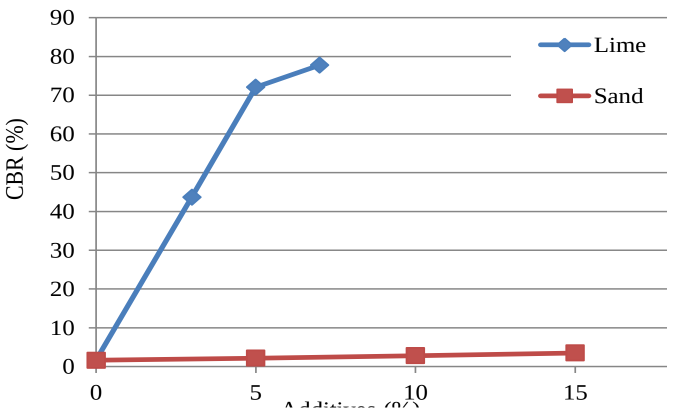

Fig .5. Effect of quicklime and sand on CBR.

5 CONCLUSION

In this comparative study, comprehensive laboratory tests were conducted to evaluate the influences of quicklime and fine sand on the engineering properties of expansive soil. The conclusions of the study can be summarised as follows:

- The study considered quicklime as chemical stabilizer agent and fine sand as mechanical stabilizer in accordance with the chemical reactions of quicklime proved by several researchers.
- In general, the results showed that quicklime and fine sand can be used as stabilizer agents because of their positive effect on the engineering properties of expansive soil.
- Additives have improved soil plasticity. However, quicklime improved soil plasticity further than fine sand. More contents of both quicklime and fine sand resulted in more reduction in soil plasticity.
- Quicklime showed better effects in improving swelling potential of the tested soil far further than fine sand did. This fact is due to chemical reactions of quicklime composition with minerals of clay particles. Swelling potential were measured by free swell index and swelling pressure tests. The use of fine sand did not reduce swelling potential to significant values despite the remarkable contents of fine sand used.
- Compaction parameters have considerable effect on strength which is measured by CBR in this study. Laboratory testing showed that fine sand have considerable effect on compaction characteristics than quicklime, while quicklime improved the CBR much greater than fine sand. This great increment on CBR resulting from the addition of quicklime is due to soaking and curing condition of quicklime which resulted in hardening of lime. Consequently, it is recommended to consider further strength parameters such as unconfined compression strength. On the other side, knowing that sand particles align themselves well when compacted, especially when sand is used just below concrete foundations for their uniform settlement. These advantages of sand are consolidated by the higher MDD measured in this study particularly when more sand contents are added. But regarding CBR, the sand used in the study did not increase the CBR to a significant value. This insignificant increment is due to the fact that the sand used was fine.

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