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Effect Of Salinity On Hydrated Lime Stabilized Swelling Clay Soils From Sudan

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Abstract
Saline and sodic soils are found in the central and eastern clay plains of Sudan which are dominated by highly plastic fertile swelling clays. Lime has been found to be an effective stabilizer for swelling clays. This paper presents the outcome of a laboratory testing program intended to study the effect of salinity on engineering properties of the lime stabilized swelling clays. Typical highly plastic swelling clay from Alfao in eastern Sudan was tested by applying artificial sodicity. The natural salinity was ECe 0.5 dS m^{-1} and artificial samples were prepared at 2.5, 7.0 and 12 dS m^{-1} related to the volume of Na-CL concentration used. The increase in sodicity for the swelling clay soil resulted in decrease of its plasticity and linear shrinkage and increase in strength for the untreated and lime treated sodic soil tested.
Keywords: *Stabilization, salinity, hydrated lime, plasticity, linear shrinkage, free swell, unconfined compressive strength.*

1. Introduction

Salinity and sodicity are separate and unique descriptions of the impact of soluble salts in soil and water. Sodicity represents the relative predominance of exchangeable sodium compared to other exchangeable cations, mainly calcium, magnesium, potassium, hydrogen and aluminium and is expressed as ESP (exchangeable sodium percentage). The sodium adsorption ratio, SAR, is another expression of sodicity that refers to the ratio of adsorbed sodium and the sum of calcium and magnesium [6]. Soil salinity is a characteristic of soils relating to their content of water-soluble salts. Salinity and sodicity are both measured by the electrical conductivity ECe expressed in decisiemens per meter (dS m^{-1}) of the extract of the saturated soil paste [1]. A strong association between saline and sodic soils has been reported for soils from Sudan. Typical values for Sudanese soils are less than 20 dS m-1 [2, 5].

Saline and sodic soils are dominant in Sudan especially within the arid lands in the central clay plain (the area between the White and the Blue Niles) and the terraces of the Nile north of Khartoum [2, 5]. Most of these areas are known to be covered by Vertisols or potentially expansive clay soils. Salinity seems to increase with aridity and highly saline soils occur where the average rainfall is less than 200 mm which is the case for the northern areas of Sudan and of Khartoum in particular [5]. According to Musfafa most of the salt accumulation occurs at soil depth 0.3 to 0.6 m. In most soils average salinity values tends to increase with depth as does its coefficient of variation. The dominant cation for soils from Sudan was found to be Na+ [5].

Almost 40% of the area of Sudan is covered with highly plastic potentially expansive clay plains (Vertisols). These plains are characterized by poor traffic-ability during the rainy season. Many villages and small towns are linked with un-paved roads therefore are totally isolated during the rainy season. Experience and research have shown that addition of hydrated lime substantially reduces plasticity and subsequently improve traffic-ability of the highly plastic expansive soils.

Previous researchers studied the improvement of saline clay soils using different chemical stabilizers. Ziaie (2011) [5] studied the volume change behavior of saline soils and also the effect of lime on the improvement of these soils using laboratory tests, namely, consolidation, swelling pressure and free swell test. The results showed that lime reduced the liquid limit and free swell and increased the coefficient of consolidation of stabilized saline clay soils.

Given the fact that the clay plains of the central and northern Sudan are characterized by the presence of saline and sodic soils and their improvement with lime could be technically and economically viable [4], the influence of soluble salts on lime stabilization of these soils need to be investigated.

2. Material, Test Procedure and Results

The experimental testing program was aimed at studying the effects of salinity on lime stabilization of a typical highly plastic potentially expansive clay soil from the clay plains of Sudan. The clay sample studied here was obtained from Alfao in eastern Sudan and is characterized by its low salinity. It was intended to prepare clay samples with electrical conductivity levels up to about 12dSm^{-1} to cover the salinity/sodicity levels normally found in Sudanese clay soils. Given the good association between salinity and sodicity, the dominance of Na+ in the pore water of Sudanese soils and the ease of preparing and adding sodium chloride salt to the soil, this investigation mainly assessed the effect of salinity on the lime-soil reaction.

A bulk sample was obtained from 0.5 m depth in Alfao. Its electrical conductivity was measured and was found to be 0.5dS m^{-1}. The bulk sample was divided into four samples. The first one was considered as natural sample whereas the other three samples were mixed with sodium chloride solutions with different concentration levels to prepare the saline samples. About 1.0 kg of dry soil from each of the three samples was mixed with sodium chloride (Na CL) solution. The concentrations were 100 mmol, 150 mmol and 200mmol respectively. The samples were then left for two days to dry in the air after which their salinity levels were measured by electrical conductively. The values obtained were 2.5, 7.0 and 12 dS m^{-1}, related to the volume of (Na CL) concentration used. The sample preparation procedure ended up with four samples, a natural one with ECe value of 0.5 dS m^{-1}, and samples with ECe values 2.5, 7.0 and 12.0 dS m^{-1}.

The next step was to treat the samples with calcium hydroxide (lime). The optimum lime content (OLC) of the tested soil was found from previous studies to be 6.5% [3]. It was decided to add 3.0% and the OLC (6.5%) to the prepared soil samples. Each of the four samples was further divided to three subsamples; two of them were mixed with lime, one with 3.0% and the other with 6.5% whereas the third was not mixed with lime (0%). The following tests were then performed on each of the subsamples: Atterberg limits, linear shrinkage (LS), free swell (FS) and unconfined compressive strength (UCS). The tests were performed following the guides of BS 1377-1990 procedure. The results are presented in Table 1. The zero percent lime and 0.5 dS m^{-1}represent the natural un-stabilized soil properties.

Table 1: Atterberg limits, LS, FS and UCS for different salinity/sodicity levels

Sample	Ec (dS m^{-1})	Lime %	Atterberg Limits			LS %	FS %	UCS (kPa)
			LL	PL	PI			
Alfao	0.50	0	66	29	37	19	168	275
		3	61	40	21	9.9	83	406
		6.5	55	45	10	5.0	32	1565
Alfao	2.5	0	66	29	37	18	167	281
		3	61	40	21	9.1	78	521
		6.5	55	45	10	4.8	30	1654
Alfao	7.0	0	64	30	34	17	158	290
		3	60	40	20	8.1	69	580
		6.5	51	41	10	4.7	28	1681
Alfao	12	0	61	32	29	16	151	297
		3	58	40	18	6.2	59	610.6
		6.5	50	42	8	4.5	27	1705.7

Note: LS for linear shrinkage; FS for free swell; LL for liquid limit; PL for plastic limit; PI for plasticity index

3. Discussion of the Results

Salinity/sodicity effects on plasticity and strength had been studied by imposing artificial sodicity to a typical swelling clay sample from Alfao in eastern Sudan. The natural salinity of Alfao soil was very low, i.e. ECe 0.5 dS m^{-1}. Soil samples with various levels of sodicity were prepared. The Atterberg limits, linear shrinkage, free swell and unconfined compression strength were obtained for the natural, un-treated sodic and lime-treated sodic samples (Table 1). The Figures 1 through 5 are plotted in this format to clearly observe the changes in the engineering properties for samples mixed with different amounts of sodium chloride, untreated or treated with the same amount of lime.

This investigation has shown that liquid limit, plasticity index, linear shrinkage and free swell of the untreated sodic soil from Alfao generally decreased with increase in sodicity. The decrease is more effective for the untreated sodic samples (0% lime) with ECe equals 7.0 and 12.0 dS m^{-1}(Table 1 and Figures 1, 2, 3 and 4). The unconfined compression strength showed steady increase with increase in sodicity for the untreated sodic soils (Figure 5). The results clearly show that sodicity reduces the activity of the tested soil and tends to improve its engineering properties. As for the lime-treated soils small increase in sodicity (2.5 dSm^{-1}) did not affect the liquid limit and plastic limit of the sodic samples (Figures 1 and 2). However, there is small effect, noticed for the samples with ECe 7.0 and 12.0dS m^{-1}. The sodicity effect on plasticity decreases with increase in lime content. The linear shrinkage and free swell decreased with increased sodicity for the samples treated with the same amount of lime. The unconfined strength increased with increase in ECe for the lime treated sodic soils with the same amount of lime (Figure 5). Therefore, the increase in sodicity caused an increase in strength for the untreated and lime-treated soils (Table 1 and Figure 5). Sodicity did not inhibit or adversely affect the reaction between lime and the swelling soil.

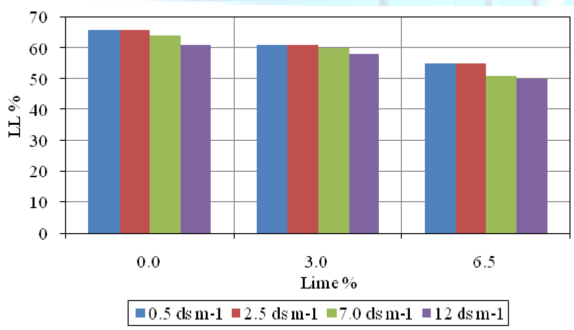

Fig.1 Effect of salinity and lime content on liquid limit

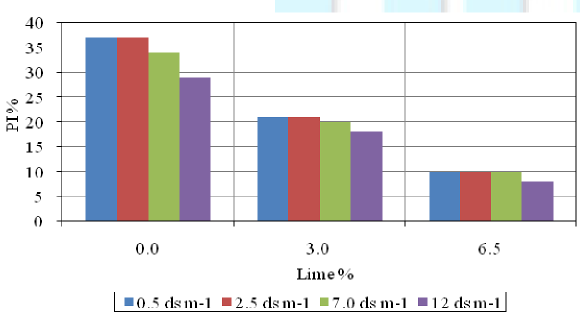

Fig. 2 Effect of salinity and lime content on plasticity index

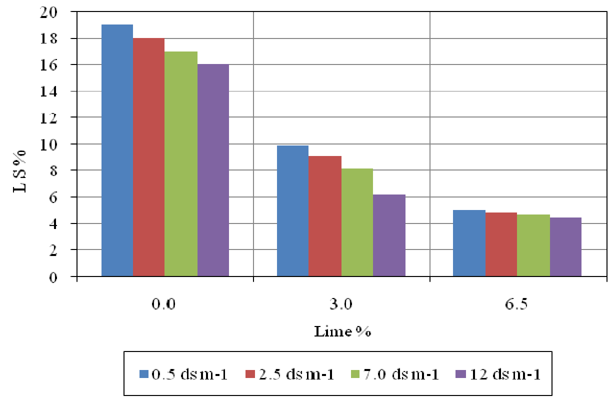

Fig. 3 Effect of salinity and lime content on linear shrinkage

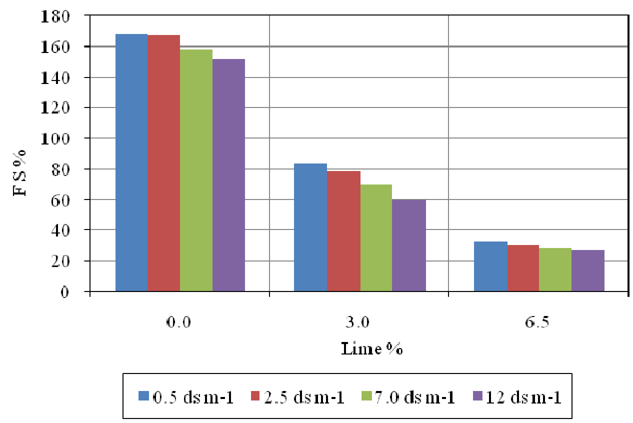

Fig. 4 Effect of salinity and lime on free swell

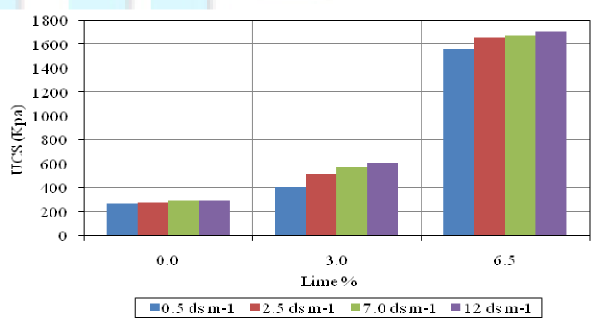

Fig. 5 Effect of salinity and lime content on unconfined compressive strength

4. Conclusions

Clay soils (Vertisols) in northern and the central clay plains of Sudan are known to be saline. Salinity increases with aridity. A strong association between saline and sodic soils has been reported for soils from Sudan. This paper studied sodicity effects on the engineering properties of lime stabilized tropical swelling soil from Sudan or the effect of sodicity on lime-treated vertisols. Sodium chloride solution was added in the laboratory to a typical swelling clay from Alfao in eastern Sudan which has very low content of dissolved salts to prepare samples with different levels of salinity (2.5, 5.0. 7.0 and 12.0dS m^{-1}). The liquid limit, plasticity index, linear shrinkage, free swell and unconfined compressive strength tests of the untreated sodic and lime treated sodic soil samples with 3.0 % and 6.5% (optimum lime content) were carried out.

This study has shown that salinity decreases the plasticity, free swell and linear shrinkage of the untreated clay soil, especially for the samples measuring 7.0 and 12.0 dS m^{-1}. Salinity also increased the unconfined compression strength of the untreated soils. The treated samples behaved in a similar manner for the samples treated with the same amount of lime. Generally the increase of sodicity caused decrease in the activity (as reflected by the plasticity, shrinkage and swelling) and increase in strength of the lime treated sodic soil tested. Therefore, sodicity tends to contribute positively or to improve the engineering properties of swelling soils when stabilized with lime.

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