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Laboratory Investigation of Expansive Soil Stabilized with Calcium Chloride

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***Abstract*—**Chemical stabilization is a technique commonly used to improve the expansive soil properties. In this regard, an attempt has been made to evaluate the influence of Calcium Chloride ($CaCl_2$) stabilizer on the engineering properties of expansive soil. A series of laboratory experiments including consistency limits, free swell, compaction, and shear strength tests were performed to investigate the effect of $CaCl_2$ additive with various percentages 0%, 2%, 5%, 10% and 15% for improving expansive soil. The results obtained shows that the increase in the percentage of $CaCl_2$decreased the liquid limit and plasticity index leading to significant reduction in the free swell index. This, in turn, increased the maximum dry density and decreased the optimum moisture content which results in greater strength. The unconfined compressive strength of soil stabilized with 5% $CaCl_2$ increased approximately by 50% as compared to virgin soil. It can be concluded that $CaCl_2$ had shown promising influence on the strength and swelling properties of expansive soil, thereby giving an advantage in improving problematic expansive soil.

***Keywords*—**Calcium chloride, chemical stabilization, expansive soil, improving.

I. Introduction

EXPANSIVE soil is one of the problematic soils that has a high potential for swelling and shrinking due to change in moisture content. This behaviour of soil is attributed to the presence of mineral montmorillonite, which has an expanding lattice. Expansive soils cover considerable land area of most countries of the world. Sudan is one of the countries with a wide distribution of expansive soils. Over one–third of the country total area has expansive soils. The major problem that arises with regard to expansive soils is that deformations are significantly great, which results in extensive damage to the structures resting on them, [1].

Proper remedial techniques are to be adopted to modify the soil or reduce its swelling potential. Many stabilization techniques are in practice for improving the expansive soils in which the characteristics of the soils are altered. Chemical additives such as lime, cement, bitumen, fly ashes, calcium chloride etc. are commonly used to alter the characteristics of the expansive soils. The main characteristics that are of concern to the geotechnical engineers are strength, swelling, compressibility and durability. The effect of the chemical additives and the optimum amount of additives to be used are dependent mainly on the mineralogical composition of the soils. In this research, the possibility of stabilizing expansive soil with a chemical stabilizer such as calcium chloride ($CaCl_2$) is investigated. The objective of the present study is to study the effect of adding $CaCl_2$ on the engineering properties of expansive soil.

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II. Literature Review

Expansive soils pose the greatest hazards that many geotechnical engineers face. Such soils may cause heavy damages in light loaded structures such as water canals, reservoirs, highways, railways and airport runways etc., unless appropriate measures are taken. Various stabilization techniques are in practice for improving expansive soils by reducing its swelling potential and increasing its strength characteristics. Modification of expansive soil by chemical admixture is a common practice for stabilizing the swell-shrink tendency of expansive soil, [2]. Advantages of chemical stabilization are that they reduce the swell-shrink tendency of expansive soils and also render the soils less plastic. In this section, the experiences of various investigators concerning chemical stabilization using calcium chloride have been reviewed.

Numerous investigators, [3]–[7], have studied the influence of lime, cement, lime-cement, lime-fly ash, and cement–fly ash mixes on soil properties, mostly focusing on the strength and swelling aspects. Among the chemical stabilization methods for expansive soils, lime stabilization is mostly adopted for improving the swell-shrink characteristics of expansive soils. As lime and cement are binding materials, the strength of soil-additive mixtures increases provided the soil is reactive with them. However, for large-scale field use, the problems of soil pulverization and mixing of additives with soil have been reported by several investigators [2], [3], [8], [9].

Calcium chloride is an inorganic salt, which is a by-product of sodium carbonates. The use of calcium chloride in place of lime, as calcium chloride is more easily made into calcium charged supernatant than lime, [10]. A recent study indicated that $CaCl_2$ could be an effective alternative to conventional lime used due to its ready dissolvability in water and to supply adequate calcium ions for exchange reactions, [11]. Calcium chloride is known to be more easily made into calcium charged supernatant than lime and helps in ready cation exchange reactions, [9]. $CaCl_2$ might be effective in soils with expanding lattice clays, [12]. The bibliography on stabilization of soil and calcium chloride is giving its wide use in highways, [8]. Hausmann [13] and Shepard [14] have stated that $CaCl_2$ enjoyed its wide use as dust palliative and frost control of subgrade soil. Calcium chloride has hygroscopic

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property. This means that calcium chloride attracts and absorbs water. This is a function of relative humidity and temperature. It can easily liquefy in moisture of its own absorption. Shepard [14] reported that calcium chloride is highly soluble and can be dissolved easily so it can be easily washed away by rain and more than one treatment in a single season may be required to maintain its effectiveness. For the same humidity and temperature, the vapor pressure of calcium chloride is lower than water. Calcium chloride has a higher surface tension and a lower freezing point compared to water, [14].

According to Bushman et al [15], calcium chloride has been used as a dust suppressant, but it is also referred to as a stabilizer because of its ability to alter material properties such as strength, compressibility, and permeability. Essentially, the function of this chemical is to agglomerate fine particles and bind them together, [15]. On-going research at Texas A&M University found that an addition of calcium chloride ($CaCl_2$) to soils and crushed limestone significantly increased the effectiveness of road base stabilization and base stabilization along with dust control in Full-Depth-Recycling (FDR) of old asphalt roads. Addition of calcium chloride affects engineering properties of the treated soils.

Calcium chloride has major effect on shear strength, depending on the soil type and curing, [16]. They found that Unconfined Compressive Strength (UCS) of soil treated with 1% $CaCl_2$ and subjected to 14 days curing showed almost two times improvement as compared to 0-day UCS. Fig. 1 shows the variation of UCS of a soil treated with $CaCl_2$ and samples tested at 0 day, 7 days, and 14 days curing period.

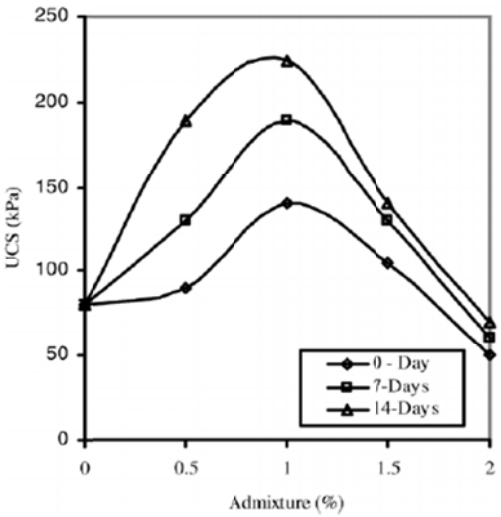


Fig. 1 Influence of $CaCl_2$ on UCS for Soil-A, [16]

Saylak et al. [17] indicated that solid calcium chloride has high water-absorbing performance. At a relative humidity of 95%, solid $CaCl_2$ can absorb 16.6 times its weight of water. Even in a relatively low humidity environment of 30%, it can absorb almost to its own weight water. In addition, calcium chloride dissociates into Ca^{2+} ions in the presence of water which will lead to ion exchange reactions with Na^+ and K^+ ions initially adsorbed on the clay particle surface. As a result, the thickness of double diffusion layer (DDL) of soil particles will be reduced and soil particle aggregates will form, [18]. Consequently, the soil plasticity will decease and strength will increase, [19].

Shon et al. [20] reported that treatment of soil with calcium chloride increases the density and strength of the compacted soil. They found that calcium chloride increases the surface tension of the retained moisture within the soil matrix, thus increasing the suction pressure of the system. This, in turn, increases the cohesive energy between the particles which result in greater strength. He found also calcium chloride-treated soils containing adequate amount of fines, can achieve ultimate strengths up to 360 psi, which are more than adequate to meet accepted specifications for the secondary roads. Based on laboratory tests, [21] emphasized that the swelling characteristics of expansive soils can be improved by means of flooding at a given site with proper choice of electrolyte solution more so using chloride of divalent or multivalent cations.

III. Materials and Experiments

A. Materials Used

In this study, the materials used for testing are expansive soil and calcium chloride additive. The soil used was obtained from Almenshia in Khartoum. The soil is dark grey stiff clay of high expansion. It was dried, pulverized, and then sieved through 4.75mm size sieve. The measured physical and mechanical properties of the soil are given in Table I.

TABLE I
Summary of Measured Properties of the Soil Used

Property		Value
Specific gravity		2.72
Clay content, %		55
Atterberg's limits	Liquid limit, %	63
	Plastic limit, %	27
	Plasticity index, %	36
Free swell index (FSI), %		180
Compaction parameters	Maximum dry density, KN/m^3	1.60
	Optimum moisture content, %	21.0
Unconfined compression strength, KN/m^2		506
Soil classification		CH

Calcium chloride is the ionic compound of calcium and chloride. It is a salt that behaves as a typical ionic halide, being solid at room temperature and highly soluble in water. Because of its hygroscopic nature, anhydrous calcium chloride must be kept in tightly sealed, airtight containers, [22]. It is used for numerous purposes at different concentrations depending on its use. This research used its highest percentage calcium chloride products. The properties of calcium chloride ($CaCl_2$) are given in Table II.

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TABLE II
PROPERTIES OF CALCIUM CHLORIDE USED AS STABILIZER

Property	Value
Molar Mass	110.99 g.mol^{-1}
Appearance	White Powder
Minimum assay	95%
Maximum limits of impurities	
Iron (Fe)	0.002%
Heavy metals (as Pb)	0.002%
Sulfate (SO_4)	0.05%
Loss on drying	10%
Boiling point	1,935 °C

B. Experiments

To evaluate the effectiveness of calcium chloride for stabilization of expansive clay, various percentages of $CaCl_2$ (0%, 2%, 5%, 10%, and 15%) were added to the soil. Laboratory tests were undertaken to determine the soil basic properties. Initially soil classification tests such as grain size analysis, liquid limit, and plastic limit were undertaken, followed by measurement of strength characteristics such as compaction and unconfined compressive strength (UCS). Furthermore, the free swell test was also performed. All the experimental programs have been performed in accordance with British Standard [23].

IV. Results and Discussion

Various laboratory experiments were conducted on samples prepared by adding different percentages of calcium chloride to the expansive soil. Atterberg's limits, compaction, strength and swelling tests were conducted with a view to investigate the influence of adding various percentages of calcium chloride to expansive soil on measured soil properties.

A. Effect of Calcium Chloride on Atterberg's Limits

The influence of $CaCl_2$ with varying percentages 0%, 2%, 5%, 10%, and 15% on liquid limit, plastic limit and plasticity index are clearly presented in Fig. 2. From this figure, it was observed that there is a significant decrease in liquid limit and plasticity index with increase the percentage of the $CaCl_2$.

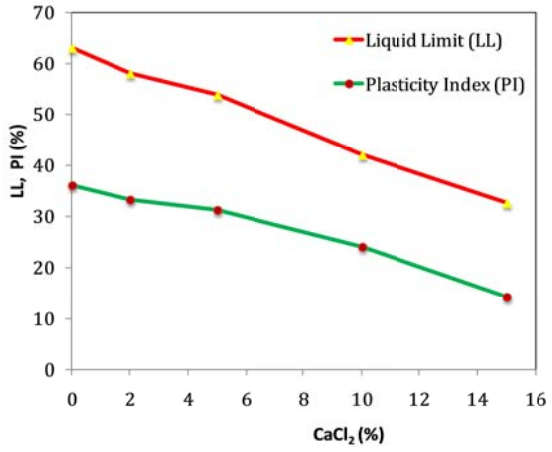


Fig. 2 Effect of $CaCl_2$ on liquid limit and plasticity index

The decrease in the liquid limit and the increase in the plastic limit cause a net reduction in the plasticity index. It is observed that, the reduction in plasticity index from 36% to 14% for 15% of $CaCl_2$ added to the expansive clay. The reduction in plasticity with $CaCl_2$ additive is almost 60% of the initial value of virgin soil and could be attributed to the depressed double layer thickness due to cation exchange by calcium ions.

B. Effect of Calcium Chloride on Free Swell

Fig. 3 shows the variation of Free Swell Index (FSI) of stabilized expansive clay with addition of different percentages of $CaCl_2$. It can be seen that the FSI is decreasing with increasing percentage of $CaCl_2$ added to the expansive soil. Significant decrease in FSI is recorded in stabilized expansive clay with increasing percentage of $CaCl_2$. The reduction in FSI values of stabilized expansive clay with addition of 15% $CaCl_2$ is from 180% to 49% compared with the expansive clay. The reduction in free swell value is around 70% with addition of 15% $CaCl_2$ to expansive soil. This result could be supported by the fact that the double layer thickness is depressed with cation exchange with calcium ions and with increased electrolyte concentration.

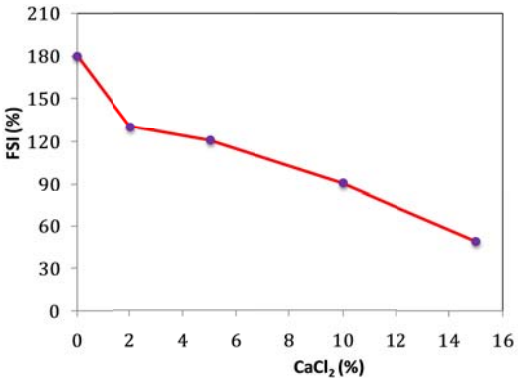


Fig. 3 Variation of Free Swell Index (FSI) with various $CaCl_2$ content

C. Effect of Calcium Chloride on Compaction Parameters

The variation of the compaction parameters such as maximum dry density (MDD) and optimum moisture content (OMC) values with different percentages of $CaCl_2$ added to the expansive soil is presented in Figs. 4 and 5. Significant change in MDD and marginal change in OMC are observed with addition of $CaCl_2$ to the expansive clay. The improvement in the compaction parameters with addition of $CaCl_2$ may be attributed to the cation exchange between mineral layers.

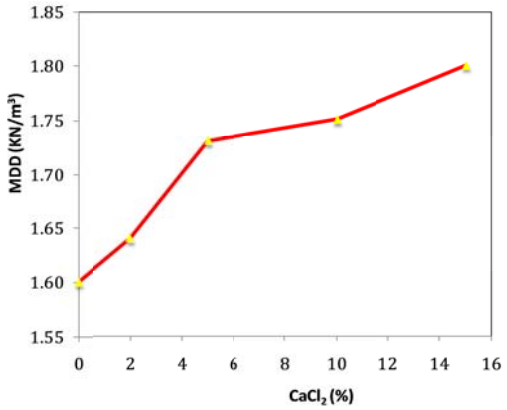


Fig. 4 Influence of $CaCl_2$ on maximum dry density

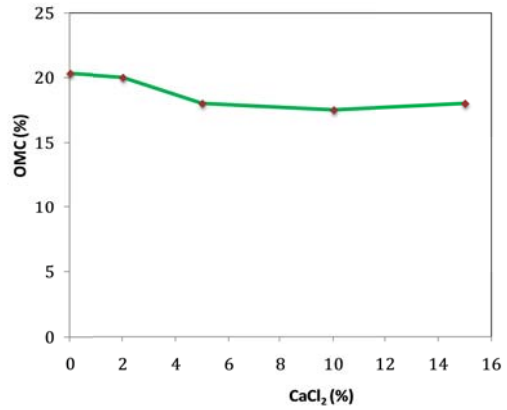


Fig. 5 Influence of $CaCl_2$ on optimum moisture content

D.Effect of Calcium Chloride on Compaction Parameters

The unconfined compressive strength (UCS) of the remoulded samples prepared at MDD and OMC with addition of 0%, 2%, 5%, 10%, and 15 % of $CaCl_2$ to the expansive soil are presented in Fig. 6. It is observed that the UCS of the stabilized expansive soil is increasing with increase in percentage of $CaCl_2$ added to the soil. Significant increase in UCS in stabilized expansive soil with addition of $CaCl_2$ up to 5%, beyond this percentage the UCS rapidly decreased. The increase in UCS values of stabilized expansive clay with addition of 5% $CaCl_2$ is almost 50% of virgin soil. The increase in the strength with addition of $CaCl_2$ may be attributed to the cation exchange of $CaCl_2$ between mineral layers and due to the formation of silicate gel. The reduction in UCS beyond 5% of $CaCl_2$ may be due to the absorption of more moisture at higher $CaCl_2$ content.

Finally, from the above discussions, it is clear that there is improvement in the swelling and strength characteristics of Expansive soil stabilized with $CaCl_2$. It is evident that the addition of $CaCl_2$ to the virgin Expansive soil showed an improvement in compaction and strength characteristics. This made the problematic expansive soil which if not stabilized is a discarded material, a useful fill material with better properties.

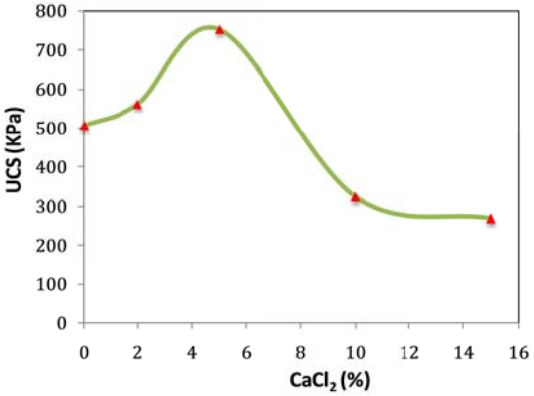


Fig.6 Variation of UCS of stabilized soil with $CaCl_2$

V. Conclusions

This study has been undertaken to investigate the influence of using various percentages of calcium chloride ($CaCl_2$) on the properties of stabilized expansive soil. The results and the conclusions are drawn as follows:

- It was pointed out that understanding the behavior of expansive soil will greatly contribute to the proper selection of an efficient stabilizer results in significant improvement of the soil properties.
- Calcium chloride could be an effective alternative to conventional lime used due to its ready dissolvability in water and supplying adequate calcium ions for exchange reactions.
- A significant decrease in plasticity and swelling of stabilized expansive clay with increasing percentage of $CaCl_2$. The reduction in plasticity and free swell with the addition of 15% $CaCl_2$ were found to be 60% and 70% respectively.
- Addition of calcium chloride has major effect on compaction characteristics of the stabilized soil. An increase in $CaCl_2$ content leads to an increase in dry density and a decrease in optimum moisture content. This result in greater strength.
- The shear strength increases up to 5% $CaCl_2$addition; beyond this percentage there is a considerable decrease is observed may be due to the absorption of more moisture at higher chemical content.
- The findings indicated an increasing trend for soil strength and decreasing in swelling with addition of $CaCl_2$, suggesting its potential applications in stabilization of problematic expansive soils.

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