Behavior of Expansive Soil Treated by using Different Electrolyte Substances

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Abstract— **Expansive soil is one of the problematic soils which need more investigation and study. This soil is expected to swell or shrink as its moisture content increase or reduce, respectively. Cracks and severe damage could be happened to structure members construct on this expansive soil. In the present work, laboratory tests were performed on expansive samples to predict the behavior of the expansive soil by adding different electrolyte substances to the soil. The tested samples are collected from Tabuk region in the northwest part of Saudi Arabia. Laboratory tests were performed to investigate the improvement of soil properties, free swell and unconfined compression test values after using the electrolyte substances compared to the original soil behavior. It is observed from the laboratory studies that a significant improvement of the expansive soil strength with a reduction in its swell behavior with adding electrolyte substances.**

Keywords-problematic; expansive; improvement; electrolyte

I. INTRODUCTION

Problematic soil is known for civil engineers as the soils which should be studied well before construct buildings on it. Behavior of these problematic soils is different than other soils due the behavior of its structure condition. Expansive soil is one type of these problematic soils which occupies about 20% of the world surface area. Expansive strata are soil and/or rocks that contain clay minerals that have potential for swelling and shrinkage under changing moisture conditions. Clay minerals could originate from the weathering of shale, slate, sandstone, and limestone.

Subtropical climate influences the development of this type of soil and accelerates the desiccation and weathering processes of the source rock. If they contain montmorillonite (smectite group) or a certain type of illite, they will have significant swelling potential when wetted.

Expansive soils were reported in several locations in Saudi Arabia, including our study area in Tabuk city to the northwest of Saudi Arabia. Shale is the primary source of expansive soils in Tabuk area as descibed in previous studies, [1], [4], [20], and [21]. As water reaches these soils, the latter are rapidly wetted and quickly swell near the ground surface to form a water barrier to further water entry. The factors that control the behavior of expansive soils have been thoroughly investigated by many researchers, [6], [7], [9] and [22].

The swelling behavior can be basically related to the combined effect of interacting factors that can be grouped into: (a) local geology; (b) engineering properties and; (c) local environment of deposition. The main geological factors include the rock type and age as related to the type and amount of clay minerals, type and amount of cementing material, [6], [17], and [24], and the soil particles arrangement [3], and [12]. The engineering factors include the moisture content, Atterberge limits, and the dry density.

The environmental factors include the confining pressure, type and degree of weathering as related to the amount of clay fraction, initial water content, [14], and [22] and water chemistry, [11], and [20].

The swelling potential is related to the geological and engineering factors while the amount and rate of swelling are controlled by environmental conditions. The expansive soils in Tabuk cause geotechnical problems to structures, especially pavements and light buildings. After recognizing the problems posed by these soils to civil engineering structures, Engineers from all parts of the world have been trying to find solutions. Among several techniques adopted to overcome the problems posed by expansive soils, lime stabilization gained prominence during the past few decades due to its abundance and adaptability, [3], and [5].

However, it is reported, [8] that lime stabilization suffers from the major drawback of difficulty in soil pulverization and mixing with it.

Recent studies, [3], [5], and [15] 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. Reference [16] made an attempt to stabilize the in-situ soil using KOH solution and they revealed that it is possible to alter the properties of black cotton soils in place by treating them with aqueous solution of KOH.

Reference, [11] studied the use of KCl to modify heavy clay in the laboratory and revealed that from engineering point of view, the use of KCl as a stabilizer appears potentially promising in locations where it is readily and cheaply available.

In the present work, the efficiency of different electrolyte substances were using as stabilizing agents, were extensively studied in the laboratory for improving the properties of expansive soil.

II. EXPANSIVE SOIL CHARACTERISTICS AND CHEMICAL SUBSTANCES PERCENTAGES USED

The study program for using the effect of electrolyte chemical substances on the properties of expansive soils were prepared to investigate the enhancement of the behavior of Tabuk expansive soil against its volume change with wetting or drying conditions. The properties of the expansive soil chosen for the study were as follow:

TABLE I. PROPERTIES OF EXPANSIVE SOIL OF THE STUDY

Soil Characteristics			
Grain size distribution	***Atterberg Limits***	***CBR****	***Free swell***
Clay 70%-80% Silt 12%-18% Sand 8%- 12%	Liquid limit 100-105% Plastic limit 24-26% Shrinkage limit 10-12%	Average 3.0%	Average 160%

*CBR (California Bearing Ratio)

Sodium Chloride (NaCl), Potassium Chloride (KCl), Calcium Chloride ($CaCl_2$) and Ferric Chloride ($FeCl_3$) are used as stabilizing agents in this study. Different percentages of the chemicals substances (ranging from 0- 2.0 % by weight) were mixed with soil for testing.

Laboratory tests were performed for each Increment of 0.50% of the different chemical substances and results are performed and discussed. The laboratory tests performed will be described in the following paragraphs.

III. LABORATORY TEST STUDY PROGRAM

As mentioned above there are four different electrolyte chemical substances were used in the study with different added percentages. For each adding percentages of these substances, the different physical properties achieved were compared with the original properties of the expansive soil without any additives.

First, the program of study was focused on prediction of the effect of adding the chemical substances to the expansive soil on its Atterberg Limits such as (liquid, plastic, and shrinkage limits) and also the change of the free swell of the dried soil samples. Second, the effect of adding these substances on the soil strength behaviors such as the unconfined compressive strength (UCS) and the value of California bearing ratio (CBR) also are predicted.

IV. LABORATORY TEST RESULTS

A. *Effect of Electrolytes on Atterberg Limits*

The effect of addition of the different electrolyte chemicals to the expansive soil on the Atterberg limits of the expansive soil are summarized as follow:

A-1. Effect of Electrolytes on Liquid Limit (LL)

Adding the different types of electrolyte substances to the expansive soils has a significant effect on its liquid limit index. Liquid limit was reduced with adding the different chemical substances up to 1.5% percentages of any of the electrolytes. More increase of the chemical percentage than 1.5% will not give a significant reduction in the liquid limit.

In the same time the ferric chloride ($FeCl_3$) gives the highest reduction in liquid limit of the expansive soil compared to Sodium Chloride (NaCl), Potassium Chloride (KCl) and Calcium Chloride ($CaCl_2$) chemical substances. Figure 1 shows the effect of the chemical percentages of the different substances on the reduction of the expansive soil liquid limit. Liquid limit values were decreased by 27%, 32%, 35% and 38%, respectively for 1.5% of NaCl, KCl, $CaCl_2$ and $FeCl_3$.

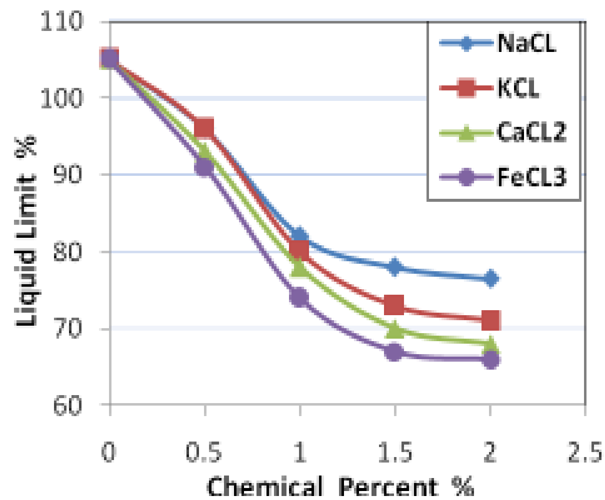

Figure1. Effect of chemical percentage on soil liquid limit

A-2. Effect of Electrolytes on Plastic Limit (PL)

Adding the different types of electrolyte substances to the expansive soils has a significant effect on its plastic limit index. Plastic limit was increased with adding the different chemical substances up to about 1.50% of the electrolytes. The increase of the chemical percentage more than 1.5% will not give a significant an increase in the plastic limit. In the same time, the ferric chloride gives the highest increase values of liquid limit compared with the other chemical substances. Figure 2 shows the effect of adding chemical percentages of the different substances on the achieved higher values of the expansive soil plastic limit.

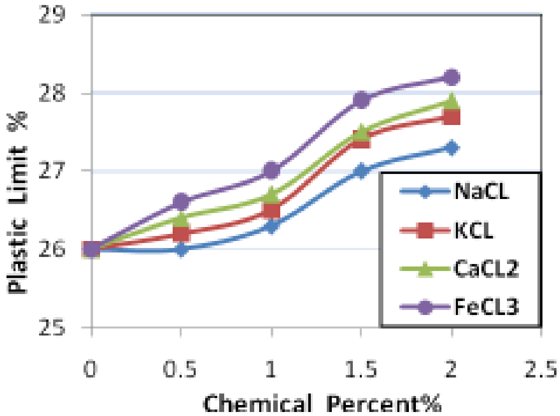

Figure2. Effect of chemical percent on plastic limit

A-3. Effect of Electrolytes on plasticity index (PI)

Plasticity index (PI) was calculated for all expansive soil samples stabilized using the different electrolyte substances where plasticity index is the difference between the liquid limit and the plastic limit. It is obvious that the plasticity index values were reduced with adding the different chemical substances up to a value nearly about 1.5% of the electrolytes additives. More increase of the chemical percentages will not give a significant reduction in the soil plasticity index. Ferric chloride (FeCL3) gives the highest reduction in the plasticity index value of the expansive soil compared to the other chemical substances. Figure 3 shows the effect of adding different chemical percentages of the different substances on the reduction of the expansive soil plasticity index. Plasticity Index values were decreased by 38%, 45%, 49% and 52%, respectively for 1.5% of NaCl, KCl, $CaCl_2$ and $FeCl_3$.

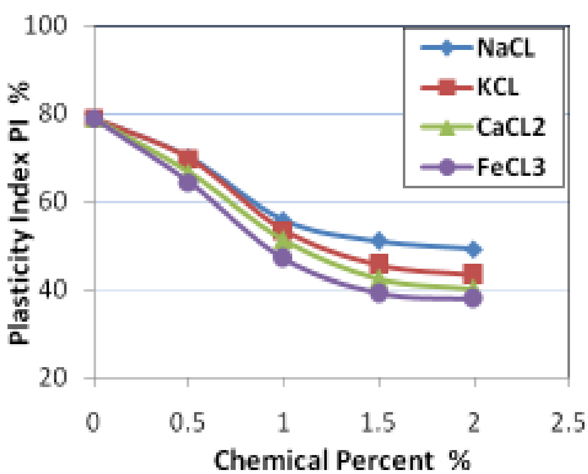

Figure3. Effect of chemical percent on plasticity index

A-4 . Effect of Electrolytes on Shrinkage Limit (SL)

Shrinkage tests were performed on expansive soil samples stabilizing with the different types of electrolyte substances. Shrinkage limit was increased with adding the different chemical substances up to 1.75% of the electrolytes and more increase of the chemical percentage will not give a significant increase in the soil shrinkage limit.

Ferric chloride gives the highest increase values for soil shrinkage limit than the other chemical substances. Figure 4 shows the effect of adding chemical percentages of the different substances on the achieved higher values of the expansive soil shrinkage limit. Shrinkage limit values were increased by 37%, 39%, 42% and 47%, respectively for 1.5% of NaCl, KCl, $CaCl_2$ and $FeCl_3$.

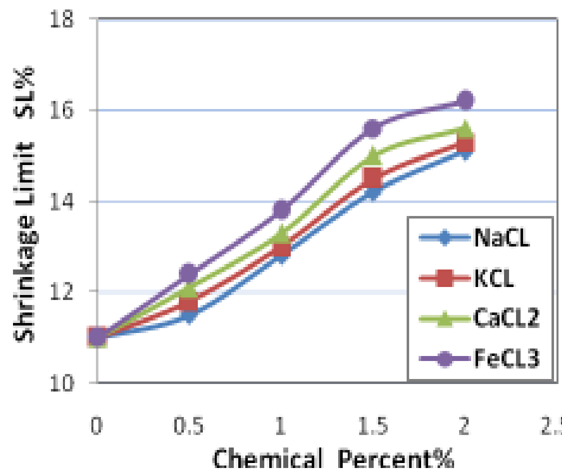

Figure4. Effect of chemical percent on shrinkage limit

B. Effect of Electrolytes on Soil Swell

Adding the different types of electrolyte substances to the expansive soils was effecting on its free swell percentage value. The free swell percentage value was achieved for the dried soil samples passing (sieve No.40). It was obvious that the free swell for the expansive soil was reduced with increasing the percentages of the adding chemical substances till about nearly 1.5% for all different substances.

After the 1.5% percent of the chemical substances the reduction of the free swell values was negligible. Figure 5 shows the effect of adding the different chemical percentages of the different substances on the reduction of the free swell of the expansive soil. Free swell values were decreased by 42%, 43%, 48% and 52%, respectively for 1.5% of NaCl, KCl, $CaCl_2$ and $FeCl_3$

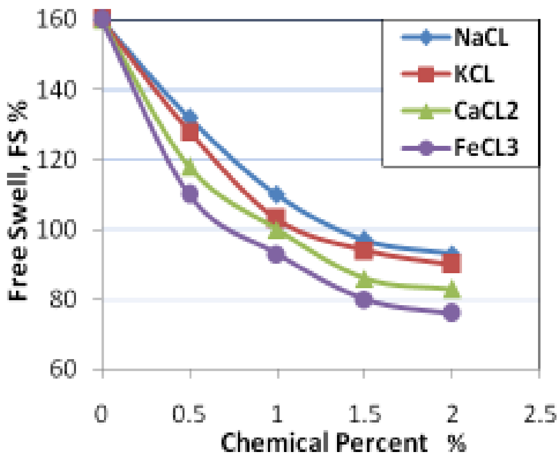

Figure5. Effect of chemical percent on free swell

C. Effect of Electrolytes on Soil Strength

C-1. Effect of Electrolytes on the Unconfined Compressive Strength of Soil

Soil samples stabilized with the different chemical percentages were tested to find its strength. Unconfined compressive strength of the samples was tested after 7 and 28 days of adding the chemicals to the expansive soils with the different percentages. Figures (6-a) and (6-b) show the result of the tested samples for 7 days and 28 days, respectively.

It is obvious that the maximum unconfined strength of the samples was achieved from adding the ferric chloride chemical substances to the expansive soils. The maximum increase in soil strength as unconfined compressive strength (UCS) is achieved with adding 1.5% percentage of any stabilized chemical.

UCS is increased by 137%, 150%, 167% and 187%, respectively for 1.5% of NaCl, KCl, $CaCl_2$ and $FeCl_3$ for curing period of 7days.

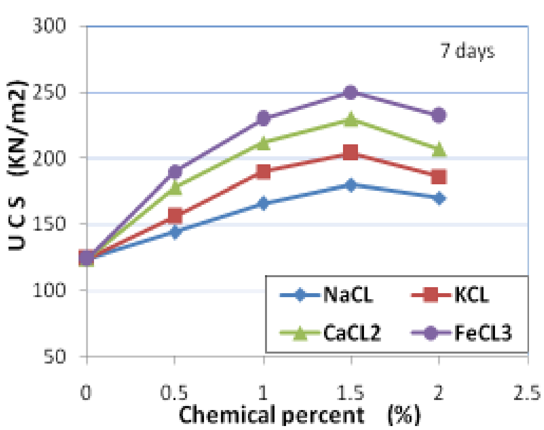

Figure 6-a. Effect of chemical percent on USC after 7 days

While, UCS is increased by 168%, 178%, 187% and 195%, respectively for 1.5% of NaCl, KCl, $CaCl_2$ and $FeCl_3$ for curing period of 28 days.

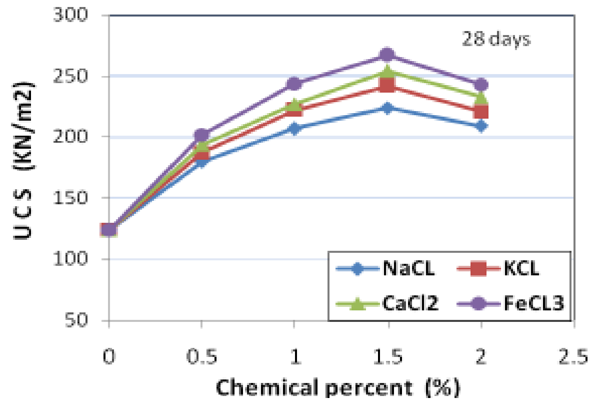

Figure 6-b. Effect of chemical percent on USC after 28 days

C-2. Effect of Electrolytes on California bearing ratio

Soil samples stabilized with the different chemical percentages were tested to find its California bearing ratio CBR. All soil samples tested for the unconfined compressive strength with the different percentages were prepared also for tested to find its CBR. Figure 7 shows the result of CBR values for the tested samples.

It is obvious that the maximum CBR values were achieved for was achieved from adding the ferric chloride chemical substances compared to the other substances. The maximum values of the CBR values were achieved nearly at1.5% percentage of any increase in the chemical percentages will not give any significant increase in CBR. CBR values were increased by 155%, 180%, 200% and 215%, respectively for 1.5% of NaCl, KCl, $CaCl_2$ and $FeCl_3$

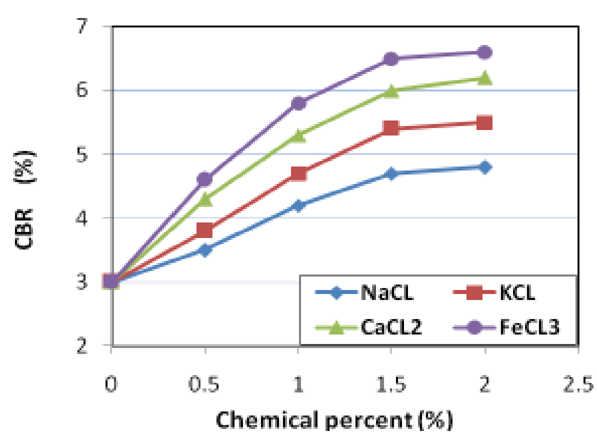

Figure7. Effect of chemical percent on CBR

V. CONCLUSION

The following conclusions are made based on the laboratory experiments carried out in this investigation.

A- From the laboratory studies, it is observed that the liquid limit values are decreased by 27%, 32%, 35% and 38%, respectively for 1.5% of NaCl, KCl, $CaCl_2$ and $FeCl_3$. There is a decrease in the values of plasticity index with respective chemical treatment because of the decrease in liquid limit and increase in the plastic limit values. Plasticity index is decreased by 38%, 45%, 49% and 52% respectively for 1.5% of NaCl, KCl, $CaCl_2$, and $FeCl_3$.

B- The Shrinkage Limit values are increased by 37%,39%, 42% and 47% respectively for 1.5% of NaCL, KCl, $CaCl_2$ and $FeCl_3$ treatments.

C- The free swell values of the stabilized expansive soils are decreased by 42%, 43%, 48% and 52% for 1.5% NaCl, KCl, $CaCl_2$, $FeCl_3$ respectively with respect to the untreated soil.

D- The UCS values, are increased by 137%, 150%, 167% and 187% respectively for 1.5% chemical percentage of NaCl, KCl, $CaCl_2$ and $FeCl_3$ treatments, for a curing period of 7 days. While, for 28 days of curing the UCS values are increased by168%, 178%, 187% and 195% respectively for 1.5% chemical percentage of NaCl, KCl, $CaCl_2$ and $FeCl_3$ treatments.

E-The CBR values are increased by 155%, 180% , 200 and 215% respectively for 1.5% of NaCl, KCl, $CaCl_2$ and $FeCl_3$ treatments.

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