

Feasibility of Calcium Chloride Dehydrate as Stabilizing Agent for Expansive Soil**Abdulla A. Sharo*, Yusuf Alhowaidi and Mohammad S. Al-Tawaha**

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Abstract

The effectiveness of stabilizing expansive soil by enhancing its geotechnical properties using calcium chloride dehydrate ($\text{CaCl}_2 \cdot 2\text{H}_2\text{O}$) as a soil stabilizing agent was investigated in this research. The chemical treatment process using calcium chloride elaborates carrying out experimental laboratory tests on an expansive soil taken from eastern side of Irbid city (Jordan) to check the influence of calcium chloride on its geotechnical engineering properties. Calcium chloride (CaCl_2) was added as a solution of 1.0 N concentration with 3:1 solution to soil ratio and soaked to allow for the occurrence of chemical reaction. The main soil properties studied in this work were the consistency limits, maximum dry density, optimum moisture content, the unconfined compression strength of the soil, swelling percentage, swell pressure and the Californian bearing ratio test (CBR). Tests results, at different curing time, revealed that calcium chloride can be considered as a good stabilizing agent for expansive soil since its use displayed a significant reduction in swelling potential (80%) and swelling pressure (50%) after 28 of curing. Also, the use of CaCl_2 enhances soil strength properties by increasing the unconfined compression strength (q_u), increasing the maximum dry unit weight ($\gamma_{d-\max}$) and increasing the CBR from 2.11 % to 8.32 %.

Keywords: expansive soil, chemical stabilization, curing, swells potential, calcium chloride.

1. Introduction

In several areas over the world, expansive soils stance significant damages to structure especially the lightweight buildings. The occurrence of these damages may take place slowly over time; moreover, these damages may cost a yearly loss of several billion dollars. To cause foundation harms, expansive soil must experience fluctuations in the amount of moisture it contains causing cyclic of wetting (soil swell) and drying (soil shrink). The swell/shrink potential and the tremendous pressure that expansive soil exerts on structures foundations may be the key to the damaging power of expansive clay in generating foundation problems.

In new developments, where expansive soil is a concern, the engineer may require to control the possible damage effect due to the presence of swell/shrink soil in such a way the harm to the new projects foundations will be minimum. A lot of research work has been conducted to find a reasonable solution for this problem. Soil stabilization is one of the most widely used methods in treating problems associated with swell/shrink soil. Stabilization is the process of which soil properties improved by mixing with other available materials called "stabilizing agent" which is commonly used to give better soil strength, reduction in consistency index, and to eliminates the swell potential to some extent. Soil stabilization can be achieved by chemical and mechanical techniques [1].

Irbid city, located in northern part of Jordan (see Fig. 1), is well-known to have a highly expansive soil especially at the eastern side of the city. Enormous cracks in buildings,

pavements, and light structures were observed. Based on that, investigations of soils stabilization were necessitated. Many studies were carried on Irbid soils to reduce the swell potential and increase the soil strength. Sharo *et al.* [2] concluded that oil shale ash can be used to enhance these properties. A burned olive waste, waste paper sludge, lime, and cement were examined by [3, 4] and prove to be good stabilizers. Nanoclay materials were also showed good results in improving strength properties of expansive soil derived from Irbid city [5].

Most of the literature studies carried out all over the world had concentrated on the use of lime and cement [6, 7] and on the use a blend of lime and cement [8, 9]. Moreover, they found that cement's effect dominant on the strength of soil at all time. Lime plays significant role in reduction of swell potential and plastic limit through a flocculation, cation exchange and pozzolanics reactions mechanisms. A little data showed negative effect of cement on the soil strength. Saride *et al.* [10] attributed the reduction of organic clay strength when added cement to reduce pH concentration. Lime had increased the swell potential in sulfate bearing clay through ettringite formation of lime within chemical reaction. Kim *et al.* [11] conducted intensive investigation on the possibility of using ground bottom ash (GBA) and red mud (RM) in soil stabilization methods and concluded that the addition of GBA, RM and chemical activators enhanced strength development especially after 28 days of curing.

Also, expansive soil chemical treatments which are intended to change the clay mineralogy and lessen the expansion potential are available. Chemical stabilization techniques include treatment of soil by ionic, polymer, and enzyme had little attention in the literature. There were many concerns about the durability of chemical stabilization. However, de Carvalho *et al.* [12] used different cationic

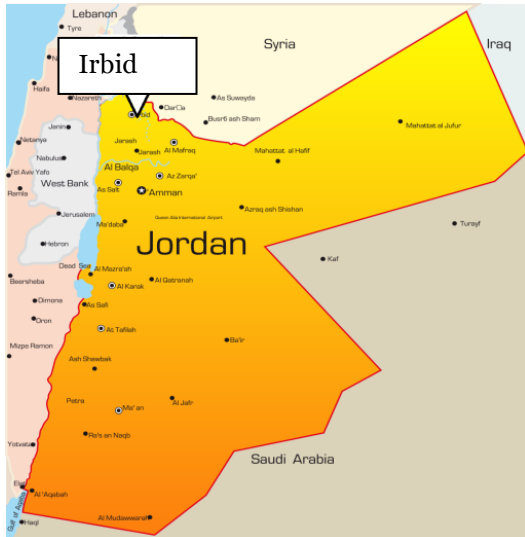
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inhibition for clay swelling. It is usually benefit for soils with clay fraction more than 25% and reduce swelling potential [13]. Chemical agents through injection's method were used by [14]. Liquid ionic such as diluted acids, and sulfonated limonene were also used, slightly increase in soil strength and significant reduction in swell potential [15] were noticed and that was explained by alert the lattice, so less swell behavior is induced. Calcium chloride with

different fly ash percent is also used by [16, 17]. The literature documented tendency of using calcium chloride is as a soil stabilization accelerator. This means that an extra cost will be needed by using the stabilizing agent to the CaCl_2 treated soil. It has been finding that calcium chloride is reasonable for early high strength. However, all of the previous study doesn't take into account the effect of dosage curing time on the soil properties.



(a)

(b)

Fig 1. (a) Location of the collected sample (Jordan, Irbid, Eastern District) (b) Sample of the collected soil (Irbid Soil).

In this research, the authors carried out experimental investigations to see the applicability of using calcium chloride dehydrate ($\text{CaCl}_2 \cdot 2\text{H}_2\text{O}$) itself as a soil stabilizing agent, not only as soil stabilizing accelerator, to improve expansive soil derived from Irbid city and to study the role of curing time on the swell potential, consistency limit, and strength.

2. Materials and Experiment Program

2.1 Soil properties

A construction site located in Eastern part of Irbid city was selected to recapture the soil sample at a depth of about 2.5m measured from the ground surface. Fig. 1- (a) and (b) shows the location and the Image of the collected soil sample.

The soil sample collected exhibited plasticity index ranged between 45-50 and a swell potential expressed as a percentage of about 7% to 9%. Accordingly, this soil can be considered as active soil and can be expressed as "highly expansive" Table 1 summarizes the properties of the nature soil and Fig. 2 shows the grain size distribution of the nature soil used in this study which reflects a clay fraction of about 67%.

Table 1. Natural untreated soil properties (Irbid soil)

Parameters	Results
Initial water content	6%
Specific gravity	2.66
Liquid limit (%)	78.2
Plastic limit (%)	32.1
Plasticity index (%)	46.1
USCS	CH

Clay fraction (%)	67.0
Maximum Dry Density g/cm^3	1.40
Optimum Moisture content	26 %

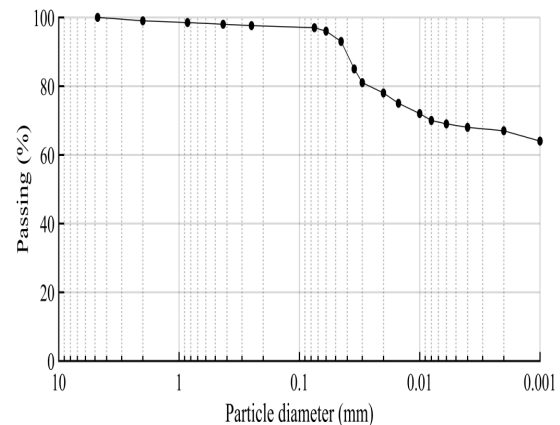


Fig. 2. Grain size distribution of Irbid expansive soil

2.2 Additives properties and samples preparation

The additive used in this research was calcium chloride dehydrate ($\text{CaCl}_2 \cdot 2\text{H}_2\text{O}$) (abbreviated as CaCl_2) holds with 99% purity. Table 2 summarizes the properties of additive. The salt (CaCl_2) was added to 1000 ml of distilled water to attain 1 N concentration. The solution is then added to the soil as a ratio of 3:1 solution to soil, then washed 3 times and infiltrated by filter paper. Thereafter, the samples were oven-dried for 24 hours and crushed using rubber hammer, then sieved on sieve No. 40. The portions of the sieved soil passing sieve No. 40 were used in all tests.

Table 2. Specifications for the used Calcium Chloride dihydrate (After Sigma Aldrich Chemicals Co.)

CAS registry number	10035-04-8
Name	Calcium chloride dihydrate
Formula	CaCl ₂ .2H ₂ O
Formula weight	147.01 g/mol
Appearance (color)	White
Appearance (form)	Powder
Solubility (turbidity)	Clear
Loss of drying	23-25.5 %
Titration with EDTA	≥99%

2.3 Standard Proctor Compaction test

As a very important bearing strength induction test, standard proctor compaction a test following ASTM D 698 “Standard Test Methods for Laboratory Compaction Characteristics of Soil Using Standard Effort” [18] was carried out. The standard proctor was used to measure the dry density of each sample and to obtain the moisture content as will. This test is conducted for both the natural and the treated soil samples with calcium chloride.

2.4 Unconfined Compression Strength of soil

This test was performed on all the soil samples (treated and untreated soil sample), in compliance with D 2166 “Standard Test Method for Unconfined Compressive Strength of Cohesive Soil” [19] to see the effect of CaCl₂ in improving the unconfined compressive strength (UCS) of the expansive soil. Soil sample for each additive was compacted to the maximum dry density and moisture content of the natural untreated soil, after that the sample were extruded from the mold and placed in the unconfined compressive testing device.

For curing purposes, the Ca²⁺-treated soil, samples were prepared and wrapped with aluminum foil and placed in plastic bags after being de-aired using vacuum, and stored to be tested after 7 days and 28 days, respectively.

2.5 Swell test

According to ASTM D 2435 [20], the test specimen is soaked under load and allowed to swell freely. Then, it is loaded and compressed to its original height; this load is denoted as the swell pressure.

The samples were prepared at the optimum moisture content, and loaded to 7 kPa, which is the in-situ overburden pressure and allowed to swell, the increase in the height denoted as free swelling. The results will be discussed in the next section.

2.6 California Bearing Ratio test (CBR)

In compliance with ASTM D 1883-99 [21] CBR test was conducted to examine the strength of cohesive soil in which 5 layers of compacted soil hold in a standard CBR mold and soaked into water for 96 hours. This procedure was adopted for both nature and treated calcium chloride expansive soil.

3. Results and Discussion

3.1 Atterberg limits

While the addition of calcium chloride was not as percentage by weight of the dry soil, yet the process of stabilization was

done using infiltration method described earlier in this paper. This process was established in order to alter the dominant cation (Ca²⁺) presented in the exchange complex (soil). The effect of the Ca-treatment and curing time on the consistency limits for the soil used herein is presented in Fig. 3.

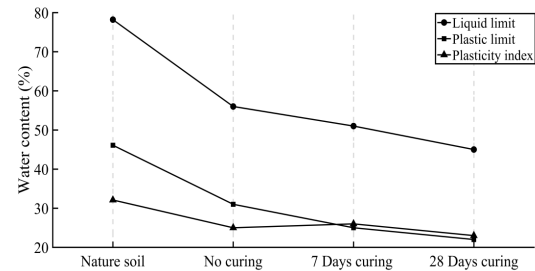


Fig 3. Effect of Ca-treatment of soil on the consistency limits

Fig. 3 elaborates that Ca-treatment of expansive soil had reduced the liquid limit. In the same manner, the plastic limit decreased when the soil treated with calcium especially at the early stages of the treatment (no curing) as shown in Fig. 3. It should also be noted that curing time reduced the consistency limits further. The decrease in the consistency limits associated with the increase in the curing time is relatively small if compared to the reduction that took place in the early stages of the treatment. Zaho *et al.* [13] observed almost a similar trend. The plasticity index (PI) of the soil decreased from 46.1% to 22% after 28 days curing. This reduction in PI value, as a good indication of less swelling potential, may be attributed to bondage formed between the calcium cation (high concentration in the exchange complex) and the clay particles which reduces the soil affinity to water.

3.2 Maximum dry density

The effect of Ca-treatment of soil on the maximum dry density and its effect on the optimum moisture content were studied and the results are presented in Fig. 4. As it can be illustrated from Fig. 4, the maximum dry density of the soil increased from 1.40 g/cm³ to 1.46 g/cm³ while the corresponding optimum moisture content decreased from 26% to 23% with Ca-treatment of the soil. This, in turns, means that the strength of the soil has been improved as it was treated CaCl₂. However, the improvement gained in soil strength represented in terms of increasing in dry unit weight and a reduction in optimum moisture content is relatively minor if compared to the improvement gained using other additives such as cement or lime. It also should be noted that curing effect was out of the scope of this work for possible dry density changes with time for the CaCl₂ treated soil.

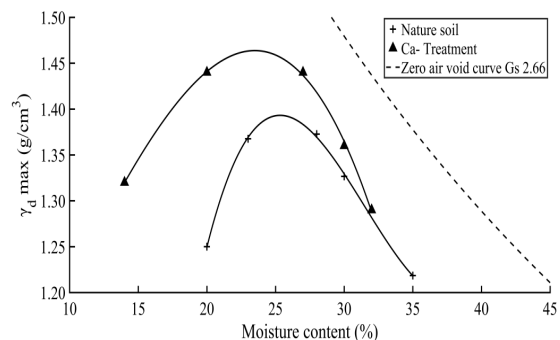


Fig 4. Effect of Ca-treatment of soil on maximum dry density and optimum moisture content.

3.3 Unconfined Compressive Strength

The influence of calcium chloride dehydrate ($\text{CaCl}_2 \cdot 2\text{H}_2\text{O}$) on the unconfined compressive strength (UCS) is offered in this section. Unconfined compressive test results, demonstrated in Fig. 5, indicated that there is an enhancement in the unconfined compressive strength of the soil when treated with CaCl_2 . This enhancement was also found to be greater as long as the curing time increased. The treated soil gained an increase of about 58% (from 194.9 kPa to 308 kPa) in its unconfined compressive strength (q_u) after 28 days of curing.

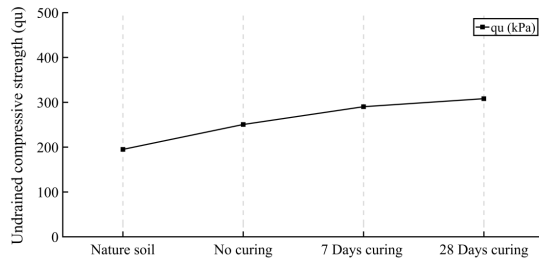


Fig 5. Calcium chloride dehydrates treatment and curing influence on the unconfined compressive strength of the soil.

Also, to give a clearer understanding the associated increasing trend on the UCS values due to the treatment with CaCl_2 Fig. 6 is offered to grasp the unconfined compressive strength of the Ca-treated soil which was tested immediately, after 7 days and 28 days of curing. From this figure we can notice that the strength enhancement was the best after 28 days of curing. Also, we can notice that the strength resistance started to show peak values (more brittle behavior) as curing time increased. This kind of behavior may be attributed to the fact that Ca-treated soil tend to keep moisture constant stable and to the possible formation of oxides such as CaO and SiO_2 with Al_2O_3 and Fe_2O_3 which will give cementitious effect that will increase the unconfined compressive strength and give more brittle to the soil.

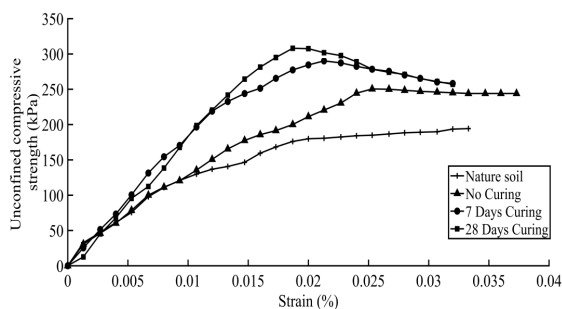


Fig 6. Effect of CaCl_2 -treated soil and curing influence on the unconfined compressive strength of the soil.

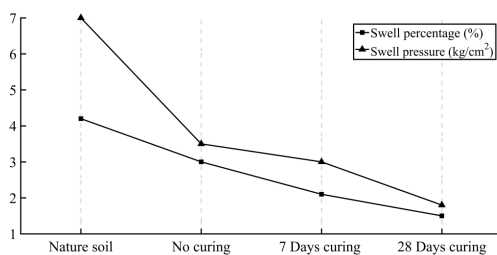


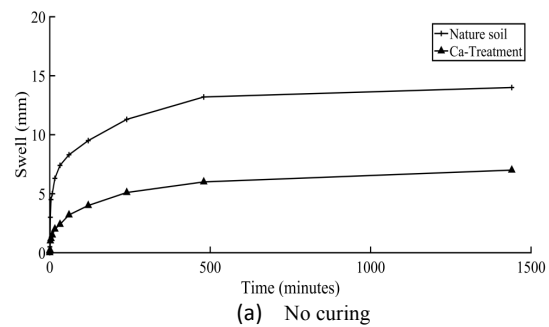
Fig 7. Calcium chloride treatment effect and curing influence on the swelling percentage and swell pressure of the soil

The increase in the unconfined strength also may due to the cation exchange reaction which firmly bond the soil particle together in presence of the dominant cation (Ca^{+2}).

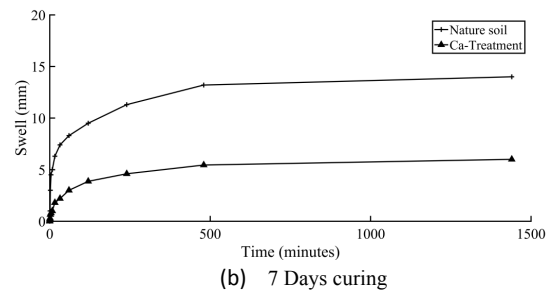
3.4 Swelling and swell pressure

Calcium treatment influence on the swell pressure and the swell potential (expressed as a percentage) of the soil is considered in this section. Results of swell pressure and swell potential are demonstrated in Fig. 7. As it can be illustrated, after the addition of CaCl_2 to the soil, swell pressure and swell percent showed a magnificent decrease. The swell pressure reduced by about 50% when the soil was treated with CaCl_2 while the swell percentage was reduced by about 80% from its original value (from 7% to 1.5%) after 28 days of curing. The reduction in the swelling potential of the soil may attributed to the high concentration of Ca^{+2} in the exchange complex, neutralizing the negative valence on the clay particle and packing the soil particles with each other, the diffuse double layer thickness depressed, and the water between the particles will be drawn out and the clay affinity to water is reduced.

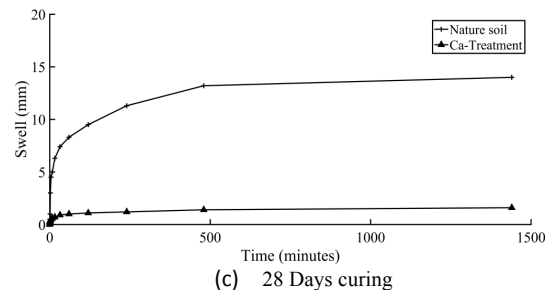
Also, to give a clear thought about curing effect in the swelling potential (expressed in mm) a comparative plots represented as Fig. 8 (a through c) is established. It is obvious from these plots that the more curing time the more efficient in reducing swelling potential. 28 days of curing (Fig. 8-c) shows the greatest reduction in the swelling. It was dropped to 35% in case of calcium treatment of the soil after 28 days.



(a) No curing



(b) 7 Days curing



(c) 28 Days curing

Fig 8. Comparison between the effects of the dosage curing on the soil swelling percentage (a) no curing (b) 7-days curing (c) 28-days curing.

3.5 CBR results

California bearing ratio (CBR) test was also conducted in this study. The test result revealed that The CBR value increased about four times its original value (from 2.11 % to 8.32 %) when treated with Ca-treatment of the soil. The increase in the CBR value after Ca-treatment of the soil complies with the increase in the unconfined compressive strength and the reduction in the swelling potential for the Ca-treated soil as well.

3.6 Statistical analysis and evaluation

Statistical analysis was constructed in an effort to see the effect of CaCl₂ in improving UCS, plasticity index (PI) and swell pressure. Table 3 summarizes this analysis which was evaluated based on increasing and decreasing in absolute

percent between base natural values and different dosage curing stage values.

From Table 3, it can be observed that the unconfined compressive strength increase 58% after 28 days curing. Also, the swell pressure and plasticity index decrease 64.3%, 52.3% respectively. These results are comparable with most of additives used in previous studies on Irbid expansive soil [2, 3, 4, and 5]. Also, it can be observed that the rate of increasing in strength was high at the early stages (no curing) and then the rate of increasing is decreased with dosage curing time. The seemingly constant rate of decreasing in the swell pressure and the significant decrease in plasticity index show depicted from Table 3 support the tendency of calcium chloride to retain water.

Table 3. Statistical summary for the effect of CaCl₂ on expansive soil properties.

Soil Tests	Base Value	No curing		7 Days Curing		28 Days Curing	
		% Increase [†] or decrease [‡] by adding CaCl ₂	% Absolute difference between base value and CaCl ₂ treated	% Increase [†] or decrease [‡] by adding CaCl ₂	% Absolute difference between no curing and 7days curing	% Increase [†] or decrease [‡] by adding CaCl ₂	% Absolute difference between 7 and 28 days curing
Unconfined compressive strength (kPa)	194.9	28.6 [†]	28.6	48.8 [†]	15.9	58.0 [†]	6.2
Plasticity Index (PI)	46.1	32.8 [‡]	32.8	45.77 [‡]	19.4	52.3 [‡]	12.0
Swell Pressure kg/cm ³	4.2	28.6 [‡]	28.6	50.0 [‡]	30.0	64.3 [‡]	28.5

† : Percent increase ‡ : Percent decrease

4. Conclusions

According to the investigation carried out in this article, calcium chloride dehydrate (CaCl₂.2H₂O) treatment on Irbid expansive soil showed a satisfactory potential to be used as stabilizing agent for expansive soil. Based on the tests results presented herein, the following conclusions may be drawn:

- The use of calcium chloride reduces the optimum moisture content and increases the maximum dry unit weight.
- Calcium chloride dehydrate treatment of the expansive soil reduces the plasticity index instantaneously, and long after indicating soil properties improvements.
- Calcium chloride dehydrate resulted in a good improvement on the expansive soil by reducing both swell percentage and swell pressure.
- The unconfined compressive strength (q_u) of the expansive soil increased by the addition of calcium chloride dehydrate for both all curing times. The longer the curing the higher the (q_u).

- The California bearing ratio (CBR) improved with the use of calcium chloride treatment.
- Over all, the longer the curing the better the improvement achieved in enhancing soil properties.

On the basis of the work carried out in study, calcium chloride dehydrate (CaCl₂.2H₂O) has proved to be an effective expansive soil stabilizing agent during early stage and long after. This result plays a major rule in decreasing the cost of stabilizing by not adding other stabilizers at a desirable soil improvement.

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