CHARACTERISTICS OF GYPSIES SOILS TREATED WITH CALCIUM CHLORIDE SOLUTION

Dr. Saad Farhan Al-Abdullah Highway Engineering Dept., Al-Mustansiria University
Nabeel Shaker Mahmood Al-Dulaimi (M.sc. Civil Engineering)

ABSTRACT

Gypseous Soils are distributed in many regions in the world including Iraq, which cover about (31.7%) of the surface area of the country. Existence of these soils, some times with high gypsum content, caused difficult problems to the buildings and strategic projects due to dissolution and leaching of the gypsum slates by the action of water flow through the soil mass.

In this study the effect of treatment with Dihydrate Calcium Chloride ($CaCl_2.2H_2O$) as water solution on compaction, compressibility, leaching, permeability and shear strength characteristics of Gypseous soil is investigated.

It is found that the maximum dry unit weight increases while optimum moisture content decreases with the increase in the concentration of calcium chloride in the molding water.

It is concluded that the engineering properties of the samples are highly improved when the samples are soaked in calcium chloride solution at (20%) concentration. Where, considerable reduction is observed in compressibility, collapsibility, coefficient of permeability, percentage of dissolved gypsum and leaching strain. Also, the treatment minimizes the reduction in cohesion component (c) upon soaking in water and slightly decreases the angle of internal friction (ϕ).

Analysis of the tests results showed that the using of calcium chloride solution in improvement the gypseous soil is more efficient than using it in any other form (powder).

الخلاصة

تتوزع الترب الجبسية في عدة مناطق من العالم ومن ضمنها العراق، حيث تغطي حوالي(31.7%) من المساحة السطحية للقطر. وإن وجود هذه الترب و بنسب جبس عالية في بعض المواقع قد سبب عدة مشاكل معقدة للمباني والمشاريع الستراتيجية، بسبب ذوبان وغسل الجبس بتأثير جريان الماء خلال كتلة التربة.

في هذا البحث تم دراسة تأثير المعالجة باستخدام كلوريد الكالسيوم المائي($CaCl_2.2H_2O$) كمحلول مائي على خصائص الرص، الانضغاط، الغسل، النفاذية ومقاومة القص للتربة الجبسية.

وقد وجد بان الكثافة الجافة العظمى تزداد وفي نفس الوقت المحتوى الرطوبي الأمثل يقل مع زيادة تركيز كلوريد الكالسيوم في الماء المستخدم في عملية الرص.

وقد تم استنتاج إن الخصائص الهندسية للنماذج تتحسن بصوره كبيرة بعد غمر النماذج بمحلول كلوريد الكالسيوم بتركيز (20%). حيث يلاحظ نقصان في كل من الانضغاطية ،الانهيارية، معامل النفادية، نسبة الجبس الذائب و انفعال الغسل. كذلك فان المعالجة تقلل النقصان في معامل التماسك(c)عند الغمر وتقلل بشكل طفيف زاوية الاحتكاك الداخلي للتربة المعالجة. كما إن

تحليل النتائج اظهر أن استخدام كلوريد الكالسيوم كمحلول مائي في تحسين التربة هو اكثر كفاءه من استخدامه باي شكل آخر (مسحوق).

INTRODUCTION

The development programs of many areas last years in Iraq was faced with a problem due to existence of various amount of gypsum in most of these areas as partially gypsum stratum or soil containing an amount of gypsum.

Many major projects suffered from several problems related to construction on or by gypseous soils such as cracks, tilting, collapse and leaching the soil. These problems could happen due to percolation of water into these soils causing dissolution of gypsum, which provides the cementing bonds between the soil particles. This process leads to collapse of soil structure and progressive compression, and the problem becomes more complicated if flow occurred causing continuous loss of soil mass and formation of serious cavities.

These considerable changes in the engineering properties of gypseous soils upon wetting or leaching necessitate geotechnical investigations of these soils and adopting more beneficial methods to improve their properties.

This study is an attempt to treat the gypseous soil adopted by using a water solution of dihydrat calcium chloride ($CaCl_2.2H_2O$) to improve its properties.

GYPSUM AND ITS SOLUBILITY

From chemical point of view, gypsum is calcium sulfate with two water molecules attached (CaSO4.2H2O), the two other natural forms of calcium chloride are anhydrate (CaSO4) and hemihydrate plaster of Paris (Bassanite) (CaSO4. 1/2H2O), alter to gypsum at the temperature and pressure normally found at the earth's surface (Nafie, 1989).

Saaed and Khorshid (1989), reported that the solubility of gypsum is of the order 2.41gm/1, while Saleam et. al.(1988), reported that the saturated solution may contains about 2.6 gm /1.

Seidell and Linke (1958), collected data from many references for the solubility of gypsum in water solutions of some salts. They showed that some salts such as [$Mg(NO_3)_2$, $Mgcl_2$, Kcl, $NaNO_3$, NaCl] increase the ionic strength and that lead to increase the solubility of gypsum. On the contrary to that, there are other salts like [$CaCl_2$, $MgSO_4$] cause an increase in common ions (Ca^{+2} or $S4^{-2}$), and thus decreasing the solubility of gypsum, see fig. (1).

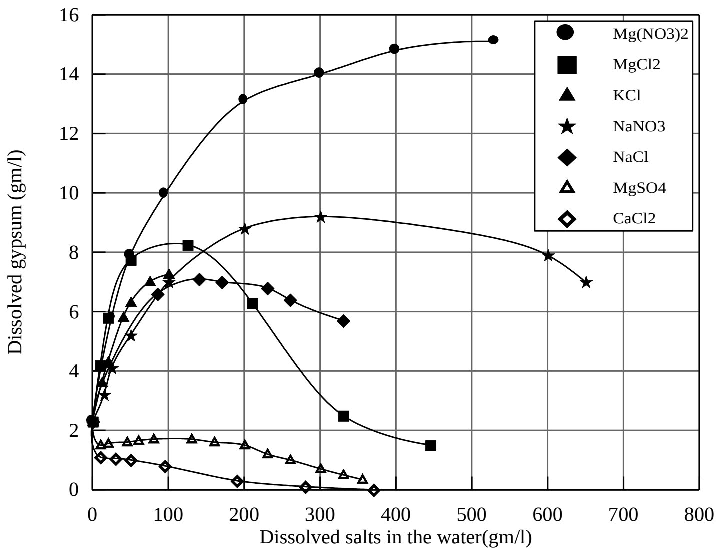


Fig. (1): Solubility of Gypsum at Different Salts Concentrations,

(Data Collected by Seidell and Linke, 1958).

EXPERIMENTAL WORK

Soil Properties

The soil of this investigation was taken from Heet site west of Iraq. Summary of physical and classification properties is presented in Table (1).

Table (1): Summary of physical and classification properties

Gypsum content %	53	$\gamma_{d\ field}$ (kN/m^3)	14.4
TSS (%)	52.39	L.L. %	31
SO_3(%)	26.6	P.L. %	16
pH	7.79	%Sand	82
G_s	2.43	%Fines	18
e_o	0.687	Soil Classification According to USCS	SC

Testing Program

Because of the difficulty of obtaining undisturbed samples for the engineering tests, the samples are prepared to satisfy dry unit weight by using static compaction method.

A series of engineering tests was conducted on the soil treated with a water solution of calcium chloride. This series including compaction, compressibility, leaching and shear strength tests.

Compressibility tests were performed using oedometer device. Shear strength parameters for both soaked and unsoaked samples were determined by using direct shear apparatus. Leaching tests were conducted using special oedometer cell called the Permeability-Consolation Cell.

Method of Treatment with Calcium Chloride Solution

The commercial product of Dihydrate Calcium Chloride ($CaCl_2$.2H2O), with purity from (94 to 97) %, was used in this study to improve the engineering properties of the gypseous soil taken from Heet area. The salt is white in color and crystalline solid in the hydrous state.

The procedure of treatment of gypsum with the salt could be summarized in following steps:

1. Preparing three concentrations (10, 20 and 30) %of calcium chloride solution by adding a specified weight of the salt to the distilled water to satisfy the required concentration. It should be noted that the adding of water to the salt causes an agglomeration of salt particles, and these will not dissolve easily. Therefore, the salt should be added to the water in small amounts with continuous mixing.
2. Preparing the samples at their field dry densities using static compaction method.
3. Soaking the samples in calcium chloride solution for about two hours.
4. After soaking period the samples were kept for (24) hours in nylon bags to insure homogeneous distribution of the solution through the samples. Then the samples were dried in the oven at (45^{o}C) until the weights stabilize. These weights compared with their original dry weights lead to determine calcium chloride content as solids in the samples with respect to each concentration.

ANALYSIS AND DISCUSSION OF THE RESULTS

Effect of Treatment on Compaction Characteristics

Compaction curves for treated soil at different calcium chloride concentrations dissolved in molding water are shown in fig. (2). It can be seen that the maximum dry unit weight increases and optimum moisture content decreases conjugate with the increase in concentration of the solution. This behavior may be attributed firstly to increase in fine particles and secondly to the lubrication between soil grains, where chlorides are considered as good lubricants when added to the soil (O'Flaharty, 1974).

Effect of Treatment on Compressibility Characteristics

The results of standard odometer tests of the soil treated with calcium chloride solution at different concentrations are shown in fig. (3). Also the tests results are listed in Table (2).

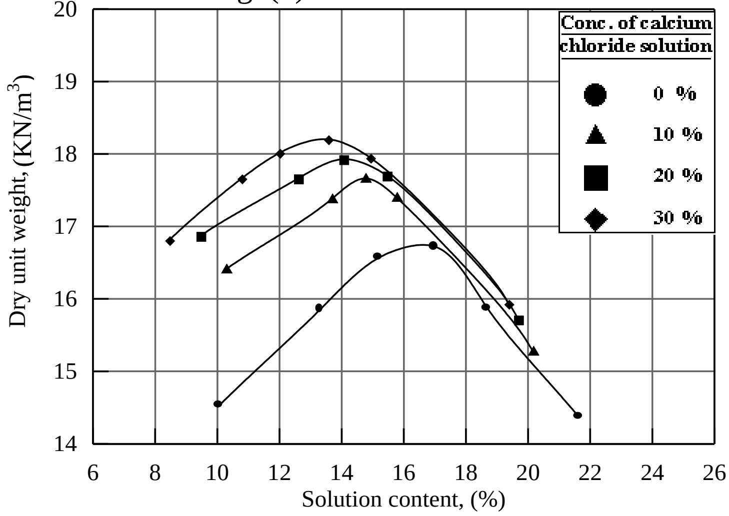


Fig. (2): Compaction Curves of Treated Soil at Different Solution Concentrations

In general the virgin compression and recompression curves are approximately linear. Also, the total volumetric strain at 800kPa ($\varepsilon_{v,800}$) decreases from (17.71 to 10.16) % and the compression index (Cc) decrease from (0.260 to 0.085), when the concentration of the used salt increases from (0 to 30) %. This behavior may be due to decrease of the dissolution of gypsum and increase of the cementing bonds between the soil particles.

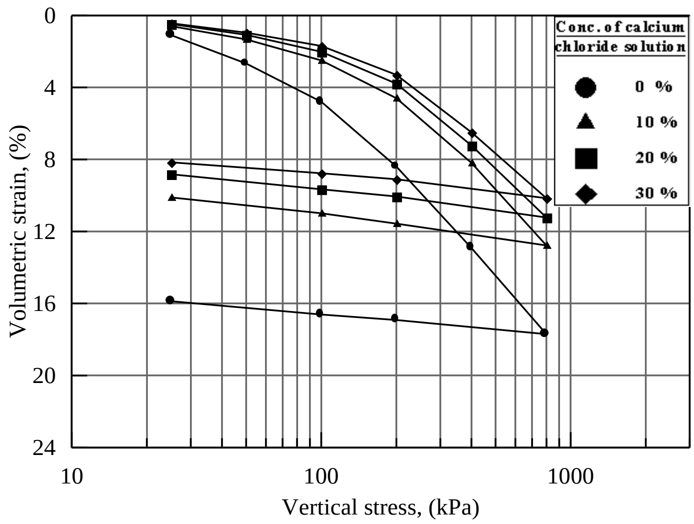


Fig. (3): Compression Test Results of Treated Soil

Table (2): Summary of Compression test Results of Treated Soil.

c.c.s* (%)	**c.c.c** (%)**	e_o	γ_d kN/m^3	$\varepsilon_{v,800}$ %	C_c	C_r
0	0	.687	14.13	17.71	.26	.022

10	1.95	.65	14.62	12.77	.139	.0251
20	3.64	.599	14.87	11.23	.137	.0260
30	5.14	.568	15.38	10.16	.085	.0260

* c.c.s: Concentration of Calcium Chloride Solution.
**c.c.c : Calcium Chloride Content as Solid in the Sample.

<u>Collapsibility Characteristics</u>

The results of collapse test are shown in fig. (4). It is obvious that the collapse potential highly decreased after treatment with calcium chloride solution.

Table (3) shows that the collapse potential of untreated soil is (5.28), where the degree of specimen collapse classified as a "Moderate" according to ASTM D5333, 2003. While this value decreases to (1.62) after treatment with the solution at (30%) concentration. Where the reduction in collapse potential is about (69.3%) and the degree of specimen collapse classified as a "Slight".

This reduction in collapse potential after treatment may be attributed to increase the common ion (Ca^{+2}), which decrease the solubility of gypsum (as explained in sec.2). In addition to that the used salt acts as a filler material in the pores of the soil and provides new commenting bonds between the particles. Also, It can be observed from Table (3) that collapse potentials obtained from the double oedometer test are greater than those obtained from collapse test

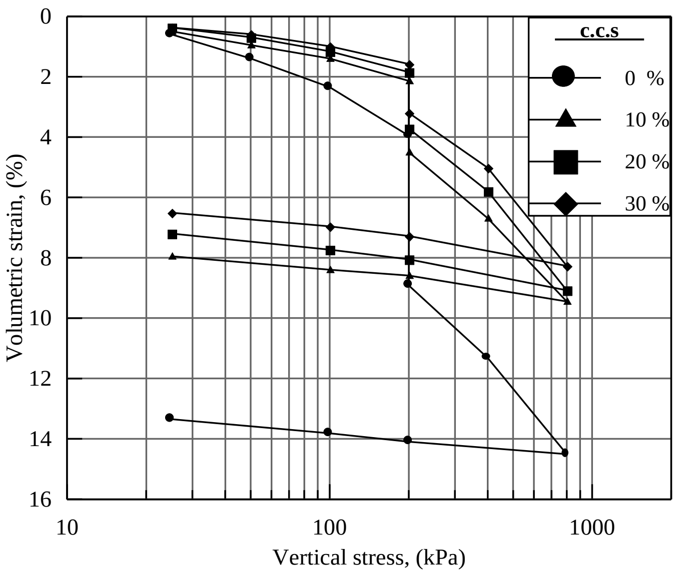


Fig. (4): Results of Collapse Test of Soil Treated with different (c.c.s)

Table (3): Collapsibility Tests Results of Treated Soil.

Soil Property	Concentration of Calcium Chloride Solution, %			
	0	10	20	30
c.c.c, %	0	1.98	3.63	5.12
e_o	0.687	0.65	0.599	0.568
γ_d (kN/m^3)	14.4	14.63	14.89	15.38

CT Collpse test	CP, %	5.28	2.36	1.87	1.62
	Reduction in CP, %	0	55.3	64.58	69.31
DOT Double Oedometer Test	CP, %	5.54	2.49	1.98	1.65
	Reduction in CP, %	0	55.05	64.26	70.21

Permeability and Leaching Characteristics

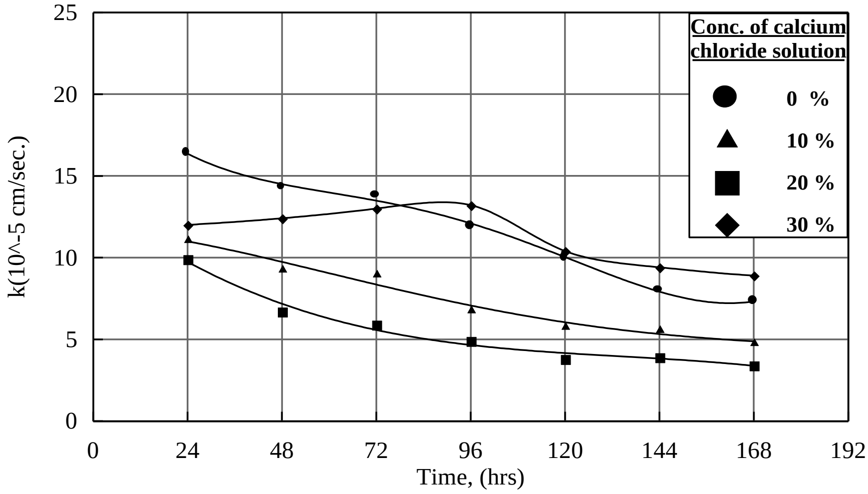
The effect of treatment on permeability and leaching characteristics of the soil was investigated. The oedometer permeability-leaching test (OPLT) was conducted under two leaching stresses (100 and 200) kPa with hydraulic gradient (i) equal to (20). A discussion of the effect of treatment on coefficient of permeability, leaching strain and dissolved gypsum could be as follows:

Permeability Characteristics

The variation of coefficient of permeability (k) with time at different concentrations of ($CaCl_2$) solution for each leaching stress level is shown in fig. (5).

It can be seen from this figure that the permeability decreases with the increase in concentration of the used solution up to 20%. But with higher concentration, i.e. (30) %, it begins to increase. Al-Busoda (1999), found similar results when treated the gypseous soil with 2.5 and 5 % calcium chloride powder. She attributed the decrease in permeability to increase in fine particles that filled the voids within soil structure. Moreover, the salt reduces the dissolved gypsum, and those decrease the construction of new voids or enlarging the original voids. While she attributed the increase in permeability with increase in calcium chloride content to hydration process of the additive to ($CaCl_2.6H_2O$) under certain conditions. This process generating a pressure tried to spread the particles from each other, therefore, the void ratio will increase. So, the coefficient of permeability will increase.

Also, it can be noticed that the permeability decreased with the increase in leaching stress level due to reduction in void ratio, which leads to the elimination of water paths. These results agree with the results obtained by Seleam (1988), Nashat (1990), Al-Busoda (1999), and Al-Qaisee (2001).



(a)

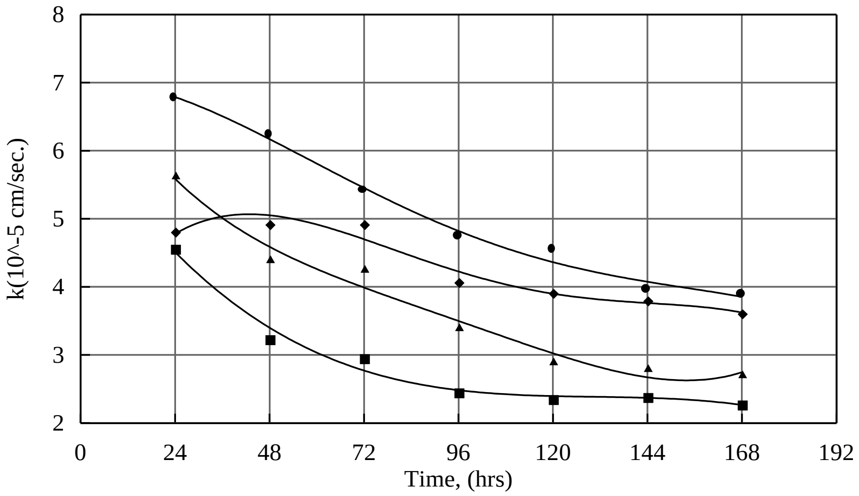


Fig. (5): Results of Oedometer-Permeability Leaching Test of Samples Treated with Different (c.c.s):
(a) Coefficient of Permeability (k) vs. Time Relation, σ_v=100 kPa
(b) Coefficient of Permeability (k) vs. Time Relation, σ_v=200 kPa

Leaching Characteristics

The variation of leaching strain and dissolved gypsum during leaching process at different $CaCl_2$ concentrations and leaching stresses are shown in figs. (6) and (7).

In general, it can be seen that the leaching strain increased with time as the leaching process continued. This behavior may be due to the continuous dissolution of gypsum that caused a continuous settlement. Also, the leaching strain increased with the increase in percentage of dissolved gypsum. Similar results are reported by many researchers such as Al-Khuzaie (1985), Seleam (1988), Al-Busoda (1999) and Al-Beiruty (2003).

Fig. (6) Shows significant reduction in leaching strain with time of the soil treated with (10 and 20) % concentrations. While with (30) % concentration the leaching strain begins to increase, but it remained below the leaching strain of untreated soil. The treatment with ($CaCl_2$,) leads to increase the calcium cations (Ca^{+2}) which represent the common ions with calcium cations of the gypsum, therefore, the amount of dissolved gypsum will decrease. So, the leaching strain decreases.

The increase in leaching strain which was observed for the specimens treated with (30) % concentration may be attributed to the increase in permeability (discussed previously in section 4.3.1) which will increase the dissolution of gypsum and calcium chloride and removal of it from soil skeleton. Hence additional leaching strain will take place due to the collapse of soil structure.

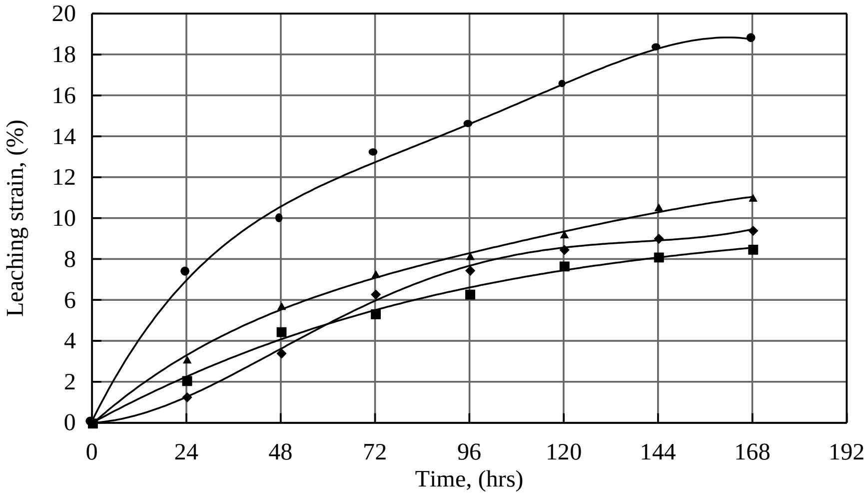


Fig. (6): Leaching Strain vs. Time Relation, σ_v=200 kPa

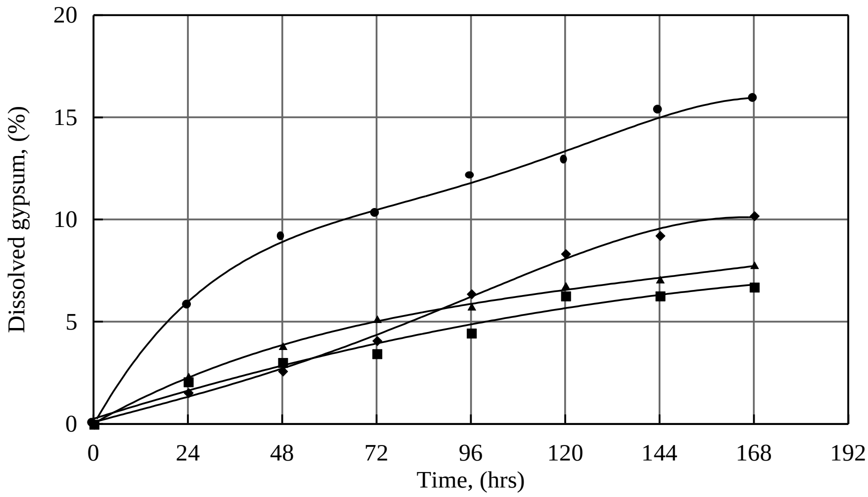


Fig. (7): Dissolved Gypsum vs. Time Relation, σ_v=200 kPa

Shear Strength Characteristics

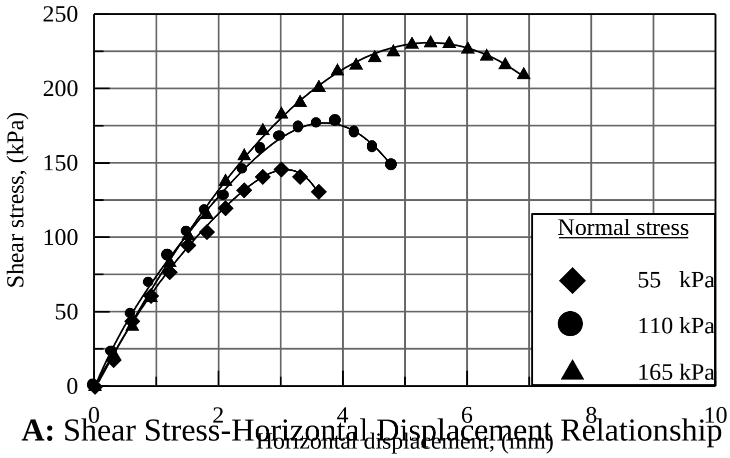
To predict the shear strength parameters (c and ϕ), two types of tests were conducted on (6) samples treated in the same concentration, three of them tested in dry state, while the other three samples were tested after soaking in water for (2) hours.

Typical results of direct shear tests conducted on the samples treated with 20% concentrations of calcium chloride solution at dry state are shown in fig. (8)

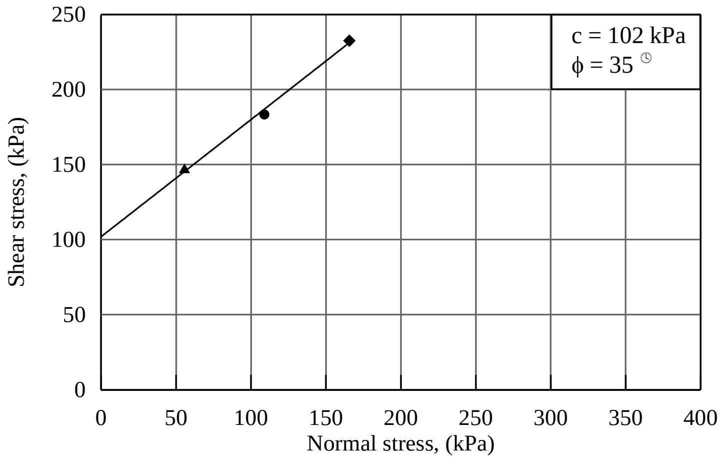
For unsoaked samples, it can be observed that the cohesion (c) increases with increase concentration of calcium chloride solution. On the other hand, the treatment minimized the reduction in cohesion (c) that occurred due to soaking. This behavior may be attributed to the existence of calcium chloride as solids in the voids which act as binder material between the particles; moreover, it decreases the destruction of the gypsum bonds after soaking in water. Fig. (9) presents the values of shear strength parameters (c andϕ) in terms of isobar.

Also, a reduction in the values of angle of internal friction (ϕ) is observed after treatment especially for soaked samples. This could be attributed to that calcium chloride acts as lubricant when added to the soil. On the other hand, the soaking leads to hydration process of ($CaCl_2.2H_2O$)

which move the soil particles far from each other (as discussed previously), therefore, the inter particle friction will be reduced and as a result of that (ϕ) will decrease.

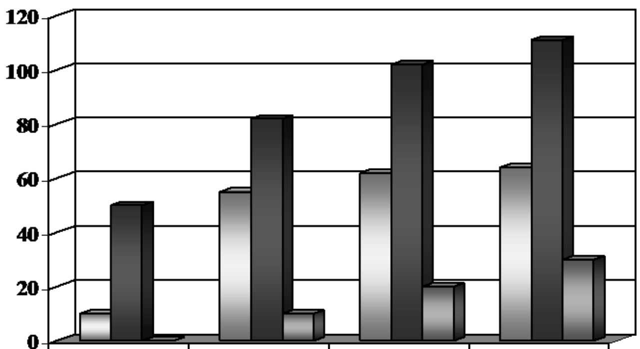


A: Shear Stress-Horizontal Displacement Relationship



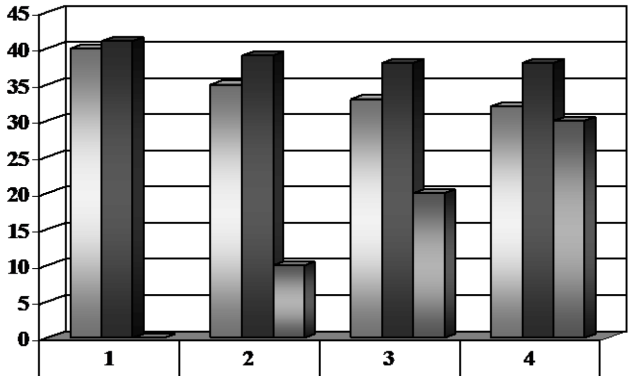
B: Shear stress –Normal Stress Relationship

Fig. (8): Direct Shear Test Results for Unsoaked Samples Treated with (20%) c.c.s



	1	2	3	4
con. Of (CaCl2) solution	0	10	20	30
c (unsoaked)	50	82	102	111
c (soaked)	10	55	62	64

A: Variation of Cohesion (c) with c.c.s of unsoaked and Soaked Samples



	1	2	3	4
con. Of (CaCl2) solution	0	10	20	30
(unsoaked)	41	39	38	38
(soaked)	40	35	33	32

B: Variation of Angle of Internal Friction (ϕ) with c.c.s of unsoaked and Soaked Samples

Fig. (9): Effect of Treatment on Shear Strength Parameters.

ANALYSIS OF TREATMENT RESULTS

From the results of the tests conducted on the samples after treatment with a water solution of ($CaCl_2.2H_2O$) at three concentrations (10, 20 and 30%) as explained previously, it can be concluded that (20%) is the optimum concentration of calcium chloride solution to be used in improvement.

The treatment at this concentration yields an increase in maximum dry density obtained from standard compaction test. Also it gives a significant reduction in compressibility, permeability and leaching characteristics see Table (4).

CONCLUSIONS

- The increase in concentration of calcium chloride ($CaCl_2.2H_2O$) in water used in compaction process of the gypseous soil causes an increase in the maximum dry unit weight which leads to decrease the optimum moisture content.
- The treatment by soaking the samples in calcium chloride solution at 20% concentration (optimum concentration) caused the following:
    a. Decrease in the compression index (Cc) and increase in the rebound index (Cr).
    b. Reduce values of the collapse potential obtained from collapse and double oedometer tests up to (64%).
    c. Decrease values of the coefficient of permeability (k).

d. Decrease the percentage of dissolved gypsum and leaching strain.
e. Minimize the reduction in cohesion component (c) upon soaking in water and slightly decrease the angle of internal friction (ϕ).

1. the calcium chloride solution can be used easily in compaction process or as a grouting material compared it as powder.

Table (4): Summary of Test Results of Untreated and Treated Samples with ($CaCl_2$, 2H2O) Solution of 20% Concentration (optimum concentration).

Characteristics			Untreated Soil	Treated with 20%	Increase or Reduction
Compression Characteristics	C_c		0.26	0.137	Red. 47.3%
	CP% ,	CT	5.28	1.87	Red. 64.6%
		DOT	5.54	1.98	Red. 64.2%
Permeability and Leaching Characteristics(at σ_v=200 kPa)	$k_{ave.}$ x10^{-5} (cm/sec.)		5.07	2.88	Red. 43.2%
	Total Leaching Strain% ,		18.75	8.49	Red. 54.72%
	Total Dissolved Gypsum,%		15.87	6.71	Red. 57.71%
Shear Strength	Unsoaked	c, kPa	50	102	Inc.100.04%
		ϕ, deg.	41	38	Red. 7.31%
	Soaked	c, kPa	10	62	Inc. 500.2%
		ϕ,deg.	40	33	Red. 17.5%

NOTATION

c : Cohesion Component of Strength, (kPa)
c.c.c : Calcium Chloride Content as Solid in the Sample, (%)
c.c.s : Concentration of Calcium Chloride Solution, (%)
Cc : Compression Index
CP : Collapse Potential
Cr : Rebound Index
Dr : Relative Density, (%)
e_o : Initial Void Ratio
Gs : Specific Gravity
i : Hydraulic Gradient
k : Coefficient of Permeability, (cm/sec)
kav. : Average coefficient of Permeability
L.L : Liquid Limit
SC : Clayey Sand
TSS : Total Soluble Salts
USCS : Unified Soil Classification System
$\varepsilon_{v,800}$: Volumetric Strain at (800 kPa) Stress, (%)
ϕ : Angle of Internal Friction, (degree)
γ_d : Dry Unit Weight
$\gamma_{d\ field}$: Field Dry Unit Weight , (kN/m^3)
σ_n : Normal Stress, (kPa)

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