Volume 63 | Issue 05 | May 2024
DOI: 10.5281/zenodo.11438664

Kinetics and Modeling of Expansive Soils and Their Stabilization Using Saline Solutions

Othmane Allam [1]*, Otbi Bouguenina [2], Abdelkrim Benahmed [3], Sidi Mohammed Aissa Mamoune [4], Khaled Bendahane [5] & Abdelmalek Bekkouche [6]

1,6. EOLE Laboratory, Department of Civil Engineering University Aboubekr Belkaid, Tlemcen, Algeria.
2,5. AMIL Laboratory, Department of Science and Technology, Nour Bachir El-Bayadh University Center, El-Bayadh, Algeria.
3. Department of Science and Technology, Nour Bachir El-Bayadh University Center, El-Bayadh, Algeria.
4. SSL Laboratory, Civil Engineering and Public Works Department, University Belhadj Bouchaib, Ain Temouchent, Algeria.
*Corresponding Author Email: all-oth@hotmail.fr, ORCID ID: https://orcid.org/0009-0004-6634-054X

Abstract

Clays exhibit significant reactivity with water, leading to various phenomena such as swelling. This swelling can cause damage to foundations and superstructures. To mitigate these effects, researchers have developed techniques and procedures for designing structures suited to such soil conditions. This study compiles the results of a geotechnical testing campaign conducted in the laboratory to characterize the materials and determine the necessary parameters for an indirect estimation of the swelling properties (both qualitative and quantitative) of the swelling soils from two provinces (Tlemcen and Saïda). However, this classification needs to be confirmed by direct measurements of swelling pressure and potential. Laboratory tests were conducted to investigate this phenomenon, using various salts at different concentrations (Potassium Chloride, Sodium Chloride, Calcium Chloride, Magnesium Chloride, and Aluminum Chloride). The objective was to analyze the effect of these salts on the pressure and kinetics of the studied soils. The results obtained from samples collected from three sites (one in Saïda and two in Tlemcen) indicate that the salts significantly affect the magnitude of swelling, while their effect on swelling pressure is not intrinsic to the material but depends on the loading path.

Keywords: *Kinetics, Pressure, Swelling, Clay, Stabilization, Salts.*

1. INTRODUCTION

The processes of shrinking and swelling in clay soil, which cause differential settlement and damage to buildings, originate from predisposing factors related to the mineralogical composition and texture of the soils involved. In Algeria, various cases of severe damage due to swelling have been reported in different regions, including the In Amenas refinery, the N'Gaous hospital in Batna, the Ramdane Djamel railway line in Jijel, the Sidi Chahmi hospital, the Mers El Kébir brickyard in Oran, and the Tlemcen-Mansourah-Chetouane area (Bekkouche *et al.*, 2001).

Various methods and apparatuses have been developed to evaluate the influence and effectiveness of solutions or products on the stabilization of swelling soils. However, different testing procedures and standards complicate comparisons. Estimating the swelling characteristics requires standardized tests that are simple, well-adapted, and above all, reliable. Swelling clays are prevalent in many contexts, and their properties can be both beneficial and harmful. Therefore, it is crucial to understand the hydromechanical behavior of these materials to better control their use.

Volume 63 | Issue 05 | May 2024
DOI: 10.5281/zenodo.11438664

The stabilization of clay soils has been extensively studied by many researchers. Various methods and apparatuses have been developed to assess the effectiveness of solutions or products on clay soil stabilization. For instance, Haxaire and Bloch (1956) determined the quantity of organic molecules that can attach to montmorillonite, connecting this attachment to the structure, nature, and ionization of these molecules. They found that certain molecules, such as guanidine and benzene, bind irreversibly to montmorillonite in quantities exceeding the basic exchange capacity.

Hazart and Wey (1965) studied the swelling kinetics of montmorillonite, highlighting the significant role of interlayer cations. Mondshine and Kercheville (1966) used sodium chloride and calcium chloride in oil sludge to dehydrate clays, concluding that calcium chloride is more effective. Reed (1972) measured the permeability of clay samples to fresh and saltwater before and after treatment with aluminum salts, demonstrating that clay formations become water-insensitive after aluminum ion treatment.

Waller and Michael (1976) found that the influence of salts on reconstituted clay samples yielded the best results when combining potassium chloride (KCl) with a polymer. Tuller and Or (2003) observed using an electron microscope (SEM) that sodium montmorillonite swells significantly more than calcium montmorillonite, with average interlayer distances being much smaller in Ca^{2+} montmorillonite than in Na^{+} montmorillonite. Hachichi and Fleureau (1999) and Bourokba (2001) analyzed the reduction of swelling in clays from the Oran region using polymer salts, noting significant reductions with the combination of aluminum chloride and polymers.

Aboubekr and Aissa Mamoune (2004) studied the influence of various salts (potassium chloride, sodium chloride, calcium chloride, ammonium sulfate) on the free swelling of clays samples of natural and artificial, finding significant reductions with potassium chloride and moderate to low reductions with calcium chloride.

Wakim (2005) tested Tournemire argillite, showing that deformations due to swelling and shrinkage are influenced by the nature and concentration of dissolved salts in demineralized water. In addition, it has been observed that normalized swelling does not depend on the orientation of the sample, which means that the anisotropy of the swelling is independent of the nature and concentration of salt. It was to confirm this observation by additional tests carried out using the hygrometric enclosure. Thus it was carried out tests to measure the evolution of potential of Hydrogen (pH) have shown that the swelling stabilizes before the stabilization of pH.

Mokni *et al*. (2010) investigated the effect of osmotic phenomena on the swelling of porous materials containing salt crystals, proposing a formulation for analyzing deformations induced by the dissolution of salts contact with water.

Study Area

The soils studied come from two different provinces (Fig. 1). The first is the Saïda province, known for its "Saïda clays." The second is the Tlemcen province, which contains swelling soils, as demonstrated by research conducted by various authors. The Saïda area is part of the Tlemcénien domain in a geological sense, representing a subset of the Atlas domain. The Tlemcénien domain is the foreland of Tell. It is of medium elevation and begins with the Ghar Rouben massif. To the east, there are the mountains of Tlemcen, Daia, Saïda, and Tiaret with Boughedou, the mountains of Frenda, and Djebel Nador. This system extends under the Sersou plateau and reemerges in the Hodna massif.

Volume 63 | Issue 05 | May 2024
DOI: 10.5281/zenodo.11438664

The Tlemcen area is built on heterogeneous formations surrounded by marl formations. In recent years, the city has expanded onto these marl formations without prior studies to understand their behavior, which partially explains the observed structural disorders. These marls, the main formations of the Tlemcen region, have caused notable structural issues in various locations. Examples include National Road 7A at Bab El Assa (78 km), residential buildings in Sidi Abdelli (35 km), and the Oum El Allou Nédroma School (60 km).

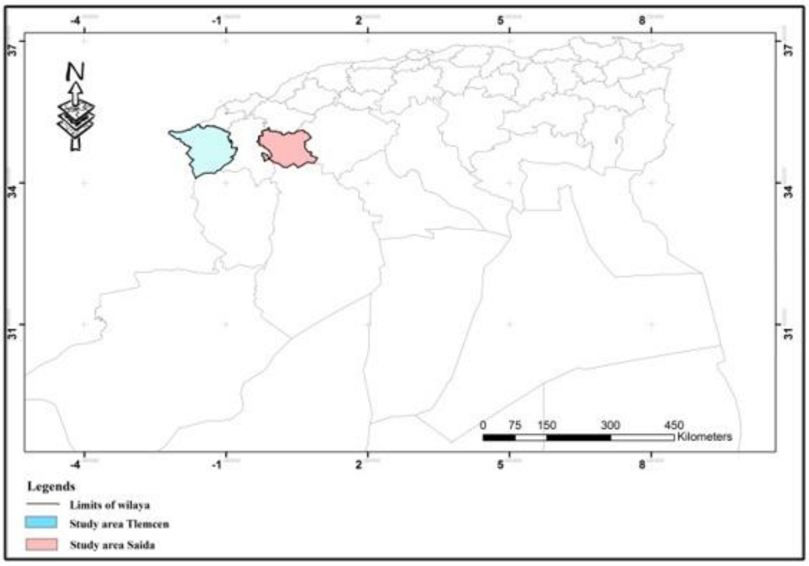


Fig 1: Geographical situation of the study area

2. IDENTIFICATION OF THE SOILS STUDIED

Before approaching this study, it was necessary to mention that the soil retained comes from carrots supplied by the antenna of Saïda of the National Laboratory of the Habitat and Construction and the Laboratory Unit of Public Works West of Tlemcen. The selected soil was the subject of the determination of all of its physic-chemical characteristics (AFNOR 1998). These are given below.

The experimental program subjected the collected samples to a series of examinations and analyzes while carrying out all the tests necessary for their identification. All the physic-chemical and mechanical identification tests were carried out in the geotechnical laboratory.

The particle size analysis of the soils studied has shown that the soil contains fine elements (less than 0.002 mm) from 20 to 34%, a variant liquidity limit between 50 and 59.42%, a plasticity limit from 22 to 29% and an index of plasticity variable between 26 to 30.5.

The chemical analysis gave a specific surface area of 115 to 138.14 m^2/g, a carbonate content of 16 to 33.73% and an activity of 0.90 to 1.89. These physic-chemical parameters presented above in Table 1 will serve us to make an estimate of the swelling, whether qualitative and / or quantitative, of course using international classifications and models of indirect measurement.

Volume 63 | Issue 05 | May 2024
DOI: 10.5281/zenodo.11438664

Table 1: Physic-chemical characteristics of the soils studied

Normes	Physic-chemical characteristics	Soil 1	Soil 2	Soil 3	Soil 4	Soil 5
-	Profounder (m)	5.60	9.20	6.80	2.30	6.70
NF P 94-051	Liquid limit (%)	59.42	53.79	51.62	55.15	50.31
NF P 94-051	Plastic limit (%)	28.92	26.92	23.84	25.81	22.02
NF P 94-051	Plasticity index	30.50	26.87	27.78	29.34	28.29
NF P 94-060-1	Shrinkage limit (%)	20.75	19.17	18.83	16.35	12.53
NF P 94-057	< 0.002 mm, (%)	34	34	24	31.50	20
IP/F2	Activity	1.05	0.93	1.46	1.11	1.89
NF P 94-068	specific-surface area (m^2/g)	127.67	138.14	115.12	136.67	123.49
NF P 94-048	$CaCo_3$ (%)	18.75	18.82	16.70	33.73	26.17
-	Classe GTR	A_3	A_3	A_3	A_3	A_3
Saïda: Soil 1, Soil 2, Soil 3; Tlemcen: Soil 4, Soil 5						

3. ESTIMATION OF SWELLING SOILS

The identification of swelling soils can be done on a microscopic scale, the shapes and assemblies of the structure of these materials are very specific. However, this recognition is very expensive and does not provide information on the mechanical parameters of shrinkage swelling.

A primary identification, from the results of simple tests, can be of considerable interest since it, will save time and cost. Indeed, the fact of suspecting that a ground could be swelling as of the preliminary reconnaissance companion makes it possible to anticipate on the confirmation reconnaissance companions by adapting them to the nature of the site (Bekkouche *et al*. 2001).

3.1 Qualitative classification

Identifying the swelling potential using easily measurable physic-chemical parameters during reconnaissance trips would be very useful to practitioners. It would allow them to modify their reconnaissance plan in order to adapt it to swelling soil. The question that arises: what are the most physical and chemical parameters indicative of the swelling character of a clay?

To avoid losses caused by swelling soils, it is essential to recognize this type of soil. Traditionally, the Atterberg limit values, the dry density, or the natural water content of the soil makes it possible to identify these soils. In the Table 2, we represent the estimate of the swelling rate of the soils studied.

Table 2: Qualitative identification of the swelling potential

Classification	Soil 1	Soil 2	Soil 3	Soil 4	Soil 5
Seed *et al*. (1962)	H	H	H	H	H
Seymour (1980)	F	F	F	F	F
Chen and Ma (1987)	F	F	F	F	F
Bigot (2000)	F	F	M	F	M
H: high; F: fort; M: moderate					

Indirect methods linking swelling to geotechnical parameters allow identifying the swelling grounds while the swelling tests characterize more precisely the swelling behavior of a sample. The different test procedures in the laboratory make it possible to determine the swelling parameters (σ_s and ε_s) to be applied in the dimensioning of the structure.

Volume 63 | Issue 05 | May 2024
DOI: 10.5281/zenodo.11438664

3.2 Quantitative classification

Experimental studies on swelling soils show that the percentage of swelling of a soil should increase proportionally with its density, with its liquid limit, with its clay content and with its plasticity indices.

The variations in percentage of swelling depending on the physical characteristics intervene in the expressions of the models, have been reported from the literature for the prediction of the amplitude of swelling, these models are used to predict the rate swelling of the tested clay samples. These empirical models relate the swelling parameters to the geotechnical parameters determined from the Table 3 identification tests.

Table 3: Qualitative identification of the swelling potential

Models	Mathematical expressions	Soil 1	Soil 2	Soil 3	Soil 4	Soil 5
Seed *et al*. (1962)	$\varepsilon g = 2.16\ 10^{-5}(Ip)^{2.44}$	7.521	5.594	5.073	6.623	5.086
Vijayvergiya and Ghazzaly (1973)	$log\varepsilon_{gonf} = (62.42\ \gamma_d + 0.65\ w_l - 130.5)/19.5$	1.771	2.415	0.791	3.008	2.091
Johnson (1989)	$\varepsilon_{gonf} = -9.18 + 1.5546\ I_p + 0.0824\ z + 0.1\ w_n + 0.0432\ w_n I_p - 0.01215\ zI_p$	4.611	6.564	2.162	10.327	8.583
Schneider and Poor (1974)	$log\varepsilon_{gonf} = \left(\frac{0.9\ Ip}{w_n}\right) - 1.19$	0.715	0.774	0.529	1.048	0.953
Nayak and Christensen (1971)	$\varepsilon_{gonf} = 0.0229\ {I_p}^{1.45}\left(\frac{C}{w_n}\right) + 6.38$	3.384	3.194	2.019	3.433	2.071

The models of Seed *et al*. (1962) do not take into account the natural water content; they are based on interdependent parameters (clay content, activity and plasticity index).

According to the results of model of Nayak and Christensen (1971) and the model of Vijayvergiya and Ghazzaly (1973) cannot be used for high values of the clay content, the natural water content and the liquid limit. The first model is based on interdependent parameters, as for the second, it does not take into account the natural water content. The Johnson (1989) model predicts overall swelling percentages within limits commonly seen in practice. The latter model seems to be applicable according to the applications.

4. MATERIALS AND METHODS

According to the results obtained in the identification and quantitative/quantitative estimation of the soils studied, samples taken at different profundity (Soil 1 (5.60 m); Soil 2 (9.20 m); Soil 3 (6.80 m); Soil 4 (2.30 m); Soil 5 (6.70 m)). Will be used to assess the influence of different concentrations of salts on the kinetics and pressure of swelling in order to deduce a simple, economical and effective method of minimizing the phenomenon of swelling.

The dimensions of all the samples used:

The samples have a variable height 19.52, 19 and 19.50 mm and a diameter of 50 mm.

From the point of view of the kinetics of the swelling which can be deduced from the values or from the shape of the curves in the figures which will be represented later, in a first step, the analysis of the kinetics of the swelling will be carried only on the evolution swelling over time in the presence of distilled water. By analyzing these different swelling evolution curves as a function of time, it is clear that the swelling amplitude is important (varies between 2.72 to 4.95 %) for all the samples tested in the laboratory.

Volume 63 | Issue 05 | May 2024
DOI: 10.5281/zenodo.11438664

4.1 Stabilization of swelling by saline solutions

To study the effect of the salts on the free swelling of the soils studied, the samples were saturated in an oedometric cell with saline solutions at different concentrations. Then the swelling was measured as a function of time until stabilization. The final swelling is compared to the final swelling of the water-saturated clay. The reduction in final swelling expressed in percent is the difference between swelling with water and with saline solutions, compared to the final swelling in the presence of water.

The reduction in swelling is given by Eq. (1):

$$\frac{\Delta S}{S} = \frac{S_{water}\,(\%) - S_{salt}\,(\%)}{S_{water}\,(\%)} \qquad (1)$$

Where:

ΔS/S: The reduction in final swelling;

S_{water}: The final swelling of the water in percent;

S_{salt}: The final swelling of the saline solutions in percent.

The reduction in swelling pressure expressed as a percentage is the difference between the pressure in water and with saline solutions, compared to the swelling pressure in the presence of water.

The reduction in swelling pressure is given by Eq. (2):

$$\frac{\Delta P}{P} = \frac{P_{water}\,(\%) - P_{salt}\,(\%)}{P_{water}\,(\%)} \qquad (2)$$

Where:

ΔP/P: The reduction in swelling pressure;

P_{water}: The swelling pressure of the water in percent;

P_{salt}: The swelling pressure of the saline solutions in percent.

4.2 Free swell test AFNOR NF P 94-091

After mounting a test piece in an oedometric cell, it is subjected to the imbibition process under a load corresponding to the weight of the piston. Vertical deformations are measured; the maximum deformation compared to the initial height corresponds to the swelling potential. Once the swelling phenomenon has stabilized, loading takes place gradually, in stages according to a chosen loading rate. The inflation pressure corresponds to the load, which it is necessary to apply to bring the test piece back to its initial height (NFP 94-091 1995).

4.3 Swelling according to ASTM D 4546-03 method A

The ASTM-D procedure adopts the correction of the effect of the rearrangement by the application of a loading-unloading cycle, the final stress of this cycle being the equivalent of the weight of the soil before l extraction of the sample. The swelling of the latter, obtained by imbibition, will be followed until stabilization. The inflation pressure will be equal to the pressure that would have returned the sample to its original height. The swelling amplitude will correspond to the maximum deformation between the beginning and the end of the swelling phase (ASTM D 4546-03 1985).

Volume 63 | Issue 05 | May 2024
DOI: 10.5281/zenodo.11438664

Method A—After the initial deformation reading at the seating pressure is recorded, inundate the specimen and record deformations after various elapsed times. Readings at 0.1, 0.2, 0.5, 1.0, 2.0, 4.0, 8.0, 15.0, and 30.0 min and 1, 2, 4, 8, 24, 48, and 72 h are usually satisfactory. Continue readings until primary swell is complete, as determined by the method illustrated in Fig. 2. After completion of swell, apply a vertical pressure of approximately 5, 10, 20, 40, 80, etc., kPa (100, 200, 400, 800, 1600, etc., lbf/ft^2) with each pressure maintained constant in accordance with 10.4 of Test Method D 2435.

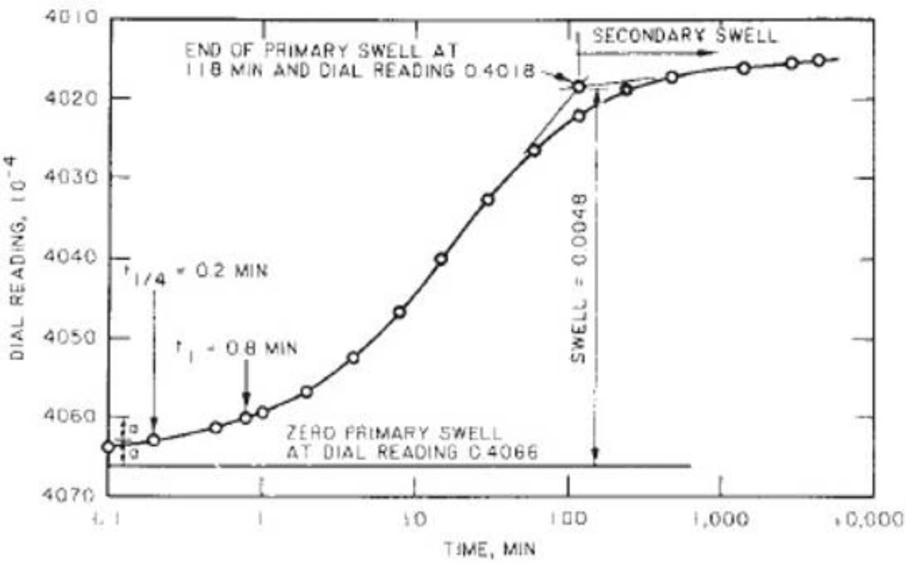


Fig 2: Time - Swell Curve

5. EXPERIMENTAL RESULTS AND DISCUSSION

5.1 Effect of salts on swelling

Salts are bodies resulting from the action of an acid on a base. In the field of civil engineering, they are generally used to fight against the swelling of the clay formation; they act on the balance of the osmotic pressure and guarantee a stabilization of the swelling soils. The saline solutions were prepared by dissolving the salts in demineralized water. The list of monovalent salts, divalent salts and a trivalent salt at different concentrations are:

- Sodium chloride NaCl, for sample Soil 1;
- Aluminum chloride $AlCl_3$, for sample Soil 2;
- Magnesium chloride $MgCl_2$, for sample Soil 3;
- Calcium chloride $CaCl_2$, for sample Soil 4;
- Potassium chloride KCl, for sample Soil 5.

The molarities of the saline solutions are 0.05 mol / liter (M); 0.10 M; 0.25 M; 0.50 M and 0.75 M. These salts were chosen because they are frequent in the composition of pore water in clay formations. The tests were carried out on intact samples of Saïda clay with three salts: sodium chloride (NaCl), aluminum chloride ($AlCl_3$) and magnesium chloride ($MgCl_2$) at three concentrations 0.25, 0.50 and 0.75 mol/l. There are some shortcomings observed during sample placement, this is due to the difficulty of sample preparation, especially when

Volume 63 | Issue 05 | May 2024
DOI: 10.5281/zenodo.11438664

it comes to intact samples, several samples were lost during handling. Other tests were carried out on reconstituted samples of Tlemcen, with the two remaining salts calcium chloride ($CaCl_2$) and potassium chloride (KCl) at three concentrations 0.05, 0.10 and 0.25 mol/l.

In order to obtain the materials for the swelling tests, the quantities of soil were homogenized by providing them with a certain water content, that is to say reconstituted the samples with physical properties are the natural water content, wet density and dry density, the latter are measured beforehand when the samples were intact according to the procedure of the hydrostatic weighing test of the standard (AFNOR 1998). With these parameters w, γ_h, γ_d and equations connect the latter, a mold with a known volume is followed by determines the amount of dry soil and the amount of water necessary to introduce it all into this mold, as it gets samples reconstituted almost to the same properties of intact samples. The two samples of Tlemcen (Sidi Abdelli) are made up of intact soil properties see Table 4. These samples will be used for the swelling test.

Table 4: Physical properties of the two intact samples

Physical properties	Soil 4	Soil 5
Water content, w (%)	21.82	21.78
Unit weight of dry soil, γ_d (kN/m^3)	15.70	15.75
Mold volume, (m^3)	$9.37\ 10^{-4}$	$9.37\ 10^{-4}$
Effective overburden pressure, σ_{v0} (kPa)	44.80	133.00

For this reason, we have chosen to use the procedure of the American standard (ASTM D-4546-03 - Method A) because it takes into account the effect of reworking; it corrects it by applying a step of loading up to the effective overburden pressure of the earth weights σ_{v0} and unloading. The experimental results of these problems of kinetics of swelling are illustrated in Table 5 and graphically shown in Figs. 3 and 4 followed by subsequent discussions.

Effect on swelling pressure

The experimental results of the swelling pressure of the samples tested for different values of molarities (M = 0.05, 0.10, 0.25, 0.50 and 0.75) are presented in Table 5 and Fig. 3. These results are compared with those obtained by existing research works in the literature: Seed *et al*. (1962), Reed (1972), Hachichi and Fleureau (1999) and Bourokba (2001) to demonstrate the validity of the results obtained.

Table 5: Variation of swelling pressure of samples at different concentrations of saline solutions

Swelling pressure (kPa)					
Concentration mol/l	Soil 1	Soil 2	Soil 3	Soil 4	Soil 5
	NaCl	$AlCl_3$	$MgCl_2$	$CaCl_2$	KCl
0.05	-	-	-	40.00	153.00
0.10	-	-	-	46.00	90.00
0.25	40.00	150.00	51.00	35.00	46.00
0.50	51.00	80.00	50.00	-	-
0.75	60.00	181.00	30.00	-	-
distilled water	77.00	100.00	54.00	69.00	61.00

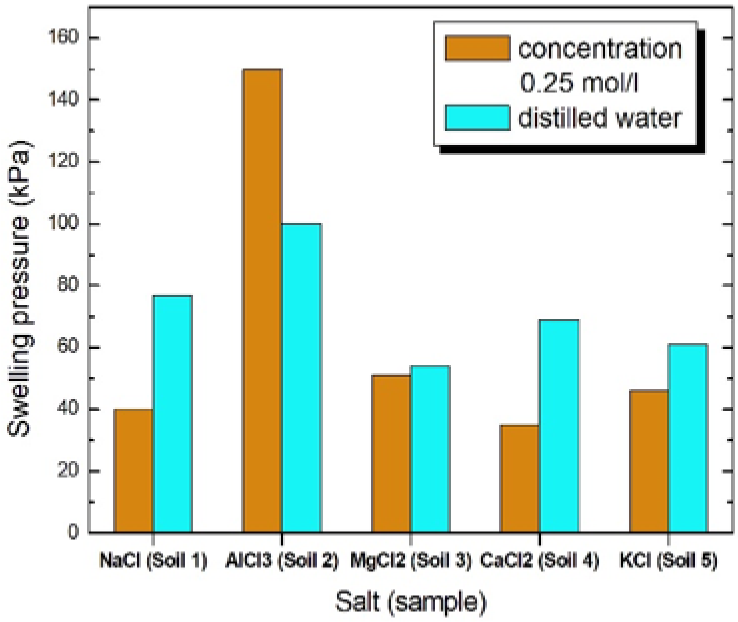
From the results obtained on the intact Saïda samples, we found that the swelling pressures measured on the samples saturated with different salts at different salt concentrations are variable to those saturated with distilled water, for example, we cannot find clear enough relationships between the presented salt (NaCl) results. For the variation of the

Volume 63 | Issue 05 | May 2024
DOI: 10.5281/zenodo.11438664

swelling pressure as a function of different concentrations of salt ($AlCl_3$), it appears that the swelling pressures obtained by the two concentrations of 0.25 mol/l and 0.75 mol/l have high values compared to compared to that measured with distilled water. On the other hand, for the two concentrations of 0.25 mol/l and 0.50 mol/l of the salt ($MgCl_2$), practically the same swelling pressure is obtained, as that measured with distilled water, for a concentration of 0.75 mol/l the decrease in swelling pressure is 44.44%.

With regard to the results obtained on the reconstituted samples from Tlemcen, it appears that the presence of calcium chloride has the effect of reducing the swelling pressure; the relationships between the concentrations are independent. For example for 0.05 mol/l on obtains a reduction of 42.02% on the other hand for a higher concentration of 0.10 mol/l a reduction of 33.33% is obtained. In addition, it should be noted that for a high concentration of 0.25 mol/l of salt (KCl) has the effect of reducing the swelling pressure, for reliable concentrations < 0.25 mol/l high values are obtained. It can be stated that the present results of the swelling pressure are in good agreement with the results reported by Seed *et al*. (1962).

Fig 3: Variation of the swelling pressure of the samples tested by the different saline solutions with a concentration of 0.05 mol/l



Kinetics of swelling

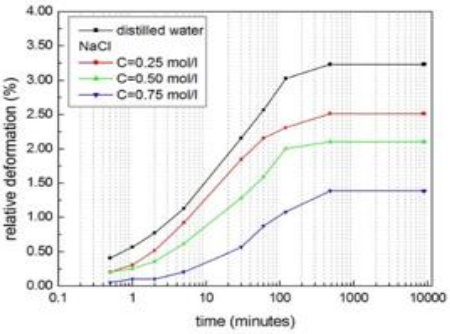
The experimental results of the kinetics of the samples tested for different values of molarities (M = 0.05, 0.10, 0.25, 0.50 and 0.75) are shown in Fig. 4, respectively. These results are compared with those obtained by existing research in the literature: Seed *et al*. (1962), Johnson (1989), Bourokba (2001) and Mokni *et al*. (2010)

Examination of Fig. 4(a)-(c) shows the kinetics obtained on the intact samples of Saïda, it is noted that with a high concentration of sodium chloride this has the effect of reducing the final swelling, for example a concentration of 0.75 mol/l gives a final swelling value of 1.60% either a reduction of 52.66%. The same remark is noted for a high concentration of aluminum chloride can reduce the final swelling. The concentration of 0.50 mol/l gives a final swelling value of 4.63%, a slight reduction of 6.46% compared to a sample saturated with distilled

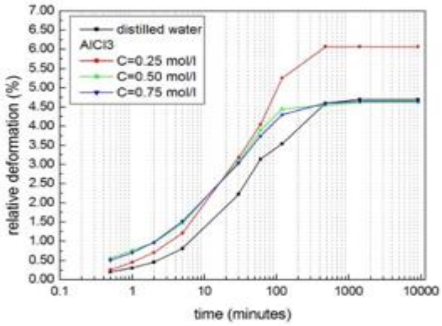
Volume 63 | Issue 05 | May 2024
DOI: 10.5281/zenodo.11438664

water, if the tendency may be for a high concentration, a good reduction is obtained. After, a high concentration of magnesium chloride has the effect of reducing the final swelling, there is a concentration of 0.75 mol / l the final swelling is 1.23%, a reduction of 54.78% compared to distilled water.

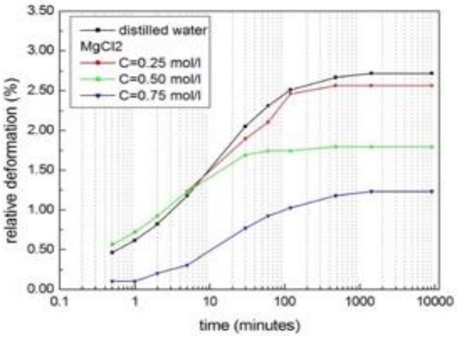
Fig 4: The kinetics of swelling of the samples tested for different concentrations of saline solutions



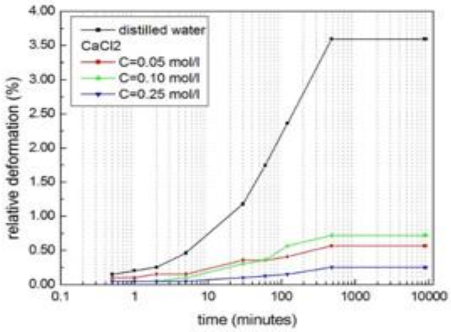
(a) NaCl



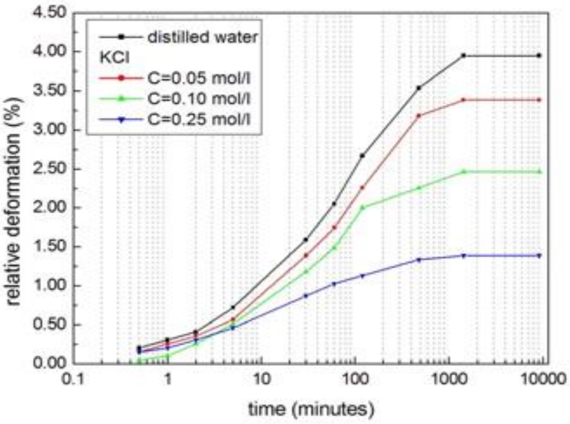
(b) $AlCl_3$



(c) $MgCl_2$



(d) $CaCl_2$



(e) KCl

Volume 63 | Issue 05 | May 2024
DOI: 10.5281/zenodo.11438664

It is also observed that the results obtained on the reconstituted samples from Tlemcen (Fig. 4(d) and (e)) that a low concentration of calcium chloride has the effect of reducing the final swelling, for example for a concentration of 0.05 mol/l, the final swelling is 0.63% or a reduction of 84.63% compared to a saturated sample of distilled water. The curve illustrates very well the effect of the saline solution on the swelling kinetics parameters such as the final swelling rate, the half-swelling time and the inclination. These are easily determined from the graphs. The curve in Fig. 4(e) illustrates very well the parameters of the swelling kinetics such as the final swelling rate, the half-swelling time and the linearity of the model. A low concentration of potassium chloride has the effect of reducing the final swelling; we can see that for a concentration of 0.05 mol/l, the final swelling of 3.43% either a reduction of 20.23% compared to a saturated sample of distilled water. It is also underlined in Fig. 4 that the results obtained in the laboratory have good argument with the results reported by Johnson (1989) and Bourokba (2001).

6. CONCLUSIONS

In this study, all laboratory tests were mainly carried out using the oedometer device for two primary reasons:

1. The state in the oedometer mold closely approximates the in-situ soil conditions.
2. The oedometer is widely used.

It is also recognized that tests for measuring swelling parameters are long and costly. Therefore, obtaining a quick initial estimate of these parameters would be highly advantageous, although direct swelling tests remain essential for large projects.

Based on the results obtained from our clay samples and their interpretations, several assumptions were made:

- The influence of saline solutions and their concentrations, valences, and sizes on swelling kinetics is significant. However, the valence effect is likely the determining factor, as higher-valence cations can easily replace those with lower valences. For ions with the same valence, the size of the hydrated ion is crucial; larger ions have a greater replacement capacity.
- For reconstituted samples from the Tlemcen province, calcium chloride is more influential at low concentrations, while potassium chloride is effective at high concentrations.
- For intact samples from the Saïda province, magnesium chloride and sodium chloride minimize the swelling of the studied soils. Sodium chloride, which allows these cations to be fixed between the sheets, reduces swelling quickly, even at low concentrations. Aluminum chloride also reduces swelling but requires high concentrations.

Consequently, it is concluded that studying the kinetics and applying the technique of stabilizing expansive soils with salts to real projects must be considered, particularly when laboratory tests do not provide a clear path to equilibrium. However, based on the conducted tests, it is essential to perform a specific, detailed study—preferably under site conditions—before each proposed treatment to define the nature and concentration of the saline solutions to be used. Future research will explore other stabilization techniques for this type of soil.

Volume 63 | Issue 05 | May 2024
DOI: 10.5281/zenodo.11438664

Recent scientific research, already published by many researchers, addresses issues such as the damage, treatment, and stabilization of expansive soils (Irem *et al*. 2016; Soumendra *et al*. 2017; He *et al*. 2018; Mahedi *et al*. 2020; Tiwari *et al*. 2021; Sriram *et al*. 2021; Zid and Rezkallah 2024; Guiz *et al*. 2024).

Acknowledgments: The authors would like to acknowledge the support provided by the Directorate General for Scientific Research and Technological Development (DGRSDT).

References

1) Abou-bekr, N. and Aissa Mamoune, S.M. (2004), "Stabilization of swelling soils using salts", Proceedings International Conference on International Geotechnical, Beyrouth, Lebanon, May.

2) AFNOR, Geotechnics (1998), Soil recognition tests, Volume 1 (2nd ed.); Paris, France.

3) Aissa Mamoune, S.M. (2002), "Contribution to the measurement, forecast and modeling of the behavior of expansive soils", Master's Dissertation, University of Tlemcen, Algeria.

4) ASTM D 4546-03 (1985), Standard Test Methods for One-Dimensional Swell or Settlement Potential of Cohesive Soils; Pennsylvanie, USA.

5) Bekkouche, A., Azzouz, F.Z. and Aissa Mamoune, S.M. (2007), "Salt stabilization of swelling soils in the Tlemcen region", Proceedings International SOMAPRO’07 on Colloquium Soils and Problem Materials, Sfax, Tunisia.

6) Bekkouche, A., Djedid, A. and Aissa Mamoune, S.M. (2001), "Identification and Forecasting of The Swelling of Some Soils in The Tlemcen Province Algeria", Bulletin of the bridge and roadway laboratories, Ref 4375 – pp. 67-75.

7) Bigot, Z. (2000), "Shrinkage, Swelling and Compaction of Fine Soils", Bulletin of the bridges and roadways laboratories, -229- NT 4252 - pp. 105-114.

8) Bourokba, S. (2001), "Contribution to the study of the chemical stabilization of some swelling clays in the Oran region", Ph.D. Dissertation, University of Mohamed Boudiaf U.S.T.Oran, Algeria.

9) Chen, F.H. and Ma, G.S. (1987), "Swelling and shrinking behavior of expansive clays", Proceedings of the 6th International Conference on Expansive Soils, New Delhi, Inde, December.

10) Guiz, A., Mebarki, K., Chekroun, L.E.H. and Bourdim, S.M.E.A. (2024), "A numerical study of landslide treatment techniques applied in the Algerian highway", *Journal of Gradiva*, **63**(01), 145-153. https://doi.org/10.5281/zenodo.10628307

11) Hachichi, A. and Fleureau, J.M. (1999), "Characterization and stabilization of a few expansive soils from Algeria", *Rev. Fr. Géotech.*, **86**, 37-51. https://doi.org/10.1051/geotech/1999086037

12) Haxaire, A. and Bloch, J.M. (1956), "Sorption of Organic Nitrogenous Molecules by Montmorillonite, Study of The Mechanism", *Bulletin of the french society of mineralogy and crystallography*, Vol. **79**, 7-9, pp. 464-475.

Volume 63 | Issue 05 | May 2024
DOI: 10.5281/zenodo.11438664

13) Hazart, J.P. and Wey, R. (1965), "Kinetic Study of The Swelling of Montmorillonite in The Presence of Ethylene Glycol by Means of X-ray Diffraction", *Bulletin of the Service of the geological map of Alsace and Lorraine*, Vol. **18**, n ° 4, Sedimentology and geochemistry of area. pp. 191-216.

14) He, S., Yu, X., Banerjee, A. and Puppala, A.J. (2018), "Expansive soil treatment with liquid ionic soil stabilizer", *Transportation Research Record*, **2672**(52), 185-194. https://doi.org/10.1177/0361198118792996

15) İrem, K., Ali, M.A., Gözde, İ.S., Selim, A. and Alper, S. (2016), "Assessment of the effect of sulfate attack on cement stabilized montmorillonite", *Geomechanics and Engineering*, **10**(6), 807-826. https://dx.doi.org/10.12989/gae.2016.10.6.807.

16) Johnson, L. (1989), "Horizontal and vertical swell pressures from a triaxial test feasibility study", *Geotechnical Testing Journal*, **12**(1), 87-92. 10.1520/GTJ10678J

17) Mahedi, M., Cetin, B. and White, D.J. (2020), "Cement, lime, and fly ashes in stabilizing expansive soils: performance evaluation and comparison", *Journal of Materials in Civil Engineering*, **32**(7), 04020177. https://doi.org/10.1061/(ASCE)MT.1943-5533.0003260.

18) Mokni, N., Olivella, S. and Alonso, E.E. (2010), "Swelling in clayey soils induced by the presence of salt crystals", *Applied Clay Science*, **47**(1-2), 105-112. https://doi.org/10.1016/j.clay.2009.01.005.

19) Mondshine, T.C. and Kercheville, J.D. (1966), "Successful gumbo-shale drilling", *Oil and Gas Journal*, **64**(13), 194.

20) Nayak, N.V. and Christensen, R.W. (1971), "Swelling characteristics of compacted, expansive soils", *Clays and Clay Minerals*, **19**(4), 251-261. https://doi.org/10.1346/CCMN.1971.0190406.

21) NF P 94-091 (1995), Swelling test at the oedometer, French Standardization Association; Paris, France.

22) Reed, M.G. (1972), "Stabilization of formation clays with hydroxy-aluminum solutions", *Journal of Petroleum Technology*, **24**(07), 860-864. https://dx.doi.org/10.2118/3694-PA.

23) Salaheddin, H. and Seyed, M.M. (2018), "Effect of clay mineral types on the strength and microstructure properties of soft clay soils stabilized by epoxy resin", *Geomechanics and Engineering*, **15**(2), 729-738. https://doi.org/10.12989/gae.2018.15.2.729.

24) Schneider, G.L. and Poor, A.R. (1974), "The prediction of soil heave and swell pressures developed by an expansive clay", Tex. Research Report, 9-74; University of Texas, USA.

25) Seed, H.B., Woodward Jr, R.J. and Lundgren, R. (1962), "Prediction of swelling potential for compacted clays", *Journal of the Soil Mechanics and Foundations Division*, **88**(3), 53-87. https://doi.org/10.1061/JSFEAQ.0000431.

Volume 63 | Issue 05 | May 2024
DOI: 10.5281/zenodo.11438664

26) Seymour Walker, K.J. (1980), "Building research establishment. In new ways to save energy", Proceedings of the International Seminar Held in Brussels, Brussels, Belgium, January.

27) Soumendra, K.M., Pradip, K.P. and Chitta, R.M. (2017), "Stabilization of expansive soil using industrial wastes", *Geomechanics and Engineering*, **12**(1), 111-125. https:// doi.org/10.12989/gae.2017.12.1.111.

28) Sriram Karthick Raja, P. and Thyagaraj, T. (2021), "Effect of short-term sulphate contamination on lime-stabilized expansive soil", *International Journal of Geotechnical Engineering*, **15**(8), 964-976. https://doi.org/10.1080/19386362.2019.1641665.

29) Tiwari, N., Satyam, N. and Puppala, A.J. (2021), "Strength and durability assessment of expansive soil stabilized with recycled ash and natural fibers", *Transportation Geotechnics*, **29**, 100556. https://doi.org/10.1016/j.trgeo.2021.100556.

30) Tuller, M. and Or, D. (2003), "Hydraulic functions for swelling soils pore scale considerations", *Journal of Hydrology*, **272**(1-4), 50-71. https://doi.org/10.1016/s0022-1694(02)00254-8.

31) Vijayvergiya, V.N. and Ghazzaly, O.I. (1973), "Prediction of swelling potential for natural clays", Proceedings of the 3rd International Conference on Expansive Soils, Haïfa, Palestine, August.

32) Wakim, J. (2005), "Influence of aqueous solutions on the mechanical behavior of clayey rocks", Ph.D. Dissertation, National Superior School of Mines, France.

33) Waller, D.D. and Michael, J. L. (1976), "Selection of drilling fluids to minimize shale instability in Indonesia", 269-279.

34) Zid, I. and Rezkallah, C. (2024), "Physico-chemical quality of groundwater used for irrigation in the Hassi Khalifa region (Eloued- Algeria)", *Journal of Gradiva*, **63**(01), 29-38. https://doi.org/10.5281/zenodo.10554651