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Study of the influence of the saline solution NaCl on the potential collapse of soil

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Abstract. Collapsible soils are unsaturated soils which present a potential for large strains and a complete change to the whole particle structure after wetting with or without loading. These soils are characterized with loose structures composed of silt to fine-sand-size particles.The objective of this experimental study is to illustrate that the resistance of collapsible soil can be improved. This study demonstrates that it is possible to minimize the collapsible potential C_p to an acceptable level after chemical treatment with salt (sodium chloride NaCl) at different concentrations (0.5, 1.0, 1.5 and 2.0 mole/liter) and at different compaction energies. The method used in this study is based on oedometric tests with variable normal stresses.

1 Introduction

Collapsible soils are unsaturated soils which may undergo inter-granular rearrangement with abrupt and significant volume reduction after wetting. Many research studies are developed to identify and prevent failure of collapsible soils as well as the measures to insure sufficient stability of structures to be built on such soils, [1, 2, 3, 4, 5]. The solutions proposed by various researchers to mitigate collapsible soils depend on the depth of soil layer in one hand, and the bearing capacity required by the structure foundation, on the other hand. Deep foundations, replacement or on-site thermo or mechanical treatment were part of the proposed solutions. Recently, chemical stabilization methods by salts were proposed [6-7]. However, it should be noted that there is few studies on the effect of soluble salts particularly sodium chloride (NaCl) on the mechanical behavior and microstructural characteristics of collapsible soils. It is proposed in this experimental work to study the influence of NaCl on the reduction of the potential for collapse C_p of a soil sample reconstituted from sand and kaolin. This study involves different salt concentrations, water contents, and energies of compaction based on œdometer test with different vertical stress.

2 Materials, Equipment and Test

The reconstituted soil sample is composed of 80% of sand and 20% of kaolin. The application of various criteria of collapse, as indicated by [8-9], show that this material is collapsible.

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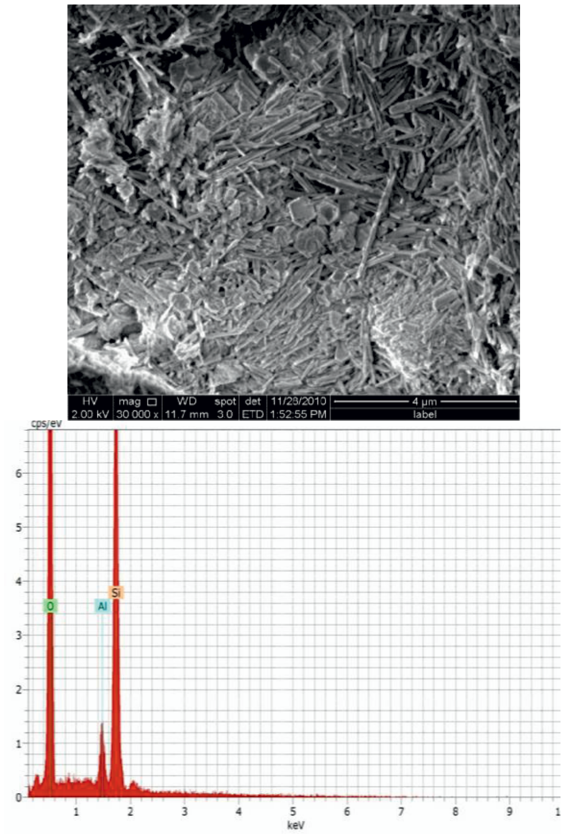
2.1 *Characteristics of Materials*

The sand used in the sample reconstitution comes from the Liwa River located in the region of Biskra, Algeria screened on the 2mm sieve; and its physical characteristics are given in the Table 1. The kaolin soil used in this study is extracted from Debbagh area of Guelma, Algeria. The physical characteristics are given in Table 1. Observation by scanning electron microscopy (SEM) (Figures 1) reveals that the experimental material consists of quartz and kaolin.The sieve analysis of the reconstituted sample is shown in Figure 2. The geotechnical characteristics of that sample are given in Table 1.

Table 1. Geotechnical characteristics of Materials

Materials	Characteristics
Sand	Sand equivalent SE = 87 % Coefficient of uniformity Cu = 3.91 Coefficient of curvature Cc = 0.95 Grain size distribution (0.08-2 mm) with 3.03% of particles < 80 µm.
Kaolin	D‹80µm Liquid limit LL = 67(%) Plastic limit PL = 39(%) Specific Gravity GS = 2.4
Reconstituted soil (80% sand + 20% kaolin)	Coefficient of uniformity Cu = 5.13 Coefficient of curvature Cc = 1.07 Liquid limit LL = 28 (%) Plastic limit PL = 16 (%) Specific gravity GS = 2.65 Maximum dry density (g/cm^3) γ_d = 1.93 Optimal water content w_{opt} = 10 (%)



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El	AN	Series	unn. C [wt.%]	norm. C [wt.%]	Atom. C [at.%]	Error [%]
O	8	K-series	72.59	67.73	78.60	8.9
Al	13	K-series	2.80	2.61	1.80	0.2
Si	14	K-series	31.78	29.66	19.60	1.3
		Total:	107.16	100.00	100.00	

Figure 1. Electron Photomicrograph of reconstituted sample (sand & kaolin).

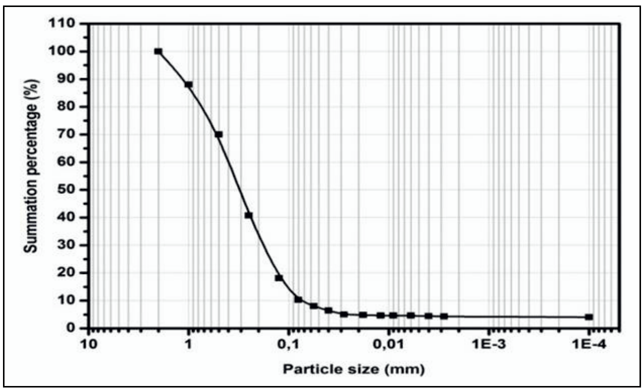

Figure 2. Sieve analysis of the reconstituted sample.

2.2 *Equipment*

The experimental equipment and tests are the same as those reported by [5], only the saline solution is different.

The equipment used is shown schematically in Figure 3. It is composed of a disc having a diameter slightly smaller than that of the oedometer ring, fixed at a guidance rod and a hammer in the shape of a disc. The 152g hammer falls along the rod with a drop of 15 cm and contacts the fixed disc resulting in the compaction of sample in the oedometer ring, with the following compaction energy:

$$E_c = n.m.g.h/v \qquad (1)$$

where Ec is the compaction energy, n is the number of drops, m is the mass of hammer disc, h is the drop height, g is the acceleration of gravity and v is the volume of material before compaction.

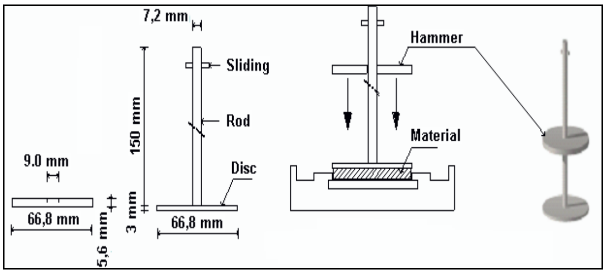

Figure 3. Experimental equipment (compaction device).

2.3 Test and Procedure

The object of this study is to reconstitute the soil in an oedometer mold with specific water content and dry density. The material is compacted in one layer because of the low thickness of the ring. Reconstituted soil exhibits good mechanical characteristics when it is compacted with a low initial water content (w_0=2, 4 and 6%). However, if higher moisture is introduced, even without additional load, the structure collapses and significant deformations occur. [10] proposed a procedure to estimate the collapse potential of a soil. That potential is evaluated by loading in an oedometer device two undisturbed soil samples at natural moisture content. One sample is then flooded for saturation. These tests provide the void ratios (e_1 and e_2) before and after flooding at a specific loading. This behavior can be observed in Figure 4 representing a typical curve of a double consolidation method for such soil. The collapse potential, C_p is calculated as the vertical strain similar to an abrupt settlement and thus can be expressed as

$$C_p\ (\%) = \Delta H/H_0\ 100 = \Delta e_c/(1+e_0)\ 100 \qquad (2)$$

Where ΔH is change in height of the sample upon flooding, H_0 is original height of the sample, Δe_c= (e_1-e_2) is the change in void ratio of the sample up on flooding, e_1 is the void ratio at dry state, e_2 is the void ratio upon of flooding and e_0 is the initial void ratio before loading.

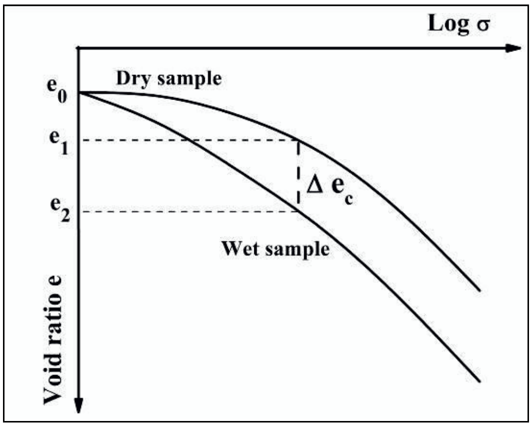

Figure 4. Typical oedometer curve for a collapsing soil [10]

Also, [10] correlated the collapse potential Cp to the severity of foundation disorder (Table 2).

Table 2. Foundation disorder level based on collapse potential C_p [10]

C_p (%)	Severity of disorders
0-1	Minor disorders
1-5	Moderate disorders
5-10	Disorders
10-20	Severe disorders
› 20	Very severe disorders

In order to obtain samples with different degrees of compaction, those samples are moistened at different water contents, then they are subject to different compaction energies (20, 40 and 60 drops) [8]. The samples thus prepared were tested using an oedometer by saturating them with solutions at different salt concentrations. Generally, work treating the effect of salts on the microstructural characteristics and hydraulic behaviour of clay materials use concentrations up to 1 mol/L [5, 11, 12]. The salt solution used for the soil treatment is sodium chloride (NaCl) with various concentrations (0.5, 1.0, 1.5 and 2 mol/L).

3 Results and Analysis

3.1. *Oedometer Results: Untreated Soils*

From the results obtained in this study, summarized in Figures 5 to 13, it is clear that the collapse of the sample without treatment correlates with collapsible soil which can cause disorders to foundation of structures [10]. Indeed, for various vertical stresses σ as well as for various compaction energies E_c, the collapse potential C_p varies from 0.98 to 12.40% for initial water content w_0=2%, from 0.82 to 10.64% for initial water content w_0=4%; and from 0.66 to 8.79% for an initial water content w_0=6%. These results correspond to minor to severe disorders (Table 2). It should be noted that the potential of collapse C_p decreases when initial water content or initial compaction energy increase. That is attributed to the reduction of the suction forces when the initial water content increases and denser structure when the energy increases. The wetting of the reconstituted sample induces a total suppression of the suction forces; which soften the material and reducing the shear resistance leading to an abrupt collapse. The collapse potential C_p is at its maximum for a vertical stress in the range of 400 kPa. This result reflects that there is a total re-arrangement of the soil skeleton under that loading, which results in the reduction of the voids. This behavior is the same regardless of the vertical stress. These results agree with those of [4, 5, 13 14]. Thus, a reconstituted soil sample has a behavior similar to those undisturbed natural collapsible soils.

3.2 *Oedometer Results: Soil Treated by Salt (NaCl)*

Results shown on figures 5 to 13 reveal a substantial reduction of the collapse potential C_p for soil samples treated with as sodium chloride (NaCl) at various ionic concentrations. Also, we note that the collapse potential C_p is at its maximum for a vertical stress in the range of 400 kPa. As stated before, this result reflects that there is a total re-arrangement of the soil skeleton under that loading, which results in the reduction of the voids. It should be noted that for a collapse potential at a vertical stress of 400 kPa, and for a low salt concentration (0.5 mol/L), the reduction ratios of C_p vary from 15% to 35%. However, for high concentrations (2 mol/L), the reduction ratios of C_p vary from 65% to 70%. The collapse reduction ratio is related to the applied vertical stress, knowing that for low concentrations (0.5 mol/L), this collapse reduction ratio varies from 15% to 25% for a vertical stress of 200 kPa, and it varies between 10% to 40% for a vertical stress of 800 kPa. For high salt concentrations (2 mol/L), the collapse reduction ratio varies between 60% to 70% for a vertical stress of 200 kPa. On the other hand for a vertical stress of 800 kPa, the values of the collapse reduction ratio vary between 30% to 65%.Thus, the behavior of a treated soil by saline solution NaCl is on one hand, affected by the initial water content and the compaction energy and on the other hand by the ionic concentration. Figures 5 to 13 show clearly that the collapse potentials in the presence of the solution NaCl at a concentration of 1.5 mo/L are close to those of 2 mol/L. As a result, we opt for an effective treatment with the saline solution at an optimal concentration of 1.5 mol/L.

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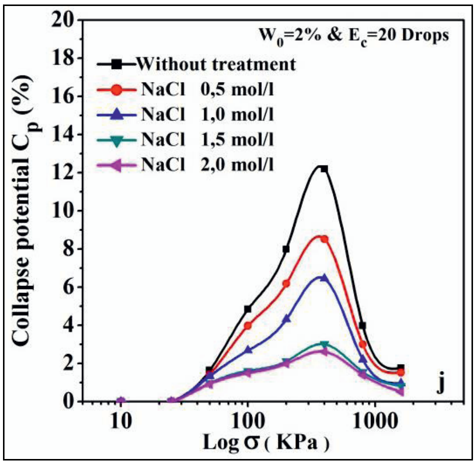

Figure 5. Variation of the collapse potential C_p with respect to vertical stress for treatment by salt NaCl (W_0=2% & E_c=20 drops).

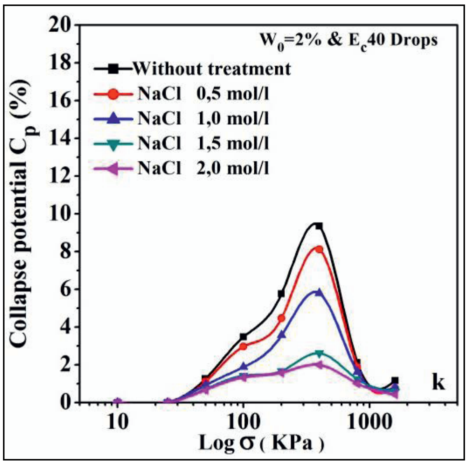

Figure 6. Variation of the collapse potential C_p with respect to vertical stress for treatment by salt NaCl (W_0=2% & E_c=40 drops).

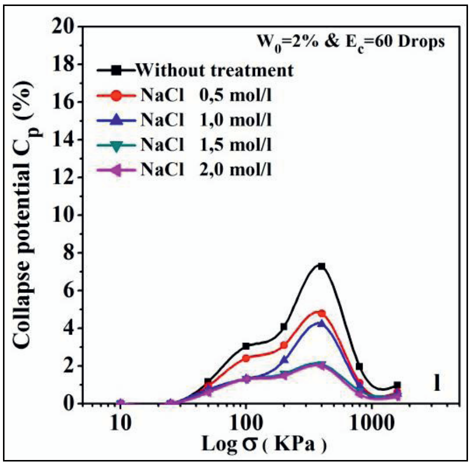

Figure 7. Variation of the collapse potential C_p with respect to vertical stress for treatment by salt NaCl (W_0=2% & E_c=60 drops).

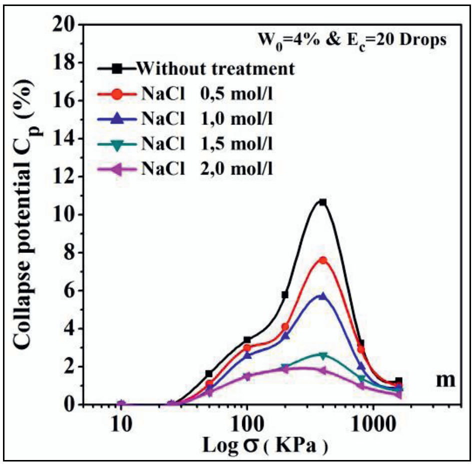

Figure 8. Variation of the collapse potential C_p with respect to vertical stress for treatment by salt NaCl (W_0=4% & E_c=20 drops).

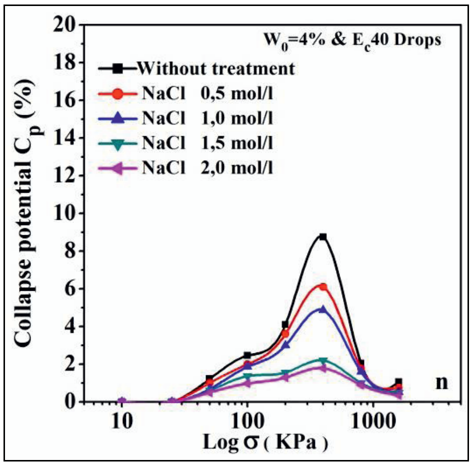

Figure 9. Variation of the collapse potential C_p with respect to vertical stress for treatment by salt NaCl (W_0=4% & E_c=40 drops).

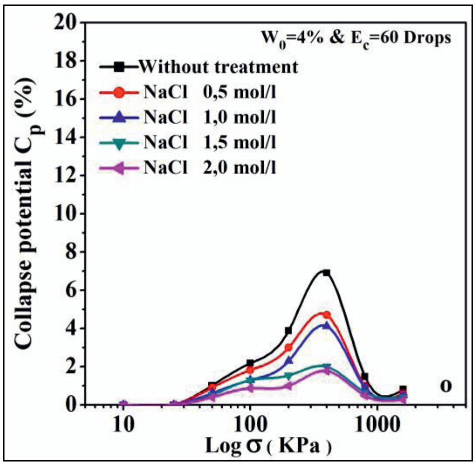

Figure 10. Variation of the collapse potential C_p with respect to vertical stress for treatment by salt NaCl (W_0=4% & E_c=60 drops).

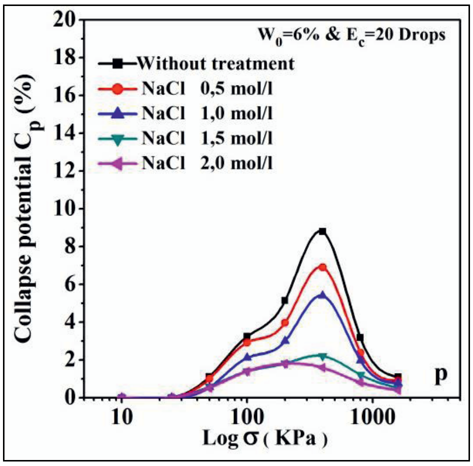

Figure 11. Variation of the collapse potential C_p with respect to vertical stress for treatment by salt NaCl (W_0=6% & E_c=20 drops).

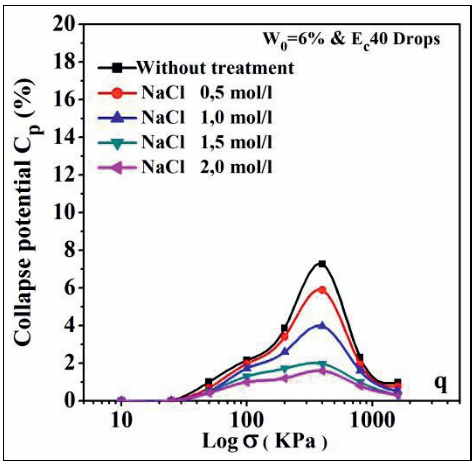

Figure 12. Variation of the collapse potential C_p with respect to vertical stress for treatment by salt NaCl (W_0=6% & E_c=40 drops).

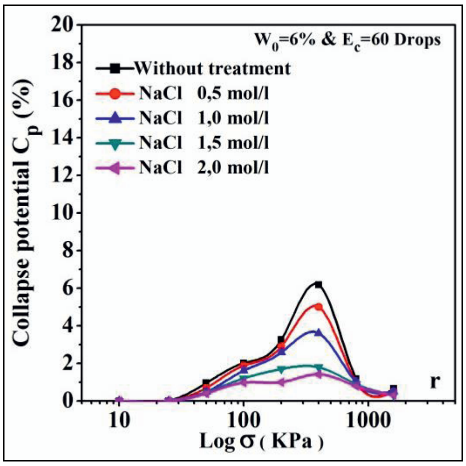

Figure 13. Variation of the collapse potential C_p with respect to vertical stress for treatment by salt NaCl (W_0=6% & E_c=60 drops).

4 Conclusions

The main observations of this study are:
The collapse potential is reduced with increase of initial water content and increase of energy of compaction;
The treatment by salt (NaCl) reduced the collapse potential and subsequently the damage associated with it to structures;
The increase in salt concentration beyond certain value (1.5 mol/L) has no significant benefit.
Thus, the physical and mechanical behavior of the reconstituted collapsible soil is related, to one hand, to the energy of compaction (Ec), the initial moisture content (w_0), vertical stress (σ).

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