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Impact of Calcium Chloride on the Microstructure of a Collapsible Soil

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ABSTRACT

The study of the collapse of soils under the effect of flooding is a major problem in soil mechanics. Most of the work done on the treatment of these soils has been devoted to the use of binders of hydraulic or organic types. However, little work has been devoted to the use of salt calcium chloride in collapsible soil treatments. The purpose of this study is to evaluate the effect salt calcium chloride on a reconstituted collapsible soil in the laboratory, at different levels of water content, compaction energy and concentration of the saline solution. The results obtained showed a significant reduction in the potential for soil deformation and an illustration and a noticeable interaction between the soil particles and the saline solution resulting in a denser material.

1. INTRODUCTION

Most of the naturally collapsible soils are relatively dry soils located in arid and semi-arid areas. The phenomenon of collapse of soils due to wetting connotes a sudden reduction of the mechanical properties, which usually results in large and irreversible deformations due to a brutal rearrangement of the particles. Barden et al. [1] found that the three main conditions at the origin of the collapse phenomenon are the following:

- An open, potentially unstable, and partially saturated structure;
- An existing or additional constraint that is sufficiently large;
- Binding elements sufficiently resistant to stabilize the inter-granular structure and relatively weak contacts that disappear during the wetting process.

A wide range of solutions and improvements techniques can stabilize collapsible soils, such as heat treatment [2], Mechanical methods: static with water supply [3], Dynamic methods: vibro-compaction and dynamic consolidation [4], Chemical methods: silica injections [5], Mixed methods: soil-mixing and pre-wetting [6]. The stabilization of collapsible soils has been studied by a large number of researchers [7-14]. The purpose of this study is to characterize the material used for testing, and followed by a physico-chemical analysis supplemented by an analysis of the microstructure using the scanning electron microscope (SEM), and finally the study of the behavior of the reconstituted soil, mainly using odometer while varying the initial water content (W_0), compaction energy (E_c), and concentrations of calcium chloride $CaCl_2$.

2. MATERIALS AND METHODS

2.1 Materials

Reconstituted samples consisting of 80% of sand and 20% of kaolin were prepared for this study. The ratio sand to kaolin was targeted in order to meet the collapse criterion [15-17]. The composite sample was classified as silty sand (SM) according to ASTM [18].

According to the studies [19-21], a soil is considered to be collapsible if one or more of the following conditions are met:

- Activity of soil (Ac) less than 1;
- Liquid index (I_l) less than 0;
- Plasticity index (P_I) less than 20;
- Consistence index (Ic) greater than 1;
- Manageability index (Iw) less than 1.

As shown in Table 1, at least three of the five aforementioned criteria are met, thus, it is likely that the reconstituted sample to be collapsible and confirming the results of the study [10].

The geotechnical characteristics of the reconstituted soil S_0 in Table 2.

Table 1. Characteristics of consistency of the S_0

W_0	A_c	P_I	I_l	I_c	I_w
2	2.60	12.00	-1.17	2.17	0.16
4	2.60	12.00	-0.67	2.00	0.33
6	2.60	12.00	-0.83	1.83	1.50

Table 2. Basic geotechnical characteristics of materials

Characteristics of materials	
Sand	
Coefficient of uniformity	Cu=3.91
Coefficient of curvature	Cc=0.95
Sand equivalent	Es=87%
Specific density	Gs=2.66
Kaolin	
Liquidity limit	Wl=67%
Limit of plasticity	Wp=39%
Specific density	Gs=2.40
Liquidity limit	Wl=67%
Soil (S_0) sand 80% + kaolin 20%	
Coefficient of uniformity	Cu=5.13
Coefficient of curvature	Cc=1.07
Liquidity limit	Wl=28%
Limit of plasticity	Wp=16%
Specific density	Gs=2.65
Dry density	γd=1.93
Optimum water content	Wopt=10%

2.2 Methods

The experimental equipment is composed of a 152-g compacting disc which drops 15 cm (Figure 1) on a soil sample within the oedometer ring resulting in a compaction energy expressed by the following:

$$E_C = \frac{n.m.g.h}{v} \quad (1)$$

where, E_c 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.

In order to study the effect of the saline solution on the collapse potential, the reconstituted sample with specific water contents and dry densities is compacted in one layer because of the low thickness of the ring. At low initial water content (w_0=2, 4 and 6%), the reconstituted soil exhibits relatively good mechanical characteristics.

However, if the moisture content of the soil sample is altered by introduction of water, the structure of the soil particles collapses and significant deformations occur, even without additional load.

The collapse potential of a soil sample is estimated by the procedure proposed by Jennings and Knight [22]. That potential is evaluated by loading two similar soil samples with the same natural moisture content and initial void ratio in an oedometer device. One sample is then flooded until saturation. The test on the flooded sample provides the void ratios (e_1 and e_2) before and after flooding at a specific loading.

The collapse potential, C_p is the vertical strain (abrupt settlement) and can be estimated by the following:

$$C_P(\%) = \frac{\Delta H}{H_0}100 = \frac{\Delta e_c}{1+e_0}100 \quad (2)$$

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.

The samples with different degrees of compaction were tested using an oedometer and saturating them with a solution at different salt concentrations. The different degrees of compaction were achieved by using different initial water contents (w_0=2, 4 and 6%), and compaction energies (20, 40 and 60 drops).

Figure 1. Oedometric mold and compacting

3. RESULTS AND DISCUSSION

3.1 Compressibility test

In order to study the effect of salt on the studied soil and the subsidence properties, the samples were saturated in oedometric cells by pure water and by saline solutions at different concentrations of calcium chloride $CaCl_2$. For this purpose, two potential C_p collapses before and after treatment will be determined by formula 2.

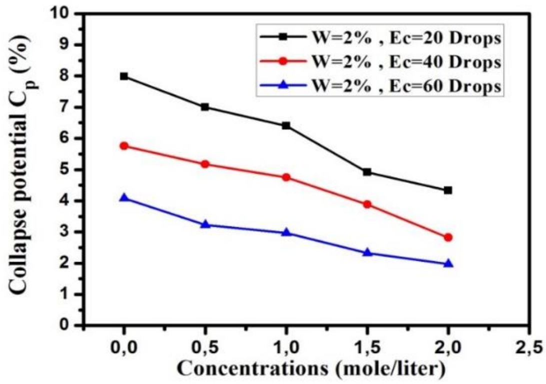


Figure 2. Variation of the collapse potential C_p as a function of the concentration for W_0=2%

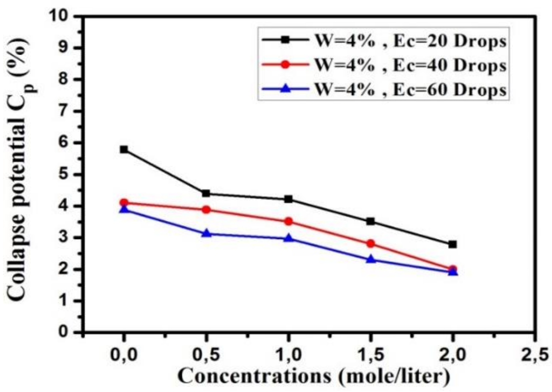


Figure 3. Variation in collapse potential C_p as function of the concentration for W_0=4%

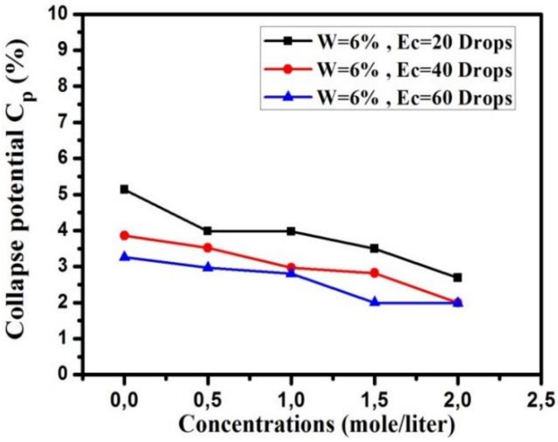


Figure 4. Variation of the collapse potential C_p as a function of the concentration for W_0=6%

According to the results obtained and presented in Figures 2-4, it appears that the collapses of the sample without treatment fit into the classification of Jennings and Knight (1975). Indeed, for a vertical stress of 400 KPa as well as the different compaction energies E_c and the initial water contents W_0, the collapse potentials C_p vary from 7.98 to 4.08% for an initial water content w_0=2%, from 5.78 to 3.88% for an initial water content w_0=4%, and from 5.14 to 3.26% for an initial water content w_0=6%. The results values correspond to no risk to severe disorders to structures [22].

It is found that the collapse potential C_p decreases when the water content or the compaction energy increase. Significant reductions in the collapse potential are observed for soil treated with the saline solution of calcium chloride $CaCl_2$ at different ionic concentrations. It should be emphasized that if we consider the C_p calculated under a vertical stress of 400 KPa, for low concentrations 0.5 mol/liter, the rate of reduction of C_p ranges from 4 to 15%.

On the other hand, for high concentrations, 2 mol/litre, the rate of reduction of C_p varies from 40 to 50% for $CaCl_2$.

3.2 Leaching test

To highlight the persistence of the effects of experimental salt, a column leaching test has been introduced. Leaching with water from the saline material with $CaCl_2$ was carried out for 7 days (Figure 5), and pH measurements were performed at the end of the test and are shown in Figure 6.

It emerges from this test of a leaching column of soil salinized by $CaCl_2$ that the pH measurements before and after leaching of this soil, show a slight drop in this indicator. This can be explained by the fact that in materials with fine content (clay), the permeability is relatively low, thus the leaching is slowed down allowing the persistence of the favorable effects of this salt.

After leaching, it can be seen that the salt is still present in the material and is observed after drying (Figure 7a). SEM observation of the sample treated with $CaCl_2$ reveals a fibrous deposit of salts forming an intimately intertwined network. Also, the salt crystals on the particles are highlighted by a white color and well embedded in the material (Figure 7b).

Therefore, the effect of $CaCl_2$ is longer lasting. The structure is more stable in the presence of salt, the C_P decreases compared to the control sample without salt, regardless of the initial water content and the degree of compaction, and this is due to the salt concentration of the interstitial solution.

Figure 5. Column leaching test

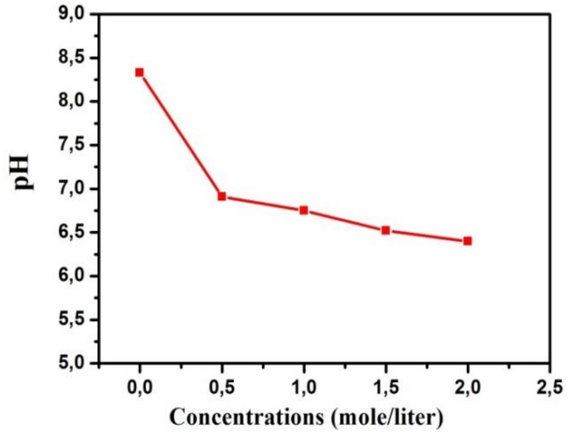
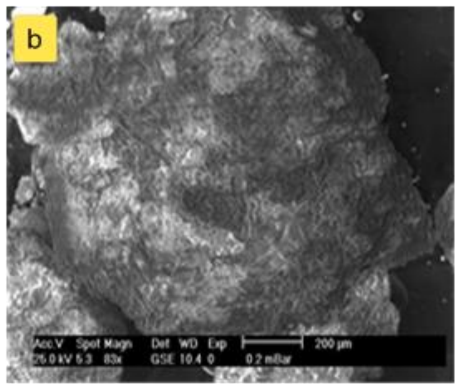


Figure 6. pH results of saline materials before and after leaching

(a) State of the sample after drying

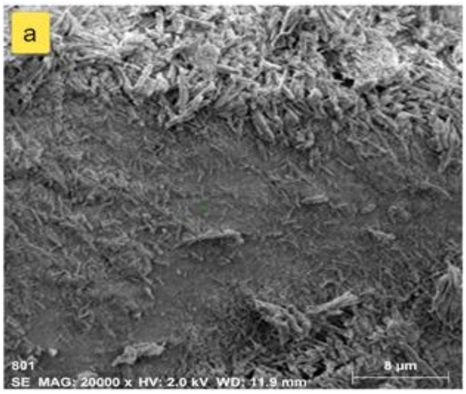


(b) Observation at SEM after leaching

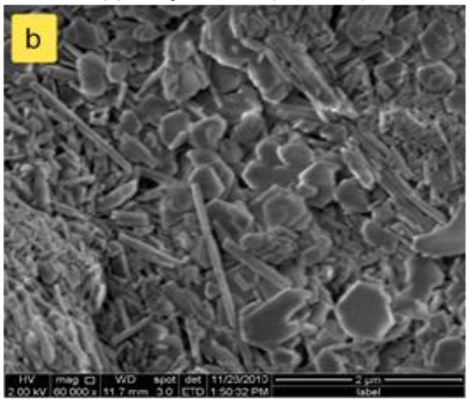
Figure 7. Observation at SEM after leaching

3.3 Scanning electron microscope (S.E.M)

For untreated soil, the microstructure in Figure 8a shows that large quartz grains are regularly distributed in the clay matrix and in general could not be observed because they were coated with clay particles. The shape of the grains is more rounded and their size is nanometric.

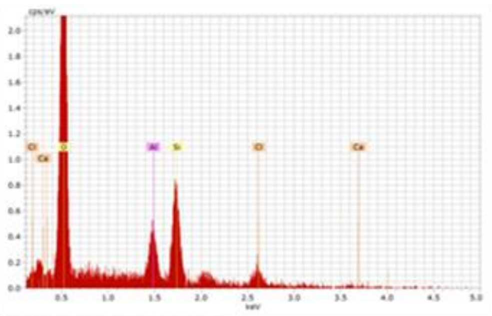


(a) Clay matrix (20000X)



(b) Fibrous structure (60000X)

Figure 8. SEM observation of untreated reconstituted soil



Spectrum: Acquisition 708

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 9. EDAX analysis of untreated soil

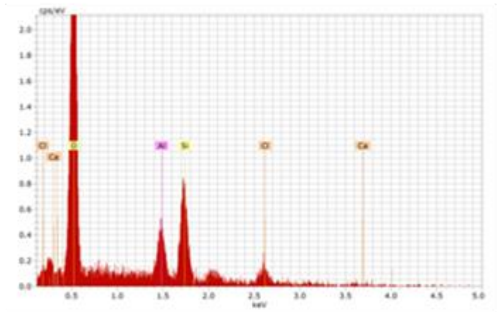
Figure 8b shows the microstructure of a untreated soil sample. The presence of kaolin flakes and a random stack of quartz crystals in the structure are observed, and a loose contact between the soil elements due to their dispersal by flooding with water is also noticed, and reveals a general appearance of a reconstituted soil without treatment and shows a fibrous structure (0.02 µm to 1.5 µm) with random orientation forming an adherent layer covering quartz crystals.

This microstructure is very loose made up of individual clay clusters and crystallite different from that of the sample in Figure 8 and the clay particles of this sample are somewhat more separate and the pore-aggregates Increase.

In the X-rays analysis (Figure 9), the untreated soil sample showed an Si concentration relative to Al, which can be related to the presence of quartz and kaolin. Also, a compact matrix and a millimeter cluster of the material elements were observed [23, 24].

3.4 Effect of calcium chloride on the microstructure

In the X-rays analysis (Figure 10), the treated soil sample showed there is a greater concentration of Si relative to Al, to be attributed to the presence of quartz. Calcium chloride is highlighted by the detection of Ca^{++} and Cl^{-}. In addition, the favorable effect of salt on the restructuring of the material is noted.



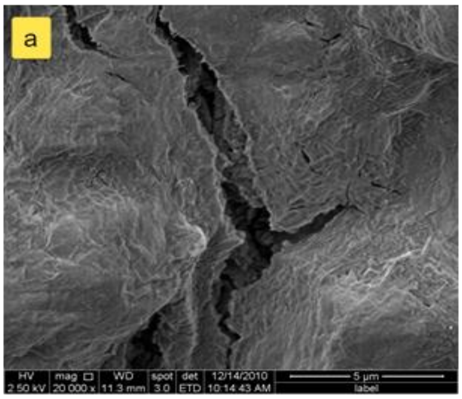
Spectrum: Acquisition 776

El	AN	Series	unn. C [wt.%]	norm. C [wt.%]	Atom. C [at.%]	Error [%]
O	8	K-series	74.56	58.27	74.01	11.0
Al	13	K-series	5.17	4.04	3.04	0.4
Si	14	K-series	20.24	15.82	11.45	1.2
Cl	17	K-series	7.94	6.20	3.56	0.7
Ca	20	L-series	20.04	15.66	7.94	6.0
		Total:	127.95	100.00	100.00	

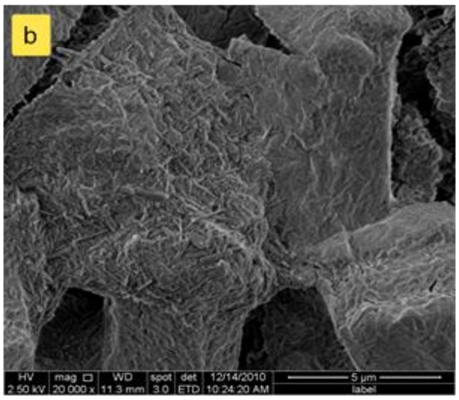
Figure 10. EDAX analysis of $CaCl_2$ treated soil with a dense structure

It is noted that the salt $CaCl_2$ precipitates in a slightly crystallized form and exhibits a rather amorphous microstructure. This amorphization would be attributed to the hygroscopicity of salt, but a close contact between the clays and the salt crystals is noted.

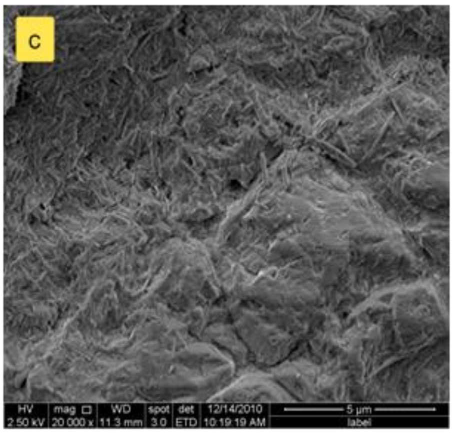
Clay occurs in a rather fibrous form on the surface of the crystals of calcium chloride $CaCl_2$. There is a strong cracking (Figure 11a), reflecting a reorganization of the material due to the flocculant effect of the salt by giving a compact and dense structure (Figure 11b, c).



(a) Apparent cracking (20000X)



(b) Amorphous microstructure



(c) Dense structure

Figure 11. SEM observation of treated soil by $CaCl_2$

4. CONCLUSIONS

After studying the effect of the variations in water content, compaction energies and concentrations of the saline solution of calcium chloride on the collapse potential of a reconstituted soil, the following conclusions can be drawn: the results obtained clearly show that mineral salt has a very strong effect on reducing soil collapse.

Salt, especially saline concentration and cation, plays a major role in the mechanical behavior of clay materials through the effects on the diffuse double layer, their relations with the electrostatically-oriented clay materials have an effect important on the collapse of the soil.

However, in the natural environment, these materials generally undergo a process of salt leaching. For our study case, the effect of chloride ($CaCl_2$) is more durable.

The SEM observation of the treated samples also shows the presence of all the elements of the microstructure of the soil varies according to the treatment.

It is realized that there is a significant interaction between the clay particles and the interstitial solution, and that the microstructure of the untreated soils and treated soils with the saline solution are relatively different.

This salt treatment was favorable on the structure by causing a rearrangement of the particles which results in the genesis of a homogeneous and colloidal material with formation of a stable structure with very low porosity because the effect of the cation Ca^{++} also known as a flocculant of colloids and therefore, it promotes the formation of large particles with a porosity fracture characteristic of materials to structural.

REFERENCES

[1] Barden, L., McGown, A., Collins, K. (1973). The collapse mechanism in partly saturated soil. Engineering Geology, 7(1): 49-60. https://doi.org/10.1016/0013-7952(73)90006-9

[2] Bell, F.G., Bruyn, I.D. (1997). Sensitive, expansive, dispersive and collapsive soils. Bulletin of the International Association of Engineering Geology, (56): 19-38.

[3] Holtz, W.G., Hilf, J.W. (1961). Settlement of soil foundations due to saturation. Proceeding of the 5th International Conference on Soil Mechanics and Foundation Engineering, pp. 673-679. https://www.issmge.org/publications/publication/settlement-of-soil-foundations-due-to-saturation.

[4] Lutenegger, A.J., Saber, R.T. (1988). Determination of collapse potential of soils. Geotechnical Testing Journal, 11(3): 173-178.

[5] Semkin, V.V., Ermoshin, V.M., Okishev, N.D. (1986). Chemical stabilization of loess soils in Uzbekistan to prevent building deformations. Soil Mechanics and Foundation Engineering, 23(5): 196-199. https://doi.org/10.1007/BF01711889

[6] Houston, S.L., Houston, W.N. (1997). Collapsible soils engineering. Unsaturated Soil Engineering Practice, Geotechnical Special Publication, ASCE proceedings of the 1997 1st Geo Institute Conference, Logan UT, USA, Part 68, pp. 199-232.

[7] Clemence, S.P., Finbarr, A.O. (1981). Design considerations for collapsible soils. Journal of the Geotechnical Engineering Division, 107(3): 305-317. https://doi.org/10.1061/AJGEB6.0001102

[8] Pengelly, A.D., Boehm D.W., Rector, E., Welsh, J.P. (1997). Engineering experience with in-situ modification of collapsible and expansive soils. Unsaturated Soil Engineering Practice, ASCE Geotechnical Special Publication, Proceedings of the 1997 First Geo Institute Conference, Logan, UT, USA, July 15-17, Part 68, pp. 277-298.

[9] Bahloul, O., Abbeche, K., Bahloul, A. (2016). Study of the microstructure of collapsible soil treated with the potassium chloride. Journal of Applied Engineering Science & Technology, 2(1): 39-42. http://revues.univbiskra.dz/index.php/jaest/article/vie

[10] Abbeche, K., Bahloul, O., Ayadat, T., Bahloul, A. (2010). Treatment of collapsible soils by salts using the double

consolidation method. In Experimental and Applied Modeling of Unsaturated Soils, pp. 69-78. https://doi.org/10.1061/41103(376)10

[11] Abbeche, K., Bahloul, O., Bahloul, A. (2016). Study of the influence of the saline solution NaCl on the potential collapse of soil. In E3S Web of Conferences, p. 07001. https://doi.org/10.1051/e3sconf/20160907001

[12] Mohamed, A.M., El Gamal, M. (2012). Treatment of collapsible soils using sulfur cement. International Journal of Geotechnical Engineering, 6(1): 65-77. https://doi.org/10.3328/IJGE.2012.06.01.65-77

[13] Karol, R.H. (2003). Chemical grouting and soil stabilization. Third edition, Revised and expanded.

[14] Nouaouria, M.S., Guenfoud, M., Lafifi, B. (2008). Engineering properties of lœss in Algeria. Engineering Geology, pp. 85-90.

[15] Ayadat, T., Belouahri, B., Ammar, R.A. (1998). La migration des particules fines comme approche d’explication du mécanisme de l’effondrement des sols. Revue française de Géotechnique, (83): 73-81. https://doi.org/10.1051/geotech/1998083073

[16] Bahloul, O., Abbeche, K., Bahloul, A. (2016). Study of the microstructure of a collapsible soil flooded with NaCl saline. In E3S Web of Conferences, p. 14001. https://doi.org/10.1051/e3sconf/20160914001

[17] Lahmadi, A., Abbeche, K., Zeghichi, L., Bakir, N. (2012). Prediction of collapsible soils by proctor tests. In CD-ROM of the 10th International Congress on Advances in Civil Engineering, Ankara, Turkey.

[18] ASTM D 5333-03. (2003). Standard test method for measurement of collapse potential of soils. https://doi.org/10.1520/D5333-03

[19] Abbeche, K. (2005). Etude de l'influence de la densité relative et l'indice de consistance sur le taux et l'amplitude de l'affaissement des sols (Doctoral dissertation, Batna, Université El Hadj Lakhder. Faculté des sciences de l'ingénieur).

[20] Ayadat, T., Hanna, A. (2007). Identification of collapsible soil using the fall cone apparatus. Geotechnical Testing Journal, 30(4): 312-323.

[21] Ayadat, T., Ouali, S. (1999). Identification des sols affaissables basée sur les limites d’Atterberg. Revue Française de Géotechnique, (86): 53-56.

[22] Jennings, J.E., Knight, K. (1975). A guide to construction on or with materials exhibiting additional settlement due to collapse of grain structure. Proc., Regional Conf. for Africa on Soil Mechanics and Foundation Engineering, Vol. 1, Balkerma, Rotterdam, The Netherlands, pp. 99-105.

[23] Pésci, M. (1990). Lœss is not just the accumulation of dust. Quaternary International, pp. 1-21.

[24] Ziani, H., Abbèche, K., Messaoudene, I., Andrade Pais, L.J. (2019). Treatment of collapsible soils by additions of granulated slag and natural pozzolan. KSCE Journal of Civil Engineering, 23(3): 1028-1042. https://doi.org/10.1007/s12205-019-0051-0