Effect of salts on the determination of the water content and Atterberg limits of El-Hodna sabkha soil

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ABSTRACT
In this paper, the effect of salts on the determination of the water content and Atterberg limits of sabkha soils has been studied. The tests were performed using distilled water, natural sabkha brine and saline solutions with different salt concentrations. The results indicate that the liquid and plastic limits decrease with pore fluid salinity when the conventional water content procedure is used, but increase when the fluid content method is used. Also, the liquid and plastic limits measured using percussion-cup test and rolling test method are compared to those measured using the fall cone test method.

RÉSUMÉ
Dans cet article, nous étudions l'effet des sels sur la détermination de la teneur en eau et des limites d'Atterberg des sols d'une sabkha. Les essais sont effectués en utilisant de l'eau distillée, de la saumure d'une sabkha et des saumures préparées au laboratoire avec différentes concentrations en sel. Les résultats montrent que les limites de liquidité et de plasticité diminuent avec l'augmentation de la salinité du liquide lorsque la méthode conventionnelle de mesure de la teneur en eau est utilisée et augmentent lorsque la méthode de teneur en fluide est utilisée. Aussi, les limites de liquidité et de plasticité mesurée à l'aide de l'appareil de Casagrande et la méthode du rouleau sont comparées avec ceux mesurées en utilisant le pénétromètre à cône.

1 INTRODUCTION

Sabkha is an arabic word for salt flat, applied to both coastal and inland saline depressions in North Africa and the Middle East. Warren (1989) describes sabkhas as marine and continental mudflats where displacive and replacive evaporate minerals are forming in the capillary zone above the saline water table. The continental sabkhas correspond to playas as commonly defined in southwestern USA (Peter, 2000). Sabkha soils are recent saline sediments widely distributed in Algeria and other countries. As they are characterized by low strength and high compressibility, they are considered to be difficult foundation soils that pose special problems for design and construction engineering.

Atterberg limits are important indicators of engineering behaviour, and together with natural moisture content they are most important items in the description of fine–grained soils (Holtz and Kovacs, 1981). Several studies have been reported dealing with the effect of salt solutions on the consistency limits of fine–grained soils. Alamdar (1999), Yukselen-Aksoy et al. (2008), Mansour et al. (2008) Shariatmadari et al. (2011) and Ajalloeian et al. (2013) reported that the liquid and plastic limits of soils decrease as the salinity of pore fluid increases. In these studies the determination of Atterberg limits was based on the conventional water content definition that does not take into consideration the presence of salts in the soil. Therefore, the classification of the soil will not reflect its real engineering behaviour under field conditions.

Noorany, (1984), studied the phase relations of marine soils and developed a relationship for the seawater content (denoted fluid content) as an alternative to the standard method of the water content determination.

In this study, the effect of pore fluid salinity on the determination of the water content and consistency limits of Chott El-Hodna sabkha soil is investigated.

2 THE STUDY AREA AND BASIC CARACTERISTICS

The inland sabkha of Chott El-Hodna is located in the middle north of Algeria at about 130km from the Mediterranean Sea (Figure 1). It covers an area of approximately 1100 km^2 and is relatively flat with an average altitude of about 392m.

The sabkha region is characterized by an arid climate with an average annual rainfall of 172mm, an average temperature of approximately 22^{o}C (-3°C to 40°C) and a rate of evapotranspiration of about 1,330 mm/year. Vegetation is totally absent. During dry periods, the ground water table is located less than 1.0 m below the ground surface, at other times the area becomes a large saline lake with a water depth of up to 75cm. Subsequent evaporation causes salts (mostly NaCl) to precipitate on the land surface (Figure 2).

Figure 1. Chott El Hodna area

Figure 2a. Sabkha area during dry periods

Figure 2b. Sabkha area during rainy periods

The material used in this study is marly clayey soil collected from a test pit dug in the sabkha area to a depth of 0.6m below the ground surface. The location of the borrow area is shown in Figure 1. Sabkha brine and salt samples were also collected from the same area. The sabkha brine contains approximately 26% (by weight of brine) dissolved salts. Its specific gravity was 1.22. The chemical analysis of sabkha brine is given in Table 1. The sabkha soil contains approximately 17% of carbonates and 12% of organic matter.

Table 1. Chemical analysis of sabkha brine

pH	K^+(g/L)	Ca^{2+}(g/L)	Mg^{2+}(g/L)	Na^+(g/L)	Cl^-(g/L)
7.2	19.05	25.92	15.55	94.59	208.49

Specific gravity and grain size distribution were determined on washed samples according to ASTM D854-05 and ASTM D422-63 respectively. The average specific gravity was found equal to 2.71 and the results of the grain size distribution show that the percent passing sieve No. 200 is 94% and the clay fraction is about 64% (Figure 3).

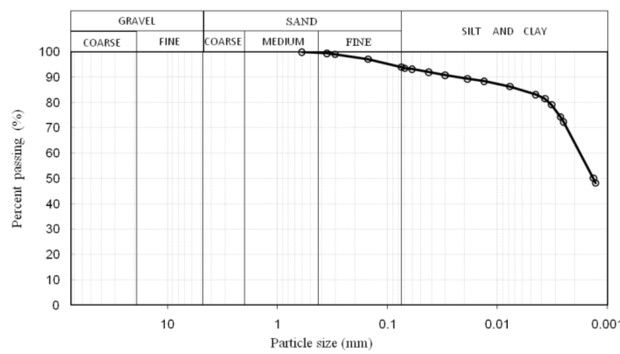

Figure 3. Grain size distribution for Chott El Hodna sabkha soil

Washed sabkha soil samples were obtained by placing the soil sample in a container and mixing it with distilled water. The slurry was left to settle for more than 48h, thereafter, the supernatant saline solution was repeatedly replaced with distilled water and the soil sample was again mixed to form a suspension. Each time, the salinity of the supernatant solution was checked using a salinity-meter until the measured salinity became negligible (0.07%).

3 WATER CONTENT DETERMINATION

The conventional procedure for determination of soil water content is problematic for saline soils because the precipitated salts are included as part of the solid components of the soil and their part in the fluid weight is ignored. Therefore, it seems more logical to express the water content of saline soils for engineering purposes as the fluid content which is the ratio between the brine weight and dry weight of soil solids, as suggested by

Noorany (1984) for marine soils. The water and fluid contents can be defined as follow:

1. Conventional water content:

$$\omega_c = \frac{W - W_d}{W_d} \quad [1]$$

2. Fluid content (Noorany, 1984):

$$\omega_f = \frac{W_b}{W_s} = \frac{W - W_d}{W_d - rW} = \frac{\omega_c}{1 - r - r\omega_c} \quad [2]$$

With $r = \frac{W_{sa}}{W_b}$ = salinity [3]

$$W_s = W - W_b = \frac{W_d - rW}{1 - r} \quad [4]$$

W_{sa} is the weight of salt, W_b the weight of brine, W the wet weight of soil (including salt), W_d the dry weight of soil (including salt), $W_w = W - W_d$ the weight of distilled (fresh) water, and W_s the weight of soil solids (excluding salt).

It should be noted that a salt crust formed on the surface of the sabkha soil samples was noticed during the drying process, inhibiting the release of moisture, especially for samples composed of larger clods (Figure 4). Therefore, a new procedure for oven drying saline soils was proposed to overcome the above mentioned issues and to dry this type of soils within reasonable time. This procedure consists in placing the moist soil sample in a container having a large surface area after cutting it into small clods (less than 20 mm size) in order to reduce the oven drying time after which the sample becomes ready to be pulverized. Then, the sample is placed in the drying oven at a temperature of 60°C. When the sample attains a brittle state, we remove it from the oven and measure its mass. Thereafter, we proceed to the pulverization of the sample with a plastic hammer to break-down clods to particles less than 2mm size in order to facilitate the release of all moisture. The pulverized sample is then spread on the container surface area, weighed and returned to the oven until a constant weight is achieved. It should be noted that any loss of soil during pulverization process will be taken into account in the calculation of the water content and/or fluid content.

After the sample has dried to constant weight, we remove it from the oven, weigh it and measure its salinity using a salinity-meter. The water content and/or fluid content of the sample can then be calculated using the above relationships. Generally, for soil samples composed of clods less than 20mm of size, the drying time after which the sample becomes ready to be pulverized is less than 48h and the equilibrium condition can be reached within 48h after pulverization.

Figure 4a. Sabkha soil sample with 50 mm size before drying

Figure 4b. Sabkha soil sample with 50 mm size after 24 hours of drying

Figure 4c. Sabkha soil sample with 50 mm size after 4 days of drying

The Liquid limit tests were performed on materials passing 425µm sieve using percussion-cup test and fall cone test in accordance with British standard BS 1377 (1990) respectively.

For the fall cone test, the cone weighs 80 g with an angle of 30°. The liquid limit is defined as the water content corresponding to a penetration depth of 20mm whereas, for the plastic limit the penetration depth is assumed to be in the ratio of 10 in comparison to the penetration depth at the liquid limit (Wood and Wroth, 1978). The plastic limit is also determined using the thread rolling test method.

The tests were performed on natural sample using distilled water (a), natural sample using sabkha brine (b), washed sample using distilled water (c), washed sample using sabkha brine (d) and washed samples using saline water at different salinities (5, 10, 15, 20 and 25%) (e). Saline water was obtained by mixing distilled water with natural salt collected from sabkha area during the dry period.

As indicated in Figure 5, there is an agreement between the percussion-cup test method and fall cone test method in defining the liquid limits. This is consistent with the findings of Leflaive (1972), who reported that for soils having liquid limits between 60% and 100%, there is an agreement between the percussion-cup method and fall cone test method using a penetration depth of 20 mm, whereas for soils having liquid limits less than 40%, a penetration depth of 16 mm was more adequate to obtain equivalent liquid limit values as determined by the percussion-cup method.

For plastic limits, the fall cone method predicts systematically higher values in comparison to the thread rolling test method (Figure 6).

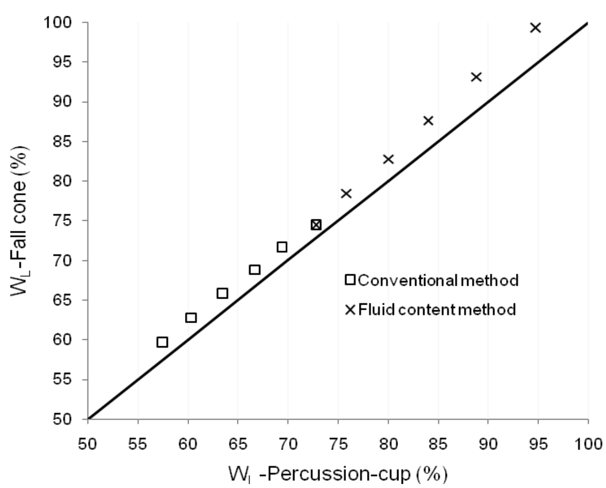

Figure 5. Liquid limits defined by percussion-cup test and fall cone test

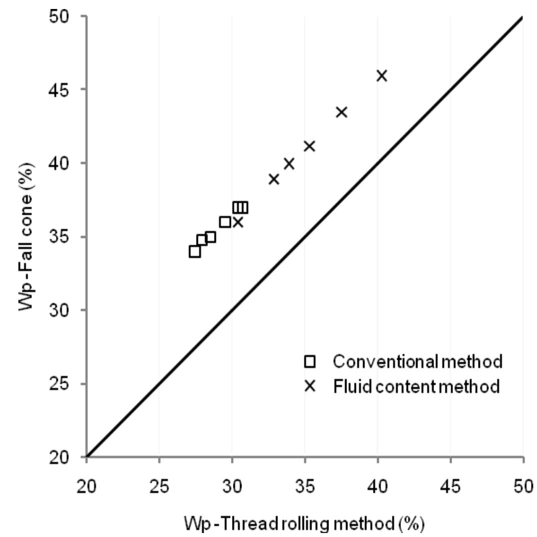

Figure 6. Plastic limits defined by thread rolling method and fall cone method

The results shown in Figure 7 and 8 indicate that the liquid and plastic limits decrease as the pore fluid salinity increases when conventional water content procedure is used, which accords with the results reported by Alamdar (1999), Shariatmadari et al. (2011) and Mansour et al. (2008). However, when fluid content method is used, the liquid and plastic limits increase as the pore fluid salinity increases. These results are in good agreement with those reported by Frydman et al. (2008) who used the fluid content method for calculations. In addition, the difference between the conventional method and the fluid content method in defining the liquid and plastic limits increases as the pore water salinity increases.

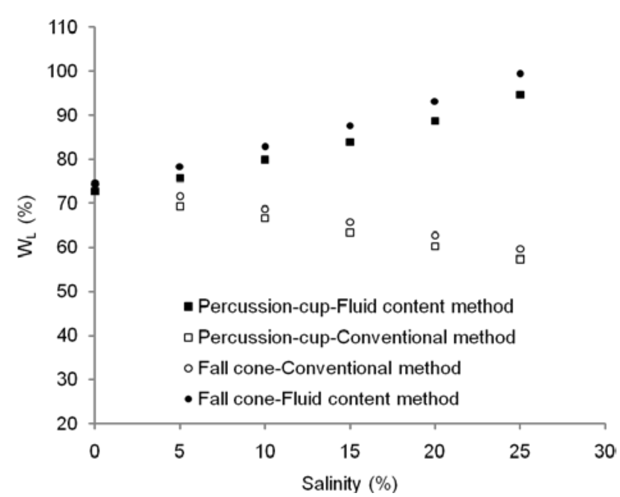

Figure 7. Effect of pore fluid salinity on liquid limits

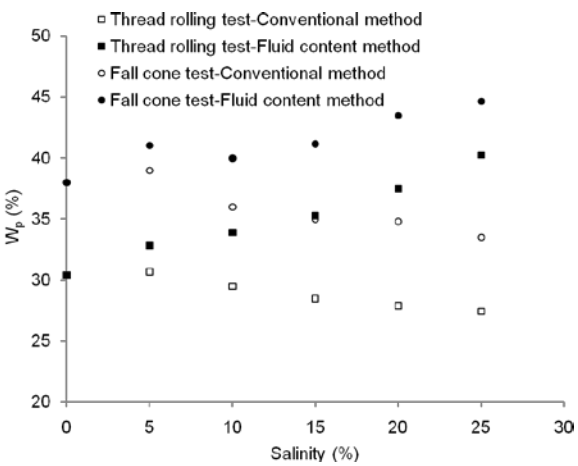

Figure 8. Effect of pore fluid salinity on plastic limits

The liquid limits obtained with both methods have good correlation with the plasticity index (Figure 9). According to British Soil Classification System (BS 5930: 1999), the samples would be classified as CH when the consistency limits were defined on the basis of conventional method, and CV and CE (for pore water salinity more than 20%) when the consistency limits were defined on the basis of fluid content method. The washed soil showed intermediate behavior and was classified as CV.

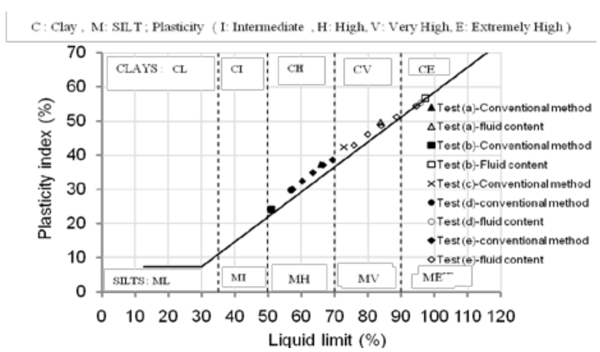

Figure 9. Effect of methodology of moisture measurement on plasticity of Chott El Hodna sabkha soil

5 DISCUSSION AND CONCLUSION

The conventional procedure currently used to determine the water content of soils is not applicable for saline soils in which the precipitated salts are included as part of the solid weight and their contribution to the fluid weight is ignored. Therefore, it is argued that for saline soils, the fluid content is the physically relevant measure than water content, as suggested by Noorany (1984). The proposed procedure for oven drying saline soils significantly reduces the drying time, especially for soils with high pore water salinity.

The obtained results indicate that there is an agreement between the fall cone test and percussion-cup test in defining the liquid limits, whereas for plastic limits, the fall cone test predicts higher values in comparison to the thread rolling method. On the other hand, liquid limits are more affected by pore fluid salinity than plastic limits, which indicate that soils with high plasticity are more affected by pore fluid salinity than those with low plasticity.

It should be noted that the differences in plasticity of the studied soil are due to the difference between the water content and fluid content definitions, without any chemical effects on the behaviour of the clays due to salts in the pore fluid. These results should be confirmed by further studies on different types of clays to investigate the physico-chemical effects on Atterberg limits due to pore fluid salinity.

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