# Effect of Salts on the Determination of Atterberg Limits and Compaction Characteristics of Saline Soils

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**ABSTRACT:** In this paper, the effect of salts on the determination of Atterberg limits and compaction characteristics 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 indicated 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.
Moreover, the results indicated that the conventional water content procedure used to plot the compaction curve overestimate the maximum dry unit weight and underestimate the optimum moisture content.

**Keywords:** sabkha soil; Atterberg limits; compaction; fluid content; sabkha brine

## 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).

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.

Mansour et al. (2008) performed standard Proctor test on marly soil from dead sea area and reported that the optimum water content decrease and the maximum unit weight increase as the water salinity increase. Similar results were found by Alainachi and Alobaidy (2010) and Shariatmadari et al. (2011).

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.

The inland sabkha of Chott El-Hodna is located in the middle north of Algeria at about 130km from the Mediterranean Sea (Fig. 1). It covers an area of approximately 1100 km² 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°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.

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


**Figure 1.** Chott El Hodna area

## 2. Materials and Basic Characteristics

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.

Specific gravity and grain size distribution were determined on washed samples according to ASTM D854-05 (2005) and ASTM D422-63 (2007) 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% (Fig. 2).

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 |

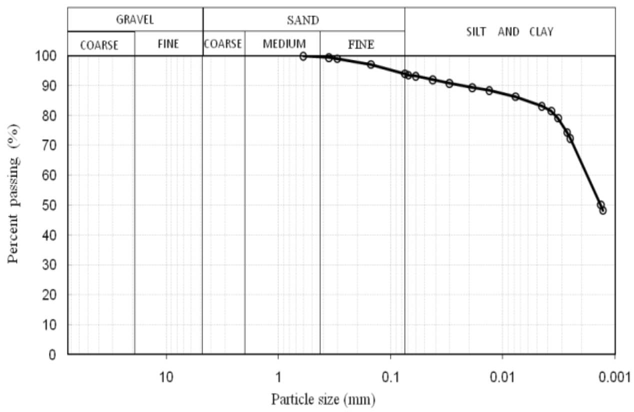


**Figure 2.** Grain size distribution

## 2.1 Moisture 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. 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 breakdown 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.

## 3. Liquid and Plastic Limits

The Liquid limit tests were performed on materials passing 425μm sieve in accordance with British standard 1377 (1990).

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.

The results shown in Figure 3 and 4 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), Mansour et al. (2008) and Shariatmadari at al. (2011). 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.

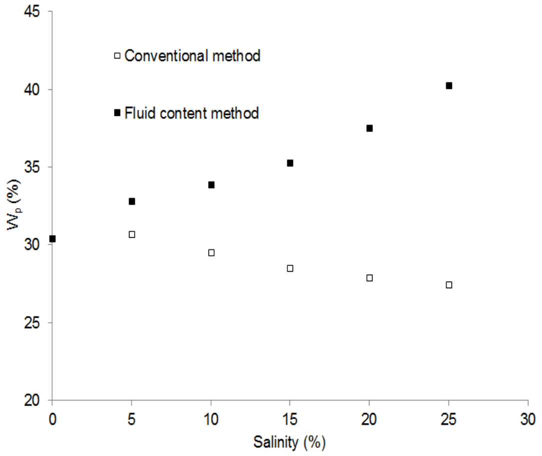


**Figure 3.** Effect of pore fluid salinity on liquid limits

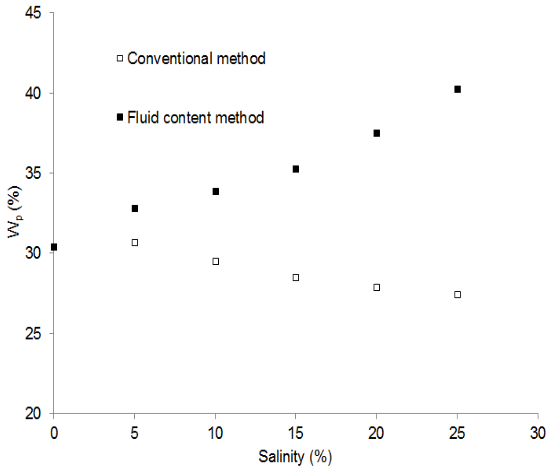


**Figure 4.** Effect of pore fluid salinity on plastic limits

## 4. Compaction

Standard Proctor tests were conducted on the Sabkha soil to evaluate the effect of water salinity on the compaction characteristics (i.e. optimum moisture content and maximum dry unit weight). The Standard Proctor tests were performed based on the procedure outlined in ASTM D698 on washed soil samples passing No. 4 sieve using distilled water and Sabkha brine.

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.

The compaction characteristics were determined using conventional water content and fluid content methods (Table 2 & Fig. 5).

Table 2. Compaction test results

| Type of fluid | Conventional water content procedure | | Fluid content method | |
|---|---|---|---|---|
| | $\gamma_{d\text{-}max}$ (kN/m$^3$) | $w_{opt}$ (%) | $\gamma_{d\text{-}max}$ (kN/m$^3$) | $w_{opt}$ (%) |
| Distilled water | 13.7 | 33.0 | - | - |
| Sabkha brine | 14.5 | 27.0 | 13.3 | 38.0 |

The results show that the maximum dry unit weight (MDUW) obtained from fluid content procedure is lower than that obtained from conventional water content procedure. However, the optimum moisture content (OMC) obtained from fluid content procedure is higher than that obtained from conventional water content procedure.

When the conventional water content procedure is used to plot the compaction curve, the results show that the compaction test using Sabkha brine led to the increase of the MDUW by about 6% and the decrease of the optimum moisture content by about 18% compared to compaction test using distilled water. These results accord well with those reported by Mansour et al. (2008).

However, when the fluid content method is used to plot the compaction curve, the MDUW decreased by about 8% and the optimum moisture content increased by about 41% compared to the results obtained by the conventional water content procedure. Moreover, the compaction curves obtained using fluid content method become flatter and therefore less sensitive to moisture content.

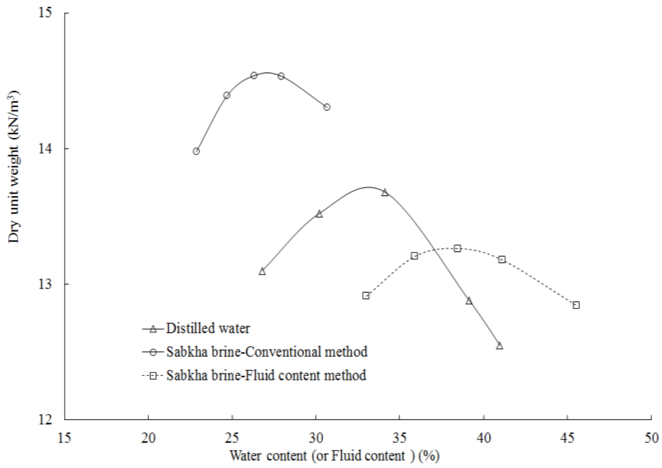


**Figure 5.** Compaction test curves

## 5. Conclusions

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.

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.

The results of compaction tests indicate the significant effect of the water salinity on the compaction characteristics of saline soils. The use of conventional water content procedure to plot the compaction curve of saline soils overestimate the maximum dry unit weight by about 9% and underestimate the optimum moisture content by about 29%.

Moreover, the results indicate that the maximum dry unit weight is less affected by the type of fluid and method used to determine the compaction curve compared to the optimum moisture content.

Therefore, for the case of saline soils, it seems more logical to use the fluid content method to determine the compaction characteristics than the conventional water content procedure.

The results presented here should be confirmed by further studies on different types of saline soils.

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