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An Assessment of Soil Collapsibility Due Dissolution of Salts

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AN ASSESSMENT OF SOIL COLLAPSIBILITY DUE DISSOLUTION OF SALTS

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ABSTRACT

Since the building of first dike in the Dead Sea (DS) 60 years ago, the DS harsh environment sparks new geotechnical challenges. The DS level as well as the surrounding ground water table continued to drop severely. The DS level drops 35 m from 392 mbsl in late 1950s to around 423 mbsl in 2011. Recently, the rate of descending is 1.2 m/year and is on brink to increase. The dramatically dropping of the DS level pushes fresh water brackish water divide and generates numerous sink holes in the southern part of the east coast of the DS. The thing that costs more than $100 million investments lost. Moreover, the stability of foundations soil of many existing projects and in a construction stages were at risk. Therefore, a Soil samples of CL-ML were prepared to mimic the changes occur on the soil in vicinity of the east cost of the Dead Sea due to fresh water movement. The main goal of this modification was to examine the effect of salts dissolution on the collapse potential of the soil. A detailed findings will presented and analyzed.

INTRODUCTION

The Dead Sea basin, the lowest point on Earth, tectonically subsiding is located within the Dead Sea transform that separates the Arabian and Sinai plates. Nowadays, the Dead Sea is a terminal lake of magnesium, calcium, sodium and potassium chloride brine composition (Frydman et. al, 2008). The Dead Sea level historically has been fluctuated due to its high sensitivity to climatic change. In the last century the Dead Sea put under extremely arid conditions, and therefore, is getting most of its water from a moister region. Moreover, and due to the utilization of the fresh head water either from the Sea of Galilee or the Jordan River and its tributaries, the Dead Sea has receded and the Southern part of it becomes dry. Large mining industries, based on the harvesting of minerals from the Dead Sea, were developed on the Dead Sea shores. Such industries required constructing evaporated ponds and dikes. The construction of these ponds and dikes requires using the evaporated Dead Sea soil as a foundation soil or as construction materials. The evaporated soil mainly composes from lime carbonate soils and layers of salts.

Several subsidences and many sinkholes have been found in the cultivated area in the east basin. Some of the sinkholes are more than 20m in diameter and 10 to 15m meters in depth.

Many studies for different purposes have been conducted in the basin to determine the geological, geotechnical and geochemical aspects behind the sinkholes formation. Following the formation of sinkholes in the west Lisan Peninsula, Gibb Eengineers (1993) concluded that the primary cause of the sinkholes is collapse settlements due to fresh water entrance along former flood channels. Isa et al. (1995) carried out a study including geological, geotechnical, hydrogeological and geophysical investigations. The study concluded that the sinkholes are formed mainly by fresh water entrance. The lowering of the Dead Sea level affects the forming of cavities as it lowers the level of underground water zones, thus causing more solutions, and erosion as will as creating of subsurface cavities. On the other hand, Taqiddin et al., (2000) studied the geological and Geotechnical formation of sinkholes at east part of Dead Sea Shore. The study concluded that, the prime cause of sinkhole development is the lowering Dead Sea level and tectonic movements. Similar results were also attained by Abelson et al., (2003) where they added that the dissolution of salts layer occurs by the ground water as a result of lowering the water table as a result of lowering the Dead Sea water level.

Collapsibility of soils is defined as the large reduction in the volume of soil upon saturation or wetting. This change may or may not be the result of applying additional load. The most common occurrence of soil collapsibility is the earth subsidence and sinkholes. On the other hand, the soil at a construction site may not always be suitable for supporting structures such as buildings, bridges highways and dams. For example, if soil is placed in certain none desire density, a large settlement will occur either due to loading or to wetting of soil deposits. Moreover, if the soil is placed on the desired density, and the bridge between the soil particles is a salt, it might be dissolved due to the rise of water table or wetting of the soil (e.g. the movement of fresh/brackish ground water divide). Hence, a collapse will occur and create a large subsidence or a sinkhole.

The main focus of this paper is to evaluate the collapsibility of prepared soil samples that mimic the effect of dissolving salt bridge by pore water movement.

EXPERIMENTAL PROGRAM
MATERIAL

The material used for the tests was natural soil from Lisan Marl of southern Dead Sea basin, with a color of grey to light green Clay. The specific gravity of Soil is 2.75 determined in a standard manner; however, kerosene instead of water was used due to the presence of gypsum and other salts. The grain size distribution soil indicates that it contains more than 98% of fine particles. The soil is classified as CL-ML soil according to the Unified Soil Classification System (USCS). Moreover, the brine of the Dead Sea contains many salts, such as halite, carnallitie, and bischofite. The brine of the Dead Sea, either in soil pores or freely saturated with halite with a concentration around 33%, has a specific gravity of 1.27.

The construction of dikes on the Dead Sea basins requires a placing fill to a desire density. The desire density need to be verified according to a standard density achieved in the laboratory. Therefore, the effect of brine in compaction characteristics was assessed using Harvard Miniature compaction apparatus. The soil specimens were compacted in five layers with ten tamps per each layer. The results of dry density and molded fluid content are then depicted in the compaction curve.

Figure 3 shows the compaction curve which was calculated based on classical geotechnical definition of dry density versus water content, (as defined by ASTM D5550), for different treated percentage of soil with brine.

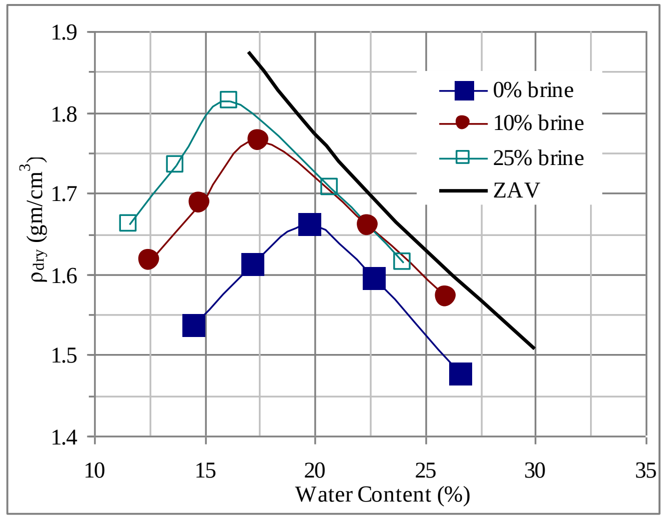

Fig. 1: The Compaction Curve for Different Percent of brine added, based on classical geotechnical definition.

The classical geotechnical definition of water content is:

$$w = \frac{M_w}{M_s} \quad (1)$$

Where, Where Mw = mass of distilled water, M_s = oven dried mass (45 ^oC).

It is clearly shown that the increasing amount of salts causes the maximum dry density obtained to increase and reduce the optimum moisture content. However, using corrected water content for the presence of brine in pore fluid is shown in Eq. (2), clearly shows an opposite trends, as depicted by Figure 4.

$$w = \frac{(1 + \frac{S}{1000 - S})M_w}{M_s - [(\frac{s}{1000 - s})M_w]} \quad (2)$$

Where S = salinity = M_{sa}/M_{sw}=mass of salt / mass of brine fluid.

As the percentage of brine increases, the dry density decreases since it has two contributions; one come from soil solids; one the other from the salts of the brine. Thus, the increases in amount of brine cause the total mass of dry salts in a given volume to be increased. Since the density of salts in brine is less than that of soil solids, the total density of the sample decreased as salts particles replace those of soil. Moreover, since the amount of energy applied to the mold is constant, it's clearly observed that the addition of brine will increase the pore water suction (negative pore water pressure), and the deficiency for fluid to reach equilibrium fluid content will increase, therefore the optimum water content increases. Moreover, since the maximum dry density tends to decrease, the soils particles tend to orientate toward disperse structure.

This conform with the findings of Abdullah et al. (1997, 1999) study on the influence of pore water chemistry on swelling behavior of compacted clay.

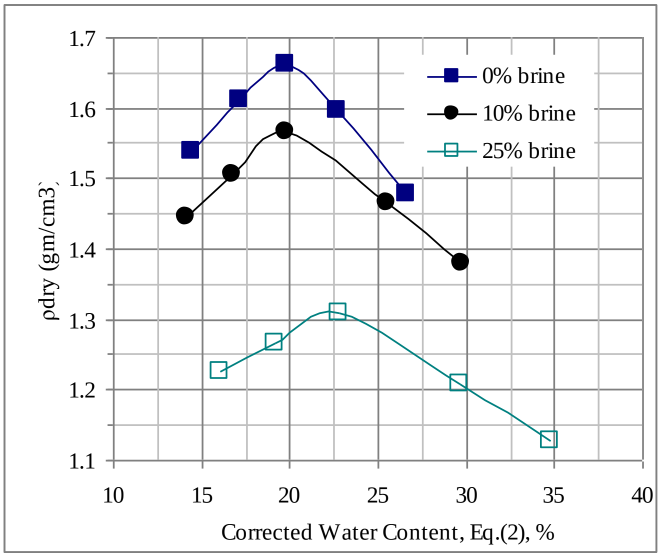

Fig. 1: The Compaction Curve for Different Percent of brine added, based on Eq.(6).

SOIL PREPARATION FOR TESTING

The soil was first washed under tap water through sieve # 40 and the larger sizes were discarded. The soil samples then dried at a temperature of 45°C for 8 days until the dry weight of the sample becomes constant. The samples, were entered a cycle of washing and drying in distilled water, and placed in filter paper overlaid a funnel to ease the drained of brine for 24 hours, thereafter, being washed again until the total dissolved solids of pore fluids drained from specimen have a concentration by mass less than 1%. Then the soil samples were dried again at a temperature of 45°C until they becomes completely dried. The soil samples then were pulverized using rubber tipped pestle until they pass sieve # 40 again. Moreover, soil samples were washed with different concentration of Dead Sea brine. The brine was diluted with distilled water to give a concentration of total dissolve solids of 25% (undiluted brine), 15%, 10%, 5% and 0%. The samples then were dried as preceding manner. The effects of brine additive on collapsibility were performed.

COLLAPSE POTENTIAL OF PREPARED SAMPLES

A set of three double - Oedometer soil specimens (20 mm in height and 76 mm in diameter) was prepared for each testing state. The chosen water contents were selected to allow the clay specimen's structure alters from flocculated structure to dispersed structure (Lambe, 1961). The collapse potential tests were conducted according to the ASTM D 5333 – 03. Applied stresses, initial and final height, thereafter, initial and final voids ratios were determined for each tested specimen. Voids ratios versus applied stresses for the set of pair samples were plotted. The collapse potential for each pair specimens was determined for all tested cases.
The soil compressibility for wet and dry samples of the clean clay specimens (i.e. Fluid has zero brine) at a dry density of 1.60 gm/cm^3 and a molding water content of 15 and 25 were shown in Figures (3) and (4).

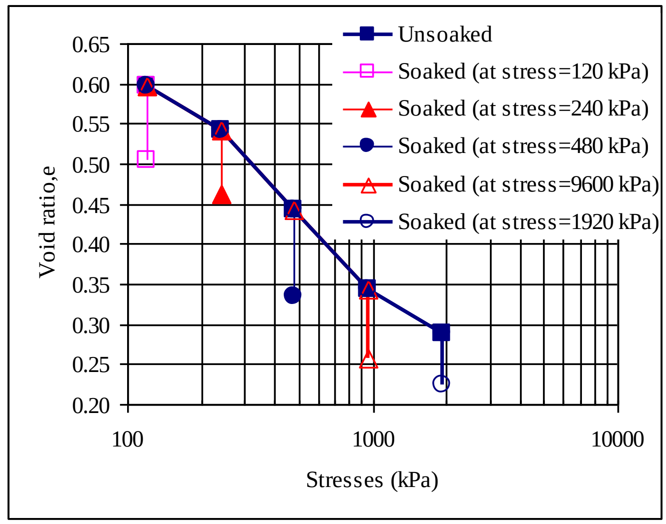

Fig.3: Compressibility of neat remolded clay sample at a ρ_d of 1.60 gm/cm^3 and a molding water content of 15%.

It is clearly shown from Figures (3) and Figure (4) that the soil in both dry and water-inundated samples were hardening with the applying stresses, and a substantial volume decrease occurs. This primarily occurs due to the fact that the soil initial fabric was flocculated. With the increasing pressure induced on the samples, the soil fabric tries to reach into a new equilibrium fabric and tries allied into parallel fabric which named as disperse fabric.

Figure (5) and (6) shows the compressibility curves for the clay sample molded with different percentage of brine fluid. It is obvious from the above set of curves (5-6) that the added amount of brine changes the characteristics of collapsibility curve despite the fact that the curves tend to a hardening behavior when the stress applied. Thus the curves typify with those curves are similar to the soil with sensitive structure and highly disturbance.

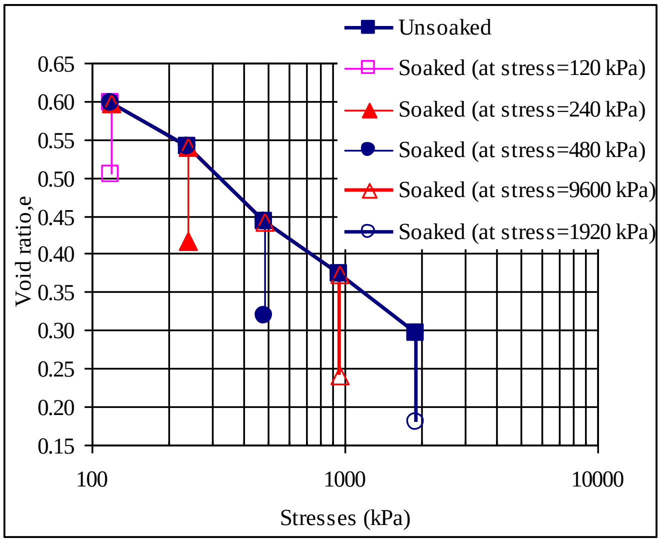

Fig.4: Compressibility of neat remolded clay sample at a ρ_d of 1.60 gm/cm^3 and a molding water content of 25%.

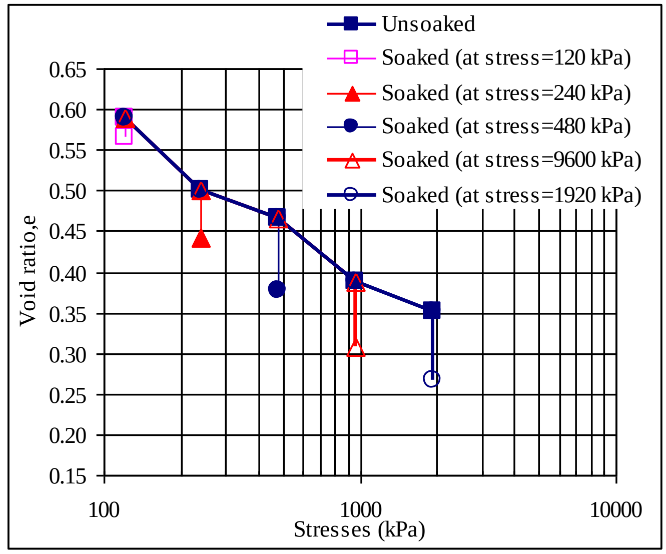

Fig. 5: Compressibility of remolded clay sample at a dry density of 1.60 gm/cm^3 and a molding water content of 15% and brine 15%.

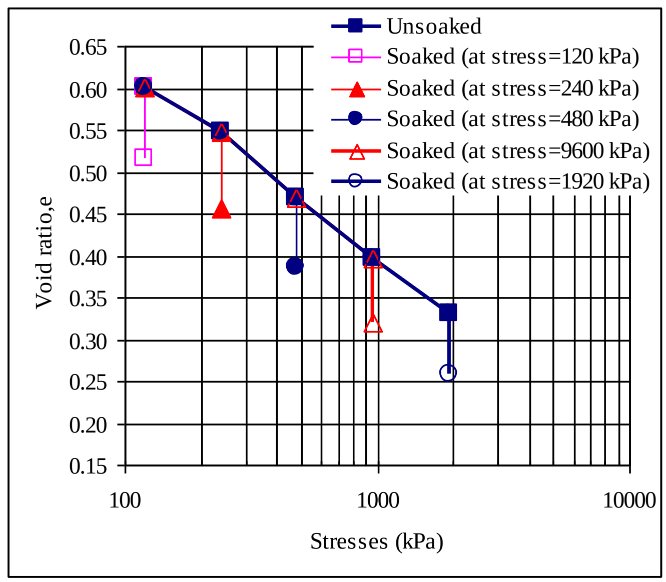

Fig. 6: Compressibility of remolded clay sample at a dry density of 1.60 gm/cm^3 and a molding water content of 15% and brine 25%.

THE EFFECT OF BRINE ON THE COLLAPSE POTENTIAL

The amount of collapse potential was evaluated after the dry specimen, while in Oedemeter, reaches the required stress level inundated of brine solution for 24 hours. Thus the collapse potential given as:

$$I_c = \frac{d_f - d_i}{h_o} \qquad (1)$$

Where, d_f = dial reading at the appropriate stress level after wetting, d_i = dial reading at the appropriate stress level before wetting, and h_o = initial specimen height.

Figure 7 shows the variation of collapse potential with applied stresses for different amount of brine. It is clearly indicated that as the amount of stresses increases, the amount of collapse increases. Moreover, increasing the amount of salts by weight is not necessary to cause the amount of collapse due to the fact that the salts are not fully washed away when the sample is inundated, which add an amount of solids to soil solids part, which in this range of stress applied is in crushable. Moreover, the amount of remolding water is deficient to reach an equilibrium amount of water that is fair enough to dissolve all the salt solids.

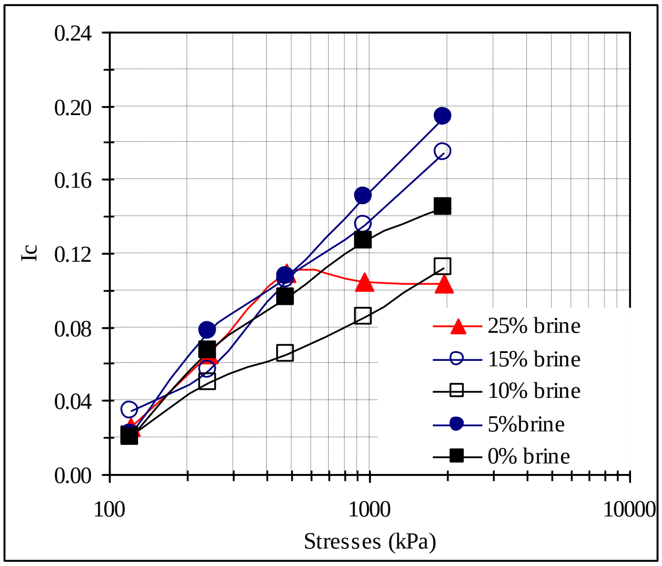

Fig.7: variation of collapse potential of remolded clay sample at a dry density of 1.60 gm/cm^3 and a molding water content of 15 with stresses for different brine percentage at molding brine content of 15%.

CONCLUSIONS

In this study, a set of soil samples of evaporated Dead Sea soil were prepared and tested to evaluate the effect of the presence of brine in the collapse potential of the soil. The soil specimens after being washed from the dissolved and precipitated salts were treated by adding Dead Sea brine. Time was allowed for the additive brine to be crystallized or fully dissolved before the test was initiated in Oedometer cell.

A considerable amount of collapse takes place for the sample with increasing the initial applied pressure on the sample regardless the initial molding water content. However, the dry of optimum sample shows larger collapse than that on wet side of optimum. At low applied initial stresses, the more the brine percentage present on the sample is increased, the larger the collapse occurs. Moreover, the amount of collapse tends to increase with increasing the applied pressure to reach certain value for a given brine percentage, then the amount of collapse asymptote to its maximum value with increasing the pressure on the sample.

Lastly, this method of preparation the soil samples is proven to mimic the real situation in situ, therefore, no restriction shall be made when using the results to evaluate the assessment of collapsibility in future construction in vicinity of saline water body.

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