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Characterizations of Soil Collapsibility: Effect of Salts Dilution

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ABSTRACT

Collapsibility of soils is the large change in volume of soil upon saturation or wetting. This change may or may not be the result of the application of additional load. 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 a certain none desire density, a large settlement will occur either due to loading or wetting of soil deposits. Hence, a collapse will occur which will create a large subsidence or a sinkhole.

In this study, soil samples of CL-ML soil were modified by adding different amounts of brine. The main goal of which was to examine the effect of brine presence on the collapse potential of the soil. Soil index properties, compaction characteristics, and a collapse potential were evaluated according to ASTM standards. The test includes Atterberg's limit, Harvard miniature compaction, and double oedometer tests.

It has been shown that brine additive has pronounced effect on the Atterberg's limits; it is clearly shown that as the amount of brine increases both liquid limit and plastic limit decrease. Compaction curve characteristics of soil were altered by the presence of brine, the maximum dry density, obtained using Harvard miniature device, increased as brine percentage increased, however, the optimum moisture content showed substantial decrease with increasing the amount of brine.

1 Introduction

The volume reduction of soil upon loading and wetting is defined as collapse. Collapsible soils in general appear in strong and stable dry natural state. Unfortunately, they rapidly consolidate under wetting and loading, thereby, generating considerable and often unexpected settlements. Such huge settlements can yield catastrophic consequences for structures built on such deposits. These soils are often termed collapsible or metastable, and the process of their collapsing is often called collapse or hydro-collapse [1-3] among many others references.

Collapse process is observed in semi saturated layers of soil such as compacted soils as well as dry natural soils deposits. The collapse settlement tends to modify metastable soil and converts it to stable non-collapsible soil after wetting

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and saturation. The stability of dry collapse soil is attained primarily due to either the presence of thin film of water under tension (i.e. capillarity) or cementation bridge of fine material present between sand or silt particles.

The structure of such soil cemented by silts and clayey is referred to as a honeycomb structure that also might be due to the presence of salts. The capillary tension in semi saturated soils seems to vanish after soil voids saturation. In the case of dry soils, the bond between soil particles of fine materials and salts is washed away during saturation process, causing general soil collapse. Several criteria are available for evaluation of the prone of soil to collapse [4, 5]. Moreover, the presence of brine fluid in the soil pore space alters the determination of basic soil indices.

1.1 Phase Relations of Unsaturated Salty Soil

If a substantial amount of dissolved salts are present in a soil sample, a correction of the pore fluid indices are required [6-9]. Figure 1 shows an elementary cube which illustrates phases of unsaturated salty soil. The water content (w), fluid content (w_f), total density (ρ_T), dry density (ρ_{dry}) and void ratio (e) used in this work are defined respectively as follows:

$$w = \frac{M_w}{M_d} \tag{1}$$

$$w_f = \frac{M - M_d}{M_d - sM} \tag{2}$$

$$\rho_T = \frac{M}{V} \tag{3}$$

$$\rho_{dry} = \frac{\rho_T}{1 + w_f} \tag{4}$$

$$e = \frac{G_s \rho_w (1 + w_f)}{\rho_T} - 1 \tag{5}$$

Where Mw = mass of distilled water, Md = oven dried mass (45 ^{o}C), M = total wet mass, s = salinity = Msa/Msw=mass of salt / mass of brine fluid, ρw = density of distilled water at 4^{o}C, and V = total volume.

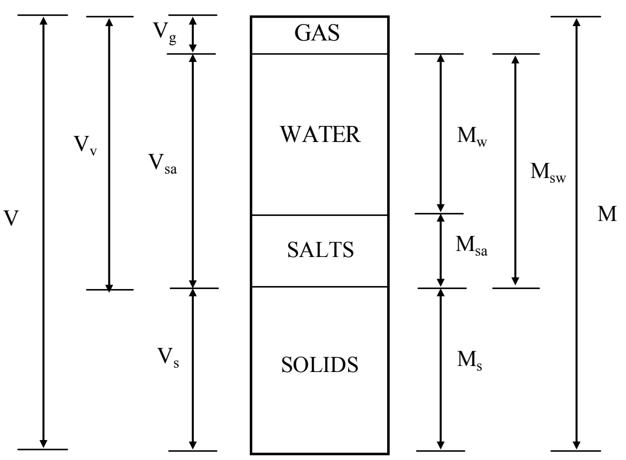

Fig. 1- Elementary cube showing the phases of unsaturated Salty Clay

Moreover, Frydman et al. [9] derived the following equation Eq.(6) for determining the fluid content in the case of fully saturated soil sample, and thereafter the corrected water content for salinity (Eq. (7)) of ASTM D5550 [10] can be used. They are given as:

$$w_f = \frac{G_{sw}}{G_s} \cdot \frac{(G_s \cdot \rho_w - \rho_T)}{(\rho_T - G_{sw} \cdot \rho_w)} \tag{6}$$

$$w = \frac{(1+\frac{S}{1000-S})M_w}{M_s - [(\frac{s}{1000-s})M_w]} \tag{7}$$

Where Gs=soil specific gravity, ρw=density of water, Gsw =specific gravity of diluted brine, S=salinity of pore fluids per mil, Mw mass of water, and Ms = mass of specimen includes salt.

The present of the dissolved salts in a soil sample, especially in clayey soil, not only amend the definition of soil indices, it also alters the structure of clayey particles.

1.2 Diffuse Double Layer Theorem

It is well known that clay surfaces acquire residual negative charges because of the isomorphous substitution of silicon or aluminium by ions of lower valency or via disassociation of hydroxyl ions. Such carrying ions will attract the cations. The negative charges results in cations exist in the pore fluid. Cations may also being replaced by other cations of high valency or moved to higher pore fluid concentration. The description of negatively charged layer and the dispersion of the cations in the vicinity of pore fluid are dubbed as a double layer. Gouy – Chapman theory [11] used in literature to model the double layer and given as [12]:

$$\frac{d^2 w}{dx^2} = \frac{-e}{\varepsilon} \sum_{i=1}^{m} v_i n_{io} e^{\frac{-e v_i w}{KT}} \tag{8}$$

where; ω = electric potential, e = electronic charge, vi= ionic valence, ni0 = ions' concentration in the pore fluid, k = Boltzmann constant, T = absolute temperature and ε = permittivity.

For a particular case of two ion species (cations and anions) of equal valence and concentration in the pore fluid, the solution for the above partial differential equation is given by Mitchell [12], and Mitchell and Soga [13] as:

$$\frac{1}{K} = \sqrt{\frac{\varepsilon_o DKT}{2 n_o e^2 v^2}} \tag{9}$$

where; 1/K = measure of the thickness of the double layer, D= dielectric constant and ε_0 = permittivity of vacuum.

As clearly seen from the above solution, the thickness of the double layer is inversely proportional to the concentration of ions in the pore fluid. Moreover, a set of repulsion (attraction) forces occur between adjacent clay mineral particles of similar (different) charges. The repulsion force depends on the characteristics of the double layer; Repulsive force decreases as the concentration increase and vice versa. However, attractions between clay particles do also occur due to short-range van der Waals forces independently of the double layer. Such forces are vanishing quickly with increasing distance between clay particles. The overall particle interactions have a great influence in the structure of clayey particles. Hence, if the repulsion forces dominate, the particles tend to orient in a face to face structure which is called dispersed structure. On other hand, if the attraction forces are dominant, the particles tend to orient in edge to face or edge to edge structure which is called flocculated structure.

The main objective of this paper is to focus on evaluating the collapsibility of salty soils deposits, and mimic the effect of fresh groundwater / brackish groundwater divide movement on the characteristics of soil collapsibility.

2 Experimental Program

2.1 Material

The material used for the tests was natural soil from Hashemite town, Jordan. The specific gravity of Soil is 2.63. The grain size distribution of the soil sample indicates that it contains more than 82% of fine particles. Based on the consistency test of clean, washed, and dry samples, the soil is classified as CL-ML according to the Unified Soil Classification System (USCS).

2.2 Soil Preparation For Testing

The soil was first washed under tap water through sieve # 40 and the larger sizes were discarded. The soil then dried at a temperature of 100°C for 24 hours. The soil then was pulverized using rubber-tipped pestle until they pass sieve # 40 again. Moreover, soil samples were prepared with different concentrations of brine. The brine was diluted with distilled water to give a concentration of total dissolved solids of 25% (undiluted brine), 15%, 10%, 5% and 0%. The effect of brine additive on dry density and collapsibility of CL-ML soil samples sample were performed.

3 Test Results and Analysis

3.1 Compaction Curves

The construction of dikes at places with high salts concentrations such as on the Dead Sea basin requires a placing fill to certain density. The desired density needs 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. Dry bulk density is defined as the mass of the dry solids divided by the total volume of the wet sample.

Figure 2 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 percentages of brine. It is clearly shown that the increasing amount of salts causes the maximum dry density obtained to increase and reduces the optimum moisture content.

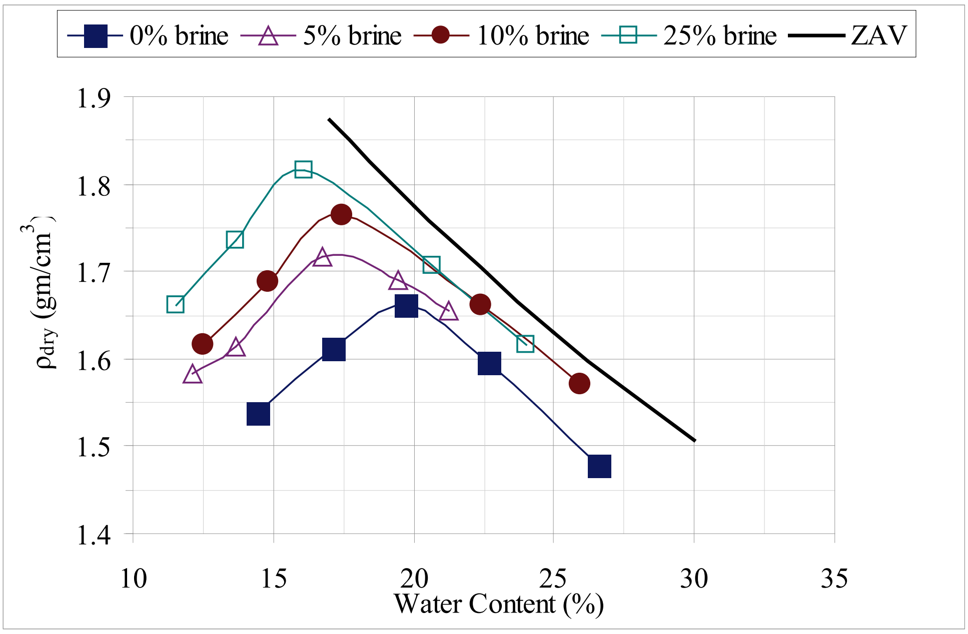

Fig. 2- The Compaction Curve for Different Percent of brine added, based on classical geotechnical definition.

However, using corrected water content in Eq. (7) clearly shows an opposite trends, as depicted by Figure 3. As the percentage of brine increases, the dry density decreases since it has two contributions; one comes from soil solids, and the other from the salts of the brine. Thus, the increasing the amount of brine causes the total mass of dry salts in a given volume to elevate. Since the density of salts in brine is less than that of soil solids, the total density of the sample decreases 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. Furthermore, 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. [14, 15] on the influence of pore water chemistry on swelling behavior of compacted clay.

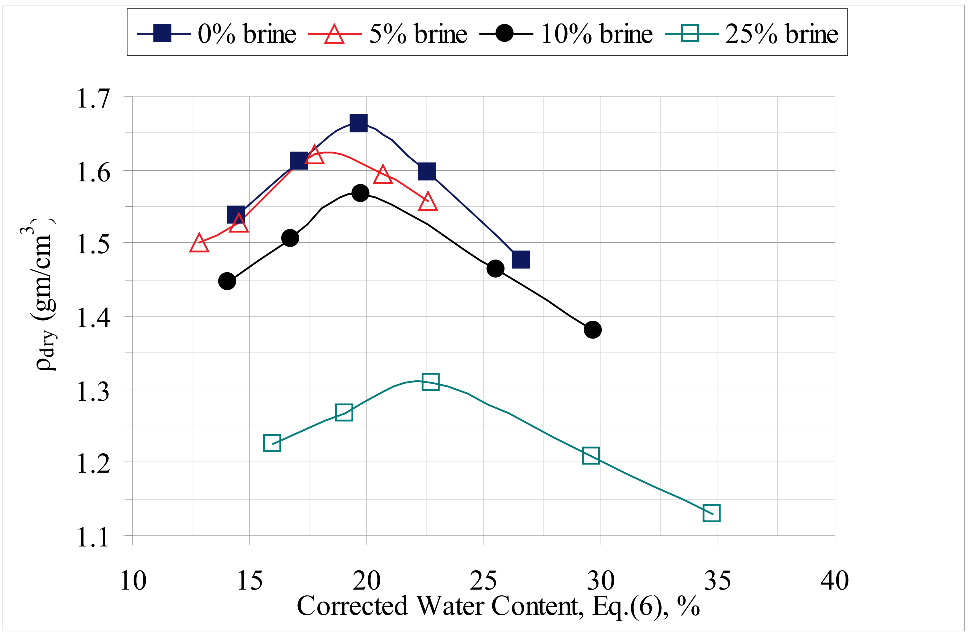

Fig. - The Compaction Curve for Different Percent of brine added, based on Eq. (6) and Eq. (4)

3.2 Collapse Potential of Prepared Soil Specimens

A set of three double - Oedometer soil specimens (20 mm in height and 76 mm in diameter) was prepared for each testing state. Table 1 summarizes the state of compaction, percent of brine, and number of specimen tested. The chosen water contents, as given in Table 1, were selected to allow clay specimen's structure to alter from flocculated structure to dispersed structure [16]. The collapse potential tests were conducted according to the ASTM D 5333 – 03. Applied stresses, initial and final heights, thereafter, ratios of initial and final voids 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/cm3 and a molding water content of 15, 20, and 25 were shown in Figures (4) through (7). It is clearly shown from Figures (4) through Figure (7) that the soil in both dry and water-inundated samples were hardening with the applying stresses, and a substantial volume decrease occurs. This occurs primarily 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 named as disperse fabric. Figures (8) through (18) show the compressibility curves for the clay sample molded with different percentage of brine fluid. It is obvious from the set of curves in Figures (8-18) 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. The increases of the amount of brine fluid in molding the test specimen obviously increase the concentration of ions. Thus, it will increase the thickness of the double layer as seen by the solution of the double layer presented in section 1.2 above. Therefore, clays structure will favor dispersing structure. Since the specimen is allowed to be dried before the test carried out, the salts acting as a holding bridge of the clayey structure and a honeycomb voids is formed, followed by a large collapse when wetting occurs as shown in Figures 8 to 18.

Table. 1 State of soil compaction, percent brine and number of specimens

NUMBER OF SPECIMENS	Initial Dry Density (gm/cm^3)	Initial Water Content (%)	Diluted brine (%)
6	1.6	15	0
6	1.6	20	0
6	1.6	25	0
6	1.6	15	2.5
6	1.6	20	2.5
6	1.6	25	2.5
6	1.6	15	5
6	1.6	20	5
6	1.6	25	5
6	1.6	15	10
6	1.6	20	10
6	1.6	25	10
6	1.6	15	25
6	1.6	20	25
6	1.6	25	25

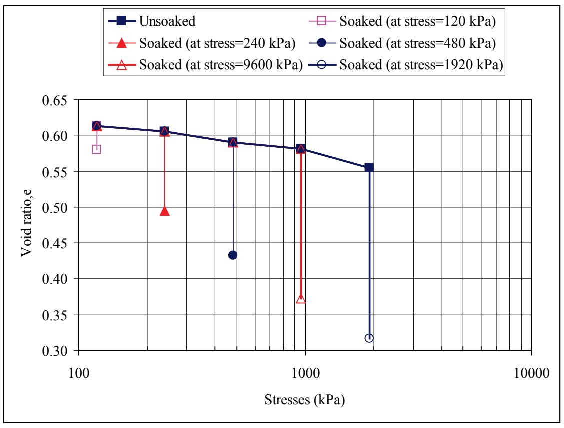

Fig. 4- Compressibility of neat remolded clay sample at a dry density of 1.60 gm/cm^3 and a molding water content of 15%.

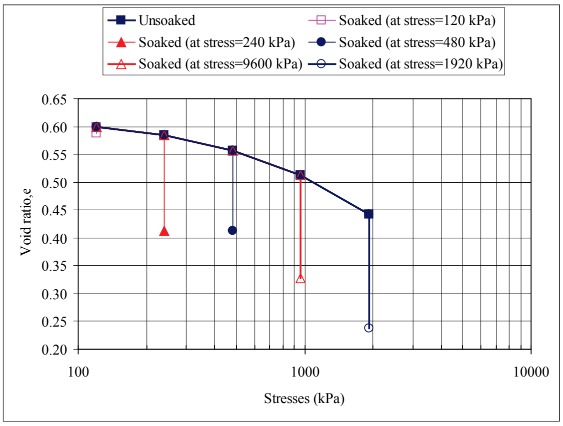

Fig. 5- Compressibility of neat remolded clay sample at a dry density of 1.60 gm/cm^3 and a molding water content of 20%.

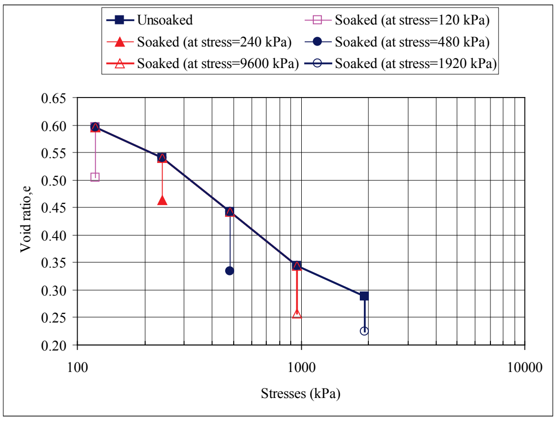

Fig. 6- Compressibility of neat remolded clay sample at a dry density of 1.60 gm/cm^3 and a molding water content of 25%.

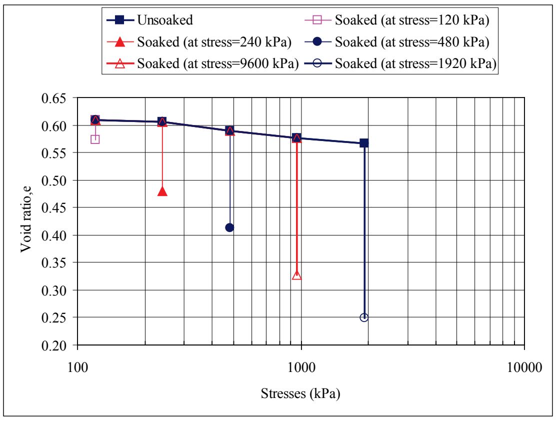

Fig. 7- Compressibility of remolded clay sample at a dry density of 1.60 gm/cm^3 and a molding water content of 15% and brine 5%.

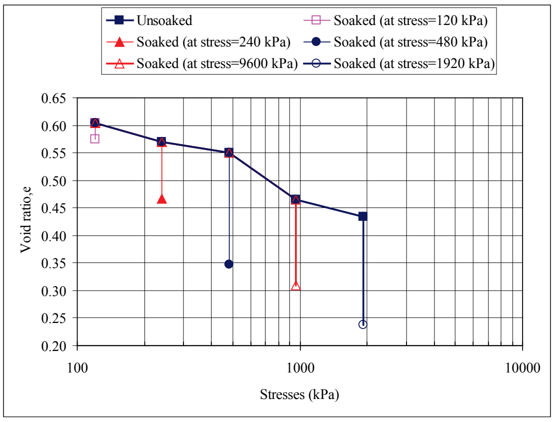

Fig. 8- Compressibility of remolded clay sample at a dry density of 1.60 gm/cm^3 and a molding water content of 20% and brine 5%.

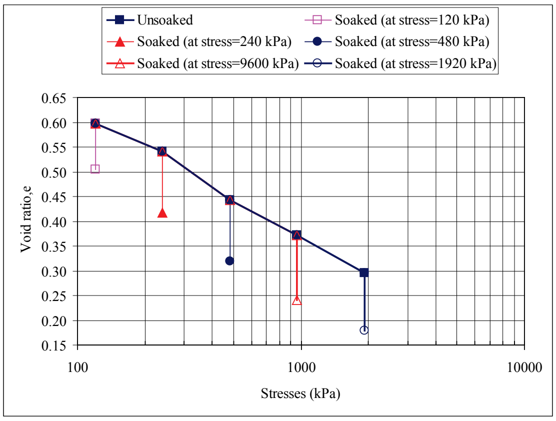

Fig. 9- Compressibility of remolded clay sample at a dry density of 1.60 gm/cm^3 and a molding water content of 25% and brine 5%.

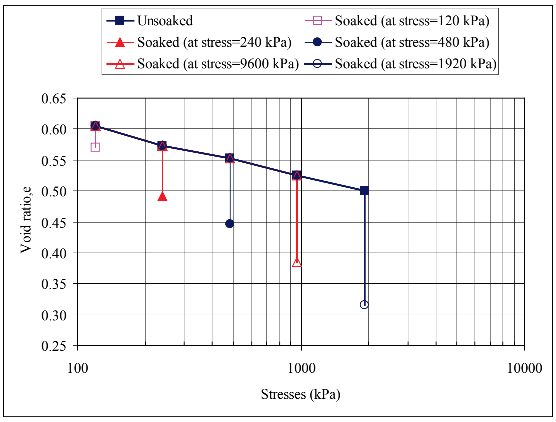

Fig. 10 - Compressibility of remolded clay sample at a dry density of 1.60 gm/cm3 and a molding water content of 15% and brine 10%.

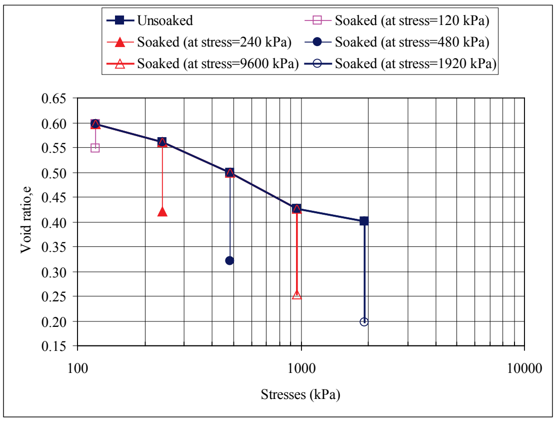

Fig. 11- Compressibility of remolded clay sample at a dry density of 1.60 gm/cm3 and a molding water content of 20% and brine 10%.

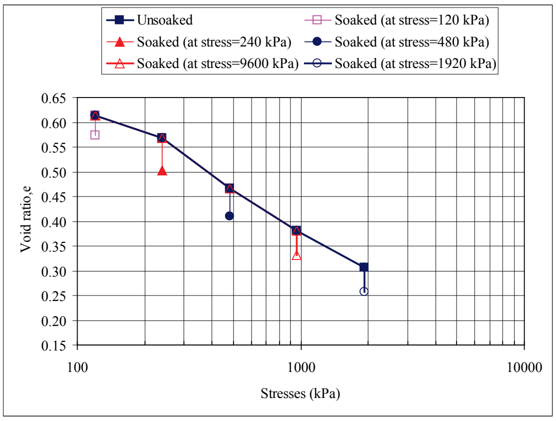

Fig. 12- Compressibility of remolded clay sample at a dry density of 1.60 gm/cm³ and a molding water content of 25% and brine 10%.

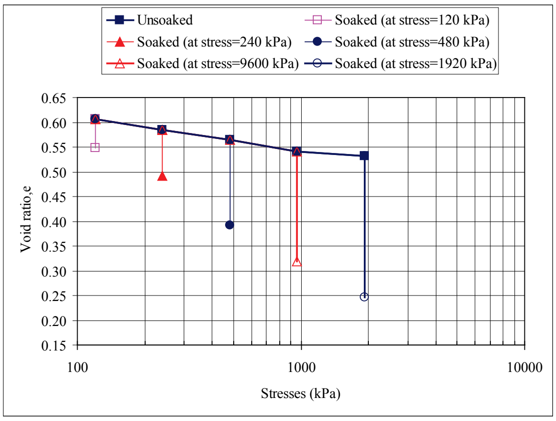

Fig. 13- Compressibility of remolded clay sample at a dry density of 1.60 gm/cm³ and a molding water content of 15% and brine 15%.

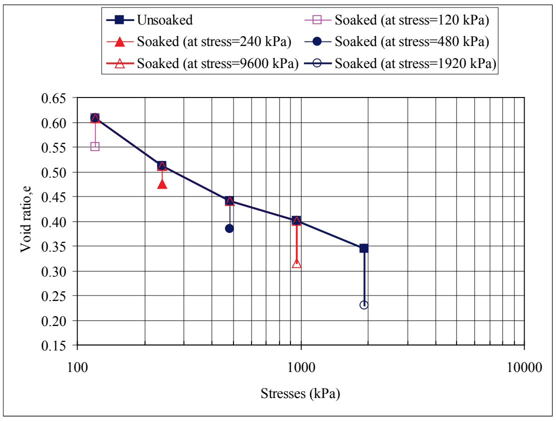

Fig. 14- Compressibility of remolded clay sample at a dry density of 1.60 gm/cm³ and a molding water content of 20% and brine 15%.

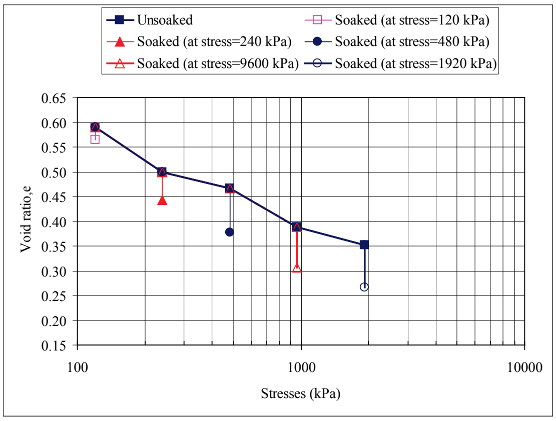

Fig. 15- Compressibility of remolded clay sample at a dry density of 1.60 gm/cm³ and a molding water content of 25% and brine 15%.

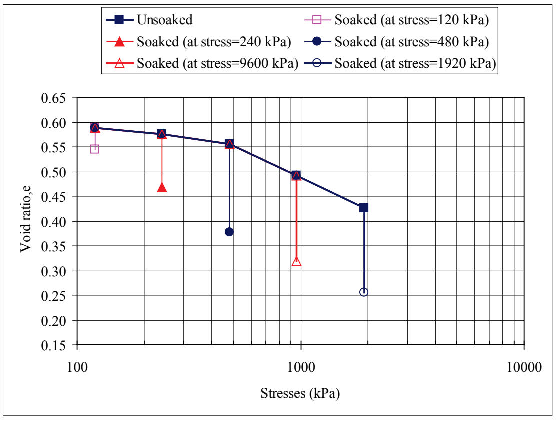

Fig. 16- Compressibility of remolded clay sample at a dry density of 1.60 gm/cm³ and a molding water content of 15% and brine 25%

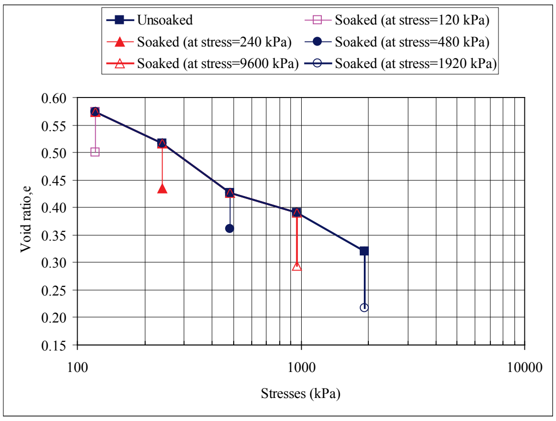

Fig. 17- Compressibility of remolded clay sample at a dry density of 1.60 gm/cm³ and a molding water content of 20% and brine 25%.

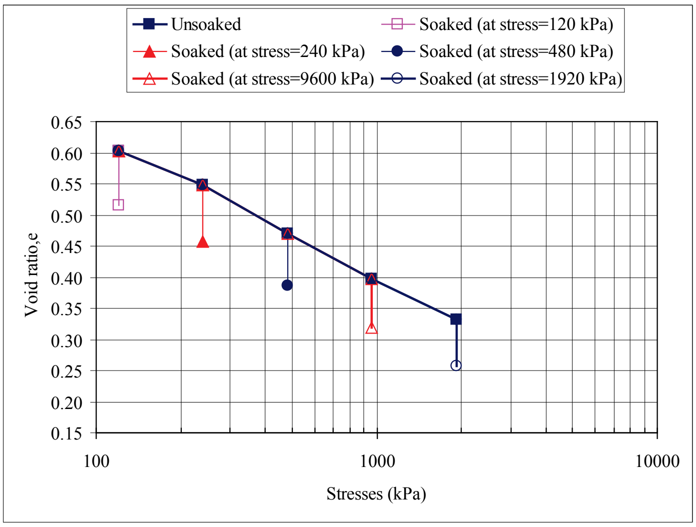

Fig. 18 - Compressibility of remolded clay sample at a dry density of 1.60 gm/cm^3 and a molding water content of 25% and brine 25%.

4 The Effect of brine on the Collapse Potential

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:

$$I_c = \frac{d_f - d_i}{h_o} \tag{10}$$

Where, df = dial reading at the appropriate stress level after wetting, di = dial reading at the appropriate stress level before wetting, and ho = initial specimen height.

Figure 19 shows the variation of collapse potential with applied stresses for different amounts of brine. It is clearly indicated that as the stresses value 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 adds an amount of solids to soil solids part, which in this range of applied stress is incrushable. 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.

Figure 20 shows the variation of collapse with applying pressure at water content of 20% and dry density of 1.60 gm/cm3. In this Figure the amount of collapse depends primarily on the stresses applied for a given percentage of brine added.

Figure 21 shows the variation of collapse with applying pressure at water content of 25% and dry density of 1.60 gm/cm3. In this Figure the amount of collapse reaches a maximum value within the range of applied pressure then seizes to increase or level off.

Moreover, the relative compaction (RC), which is used intensively on the field to indicate the acceptance of the compaction process, is defined as the ratio between the fields' compacted dry density to maximum dry density attained in the laboratory. In this study, RC will be defined as the ratio between the initial densities in which the soil sample was prepared to the maximum dry density. Figure 22 shows the variation of average collapse potential for different applied stresses. For stresses ranges below 200 kPa the lower the relative compaction is the greater the collapse potential. However, for applied pressure above 1000 kPa, the higher the relative compaction the higher the collapse potential since in this range the particles tend to collapse and be oriented in a disperse fabric.

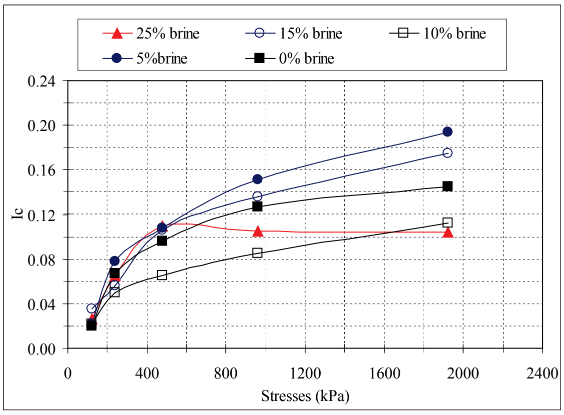

Fig. 19-Variation of collapse potential with stresses for different brine percentage at molding brine content of 15%.

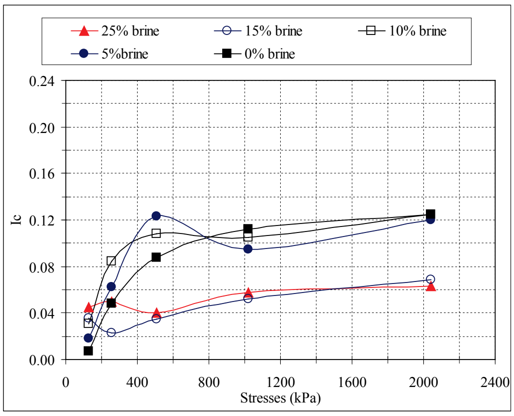

Fig. 20-Vvariation of collapse potential with stresses for different brine percentage at molding brine content of 20%.

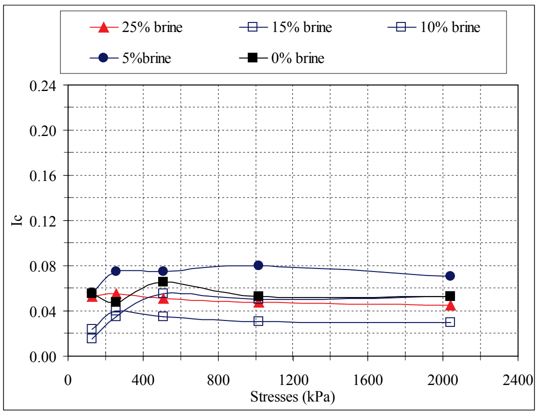

Fig. 21- variation of collapse potential with stresses for different brine percentage at molding brine content of 20%.

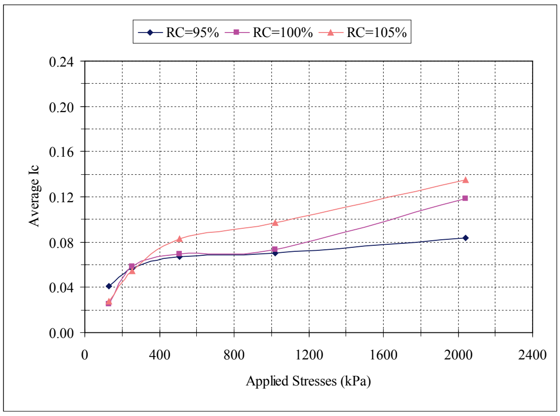

Fig. 22- Variation of average collapse with relative compaction

5 Conclusions

In the present study, a set of soil samples were prepared and tested to evaluate the effect of the presence of brine in the collapse potential and other soil indices properties. The soil specimens were treated by adding the brine to the dry mass of soil sample. Based on the results obtained, the following conclusions can be drawn:

1. Compaction curve characteristics of soil were altered by the presence of Salts additive. The maximum dry density, obtained using Harvard miniature device, was decreased with increasing the brine percentage at the same time. However, the optimum moisture content drastically increases.

2. A considerable amount of collapse takes place for the sample with increasing the initial applied pressure on the sample regardless of the initial molding water content. However, the dry side of optimum sample shows larger collapse than that on wet side of optimum sample and vice versa.

3. At low applied initial stresses, the higher the brine percentage in the sample, the larger the collapse occurs. However, at large applied stresses, the opposite trend is observed. Moreover, the amount of collapse tends to increase with increasing the applied pressure to reach a certain value for a given brine percentage, then the amount of collapse asymptotes to its maximum value or level off with increasing the pressure on the sample.

4. At a lower relative compaction, the amount of collapse will be higher for low applied pressure.

A final remark, caution shall be made when using classical geotechnical definition in controlling field compaction, classification of soil samples and assessment of collapsibility in future construction.

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