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Fresh-Brine Water Effect on the Basic Engineering Properties of Lisan Marl-Dead Sea-Jordan

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Abstract: A recent and largest dike body constructed in Lisan peninsula, Jordan to retain the brine pumped from the Dead Sea is composed of marl. Investigating the properties of the marl and the influence of using brine/fresh water on the engineering behavior of this material is important, particularly during the design and construction stage in order to identify, evaluate and avert unforeseen problems. Techniques to be used to determine the engineering properties of Lisan Marl shall take into consideration the presence of soluble minerals in this soil. The properties considered in this study were mineralogy, grain size distribution, consistency limits, moisture content-dry density relationship (Proctor test), specific gravity and unconfined compressive strength. The results showed that brine water significantly increased the maximum dry density, while the optimum moisture content, liquid limit and the fine particles were decreased upon using brine for sample treatment compared with tests fresh/distilled water. The unconfined compressive strength recorded higher values upon molding the samples with fresh water.

Key words: Dead sea, lisan marl, brine water, soluble salts, dike construction,

INTRODUCTION

At the southern tip of the Dead Sea in Jordan, a series of evaporation pans or ponds have been established by The Arab Potash Company, in which the brine pumped from the Dead Sea is concentrated. The carnallite salts (the raw compound of potash) were then harvested from the pans and refined in the plant to form potash (KCl), which is mainly used as fertilizer. Increasing the potash production requires the construction of more salt pans. The salt pans are surrounded by large watertight dike structures built on soft silty clay foundation (Madadhe and Tabbal, 1997).

A recent and largest dike body constructed is composed of marl which is considerably exposed at the construction location. The marl was scarified in borrow areas, sprayed by brine, soaked for few days and then the dry and wet marl are mixed to obtain a moisture content close to optimum before transported to the construction site. Marl was used in other locations in Jordan in dam construction (to retain fresh water) but by processing the marl with only fresh water.

Earth dams which have been satisfactory in retaining reservoir of salt water for long periods have been known to quickly develop piping problems when fresh water replaced the salt water. This is a result of dilution of ion concentration in the clay layer and consequently forming

dispersive material. This type of clay structure will deflocculate in still water and erode if exposed to low velocity water (McCarthy, 2007).

Reliable assessment of the long term stability of clay-water-electrolyte systems particularly when used in engineering structures as well as improving the strength of Lisan Marl as dike construction material and determining the optimum moisture content-dry density relationship upon molding this soil with brine/fresh water are the main objectives of this research.

MATERIALS AND METHODS

The study area

The dead sea: The Dead Sea is the lowest place on the earth with water level of 418 m below sea level was recorded in 2005. It is situated at the deepest part of the Jordan Rift Valley between Jordan to the East and occupied Palestine/Israel to the West (Fig. 1). The Dead Sea possesses unique chemical properties significantly different from other oceans, seas or lakes (Abed, 1985). The Dead Sea brine salts percentage are calcium chloride (CaCl_2) 14.4%, potassium chloride (KCl) 4.4%, magnesium chloride (MgCl_2) 50.8% and sodium chloride (common salt, NaCl) 30.4% (Table 1).

The Dead Sea is a closed lake with no outlet except evaporation from the surface which amount to around

Table 1: Average ions distribution in the dead sea and normal oceans (g L⁻¹) (Abed, 1985; Mahasneh, 2004)

Anion/Cation	Na	K	Ca	Mg	Cl	Br	SO ₄	HCO ₃	Na/K	Cl/Br	TDS
Dead sea	38.90	7.10	16.720	39.70	208.90	5.000	0.50	0.23	4.60	35.10	332
Oceans	10.56	0.38	00.400	01.27	018.98	0.065	2.65	0.14	27.90	289.70	30-40



Fig. 1: Dead Sea-geographic location

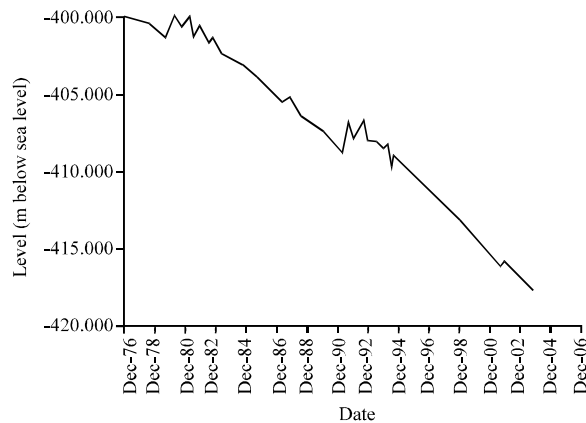


Fig. 2: Dropping of the Dead Sea brine level

0.8-1.0 m year⁻¹ drop in the brine level (Fig. 2). The climate of the Dead Sea is classified as arid with annual rainfall of 65 mm and temperature exceeding 40°C in dry season. The salinity of the Dead Sea is around 332 g L⁻¹ (Asmar and Ergenzinger, 2002), resulting in an average specific gravity for the brine of 1.23. The current area of the Dead Sea is around 650 km² with average width of 12 km. The dikes which belong to the Arab Potash Company are located on the Lisan peninsula at the southern part of the Dead Sea (Fig. 3).

Geology of the study area: The Dead Sea is a pull-apart basin or Graben formed as part of the formation of the Jordan Valley Rift around 25 million years ago. The rift runs from the spreading Red Sea, through Gulf of Aqaba in Jordan, the Araba Valley, the Dead Sea, Jordan Valley,

Lebanon, Syria, approaching Taurus Mountains in Turkey. The formation of the rift is a matter of dispute between two schools of thought, i.e., one supporting the theory of vertical displacement along parallel normal faults, while the other suggest the left lateral (strike-slip fault) shear of 105 km along the rift as the main movement resulted from the spreading of the Red Sea (plate-tectonic theory) (Lyakhovsky *et al.*, 1994; Sneh, 1996; Ben-Avraham and Schurbert 2006).

The marl deposits in the Dead Sea area is called Lisan Marl after the Lisan Lake which is the preceding of the Dead Sea. Lisan Lake extends from Tiberia Lake in Palestine in the north to about 35 km south of previous existing southern basin of the Dead Sea, with a total length of 225 km (Abed, 1985). The stratigraphic units in the Lisan Peninsula from oldest to youngest are as follows:

- Pre-rifting formation composed of conglomerates, sandstone, dolomite, clay stone, chert and bituminous shale
- Usdom formation with thickness of 4000 m composed of rock salt and forms the Lisan diapers
- Amora formation composed of sandstone, conglomerates, mudstone and minor amount of salt, marl and chalk
- Lisan formation composed of lacustrine calcareous marl
- Dead Sea deposits composed of salt, wadi deposits and chemical deposits

The Lisan Marl is an alternation of white (dominated by aragonite) lamina and grey (dominated by calcite) lamina. Gypsum, clay minerals (illite and kaolinite), quartz, halite, feldspar and diatom fossils are also recognized in this formation (Abed, 1985). The exposed thickness in the Lisan Peninsula is more than 50 m (Fig. 4).

At several locations under the Lisan Peninsula there exist salt diapers or salt domes. It is believed that the salt domes are moving upward as a result of low salt density compared with the overlying soil. This slow movement resulted in the formation of boundary faults, drag folds and radial fractures in the overlying sediments (Clossen, 2005) which could also enhance the fresh water infiltration.

Experimental program: The samples were collected from two borrow areas. The distance between them is approximately 500 m and the different in level about 35 m.



Fig. 3: Arab Potash Company Salt Pans system (aerial photos)



Fig. 4: Lisan Marl cliff, Dead Sea, Jordan

The samples from the higher level borrow area is denoted here as H location while the other is designated as B location. The sampling locations were chosen after visiting the site and the personnel communications with the dikes contractor and engineer staff. The B location was showing different compaction values compared with all other borrow areas. In each borrow area a strip of about 30 m long and 10 m width was chosen. For simulating as close as possible the procedure adopted in the site (refer to clause 1 above) for marl preparation in borrow areas, a dozer and backhoe (provided by Arab Potash company) were employed to collect a representative samples. After dozing the material (to average depth of 0.5 m) and collect it in one heap for each location; the backhoe thoroughly mixed the soil in position. By quartering (by the backhoe) a representative samples weighing about 30 kg per each location from the two borrow area collected. Riffle box was used in the

laboratory to get a representative subdivision of the collected large samples for each test.

Mineralogy: Powder X-ray diffraction analysis was conducted on representative oven dry samples (50 ± 5 °C) from the two sampling locations, after grinding the material into fine powder. Oriented samples were prepared from the two samples locations, by removal of carbonate using diluted HCl. Shimadzu-XRD-6000, Cu Tube device available in the Faculty of Archeology and Anthropology, Yarmouk University, Jordan was used in this analysis.

Specific gravity: The specific gravity of solids (G_s) for samples from the two borrow area locations (H and B) were determined according to the BS standard as detailed by Head (1992) by using small pycnometer. Since the soil contains soluble minerals (halite and gypsum) which will dissolve in distilled water when tested in the pycnometer

and consequently the volume of the solid will be underestimated, the samples were then tested using kerosene (Head, 1992). The specific gravity of the kerosene was determined in the laboratory and obtained as 0.785 which is required in the calculation of soil specific gravity.

Particle size distribution

Using distilled water: Two representative samples from the two locations weighing about 150 g in natural state (without drying) were used in wet sieving process according to the procedure stated by Head (1992). The samples were soaked in dispersion solution composed of 2 g of sodium hexametaphosphate dissolved in 1 L distilled water for 1 h to disaggregate the lumps. Thereafter, the samples were wet sieved using tap water through the 63 μm sieve. The two portions, the part retained on the 63 μm sieve and one that passed the sieve were oven dried at $60\pm 5^\circ\text{C}$. The portion retained on the 63 μm sieve was then weighted and disaggregated by rubber hammer before undergoing the standard mechanical sieving, while part of the portion finer than 63 μm was used for hydrometer test.

The hydrometer tests were conducted according to the BS standard (Head, 1992). A 50 g of oven dried ($60\pm 5^\circ\text{C}$) soil passing the 63 μm sieve were dispersed using solution composed of 35 g sodium hexametaphosphate, 7 g sodium carbonate and distilled water to produce 1 L of solution. The slurry composed of the dispersion agent; the soil and the distilled water were shaken overnight to ensure that the soil particles were completely dispersed.

Using dead sea brine: Another two representative samples from the two locations weighing about 150 g in natural state (without drying) were used in wet sieving through the 63 μm sieve using Dead Sea brine. The part retained on the 63 μm sieve was collected and left to settle for about 30 min. Then the extra brine was carefully dried in the dish by sponge to avoid the precipitation of the salt during drying. Thereafter, the samples were oven dried at ($60\pm 5^\circ\text{C}$), weighted and disaggregated by rubber pestle before undergoing the standard mechanical sieving. The portion passed the 63 μm sieve was discarded.

Consistency limits: The test was conducted according to BS standard as detailed by Head (1992). The soil was wet sieved on the 425 μm sieve using distilled water and partially oven dried on ($60\pm 5^\circ\text{C}$) to reach its plastic state. The distilled water and the Dead Sea brine were used as molding media for comparison purposes.

Standard proctor compaction test: Standard Proctor test was conducted following the procedure mentioned by Day (2001). Samples of 3000 g of marl passing the No. 4 sieve from the two sampling locations were subjected to standard Proctor test in their normal state (without drying). From each location two samples were prepared. One was tested using tap water while the other was tested by using Dead Sea brine and thereafter air dried for at least 6 days before re-testing (re-compacted) by brine as molding media.

Unconfined compressive strength: Specimens were prepared by using the Harvard Miniature Compaction Apparatus, with 20 pounds spring tamper (Head, 1992). Samples of 300 g of marl passing the No. 4 sieve from the two sampling locations were subjected to compaction in the Harvard mold of 33.34 mm diameter and 71.5 mm height. The soils were compacted/kneaded in five layers by applying 15 tamps per layer. From each location two samples were prepared. One was tested using tap water and the other was tested by using Dead Sea brine and thereafter air dried for 6 to 14 days before re-tested again by brine as molding media (drying and re-hydration).

The compacted sample was extruded from the compaction mold, trimmed, weighted and placed at the center of the lower load platen in the unconfined compression testing machine. Rate of displacement used was 1% of the specimen length per minute. The readings were taken at intervals of 0.5% strain. The test was terminated at 20% strain.

RESULTS AND DISCUSSION

X-Ray results: Figure 5 shows a representative X-ray diffraction diagram. The marl sample from the B location shows that calcite is the predominant mineral in addition to aragonite and quartz. The predominant mineral for the samples from the H location is aragonite with lesser percentage of calcite and quartz. Gypsum and Halite also exist in H location. Koalinite was found to be the major clay mineral in the two sampling locations (Fig. 6). This conforms to the findings of Abed (1983) who conducted a mineralogical study for the white and grey laminae of the Lisan Marl. Traces of anhydrite and dolomite in some samples were also reported by Abed (1983). On the contrary of other marly soil as stated by Ouhadia and Yong (2003), the clay fraction of Lisan Marl did not show any traces of palygorskite and/or sepiolite.

Specific gravity: The average specific gravity for the samples from the H location was 2.44 and the

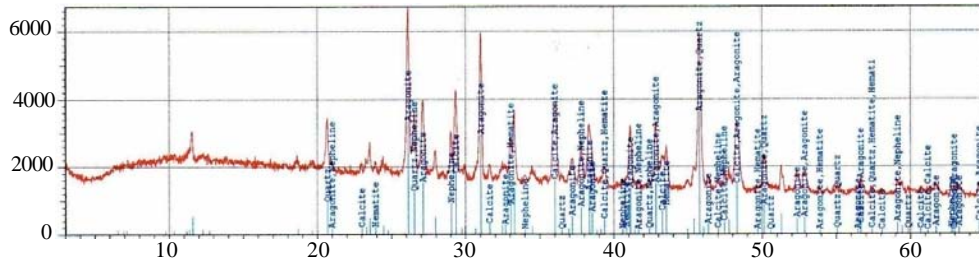


Fig. 5: Representative random X-ray diffraction

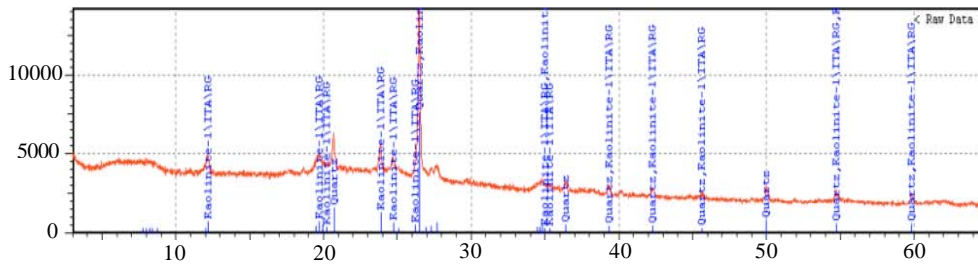


Fig. 6: Representative oriented X-ray diffraction treated with HCl

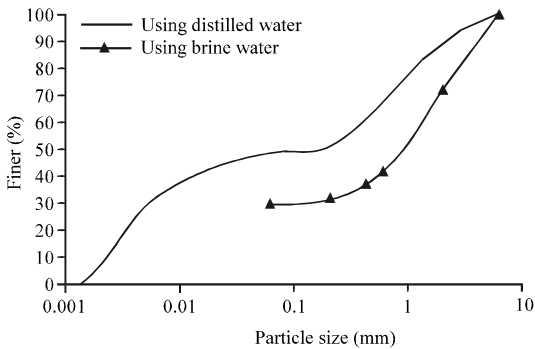


Fig. 7: Grain size distribution-B location

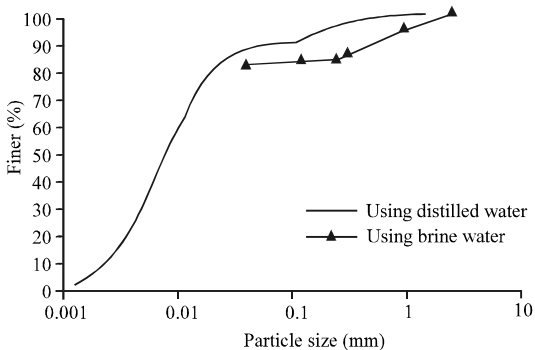


Fig. 8: Grain size distribution-H location

corresponding value for B location is 2.66. The lower G_s value of the samples from the upper location is thought to be resulting from the presence of higher content of gypsum compared to the samples from bottom location,

since the specific gravity of the gypsum ranged between 2.3 and 2.4 (Jones, 1989).

Particle size distribution: The results of the grain size analysis are presented in Fig. 7 and 8 for the two sampling locations. The percent passing 63 μm for wet sieving are 50% for the B location and 88% for the H location. The corresponding values when brine was used as the washing media are 30 and 80%, respectively. The difference is attributed to the dissolution of the soluble minerals such as halite and to lesser degree gypsum from the soil matrix by the distilled water. In addition the distilled water also dissolved the cementing materials in the soil which degraded the relatively large flakes to finer particles. Frydman *et al.* (1977) found that mixing potassium chloride (KCl) with heavy clay decreases the clay fraction (less than 0.005 mm) from 75% to 50%. It is worth to mention that after drying the portion retained on 63 μm sieve, the paste mainly composed of hard flakes of cemented aragonite resulted from brine wet sieving. This portion becomes sticky and oily when taken out of the oven. Consequently, the soil particles adhere to each other and adsorb on the sieve mesh during dry mechanical sieving. In addition, overnight soaking of the sample from the H location without shaking led to cementation of the sample (the sample harden and gypsified) and water was found to be completely dried after the overnight soaking. Nevertheless and since the dry sieving does not reflect the actual situation as the aggregated particles will not broken down, the brine shall

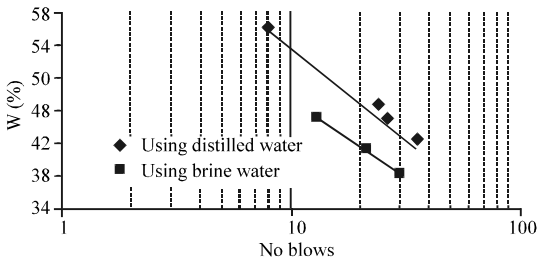


Fig. 9: Liquid limit using Casagrande device- H location

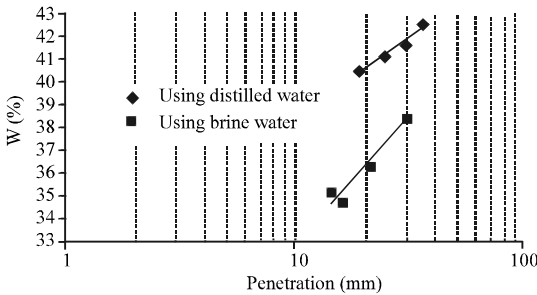


Fig. 10: Liquid limit using cone penetration- B location

be adopted as wet sieving washing media as it is representative for site conditions.

Consistency limits test: A decrease in liquid limits (LL) for both sampling locations occurred when brine is used as molding agent instead of distilled water, i.e., from 46 to 40.5% for H location and from 40.5 to 36% for the B location (Fig. 9, 10). Similarly the plastic limits (PL) decreases from 32 to 27% for the H location and from 30 to 28% for the B location.

The presence of high valence exchangeable cations (such as Mg^{+2} and Ca^{+2}) in the Dead Sea brine decrease the distance between particles by decreasing the repulsive forces in the soil microstructure. This causes the Van der Waal's attractive force to be dominant, hence increasing of capillary stress that formed between particles boundaries (Pandian *et al.*, 1991) and finally forming the aggregation. The aggregation reduces the available surface for interaction with water which negatively reflected on the Atterberg limits (Okagbue and Onyeobi, 1999). The presence of K^+ ions in Dead Sea water (even monovalent) decreases the LL and compressibility (Torance, 1975; Rao *et al.*, 1989). This also conformed with the findings of Frydman *et al.* (1977), who found that mixing KCl from the Dead Sea with heavy clay decreases the clay activity (decreasing and plasticity index, PI). The decrease in LL when Dead Sea brine used as soil improvement agent by Mahasneh (2004) is

attributed to the substitution of water by salts that decreases the double layer thickness and water content and consequently increasing the soil stiffness. However, according to USC soil classification, both soils are classified as ML. Thus, changing the molding agent did not affect the soil classification.

It was noted that the samples from the H location hardens after curing overnight. So, the sample was discarded and other samples were used with continuous mixing for few hours before placement in the testing apparatus. Another difficulty appeared during the testing of the samples from B location was the displacement of the soil sample from its position during the cutting of the sample by the Casagrande grooving tool. This is possibly due to low plasticity of this soil. This problem arise when brine, which has an oily touch, was used as a molding agent, which significantly lubricates the sample and hence displacement/slipping during grooving. Consequently, the fall cone method was used instead of Casagrande device for testing the samples collected from B location. Generally, a reduction in plasticity is an indicator of improvement (Degirmencia *et al.*, 2006).

Compaction test: Figure 11 and 12 represent the compaction test results for the studied soil samples. For the H location, the maximum dry density (MDD) increased from 1.48 g cm^{-3} in the case of tap water to 1.61 g cm^{-3} after the first addition of brine water, with a decrease in optimum moisture content (OMC) from 30 to 23.8%. A further increase in MDD to 1.68 g cm^{-3} and decrease in OMC to 22% were recorded upon drying the sample tested by brine and re-testing it again by adding the Dead Sea brine as molding agent. The corresponding values for the B location were 1.53 g cm^{-3} at OMC 26.5%, 1.66 g cm^{-3} at OMC 21% and 1.77 g cm^{-3} at OMC 15.5%, respectively.

Flocculent soil has usually lower weight, higher void ratio and consequently lower density (Lambe, 1958; Das, 2007; Okagbue and Onyeobi, 1999). In the case of the soil under study which was precipitated in saline environment, the flocculated structure already exists. So, the increase in MDD and the decrease in OMC could be attributed to the substitution of water by salts that decreases the moisture content and the lubrication effect of the oily touch Dead Sea brine that facilitated the soil packing which in turn resulted in a denser soil. This is stated by Spangler and Handy (1982), that NaCl and $CaCl_2$ which are very common in Dead Sea brine lubricated the soil particles and improved compaction.

Mahasneh (2004) attributed the increase in dry unit weight for base course soil upon using brine water to the chemical reaction between salt molecules and soil solids

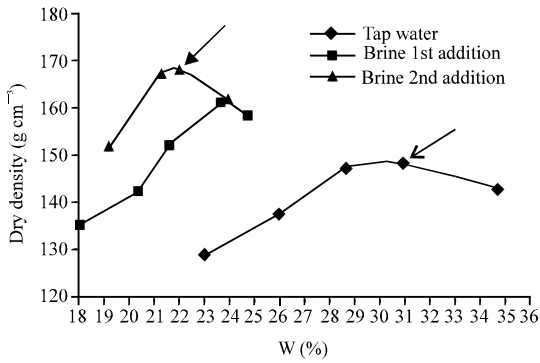


Fig. 11: Water content-dry density relationships-H location

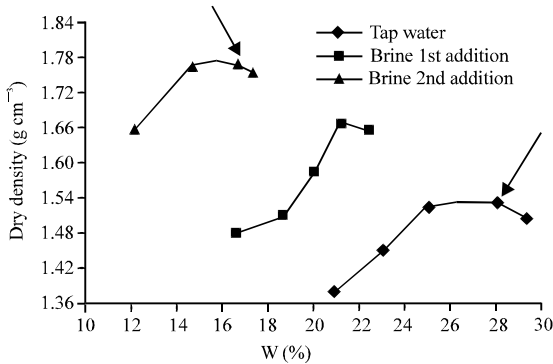


Fig. 12: Water content-dry density relationships-B location

that partially contain lime to produce CaCl_2 which in turn enhance the hardening of the soil and consequently increasing the density. Knowing that Dead Sea brine contain high percent of CaCl_2 (Abed, 1985), the increase in dry density of the studied soil could be explained likewise.

The difference in MDD between the two locations may due to the difference in carbonate content. El-Amrani *et al.* (1998) found that the MDD is increased with increasing carbonate content. In other words, the clay activity is significantly inhibited by higher carbonate content, or it could be attributed to the difference in particle size distribution (Okagbue and Onyeobi, 1999; Torrance, 1999). It was noted that at moisture content just slightly higher than the optimum moisture content and before the sample start showing a decrease in dry density (the points indicated by arrows in Fig. 11, 12), the soil showed a spongy behavior during compaction which complicated the compaction process. This implies that the soil could record a relative compaction exceeding 100% at 1-2% moisture content wet of the optimum, but this will cause rutting and spongy behavior during field rolling.

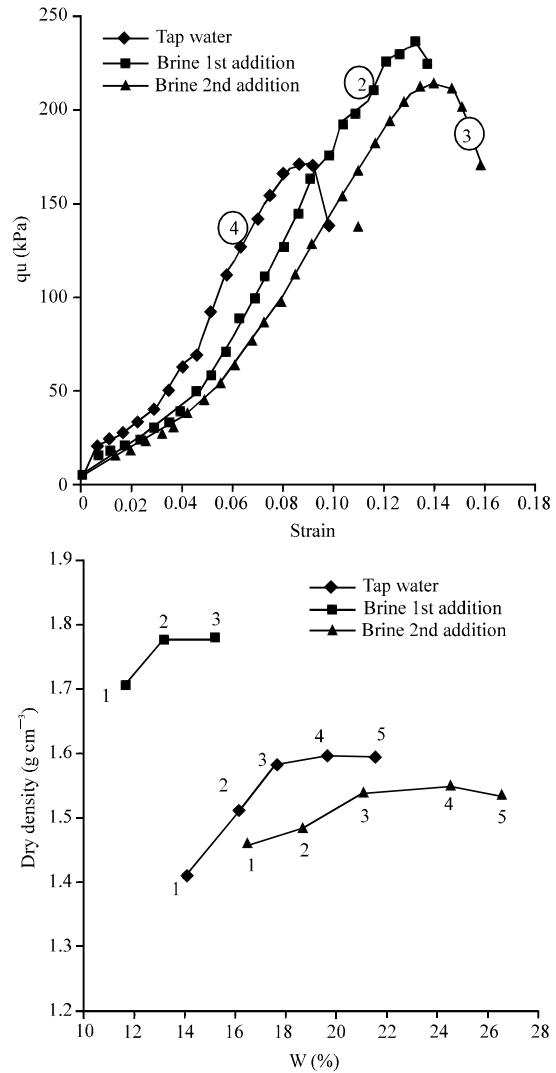


Fig. 13: Influence of fresh/brine water on the uniaxial strength and dry density-water content relationships-H location

Unconfined compressive strength: Figure 13 shows the unconfined compressive strength test results and the compaction curves for the H location. It is clear that the brine enhanced the marl compressive strength from 170 kPa in the case of 1st brine addition to 235 kPa after the second addition of brine water, while the strength recorded a value of 212 kPa in the case of using tap water. The increase in unconfined compressive strength upon using the brine for second time could be attributed to the precipitation of salts during drying the sample which play the role of cementing agent and/or to the lubricating effect of the Dead Sea brine that facilitated particles packing. The recorded higher value upon using tap water compared with brine (1st brine addition) is thought to be

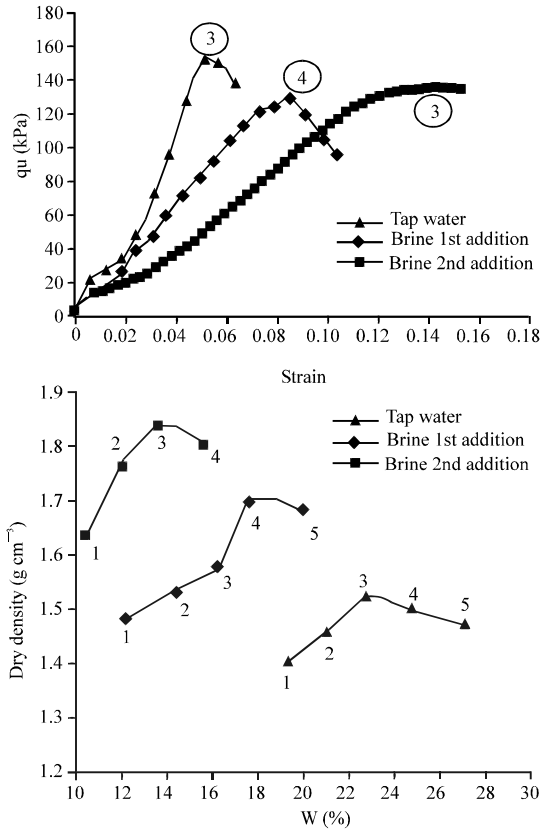


Fig. 14: Influence of fresh/brine water on the uniaxial strength and dry density-water content relationships-B location

resulted from chemical reactions of the tap water with the gypsum which was very clear during the soaking of the samples prior to conducting the specific gravity and liquid limit tests. López-Lara *et al.* (1999) defined gypsum as calcium sulfates with varying degrees of hydration and they found that it is possible to effectively employ gypsum as soil stabilizer, provided it has the proper hydration state. This explanation could be applied also to B location (Fig. 14). In addition, Gillot (1968) reported that the mineralogy, particle shape and particle size distribution have a significant effect on the soil strength. Okagbue and Onyeobi (1999) found that the large size and flakey shape of the mica present in certain soil in Nigeria inhibited the effectiveness of marble dust as stabilizing agent. For the soil in this study, the increase in unconfined compressive strength upon using tap water is possibly due to the weakening/dissolving of the cemented aragonite flakes (which were in abundant especially in the B location). The change in size and shape of the flakes during compaction affect the degree of packing and consequently enhance the compressive

strength. From chemical point of view, Frydman *et al.* (1977) found that adding KCl (which is one of the major salts in Dead Sea) to heavy clay decreased the cohesion intercept from 6.4 to 4.5 kg cm⁻² and increased the friction angle from 24° to 30°.

CONCLUSIONS

Based on the research results, the following conclusions are drawn

- Using of Dead Sea brine as testing media instead of distilled or tap water decreases the fine content, decrease liquid limit, increase maximum dry density and decrease optimum moisture content and increase the compressive strength of the Lisan Marl provided that the marl is hydrated with brine, dried up and thereafter rehydrated again with brine
- Compaction of the studied marl at wet side of OMC, even 1-2% beyond optimum, causes rutting and spongy behavior upon laboratory compaction test and site rolling or trafficking
- Since the dry sieving is inappropriate as the aggregated particles are not broken down the use of brine as washing media shall be adopted to reflect the actual site situation. This also applicable for determining the Atterberg limits
- For the H location the compressive strength could be significantly enhanced by soaking the marl by brine in borrow areas and then leave it to partially dry under the sun, re-spray it again with brine before mixing with the drier marl to obtain moisture content close to the OMC
- Fresh water gives higher unconfined compressive strength, lower MDD and higher OMC compared with brine water

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