STABILIZATION OF RAS AL-GHAR SABKHA
SOIL WITH LIME

Saad A. Alban, Ibraahiin M. Asi and O.S. Baghbra Al-Amoudi
Kuwait University of Petroleum and Minerals, Dharhan, Saudi Arabia

ABSTRACT: Sabkhas possess low density and strength in their natural state that necessitate their improvement prior to any construction. The available literature indicates that many geotechnical problems are associated with these soils mainly due to their high salt content, high compressibility and their susceptibility to strength loss and collapse upon wetting. This research program was carried out to assess the performance of lime-stabilized sabkha soil obtained from the Ras Al-Ghar area, eastern Saudi Arabia. The laboratory evaluation includes soil characterization, compaction, and unconfined and triaxial compression tests. Samples were compacted at different moisture and lime contents for washed and unwashed sabkha soils. The experimental results show that the molding and final moisture contents and the presence of salt significantly affect the strength of the sabkha. The addition of 5% lime improves the strength of the soil even when the samples are compacted at moisture contents higher than the optimum value.

1. INTRODUCTION
The large, salt-encrusted, evaporative flats are well-distributed over the globe. They exist in many places such as the Arabian Peninsula [1-3], Australia [4], the United States [5,6], and North Africa [7]. In Saudi Arabia, sabkhas extend intermittently for more than 1700 km along the Arabian Gulf southern and southwestern coasts with varying inland extensions that average 20 km in width. Sabkhas are also present along the eastern coasts of the Red Sea. These soils are situated either along the coasts or farther inland of many arid and semi-arid countries, where evaporation is considerably more than precipitation. Many geotechnical problems are associated with these soils due to their low strength, high compressibility and sensitivity to water. These problems emerge principally from the high salt concentration and the open "metastable" structure of these soils whereupon wetting water can easily penetrate through the soil, dissolve the salt and weaken the profound cementation. Therefore, the existence of such soils requires special considerations.

The term "sabkha" is an Arabic word used to describe the large, flat, evaporative areas, situated either along the coast "coastal sabkha" or farther inland "continental or inland sabkha". Sabkhas are saline flats that are underlain by sand and silt layers intercalated with halite and gypsum/anhydrite layers of various crystal shapes and thickness [3]. The high rates of evaporation result in the concentration of various salts in the groundwater that will ultimately diagenetically precipitate in the uppermost portion of the sediment profile or within the groundwater [5]. The buildup of salts at the surface results in the formation of the
hygroscopic crust which is usually hard when dry and becomes impassable when wetted. This also leads to the increase in salt concentration in the groundwater where layers of different salts can form within the soil.

Sabkha sediments are unusual deposits consisting mainly of sand (either silica or carbonate or both) and silt particles often cemented with different salts. The cemented layers are often separated by layers of uncedmented quartz sand and thin (1 to 6 cm thick) layers of soft white anhydrite. Layers of crystallized halite sometimes exist in sabkha soils with halite crystals of up to 4 cm in length. Further, small proportions of mud, clay and digenetic minerals could be observed at various depths. Thus, it has been postulated that each cemented layer is most likely the consequence of early digenetic changes at the top or close to the top of the prograding sediments prior to their burial under recent sediments [8].

It is well documented that the principal cementing materials filling the intergranular spaces and locally replacing grains are aragonite (in several growth forms) and microcrystalline magnesium calcite. The aragonite cement seems to be unstable and inverts locally to the more stable calcite form. Based on the evidence from several boreholes, it has been reported that the sabkha deposits appear to be cemented, and the process of cementation appears to be selective and varies with depth [9]. The coarser, more porous layers tend to be more readily cemented, while the finer, more sily layers frequently remain uncemented. The major constituents of coastal sabkhas are aragonite and calcite, in addition to the parent quartzose soil, with inclusions of gypsum and anhydrite, while the sediments of continental or inland sabkhas are dominantly composed of gypsum (desert roses), quartz and calcite, with halite always existing at the crust [9].

The main features of sabkha soils are: (1) concentrated groundwater brines, (2) low density and strength, (3) the existence of alternating soil/salt layers of varying thicknesses, (4) the variability of the geotechnical properties both in the horizontal and vertical directions, and (5) the existence of faint polygonal pattern with irregular units at the surface. These features have led to many problems such as: (a) the formation of depression and settlement in roads [8, 10], (b) the high collapse potential due to the high salt content and the open structure [3,11], and (c) variability in strength and compressibility leading to differential settlement [12,13]. These problems and others are challenging, while both the short- and long-term consequences are not fully understood. This presents an unacceptable risk in normal practice and requires urgent consideration for the improvement of the geotechnical properties of such soils prior to any construction [14].

2. SABKHA STABILIZATION
The increasing number of construction projects such as the expansion of the Saudi ARAMCO facilities, construction of new highways and airports, and the expansion of many localities in eastern Saudi Arabia, combined with the large extent of sabkha soils in the region, make the use of these soils inevitable. Such soils are used as a construction material for highways and roads or other constructions which are built over sabkha. Because of their low strength, these soils cannot be used as a foundation material in their natural state. However, when improved, they can be utilized for many applications [11]. Therefore, the improvement of sabkha soils, for construction purposes, should be a normal practice.
Several techniques have been employed to improve the inferior properties of sabkha. These techniques include: soil replacement, vibratory rollers, preloading, deep densification, stone columns, dynamic compaction, geotextiles and chemical stabilization [11,15]. For shallow depths, chemical stabilization of soils gained popularity due to its effectiveness and economical superiority. A search of the literature [3,11] indicates that chemically-stabilized sabkha has numerous applications as well as many advantages in the field of geotechnical engineering and pavement design. Farwana and Majidzadeh [10] used emulsified asphalt and investigated the effect of soaking on the engineering properties of both treated and untreated sabkhas. They observed some improvement in strength and stability and an ability to withstand repeated wet-dry cycles. Stipho [16] used lime and cement for the improvement of fine-grained and coarse-grained simulated-sabkha soils. Al-Amoudi et al. [17] studied the effect of adding cement, lime and emulsified asphalt at different percentages on the unconfined compressive strength of sabkha. They indicated that significant improvements were observed only for cement- and lime-stabilized sabkha mixtures. The addition of cement to the emulsified asphalt improved the engineering properties of sabkha [18,19]. This research presents a laboratory program to evaluate some engineering properties of lime-treated sabkha mixtures.

3. EXPERIMENTAL PROGRAM

3.1 Material
The sabkha soil and its brine were obtained from the Ras Al-Ghar vicinity, eastern Saudi Arabia. Samples were collected from all layers above the groundwater excluding the salt crust. The soil was mixed thoroughly and air-dried in the laboratory. Plastic hammers were used to gently break down the aggregated particles until all particles passed ASTM No. 10 sieve. The grain-size distribution curves for wet and dry sieving are shown in Fig. 1. According to the dry sieve analysis, the USCS and AASHTO classifications are SP and A3, respectively, compared to SW and A-2-4 according to the wet sieving. The wet sieving was performed using distilled water. Washing of samples resulted in a finer gradation because the salt was washed away. The percent passing ASTM sieve #200 is about 32% for the washed sample compared to only 2% for the dry sieving. This is attributed to the presence of halite which comprises about 15% of the sabkha matrix as determined from the XRD results [9].

3.2 Moisture-Density Relationship
The moisture-density curves for sabkha samples treated with different percentages of lime are shown in Figs. 2 and 3 for washed and unwashed samples, respectively. It is seen that the lime-stabilized unwashed sabkha mixtures did not bring any noticeable improvement in the maximum dry density ($\gamma_d,_{\text{max}}$) or the optimum moisture content ($w_{op}$). However, small variations were observed for the washed samples where the $w_{op}$ and $\gamma_d,_{\text{max}}$ are affected by the percentage of lime added. The $w_{op}$ varied between 12 and 14% while $\gamma_d,_{\text{max}}$ was in the range of 1.83 to 1.86 g/cm$^3$.  

Figure 1: Grain-size distribution of untreated sabkha samples.
3.3 Unconfined and Triaxial Testing

Cylindrical samples, 71 mm in diameter and 142 mm in length, were prepared at different percentages of moisture and lime contents. Both washed and unwashed sabkha soils were used and samples were allowed to cure for different periods. Three types of curing regimes were tried. In the first type, samples were allowed to cure in the laboratory without wrapping while in the second type, samples were wrapped in plastic sheets and were allowed to cure in the laboratory. In the third type, samples were allowed to cure outside the laboratory (outdoor) without any wrapping. The effect of molding moisture content ($w$) was investigated by preparing washed and unwashed sabkha samples treated with 5% lime at different moisture contents.

4. RESULTS AND DISCUSSION

Results in Fig. 4 show that the maximum unconfined compressive strength ($q_u$) occurs at $w = 14.5\%$. It also shows the $q_u$ for untreated sabkha samples compacted at $w = 14.5\%$. The 14.5% moisture content gives the maximum $q_u$ values because enough water was provided for lubrication and sabkha-lime reaction. In addition, the suction provided by the pore fluid decreases as $w$ increases. However, when $w$ increases beyond the 14.5%, the salts will dissolve and the bonding between particles will decrease. As a consequence, the 14.5% moisture content value was adopted for further investigation. This moisture content value was used for lime percentages other than 5% since the moisture density curves for these soils (Figs. 2 and 3)
show that the maximum density is not sensitive to the added lime. In addition, results in Fig. 4 show that the variation of the unconfined compressive strength values is not significant when the moisture content varies between 13 and 17%. It was, therefore, assumed that for other percentages of lime the 14.5% will give reasonable results.

It is also clear from the curves that the presence of salts (in the case of unwashed samples) results in higher $q_u$ values compared to those for washed sabkha. The influence of cementation provided by the salts resulted in an increase in $q_u$ from 42 kPa to 54.3 kPa (average values at $w = 14.5\%$), which corresponds to approximately 29%, and is totally attributed to the presence of salts. The $q_u$ values for washed and unwashed sabkha samples treated with 5% lime, at $w = 14.5\%$, are 3.4 and 3.8 times that for the untreated washed and unwashed sabkhas, respectively. It should be clear, however, that the strength gain due to the lime addition is not significant when compared to that due to cement addition [11].

The $q_u$ values for washed and unwashed sabkha samples treated with different percentages of lime and compacted at a moisture content of 14.5% are shown in Fig. 5. Fig. 6 shows the effect of curing period for samples prepared at $w = 14.5\%$. It is clear that the strength gain continues with time even after 18 days of curing. These results indicate that the $q_u$ values for unwashed sabkha are higher than those for washed sabkha regardless of the lime content or curing period.

The data in Fig. 7 indicate that the $q_u$ values are highly dependent on the curing regime. These results show that samples cured outdoor under unwrapped conditions have higher $q_u$ values compared to those cured indoor (in the laboratory) under unwrapped conditions. These results also show that the laboratory unwrapped samples have higher $q_u$ values compared to the wrapped ones. This is mainly due to the low moisture content at testing at which the lime particles form a bridging effect between the sandy particles thereby providing cementation. The effect of curing temperature has also a significant effect on the strength of lime-treated soil. Higher temperature accelerates the reaction between the soil and lime and early strength gain is obtained. The presence of salt in the unwashed sabkha samples results in an increase in the $q_u$ values.

![Graph showing variation of $q_u$ values with lime content](image1)

**Figure 5:** Variation of $q_u$ values with lime content ($w = 14.5\%$, wrapped in the laboratory for 7 days).

![Graph showing effect of curing period on $q_u$ values](image2)

**Figure 6:** Effect of curing period on the $q_u$ values ($w = 14.5\%$, 5% lime, wrapped in the laboratory).
Consolidated-undrained triaxial tests were conducted using specimens similar to those used in the unconfined compressive strength tests. The samples were wrapped in plastic sheets and were allowed to cure for 7 days in the laboratory at room temperature and tested in as-molded condition (i.e. without saturation). No volume change or pore pressure was measured during the test. The peak values for each test are plotted in Fig. 8. The values of the angle of internal friction ($\phi$) for the washed and unwashed sabkhas are 36.8° and 37.2° and the cohesion values are 23.6 and 34.2 kPa, respectively. It is clear from the curves that the difference between washed and unwashed treated sabkhas is not great especially with respect to $\phi$. This trend has recently been observed by Al-Amoudi and Abduljauwad [20] when testing undisturbed sabkha samples using consolidated-undrained and consolidated-drained triaxial tests.

5. CONCLUSIONS
The experimental work undertaken in this research program produced data for lime-stabilized sabkha soils. In addition to the lime content, the strength of the soil is highly dependent on the molding moisture content, the curing regime and curing time, and the presence of salt in the sabkha. The maximum dry density and optimum moisture content were found to be insensitive to the percentage of added lime for the case of unwashed sabkha, however small variations were noticed for the washed sabkha samples. The unwashed sabkha has higher strength compared to the washed sabkha due to the presence of salt. Samples cured outdoor have higher strength compared to those cured in the laboratory. In addition, the lower the moisture content at testing the higher are the $q_u$ values. The addition of small percentages of lime to sabkha soils will improve the strength and the strength increases with time even after 18 days of curing.

ACKNOWLEDGEMENT
The authors acknowledge the support provided by King Fahd University of Petroleum and Minerals, Dhahran, Saudi Arabia.
REFERENCES


