Variability and characteristics of eastern Saudi Sabkha soils

Variations et caractéristiques des sols du Sabkha de la province Est de l'Arabie Saoudite

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ABSTRACT: Sabkha soils constitute relatively a large proportion of the eastern Saudi surficial soils. These soils possess low density and strength in their natural state. Many geotechnical problems are associated with these soils due to their high salt content and their susceptibility to strength loss and collapse upon wetting. Further, the heterogeneity of sabkha soils is reflected by their variable characteristics and layering of different constituents, even within the same site. Accordingly, the retrieval of representative samples tends to be a fundamental problem facing the geotechnical society. In order to study the variability of sabkha soils and their engineering characteristics, samples were collected from 20 pits distributed all over the Eastern Province of Saudi Arabia. For each pit, the morphology of the sabkha was described and representative samples were taken for soil characterization and classification. In addition, compaction and CBR tests were conducted to determine the optimum moisture content from both density and strength perspectives. Results of this investigation indicate that sabkha soils in eastern Saudi Arabia exhibit significant variability and the strength is mainly dependent on the moisture content regardless of the dry density.

RESUME: Les sols du sabkha constituent une grande proportion des terres de la Province Est de l'Arabie Saoudite. Dans leur état naturel, ces sols possèdent une densité et une force très faibles. La forte teneur en sel de ces sols et leur suscèptibilité de se fondrent quand ils sont mouillés posent plusieurs problèmes géotechniques. Par ailleurs, l'hétérogéneité des sols du sabkha est reflétée par ses caractéristiques variables et des couches de différents constituants du même endroit. En conséquence, le retrait des échantillons représentatifs s'avère être un problème fondamental pour la société géotechnique. Dans le bût d'étudier la variation des sols du sabkha et leurs caractéristiques techniques, des échantillons ont été prelevés de 20 fosses, répartis dans toute la Province Est de l'Arabie Saoudite. Pour chaque fosse, la morphologie du sabkha était décrite et les échantillons représentatifs étaient pris pour la spécification et la classification des sols. En plus, les essais de tassement et de CBR ont été réalisés afin de détèrminer le teneur maximum d'humidité dans les pèrspectives suivantes: densité et force du sol. Les résultats de cette étude montrent que les sols du sabkha dans la Province Est de l'Arabie Saoudite indiquent une variation importante du sol et sa force est principalement dépendente de la teneur de l'humidité sans tenir compte de la densité sèche.

1 INTRODUCTION

Within the tropics, hot and arid climates, with considerably more evaporation than precipitation, are conducive to the production of "evaporitic" soils. The local names for these "saline" flats are numerous with various nomenclatures, and often highly bewildering (Ellis 1973), due to the considerable ramification of shallow water table situations over the globe (Fookes et al. 1985), as well as to the interaction and interest of many fields of knowledge (i.e. geology, sedimentology, hydrology, civil engineering, etc.) in these sediments. Sabkha (spelled sometimes as sabkhah, sebkha, subkha) is originally an Arabic term, that has long been in use, to describe indefinitely saline flats that are underlain by sand, silt or clay, and often encrusted. Sabkhas' surfaces are usually hard enough to support a medium-weight vehicle, and become so impassable when wetted that a person would sink in nearly to knee depth. From geotechnical perspectives, sabkha flats are distinguished as being large, flat, salt-encrusted, evaporative terrains situated either along the coasts (*coastal sabkhas*) or farther inland (*continental* or *inland sabkhas*).

2 GEOTECHNICAL FEATURES OF SABKHA SOILS

A review of the global distribution of sabkha (Al-Amoudi 1995) indicates its extensive presence in Egypt, Sudan, Libya, Tunisia, Algeria, Ethiopia, India, Australia, USA, Russia, Mexico and Southern Africa. A recent search of the literature (Aiban et al. 1995) indicates that the variability of its geotechnical characteristics and the presence of shallow and highly concentrated brines are the distinguishing features of a sabkha system. Geotechnically, sabkha soils are considered to be highly variable in terms of grain size and shape, texture, degree of cementation, layering, density, etc. Sabkhas generally exist in the form of alternating uncemented and cemented layers, as well as in the form of lumps of quartz and/or carbonate sand. It is not unusual to observe pure layers of varying thicknesses of halite, gypsum or anhydrite (Aiban et al. 1995).

The concentrated nature of sabkha brines is reflected by a total dissolved solids five times that present in a typical sea water. Moreover, the presence of diagenetic minerals adds up to the salts' concentration. These characteristics make the sabkha media highly corrosive to both concrete and steel, thereby enhancing the susceptibility of reinforced concrete to deterioration. Despite these hostile attributes, very little has been published on the anomalous characteristics of sabkha soils. A typical example is the accurate determination of the geotechnical properties of sabkha which has not yet been fulfilled. The presence of soluble salts makes the use of distilled water (DW) in testing for permeability and grain-size distribution, for example, as recommended by international standards (i.e., ASTM, BS, DIN, etc.), inappropriate (Al-Amoudi & Abduljauwad 1994). Another peculiar characteristic of the sabkha is related to its low strength, which is primarily derived from cementation by the soluble and insoluble salts. The degree and type of cementation vary reasonably, thus making the sabkha soil susceptible to leaching and dissolution or softening thereby leading to strength loss in wet conditions or sometimes to "collapse" in extreme cases (Abduljauwad & Al-Amoudi 1995).

The surficial layers in the sabkha deposits often have excessively low strength (i.e. $q_u \leq 20$ kPa and SPT ≤ 5). These inferior

characteristics have resulted in considerable damage to pavements and superstructures of all kinds. It is fair to state that the bearing capacity and compressibility characteristics of these soils rarely meet routine design requirements. The collapse potential, itself, presents an unacceptable risk in normal practice and calls for the improvement of mechanical properties of sabkha soils prior to any construction, particularly when the sabkha flat is inundated with water (Aiban et al. 1995). Consequently, great caution is required in interpreting the field test results (Juillie & Sherwood 1983).

3 EXPERIMENTAL PROGRAMME

Sabkha terrains constitute roughly about one fourth of the eastern Saudi surficial soils. Further, the variability of sabkha soils makes it difficult, if not impossible, to retrieve representative samples from every locality therein. It was therefore decided to survey only those locations that are easily accessible and currently close to, or within, construction, urbanization, highways, etc., or otherwise may be of potential use to those types of activities in the near future. Such a decision was also demanded by the variable characteristics of each sabkha (Aiban et al. 1995), because some of the sabkhas are so extensive that many samples could be taken from them, each of these samples will exhibit distinctly different characteristics.

3.1 *Collection of samples*

Based on the above strategy, twenty sabkha locations were selected from all over eastern Saudi Arabia. Samples were collected from Ar-Riyas, Al-Fasl, An-Nabiyah, Al-Aziziyah and Al-Qurayyah sabkhas (Figure 1). Once a sabkha pit was dug out and the water table was reached, the materials from vertical slice(s) were collected to embody all the layers up to the water table excluding the crusts and pure halite layers. Thereafter, the materials were placed in plastic bags and labelled and transported to the geotechnical laboratories. They were then spread on plastic sheets for air drying and then mixed and the lumped pieces were separated in the open air using rubber hammers until all materials passed ASTM Sieve # 4. The samples were again thoroughly mixed and representative samples were stored in plastic drums until testing.

3.2 *Methodology of testing*

The Unified Soil Classification System (USCS) and the American Association of State Highway and Transportation Officials (AASHTO) system are frequently used to classify the soils based uniquely on: (i) the grain-size distribution, and (ii) the Atterberg limits (i.e. the liquid and plastic limits). When testing sabkha soils, it has been recommended to conduct these tests using sabkha brine (SB) from the same vicinity (Al-Amoudi & Abduljauwad 1994). For the sake of relative comparison, both distilled water (DW) and sabkha brine (SB) were used, however, the soil classification was totally based on the tests conducted using SB.

It is worth mentioning that: (i) the grain-size distribution for all sabkha samples was totally determined using washed sieve analysis, as per ASTM D 422, and (ii) although each sabkha pit predominantly composes of many layers, all the layers above the ground water table in each pit were retrieved as a whole unit.

The liquid and plastic limits were conducted in general accordance with ASTM D 4318 using DW and SB. The modified Proctor (i.e. compaction) test (ASTM D 1557) was used to determine the maximum dry density ($\gamma_{d\,max}$) and optimum moisture content (w_{opt}). Similarly, the California-bearing ratio (CBR) test (ASTM D 1833) was conducted for each sample prepared for the compaction test to determine the maximum CBR (CBR_{max}) and the corresponding optimum moisture content (w'_{opt}).

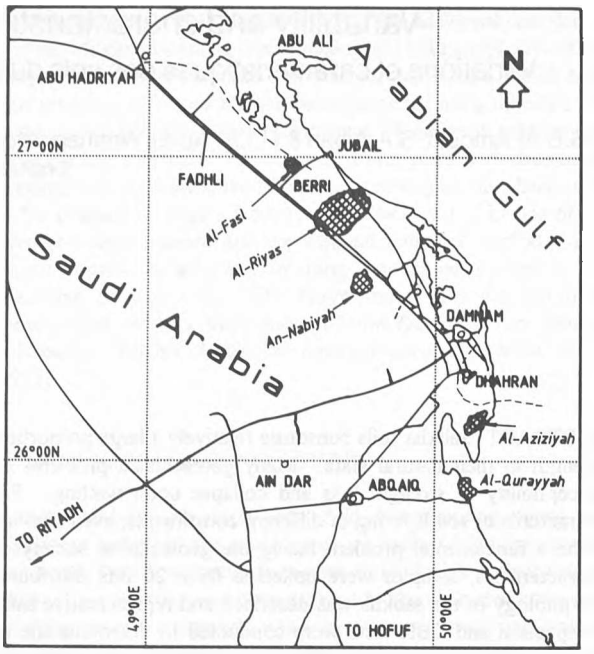

Figure 1. Vicinity map showing major eastern Saudi sabkhas.

4 RESULTS AND DISCUSSION

4.1 *Characterization of eastern Saudi sabkhas*

A summary of the classification results is presented in Table 1 for the twenty sabkha pits. The data therein indicate that out of the 20 sabkha soils, only four possess plasticity. The range of liquid limit (LL), measured using SB, varied from 24.8% to 34.5% . Similarly, the plastic limit (PL) varied from 15.2% to 21.1%. The plasticity index varied from 7.2% to 13.6%. Despite this low plasticity, it proves that some eastern Saudi sabkhas possess plasticity.

To discuss the grain-size distribution and plasticity test results, Figures 2 and 3 are presented as typical data for the sake of demonstration. For Ar-Riyas Pit # 1, the data in Figure 2 and Table 1 indicate that there is a significant amount of fine-grained particles; the percentage passing ASTM Sieve # 200 was 65% and 87% using SB and DW, respectively. Such a difference (22%) is attributed to the prevalence of halite in this pit, which was dissolved by DW.

Regarding the LL results, the data for Pit # 9 are presented in Figure 3, whereby some peculiar trends could be observed. Firstly, the LL displayed distinct and large difference in the case when either SB and DW was used. The LL was 34.5% and 44.9% for SB and DW, respectively; the difference being 10.4%. Logically, DW will dissolve some of the salts in the sabkha matrix and will, therefore, alter the plasticity of the soil. The PL values were 21.1% and 27.8% for SB and DW, respectively. This behaviour was also observed for all the other plastic sabkha soils (Table 1). Secondly, the higher liquidity and plasticity due to the use of DW, as compared with SB, is attributable to dissolution of the salt thereby making the sabkha more fluidized compared with the presence of crystallized halite that will inhibit this behaviour. Lastly, the variation in the number of blows with moisture content observed in Figure 3 follows the classical trend when DW was used. However, when SB was used, there was practically no difference in the moisture content with the change in the number of blows; such a behaviour is, more or less, observed for all the plastic sabkha soils.

4.2 *Geomorphology of eastern Saudi sabkhas*

The data in Table 1 indicate that each sabkha displays its own characteristics. Due to space limitation, the geomorphology of only

Table 1. Summary of the sabkha classification, compaction and CBR test results.

Pit No.	Sabkha Brine				Distilled Water				Classification*		Compaction Test		CBR Test	
	- # 200	LL (%)	PL (%)	PI (%)	- # 200	LL (%)	PL (%)	PI (%)	USCS	AASHTO	γ_{dmax}	w_{opt} (%)	CBR_{max}	w'_{opt}
Ar-Riyas 1	65	-	-	NP	87	-	-	NP	ML	A-4	1.91	10.8	66	6.0
Ar-Riyas 2	34	-	-	NP	64	-	-	NP	SM	A-2-4	2.03	7.7	84	6.4
Ar-Riyas 3	21	-	-	NP	41	-	-	NP	SM	A-2-4	1.94	11.2	89	9.4
Ar-Riyas 4	1.8	-	-	NP	13.4	-	-	NP	SP	A-3	1.85	10.5	32	8.6
Ar-Riyas 5	17.3	-	-	NP	34.5	-	-	NP	SM	A-2-4	2.02	10.8	90	8.7
Ar-Riyas 6	14.6	-	-	NP	31.4	-	-	NP	SM	A-2-4	2.02	8.3	73	6.2
Ar-Riyas 7	43	-	-	NP	62	-	-	NP	SM	A-4	1.89	11.5	78	7.2
Ar-Riyas 8	34	-	-	NP	47	-	-	NP	SM	A-2-4	2.00	9.1	80	6.5
Ar-Riyas 9	76	34.5	21.1	13.4	97	44.9	27.8	17.1	CL	A-6	1.73	16.5	56	14.0
Ar-Riyas 10	78	-	-	NP	92	-	-	NP	ML	A-4	1.75	17.4	65	11.3
Ar-Riyas 11	7.5	-	-	NP	26	-	-	NP	SP-SM	A-3	1.84	11.9	93	9.8
Ar-Riyas 12	9	-	-	NP	25	-	-	NP	SP-SM	A-3	2.03	8.0	88	5.8
Ar-Riyas 13	19	-	-	NP	33	-	-	NP	SM	A-2-4	1.97	11.8	108	9.8
Ar-Riyas 14	81	24.8	17.6	7.2	95	36.1	23.5	12.6	ML-CL	A-4	1.76	16.2	70	9.0
Al-Fasl 15	36	27	18.7	8.3	46	30.7	20.7	10	SM-SC	A-4	1.90	13.6	113	12.7
An-Nabiyah 16	53	28.8	15.2	13.6	62	38.8	21.4	17.4	CL	A-6	1.75	17.6	80	14.2
Al-Aziziyah 17	4.4	-	-	NP	12	-	-	NP	SP	A-3	2.05	6.5	46	6.5
Al-Qurayyah 18	28	-	-	NP	44	-	-	NP	SM	A-2-4	1.91	12.6	124	9.6
Al-Qurayyah 19	55	-	-	NP	73	-	-	NP	ML	A-4	1.85	15.0	52	10.8
Al-Qurayyah 20	39	-	-	NP	52	-	-	NP	SM	A-4	1.83	15.3	108	10.9

*Based on tests using sabkha brine LL : liquid limit PI : plasticity index

PL : plastic limit - # 200 : passing sieve # 200

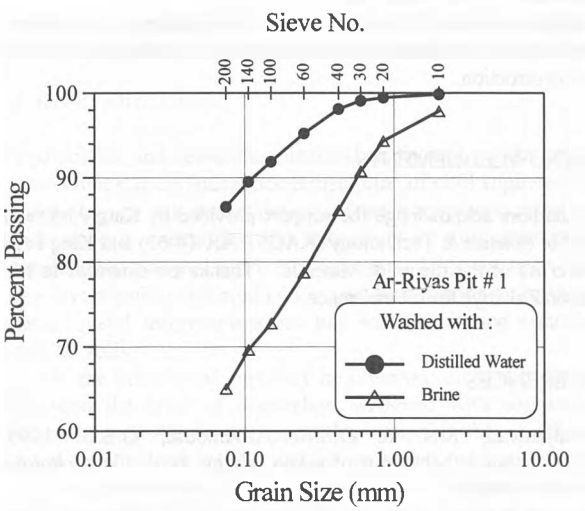

Figure 2. Typical grain-size distribution curves for sabkha.

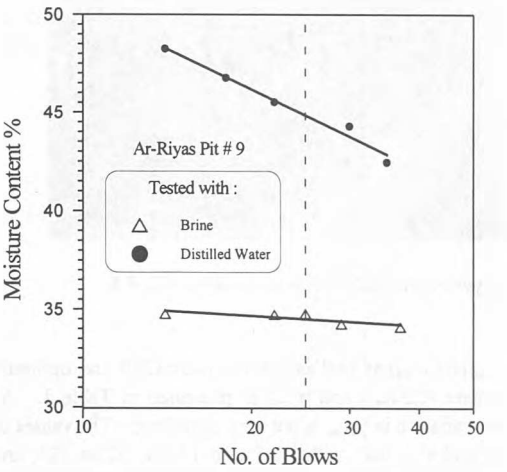

Figure 3. Typical liquid limit data for sabkha.

two sabkha sediments; from the gigantic Ar-Riyas sabkha is described below. It is worth mentioning that this sabkha is described in detail by Al-Amoudi et al. (1992) and Johnson et al. (1978). The two pits were close to each other, nevertheless, they exhibited significantly different geomorphology thereby demonstrating the variability of sabkha soils.

Ar-Riyas Pit # 1: This pit was located at 1.3 km west of the Dammam-Jubail highway, near Al-Ju'aimah exit (60 km from Dammam), as shown in Figure 1. The surface is even and predominantly covered with polygons, which were not well-formed in the vicinity of the pit. When this pit was dug, a thick (i.e. 4 to 6 cm), hard salt layer was observed on the surface. Thereafter, there existed a sandy silt layer of 11 cm interbedded with anhydrite and large (i.e. up to 4 cm in length) crystals of halite. Followed in succession was a 5 cm layer of pure anhydrite with some halite crystal. A 4 cm layer of brownish-yellowish clayey silt with some anhydrite was observed thereafter, followed by another 4 cm layer of brownish clay layer of low plasticity. At a depth of about 30 cm, a layer of large crystals of halite was observed with traces of greenish-grey, hard clay. This layer could not be dug using manual equipment and also a loader failed to go through, even for 30 cm. The water table was observed at a depth of 37 cm.

Ar-Riyas Pit # 8: Its location was about 1.4 km southeast of Pit # 1. It was characterized by large polygons, the height of their fractures (pressure ridges) was about 40 cm (Figure 4). The surficial layer consisted of about 4 to 5 cm of solid salt, followed by brownish clayey silt layer of about 8 cm. Thereafter, an anhydrite layer of about 10 cm thick was observed with some grey sediments, followed by dark brown, fine silty soil with very low plasticity. Another pure anhydrite layer was encountered thereafter. Some halite crystal cubes, 1 to 1.5 cm in size, were observed throughout the sediments. Three to four hours after digging, the water table depth was observed to be 60 cm. Figure 5 depicts the geomorphology of Ar-Riyas sabkha # 8.

The geomorphology of Pits # 1 and 8 indicates that the presence of gypsum/anhydrite layers is a characteristic of the Arabian Gulf sabkhas. Sometimes, many bands of anhydrite layers could be seen, in a way similar to varved clays observed in soil mechanics textbooks. These characteristics are known to affect not only the characterization of sabkha soils but also their geotechnical properties, because the hydration/dehydration of gypsum/anhydrite is associated with a significant volume change (Al-Amoudi 1995).

4.3 *Density and strength of eastern Saudi sabkhas*

A summary of the maximum dry density and optimum moisture

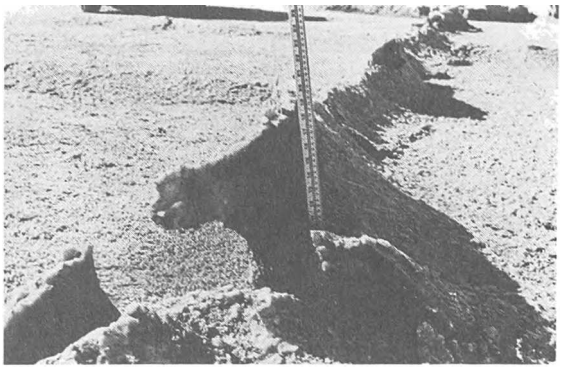

Figure 4. A typical pressure ridge in sabkha (around Pit # 8).

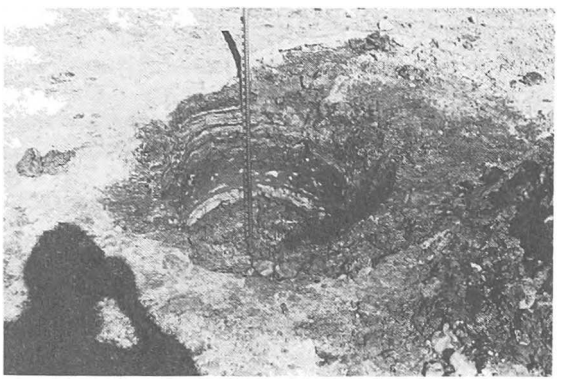

Figure 5. Layering characteristics in Ar-Riyas Pit # 8.

content ($\gamma_{d\,max}$ and w_{opt}) as well as the maximum CBR and optimum moisture content (CBR_{max} and w'_{opt}) is presented in Table 1. As expected, the variation in $\gamma_{d\,max}$ is not very significant. The values of w_{opt}, CBR_{max} and w'_{opt} vary within 6.5% to 17.6%, 32 to 124, and 5.8% to 14.2%, respectively. These values, particularly the CBR ones, are very broad and vividly demonstrate the heterogenous nature of the mechanical properties of sabkha soils. Such variability calls for proper characterization prior to any construction. It is worth mentioning that the sabkha soil in Pit # 17 recorded the highest $\gamma_{d\,max}$, however, its CBR was the second lowest. This indicates that the $\gamma_{d\,max}$ cannot be considered as a decisive criterion in any strength or stabilization programme (Al-Amoudi 1995).

A typical presentation of the γ_d–w and CBR–w curves for Ar-Riyas Pit # 1 is reported in Figure 6, whereby the $\gamma_{d\,max}$ and w_{opt} were 1.91 g/cm^3 and 10.8%, respectively. At this w_{opt}, which was obtained from the γ_d–w curve, the CBR was only 20, which is much lower than the CBR_{max} of 66 at an w'_{opt} of 6%. Should any further reduction in w have occurred, it might have brought an increase in CBR. Consequently, the CBR attained very low values at high moisture contents. These data indicate that sabkha soils possess low strength at high moisture contents. Such characteristics are observed for all the twenty sabkha soils (Aiban et al. 1995) and, hence, demonstrate the susceptibility of sabkha soils to strength loss once inundated by water.

5 CONCLUDING REMARKS

This investigation was conducted to characterize eastern Saudi sabkha soils. The results indicate that sabkha soils display significant variations in terms of classification, density and strength. Such variations were observed even within short distances and attributed

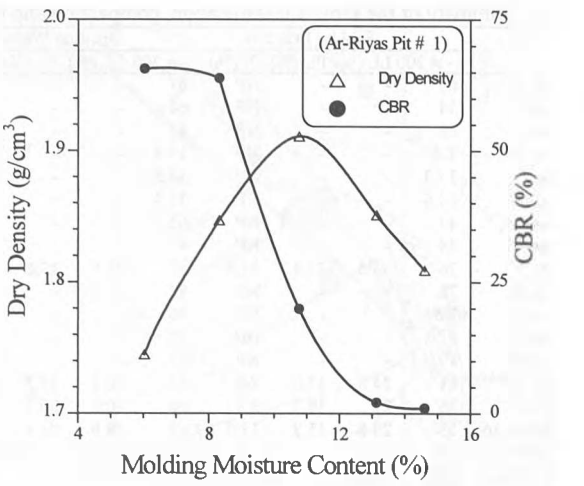

Figure 6. Typical compaction and CBR data for sabkha.

to the presence of diagenetic minerals, namely: gypsum, anhydrite and halite. The results also demonstrated the susceptibility of sabkhas to strength loss once wetted, irrespective of the density. Such characteristics call for the improvement of sabkha soils prior to any construction.

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