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Geotechnical and Geochemical Properties of Al-Nekhaila Sabkha, South of Jeddah

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ABSTRACT. Sabkhas are widespread along the coastal plains of the Red Sea. The development of sabkha is mostly attributed to the hot climate where evaporation, which is responsible of the development of brines, largely exceeds precipitation. The soil poses several geotechnical problems specially when wet. The high sulfate and chloride content in the groundwater may also cause corrosive action on reinforced concrete.

The city of Jeddah is rapidly expanding and new residential and commercial buildings are constructed each year in the area close to the shoreline where sabkhas exist. If the expansion extends southward, it will reach Al-Nekhaila sabkha. Therefore, the geotechnical and geochemical characteristics of this sabkha were considered. The field investigations were performed by three in situ tests, namely Mackintosh probing, vane shear, and sand cone, to a maximum depth of 9 m.

Three main soil units have been identified; sand (SM, SC, and SP), silt (ML, and MH) and clay (CL, and CH). The salts are present as cementing material between the soil grains in the top one meter. The sand ranges from loose to medium dense as indicated by the soil probing. The average undrained shear strength for the silt is 84 kN/m^2 and for the clay is 90 kN/m^2. Some geotechnical problems are expected from the clay layer. The groundwater level is 1 m to 2.5 m deep and is classified as saline to brine.

Introduction

The studied sabkha lies in the coastal plains of the Red Sea known as Tihama. The coastal plains vary in width from 2 km to 40 km where a series of isolated sabkhas extend from Ummlajj in the north to Jizan in the south. They are associated with wadi outlets, lagoonal margins intertidal or supratidal flats and low lands bounded by corals or sheets of sands close to the shore (Kinsman, 1969; and Ali and West, 1983). To the east of the sabkha areas lies piedmont cut on Tertiary and Precambrian rocks. The piedmont is covered in part by alluvial fans, eolian sand and wadi alluvium.

Numerous geotechnical studies have been conducted in the city of Jeddah and to the north of it, but very few have been investigated in the south (Sabtan and Shehata, 1984; Ali and Hossain, 1988; and Bahafzullah *et al.* 1993). Al-Nekhaila sabkha (Fig. 1) is located 27 km south of Jeddah city center and about 3 km south west of Al-Gozane village. It is a supratidal salt flat of about 5 km^2

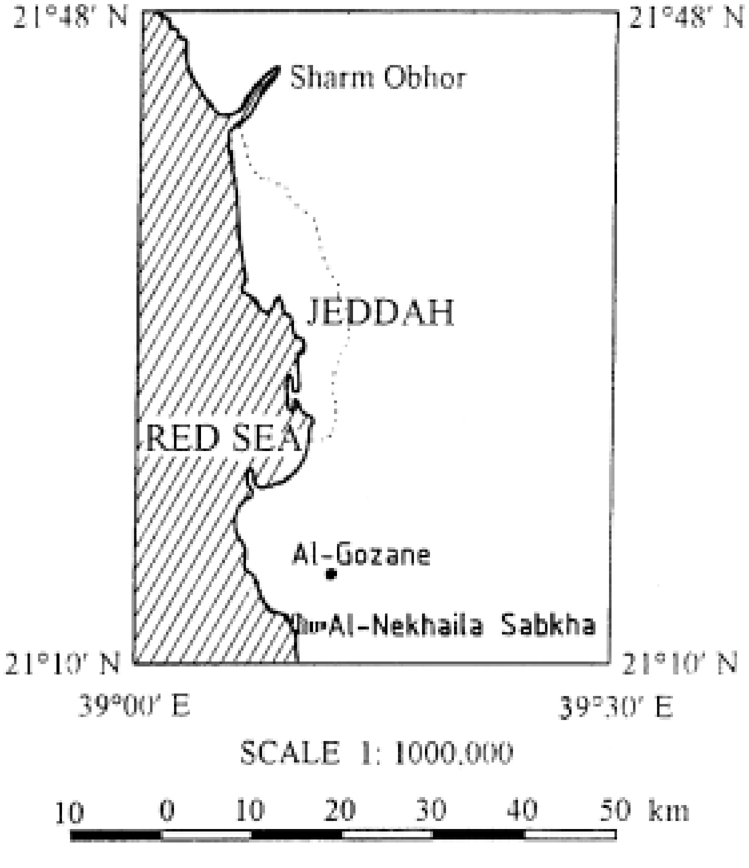

FIG. 1. The location map of Al-Nekhaila sabkha.

deposited in a shallow depression. It is restricted from the sea, but during high tide the sabkha is flooded by water through a narrow outlet in the northwest.

This outlet was however closed 20 years ago by a road pavement. The inland flooding may occur through two small tributaries from east and northeast.

The upper layer of the sabkha soil consists of a thin (50 cm - 70 cm) and hard salty crust with halite and disseminated gypsum, which is formed due to the evaporation of the groundwater. It is continuously wet due to capillarity and has the ability to capture isolated veneers of eolian sand, which accumulates around dead bushes. The sabkha is surrounded by 2 m to 3 m high areas of raised coral reefs. The area is characterized by desert climate with a maximum precipitation of 124 mm in wet period (December through January).

The objective of this paper is to investigate the geotechnical and geochemical characteristics of this sabkha, asses its engineering problems and discuss the effect on foundation and Portland cement.

Field Investigation

The studied area was outlined using aerial photographs and Landsat images, while its boundary was visually identified in the field (Fig. 2). Surveying by the

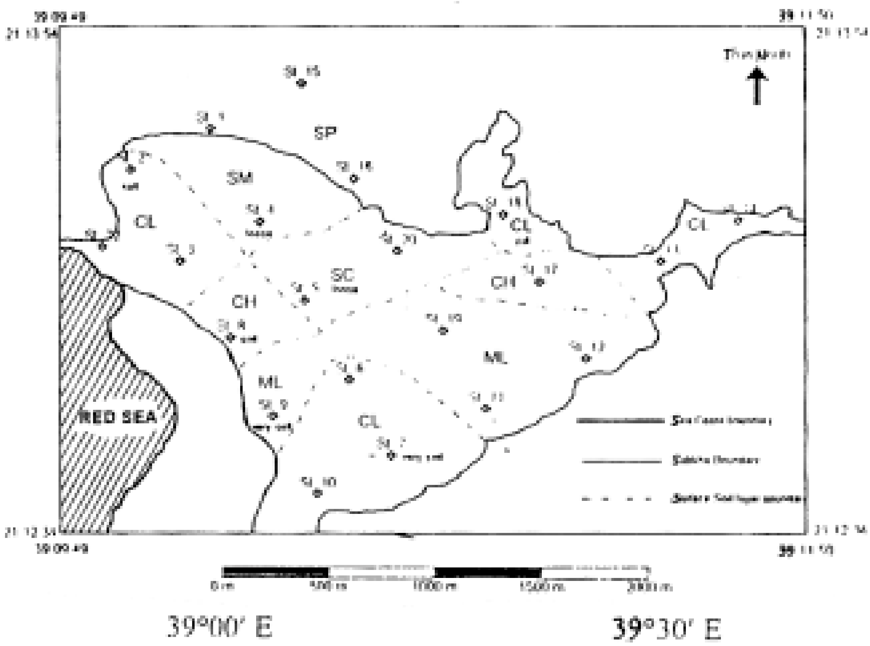

FIG. 2. Al-Nekhaila sabkha boundary and surface soil type.

aid of an Abney level (hand level) was used to establish a grid of 210 points among which 21 points, 500 m apart were chosen as stations for field investigations. Soil sampling was carried out in each station at 15 cm depth intervals using a light portable helical power auger and to a depth of 1.5 m. The soil samples were classified and a fence diagram was drawn (Fig. 3) showing the spatial and depth distribution of the soil types. The physical properties were also obtained for selected samples. Sounding using the light dynamic Mackintosh penetrometer was performed to a maximum depth ranging from 2 m to 9 m. More details of this fast and cheap probe were reported by several researchers (Chan and Chin, 1972; Hossain and Ali, 1988; Sabtan and Shehata, 1994 and Serhan, 1998). Water samples were collected and water levels were measured three days after the drilling date in order to allow the water level to attain equilibrium. The water level measurements and sampling were conducted both in the winter and the summer.

Soil Types and Distribution

Al-Nekhaila sabkha is composed of several interfingering soil units of sand, silt, and clay (Fig. 3). The sand varies both laterally and vertically, in color, grading, relative density and percentage of fines and gravel. It could be divided into three subunits: 1) silty sand (SM), 2) clayey sand (SC), and 3) poorly graded sand (SP). The silty sand (SM) is grayish brown, with 5% to 10% fine and exposed in the northern part where it ranges in thickness from 0.3 m to 2.0 m. The clayey sand (SC) is brown in color, and the encountered layers hardly exceed 1.0 m in thickness. The poorly graded sand (SP) is brown in the east to gray in the west. The silt (ML) is exposed mainly at the surface in the middle of the area where it changes in color from brown in the west to dark gray in the east. The clay is exposed at the surface except in the middle and north parts of the area and attains a thickness of 0.4 m to 3.0 m. It can be divided into three subunits that exist at different depths. A brown sandy clay (CL to CH) subunit occurs at the eastern part. As going to the west, the percentage of sand decreases and the subunits become dark gray clay with some sand (CH). The third subunit is dark brown to gray clay (CL) in the north east, in the middle and in the extreme east.

Geotechnical Properties

The range of the M-values for the silty sand (SM), poorly graded sand (SP) and clayey sand (SC) as measured by the Mackintosh probe in blows per 30 cm of penetration are 15-111 (very loose to medium dense), 15-98 (very loose to medium dense) and 19-106 (very loose to medium dense) respectively. The average moisture content (w) values are 11%-45% for the silty sand, 5%-35% for the poorly graded sand and 11%-36% for the clayey sand.

The silt is of low plasticity (ML) in general. It varies from very soft (M=5-83 blows/30cm) to very stiff (M=38-77 blows/30cm). The undrained shear strength

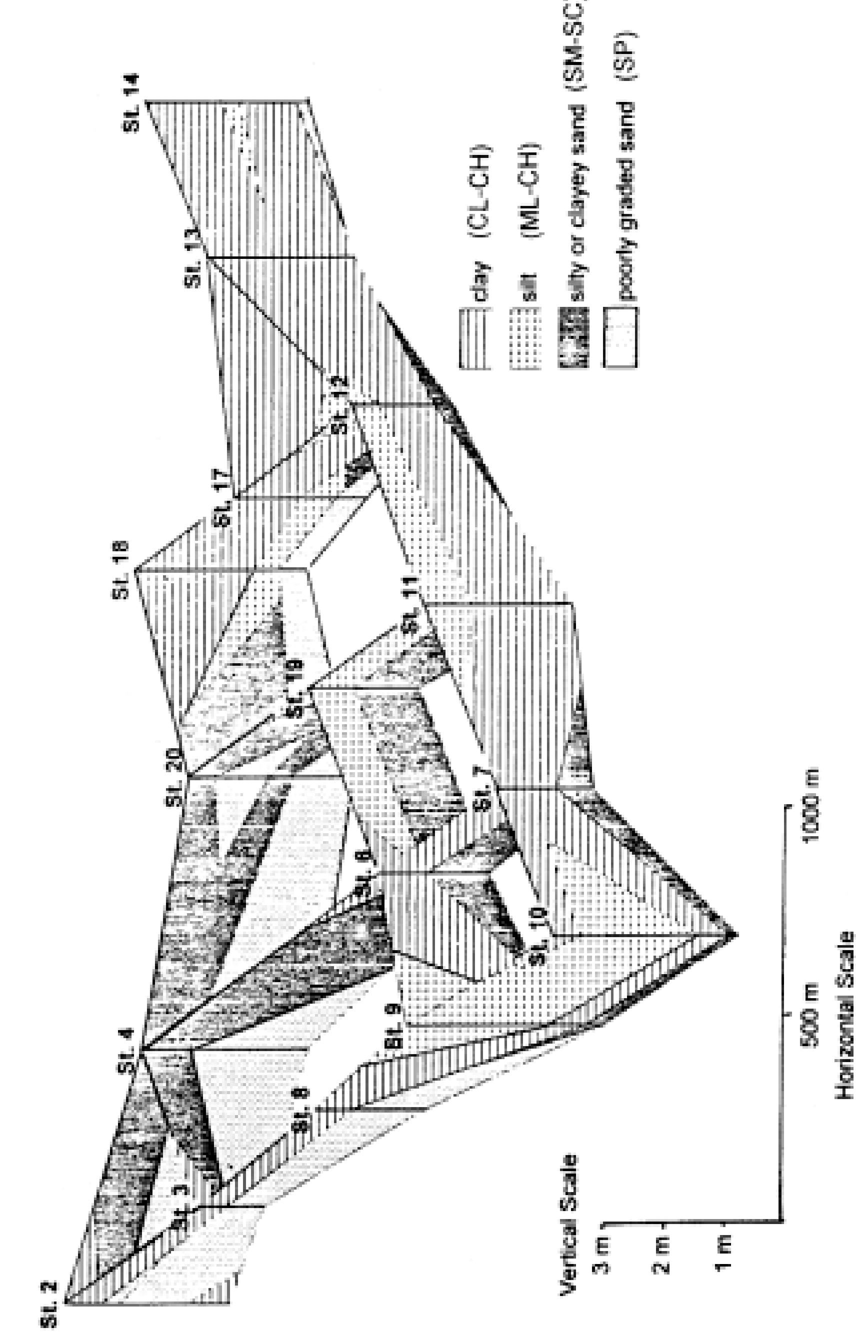

FIG. 3. Fence diagram of the different soil types of Al-Nekhaila Sabkha.

(S_u-value) of the silt ranges from 12 kN/m^2) very soft) to 140 kN/m^2) very stiff). The range of the moisture content (w) is 16% - 73%. The low plasticity silt changes gradually into silt with high plasticity (MH) in the north east. The average M-value is 18 blows/30cm (soft) and the moisture content is 52%-64%.

The characteristics of the clay (CL or CH) at different locations are demonstrated in Table 1. The plastic limits of the lean clay (CL) and the fat clay

TABLE 1. Some characteristics of the clay

Station number	2 (CL)	8 (CH)	10 (CL)	11 (CL)	13 (CL)
Field density (g/cm^3)	1.93	1.63	1.73	1.87	1.63
Specific gravity	2.87	2.57	2.40	2.68	2.64
Dry density (g/cm^3)	1.53	1.02	1.25	1.40	1.09
Saturated density (g/cm^3)	2.00	1.63	1.73	1.88	1.68
Voids ratio	0.88	1.51	0.93	0.91	1.43
Porosity	0.47	0.60	0.48	0.48	0.59
Degree of saturation (%)	85.4	99.5	99.3	98.9	91.7
M-value blows/30 cm	20-110	11-56	10-24	17-63	15-24
Su (KN/m^2)	36-60	27-45	24-35	70-155	57-78
Note: The first two properties were determined according to ASTM standards. The third through the seventh property were calculated using numerical equations.					

(CH) vary between 18.5%-26.2% and 27.5% - 30.8% respectively. The liquid limits for the lean clay and the fat clay are in the range of 27.2%-45.7% and 51.0% - 67.4% respectively. The range of natural water content of CL is 11.9% -71.3%, and of CH is 11.4%-67.0%. From Table 2 it can be observed that the moisture content for the various types of clays is always larger than its plastic limit but is smaller than its liquid limit. The M-value may be as low as 8 blows/ 30 cm for the brown soft lean sandy clay but could reach 110 blows for the gray stiff clay. The M-value of the fat clay ranges from 6 to 43 blows/30cm. The undrained shear strength (S_u) values of the lean clay and the fat clay are 10 kN/m^2 to 157 kN/m^2 and 26 kN/m^2 to 155 kN/m^2 respectively which are very soft to very stiff for both of them. Fig. 4 shows a section crossing Al-Nekhaila sabkha from south west to northeast. It shows the interfingering character of the different soil types, the lenticular character of the silt bodies and the extensiveness of the clay layer. It also shows the M-values and shear strength values at the different levels. The mineral smectite, kaolinite, illite and chlorite, arranged in their relative decreasing abundance, were identified as the existing clay minerals using the X-Ray diffraction technique. No quantitative estimates of their abundance could be determined with the available equipment.

TABLE 2. The average natural water content (w%), plastic limit (PL) and liquid limit (LL) of various types of clay .

Clay type	Unified class	w%	PL	PL
Soft clay	CL	32	21	37
(10 blows/30 cm)	CH	57	30	67
Medium clay	CL	30	23	38
(25 blows/30 cm)	CH	31	28	53
Very stiff clay	CL	33	24	41
(45 blows/30 cm)	CH	–	–	–

Geochemistry of Soil and Groundwater

The salts in the soil concentrate in the upper crust and decrease gradually with depth (Fig. 5). It is observed that the sulfate and calcium have the highest concentrations. The average sulfate content at a depth of 1.5 m is about 2% to 4% and the calcium is 4% to 6%. The dry salts do not attack concrete, but they become reactive under wet conditions. The depth to the water level in Al-Nekhaila sabkha ranges from 1.0 to 2.5 m and the fluctuation in the water level between the dry period (summer) and the wet period (winter) varies between 0.2 m to 0.3 m. It is therefore expected that the present salts will have a bad impact on any foundation placed in this soil.

The maximum water level fluctuation could be observed in the north, which indicates that the sabkha is recharged mainly from the sea, and to a lesser extent from the valley in the north. About 24 groundwater samples were collected and the major cations and anions were analyzed. Table 3 and Fig. 6 show the values of these cations and anions in both the summer and winter times. It is obvious that the salt content increases during the summer because of the increase in the rate of soil evaporation and the decrease in the fresh water recharge. The increase is clearer in the Cl and Na+K contents for being more mobile and easily soluble in water. The average total dissolved solids (TDS) of the groundwater

FIG. 4. The soil layers in a NE-SW cross section, showing the M-values, and the undrained shear strenght.

ranges between 55000 to 95000 ppm in the winter. Therefore, the groundwater can be classified mostly as saline water (less than 100,000 ppm). But the groundwater exceeds this value during the summer and range from 75000 to 115000 ppm and becomes brine according to the classification given by Carroll (1962).

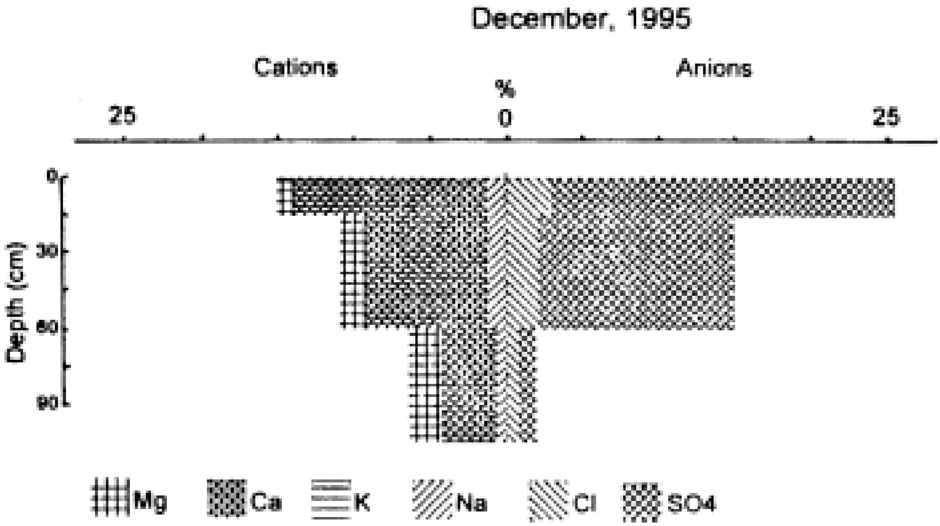

FIG. 5. Chemical analysis of the upper crust of Al-Nekhaila Sabkha.

TABLE 3. Anion and cation contents in the groundwater.

Anion or cation	Average values			
	December 1995		August 1996	
	epm	ppm	epm	ppm
Na + K	475	14700	800	24800
Ca	50	1000	125	2500
Mg	100	1200	175	2100
Cl	525	18600	800	28400
SO_4	51	2560	70	3500
HCO_3 + CO_3	0	0	0	0
TDS range	55000 - 95000 ppm		75000 - 115000 ppm	

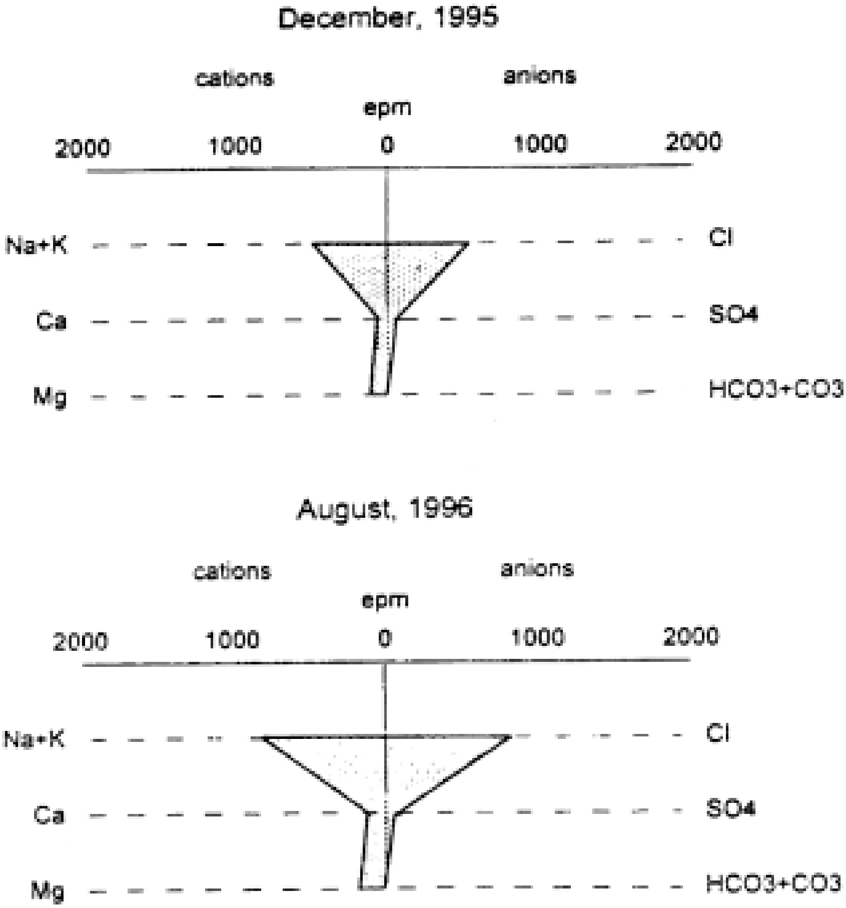

FIG. 6. Chemical analysis of the groundwater of Al-Nekhaila Sabhka.

Geotechnical Practice

The weak clay layer is expected to be a source of geotechnical problems such as low bearing capacity and settlement. It extends to a depth ranging from 1.5 m to about 3.0 m below the ground surface. An isopach map (Fig. 7) is drawn to show the thickness of the clay layer in Al-Nekhaila sabkha. The thickness was found to range between zero to up to 4 m and special care should be considered where the clay layer is thick. The smectite has a swelling characteristics and its presence may cause additional geotechnical problems and should be considered.

According to Bowles (1982) the minimum SPT N-value of the medium dense sand and the hard cohesive soils is 8. Based on Sabtan and Shehata (1994) it is equivalent to an M-value of 85 and 72 respectively. Therefore, the M-value of

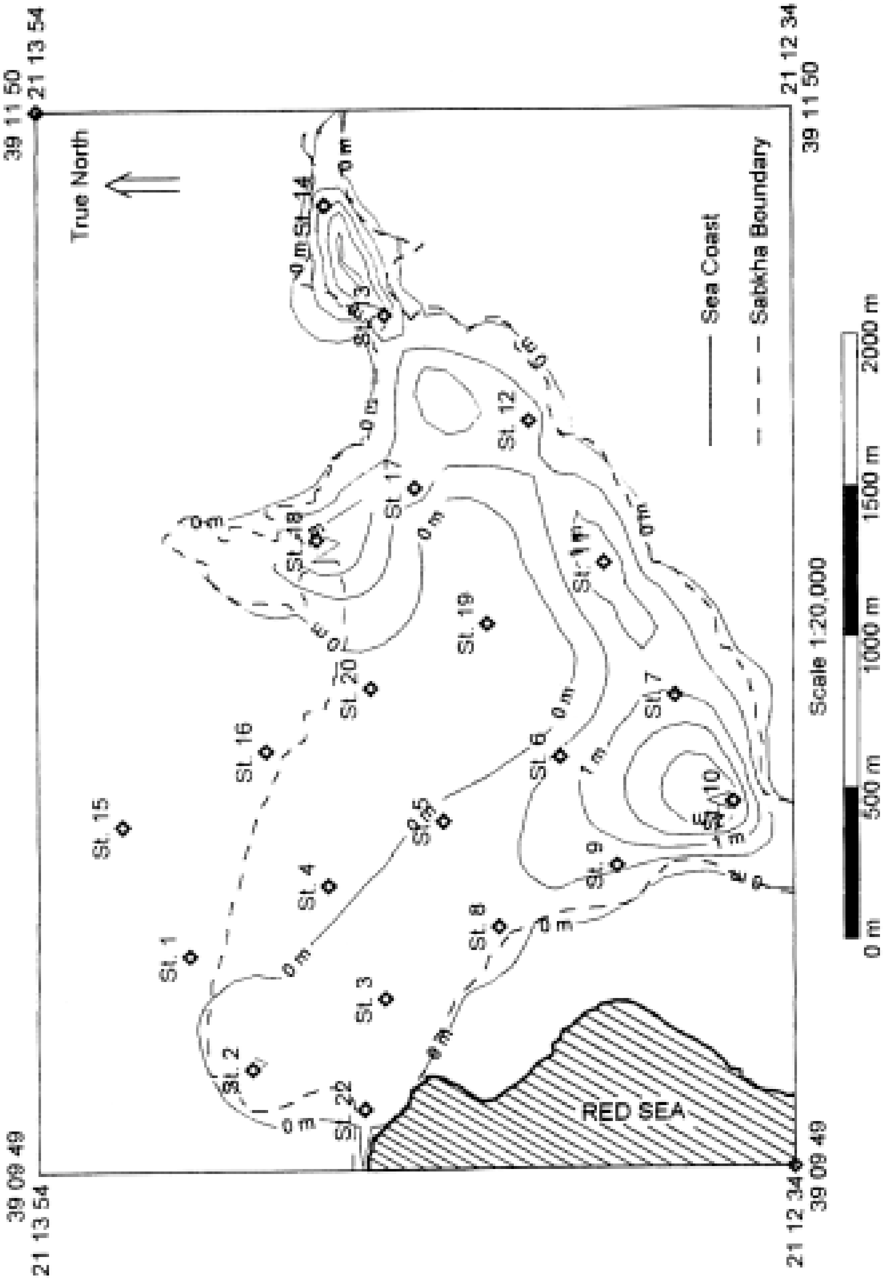

FIG. 7. Isopach contour map of the problematic clay layer.

85 and above (whether granular or cohesive) is considered to represent a safe soil layer that can withstand reasonable static construction load. A contour map for the depth of this layer in Al-Nekhaila sabkha and a surface map for the elevation of its upper boundary were produced (Fig. 8). It can be seen that the depth to the safe bed varies from 1.0 m to 5.7 m. Since the salts as cementing material between the soil grains decreases rapidly with depth (Fig. 5), the salt content in the safe bed can be assumed to be minimum and the bed is chemically inactive. Furthermore, a refusal bed with an M-value of more than 300 blows was encountered at 3 m to 9 m below the ground surface (Fig. 9) which can be considered in case of major construction projects.

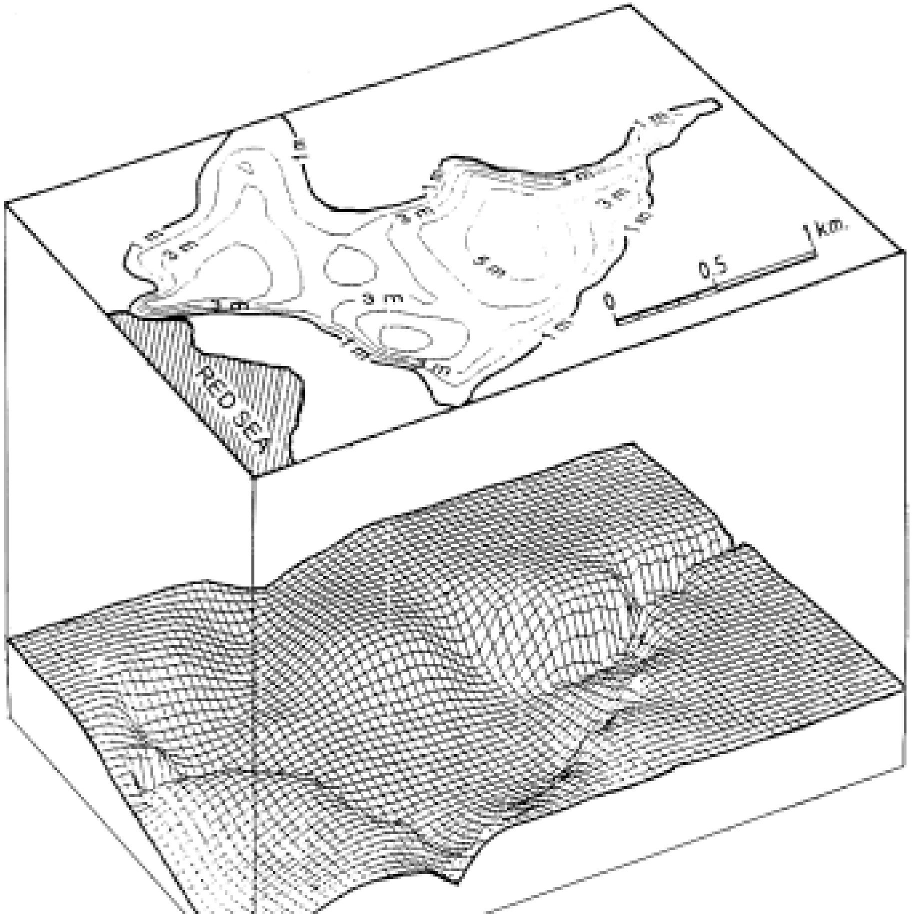

FIG. 8. Structural contour map of the depth to the surface of the safe bed.

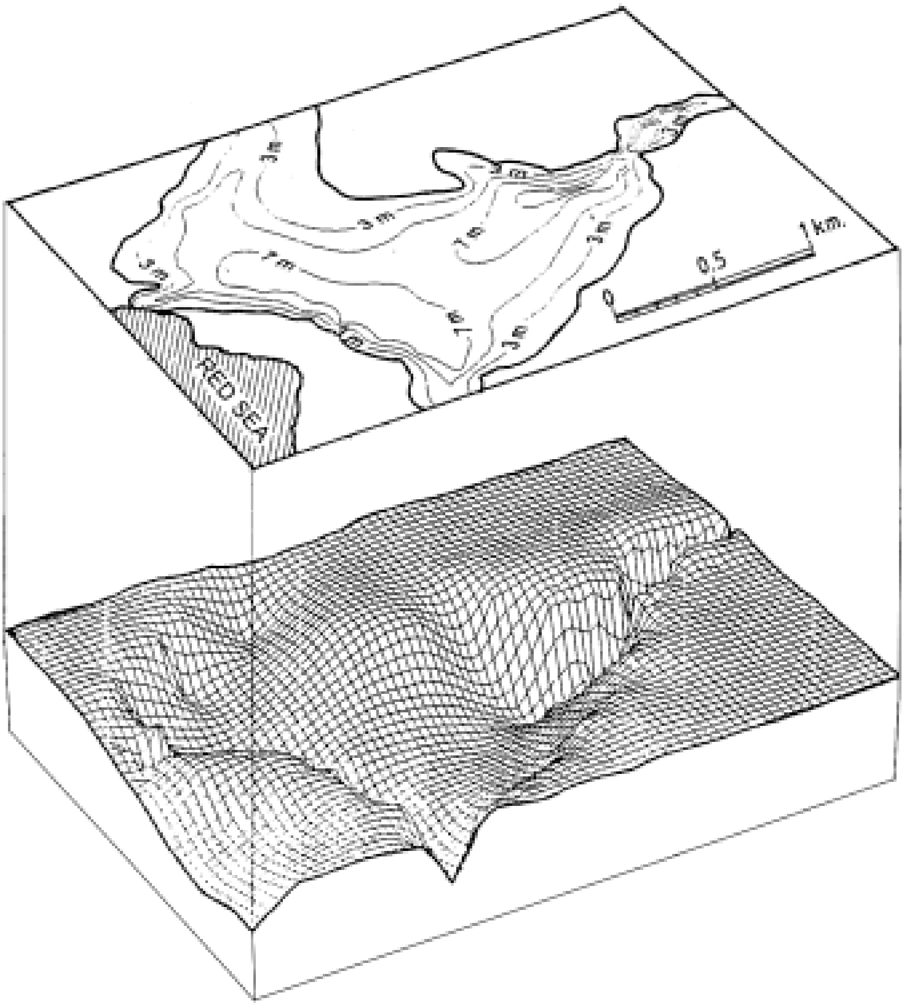

FIG. 9. Structural contour map of the depth to the surface of the refusal bed.

The sulfate content in the groundwater ranges between 2560 and 3500 ppm. This indicates a condition of sever attack by the sulfate on concrete according to USBR (1956). The normal practice in Jeddah is to place the foundation at a depth of 1.0 m to 1.5 m. This can be safely applied to the northern section of Al-Nekhaila sabkha. Other areas, especially the south and east sections, need either deep foundations or soil improvements.

Conclusions

Al-Nekhaila sabkha is composed of three main soil units: sand, silt, and clay. Each unit is divided further into subunits due to differences in the physical and/or geotechnical properties. The sand subunits are SM, SC and SP while the silt is either ML or MH and the clay is CL or CH. The top crust is hard and salty with gypsum and anhydrite as cementing material. The water level is 1 m to 2.5 m deep and the sabkha is recharged mainly from the sea. The TDS of the groundwater indicates that it is saline to brine in nature. The M-value of the sand varies from very loose to medium dense. The undrained shear strength of the clay shows that it is soft but locally it attains high values to be very stiff. The clay layers and the salt content of the groundwater are expected to cause some geotechnical problems. A safe layer could be located at depths ranging between 1.0 m and 5.7 m. A safer layer for major construction is located at depths 3.0 and 9.0 m.

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الخواص الجيوتقنية والجيوكيميائية لسبخة النخيلة جنوب جدة

طلال نايف سرحان و عبدالله عبد العزيز بن سبتان
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المستخلص . تنتشر السبخات على امتداد السهول الساحلية للبحر الأحمر . ويعزى تكون السبخات إلى سخونة المناخ حيث يتخطى مقدار التبخر وهو المسبب لتكون الأجاج كميات الأمطار . وتسبب تربة السبخات العديد من المشاكل الجيوتقنية خاصةً عندما تكون رطبة . ويمكن أن يسبب الماء الجوفي تآكل للخرسانة المسلحة بسبب محتواه من الكبريتات والكلورايد .

تتسع مدينة جدة بسرعة متنامية ، ويتم سنوياً تشييد بنايات إسكان ومحلات تجارية جديده في المناطق القريبة من الشاطئ حيث تتكون السبخات . وإذا استمر توسع المدينة في اتجاه الجنوب فسيصل إلى سبخة النخيلة . ولذلك فقد تم دراسة الصفات الجيوتقنية والجيوكيميائية لهذه السبخة . تتكون الفحوصات الحقلية ، والتي امتدت إلى عمق ٩ أمتار ، من ثلاثة اختبارات : مجس ماكنتوش ، القص بالمروحة ومخروط الرمل .

تم تعيين ثلاثة وحدات لأنواع التربة : الرمل (رمل متدرج ، رمل مع طين ورمل فقير التدرج) ، غرين (منخفض الدونة وعالي الدونة) وطين (منخفض الدونة وعالي الدونة) . وتوجد الأملاح على هيئة مواد لاحمة بين حبيبات التربة في المتر الأول من السطح . وقد دل سبر الرمل إنه يتراوح ما بين مفكك ومتوسط التماسك . وكان معدل قيمة قوة القص للغرين ٨٤ كيلونيوتن لكل متر مربع وللطين ٩٠ كيلونيوتن لكل متر مربع . ويتوقع حدوث عدد من المشاكل الجيوتقنية من طبقة الطين . ويبلغ عمق مستوى الماء من متر واحد إلى ٢,٥ متر ويتراوح من ملح إلى أجاج .