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Geotechnical Properties of Sabkha Soil in the southern part of Al-Khobar city, KSA.

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Abstract
The geotechnical properties of sabkha soil covering most parts of the southern portion of Al-Khobar area – Saudia Arabia were determined.
These soil have very low strength, low bearing capacity and high compressibility. The expected settlement is always above the recommended tolerable limits.
The chemical analysis of both soil and water from sabkha flat shows a very high concentration of salts. These high concentrations of salts give rise to a very corrosive environment and therefore it is recommended to protect concrete and reinforcement by using sulphate resisting cement, pozzolanic materials, use of corrosion inhibitors and by applying suitable water proofing membranes .
The properties determined during this study has a significant impact on both technical and economical values of each project and therefore, the outcome of the study is much important for planners and developers .

I. Introduction

Sabkha is an Arabic term which is widely used nowadays to describe the coastal and inland saline flats or playas built up by deposition of silt , clay, muddy sand and eolian sand, in shallow albeit and sometimes extensive depressions . The deposits are commonly saturated with brine and often are salt encrusted . (Powers et al , 1966) .

The Sabkha of Eastern Saudi Arabia occupy roughly 15% of a coastal strip (40km wide by 350km long) that extends approximately from Saffaniyah in the north to Salwa (border with Qatar) in the south , (Akili, 1982) .

Most cities of the Eastern Saudi Arabia lie within those coastal plains. Heavy development and construction of residential , industrial and recreational areas is within the proximity of these sabkha covered coastal plains .

In Khobar , sabkha covers wide areas of the southern part of the city as ; Shubaily , Al-Jeser , Al-Aziziyah and the Halfmoon area . These areas resemble the main future extension of the fastly growing city where many residential buildings , compounds and recreation centers are planned to be constructed in the near future.

The paleogeographic events that occurred in the Arabian Gulf and have the major effect on the formation of sabkha soil in the Eastern Saudi Arabia are the transgression and regression of the sea water in the Arabian Gulf . At the end of Pliocene epoch (about 400,000 yrs.) a transgression of sea water occurred and reached to about 150m above present level , (Kassler,1973) . The sea water , therefore , submerged the coastal areas which was covered by dune sand and the formation of sabkha terrains started at that time .

At about (100,000 yrs.) during Pliestocene glaciation , a major regression occurred and the sea water dropped to about 120m below existing level . During latest Pleistocene – earliest Holocene (about 20,000 yrs.) the Gulf basin was refilled by water due to gradual rising of sea water .

Minor transgression regression are still occurring oscillating by about 0.6m to 1m . These oscillations has resulted in the formation of present day sabkha .

The major factors that play a role in the formation of sabkhas are: climatic factors, geochemical factors, geomorphological factors, hydrogeological factors and biological factors, (Al-Amoudi, 1992).

There are essentially two types of sabkha soils; coastal and continental. The coastal sabkhas are the result of depositional off-lap of marine sediments of subtidal, intertidal and supratidal facies, while the continental sabkha is a landward and comprise continental or earlier cycle of marine sediments (Kinsman, 1969).

The sea encroachment has resulted in lagoons separated from Gulf waters by barriers islands. After transgression, the depositional environment appears to have shifted from subaerial to subaqueous causing extensive carbonate
sedimentation in lagoons which led to gradual widening of the sabkha plain and eventual progradation of the coastline. In the landward side of lagoons, where deposition had stopped, a cemented crust formed at the surface and some of this crust was later colonized with an algal mat, (Akili , 1982).

Following the deposition of the primary marine sediments and continuing even now are diagenetic processes which resulted in the formation of new minerals. Aragonite, calcite, gypsum, halite and a few other minerals forms in response to the physical and chemical conditions that prevail in the sabkha,(Kinsman ,1969).

The formation of the diagenetic minerals, their concentrations and relative positions in the sabkha is largely dependent on the hydrology of the particular sabkha under consideration and the means by which the groundwater is replenished. The water lost from the surface through evaporation is replenished by water entering the sabkha sediments during storm flooding of sabkha surface and also by lateral flow from the seaside. The inner margin of the coastal sabkha may also be replenished by influx of continental ground waters.

The evaporation from the sabkha surface causes interstitial pore fluid concentration and eventual formation of new evaporate minerals above and below the water table. These minerals are a major source of cementation that appears to hold sand and silt particles together to form cemented layers and cemented zones particularly in the near surface portion of the sabkha.

II. Geological setting

The general geology of the Kingdom of Saudi Arabia is related to the geology of the Arabian Peninsula which contains the Arabian Shield and Arabian Shelf.

The Arabian Shield is mainly a Precambrian complex of igneous and metamorphic rocks which occupies about one third of the Arabian Peninsula (western and south western parts of the Peninsula) . On this rigid stable mass , sedimentary rocks of the Arabian Shelf were deposited forming a great belt having a width of about 400km and a thickness of about 5.5km . They have a gentle slope of about 1 degree towards east and ranges in age from Cambrian to Pliocene . The study area lies entirely within the far eastern part of the Arabian Shelf parallel to the Gulf shorelines where the ground slope is very gentle towards sea shores . Fig. 1.

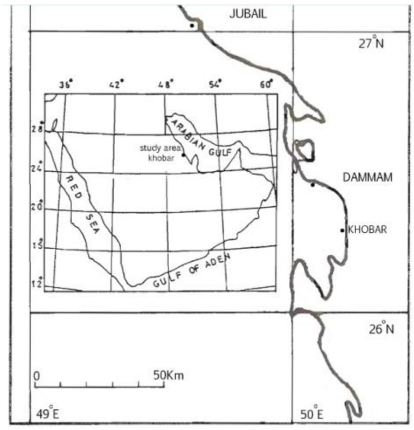

Fig.1 location and index map of the study area

III. Geological Formations

A simplified and slightly modified geological map of the study area is presented Fig.2. The geological formations and successions within the area has been identified by Powers et al (1966) . These geologic formations belongs to the Dammam Dome . The Dome represents a classical hydrocarbon structural trap . The geologic formations within the study area are ; Rus formation , Dammam formation , Hadrukh formation and Dam formation .

Recent deposits as Sabka (saline sediments) , sand silt & gravel as well as eolian sand were formed during the Quaternary period. These recent sediments cover wide portions of the study area .

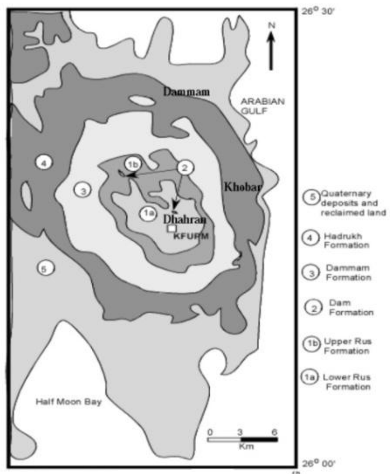

Fig.2. Geological map of the study area (Modified after Wiermars 1999).

IV. Method of investigation

Boreholes data collected from fifteen sites extended to 30m below existing ground surface were used in this study. Standard penetration test (SPT) was conducted in all boreholes at an interval of 1m to 1.5m Laboratory tests were conducted to obtain the physical and mechanical characteristic of the the soil samples.

The tests conducted in the laboratory are moisture content , grain size analysis , liquid and plastic limit , specific gravity , minimum and maximum relative density and direct shear test.
Groundwater was encountered in all boreholes drilled within, sabkha soil . The measured water levels in boreholes , as listed below are from 0.15m to 1.75m with an average value of 0.99m . Levels deeper than 1.0m were encountered in areas backfilled by imported soil to raise site level or to construct access roads within the site . Table (1) shows the water levels in boreholes within sabkha soil .

Table 1: Groundwater levels in sabkha soil.

BH No.	Z/I-1	Z/I- 2	Z/I-3	Z/I-4	Z/I-5	Z/I-6	Z/I-7	Z/I-8
GWL, m	0.4	1.75	0.2	1.4	1.15	0.15	0.6	0.95
BH No.	Z/I-9	Z/I-10	Z/I-11	Z/I-12	Z/I-13	Z/I-14	Z/I-15	
GWL, m	0.3	0.6	1.0	0.2	0.5	1.2	0.45	

V. Results

The major soil types in the study area are poorly graded sand , poorly graded sand with silt , silty sand , clayey sand ,elastic silt and sandy lean clay.
Generally, moisture content of samples from the saline crust is from 5% to 7% where moisture of soil samples obtained from depths of 0.5m to 1.0m are from 7% to 15%. The moisture content of soil samples obtained below water table is generally from 12% to 26%. Values up to 35% were noted in samples with relatively higher content of fines . The presence of sea shells was noted in some samples with high moisture content.
Minor variations in moisture contents were noted in samples collected in summer season and those collected during winter (rainy season) . The reason could be related to the high evaporation rate during summer days which keep the near surface soil always moist and not dry as may be expected .
Fig.3 shows the distribution of grain size of different sabkha soils which covers wide ranges from medium grained sand to clay. As shown in this figure, the dominant soil type is fine to medium grained, poorly graded sand (SP) to poorly graded sand with silt (SP-SM) .

The percentage of the coarser fraction (gravel content) of most samples is either zero or 1% to 3%. Most of particles having gravel size are either sea shells, evaporate minerals (gypsum crystal) or cemented carbonate sand. The absence of gravels in these samples is mainly due to the fact that this material is transported by wind , and therefore coarser and heavier gravels are left behind .

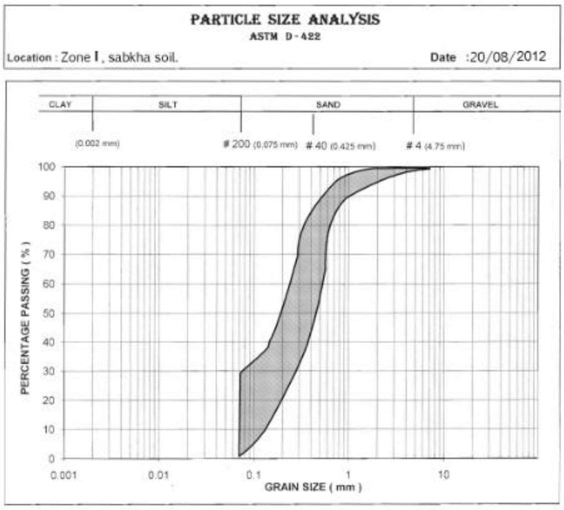

Fig.3 grain size analysis of sabkha soil.

The fine fraction (material less than 0.075mm diameter) is generally less than 3% in poorly graded sand and from 4% to 10% in poorly graded sand with silt. Silty sand and clayey sand consist up to 30% of fines . The clay content of silt and clay samples is from 52% to 70 percent. Fig. 7, show fine content of sabkha soil with depth .
According to Unified Soil Classification System and as per ASTM standards, the sabkha soil within the study area, consist of poorly graded sand (SP), poorly graded sand with silt (SP-SM), silty sand (SM), clayey sand (Sc), sandy silt (ML) and silty clay (CL).
The coefficient of uniformity (Cu) which equal D60/D10 and coefficient of curvature (Cc) which equals (D30)2 /D60 xD10 were also determined .
The coefficient of uniformity (Cu) and coefficient of curvature (Cc) were found from 3.9 to 6.4 and 1 to 3 respectively . As per ASTM D-2487, the coefficient of uniformity for clean sand should be more than 6 where for sand with less than 5% fines , it should be

less than 6 . The coefficient of curvature shall be from 1 to 3.

On the other hand, the ASTM D-3282, classifies soils into seven groups from A-1 to A-7 . This classification is used to determine the suitability of backfilling material , engineered fills and subgrade materials for use in construction of embankments , filling below foundations and soil improvement .

Sabkha soils encountered within the study area , are classified as (A-3) , (A-4) and (A-2-4) material . As per ASTM standards , these materials are considered excellent to good as backfill and subgrade material .

Generally, most sabkha sand is typically dune sand that has been transported by wind and deposited near the shoreline on flat low lying land . Silt and clay materials were usually encountered at depths deeper than 3m . It is most probably that these fine materials were deposited in lagoonal environments as indicated by the presence of sea shells and some organic matters.

Liquid and plastic limits of clay and other cohesive materials were determined as per ASTM D-4318. The liquid limit (LL) is found from 22% to 47% , where the plasticity indices are from 4% to 20% . Values obtained were plotted on the plasticity chart as shown on Fig. 10 .

Samples were found to be clayey sand (Sc), silt and clay (CL-ML), silt of low plasticity (ML) and sandy lean clay (CL). Liquid and plastic limits are highly affected by type of clay and percentage of clay minerals within the sample . The above mentioned values indicate presence of low percentage of clay minerals as indicated also from grain size analysis .

Strength properties are generally required to determine the carrying capacity and deformation characteristics of foundation material and to estimate the stability parameters for design purposes . Strength properties could be determined by insitu field tests or by testing undisturbed samples in the laboratory .

The sampling of cohesionless and loose soil, is utmost difficult and usually leads to disturbance of soil sample which will result in misleading properties . The insitu strength properties of soil as density and shearing characteristics were determined from field tests .

The standard penetration test is the most common insitu test that is widely used in soil investigation works . This test is conducted according to ASTM D-1586 standard . The main purpose of conducting this test is to determine the insitu density of soil and to obtain representative samples from the underlying soil layers . The test is considered the main and widely accepted test to determine soil properties for use in the estimation of bearing capacity and settlement of foundation soil . Many correlations are available to obtain soil properties to be used in theoretical or empirical relations for estimation of allowable bearing pressure and settlement of foundations .

Abundant SPT data is obtained from different sites located within the sabkha deposit as shown on boring logs. Generally , the SPT N-value, in the upper 8m to 12m depth , as shown on boring logs, vary from 1blow/30cm to 10blows/30cm, which indicate a very loose to loose state . In many instances, the drilling rods may sink under its own weight . The presence of medium dense soil in the upper two meters is mainly due to compaction of imported fill and or human activities .

Fig.4, show plots of SPT N-values versus depth from different locations within sabkha deposit . In general the upper seven meters of sabkha soil are very loose to loose where it grades to medium dense below that depth.

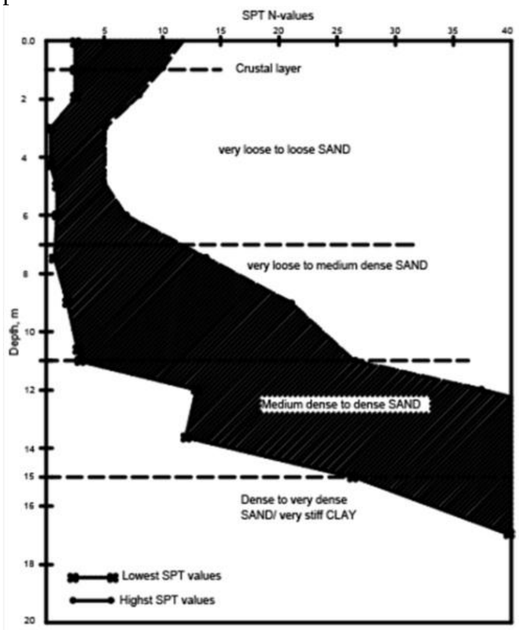

Fig.4 the results of Standard Penetration Test

In some locations, the loose soil is encountered extending to a depth of 15m below natural ground surface . The corresponding relative density as correlated by Terzaghi and others is from 1% to 35%. The presence of very loose to loose soil is a sign of low bearing capacity and higher amount of settlement .

Due to the difficulties in obtaining undisturbed samples from the sandy sabkha soil , laboratory compacted (remolded) samples were tested in the direct shear apparatus as per ASTM D- 3080 11, to obtain the shearing parameters . The values of shearing resistance of obtained from tests are from 18 degrees to 36 degrees . These values correspond well within the range obtained from correlation of SPT N-value which is from 26 to 34 degrees . In most samples, the cohesion (c) is practically zero with intercept line passing through zero (origin).

Fig12 presents plots of axial stress versus shear stress of remolded compacted sandy sample .
The maximum and minimum densities of collected sabkha sand samples were determined in the laboratory as per procedures of ASTM D-4253 and D-4254 standards . The minimum density was found in the range of 14.2KN/m3 to 14.7KN/m3 where the maximum density was from 17.2KN/m3 to 17.8KN/m3. The following table summarizes tests results obtained from relative density tests and correlated values from SPT tests .

Table 2 : Relative density from lab tests and from SPT tests .

Soil type	Depth	Min. density	Max. density	SPT, field density	SPT relative density
Poorly grd. Sand	1m	14.7 KN/m^3	17.8 KN/m^3	17 KN/m^3	0.35
Sand with silt	1.5m	14.5 KN/m^3	17.4 KN/m^3	15 KN/m^3	0.25
Silty sand	3m	14.2 KN/m^3	17.2 KN/m^3	14 KN/m^3	0.15

Chemical analysis of soil and water samples were determined mainly as per ASTM standards . The following table 4.3; summarizes major chemical contents of soil and water samples collected from different sites covered by sabkha soil.

Table 3: Chemical constituents of sabkha soil:

Location	pH value	TSS, ppm	Chloride %	Sulphates %
Z/I - 2	7.7- 7.95	10210-12710	0.452 – 0.965	0.688 – 1.874
Z/I - 11	7.6- 7.7	9270-10550	0.525 – 1.125	0.724 – 2.449
Z/I - 14	6.9- 7.6	8520-11230	0.352 – 1.335	0.258 – 2.664

Table 4: Chemical analysis of water samples from Sabkha soil.

Location	pH	TDS, ppm	Chloride, ppm	Sulphates, ppm
Z/I - 2	7.7- 7.95	21455-22610	5220 - 5335	3210 - 3290
Z/I - 11	7.6- 7.7	72420 -105310	37240 - 41120	4530 - 6420
Amoudi	6.9- 8.3	208000*	157000	5450

VI. Conclusion

This paper shows that the allowable bearing capacity in most parts of the studied area is very low. This value is generally less than the required strength for the design of even one story structure. On the other hand ,the expected settlement is always above the recommended tolerable limits.
Soil improvement is necessary in many locations in the study area. Among the available methods, the preloading, dynamic compaction and vibro-stone columns are found to be the most suitable to improve the properties of loose sabkha soil.
The selection of the proper method depends on many factors as thickness of loose soil to be improved, structural loads, and economy of the technique.
Groundwater level within sabkha flat is generally very shallow,this shallow water level will add also to construction difficulties, where dewatering will be required in most sites .
The chemical analysis of both soil and water from sabkha flat, show a very high concentration of salts,these high concentrations of salts, give rise to a very aggressive and corrosive environment. Reinforcement and concrete maybe protected by using sulphate resisting cement, addition of pozzolanic materials, use of corrosion inhibitors and by applying suitable water proofing membranes.

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