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IMPROVEMENT AND CHARACTERIZATION OF SABKHA SOIL OF SAUDI ARABIA: A REVIEW

Md Arifuzzaman[a]*, Mohammad A. Habib[b], Mohammed K. Al-Turki[b], M. I. Khan[c], M. M. Ali[d]

[a]Department of Civil Engineering, University of Bahrain, Kingdom of Bahrain
[b]King Fahad University of Petroleum and Minerals, Dhahran, Saudi Arabia
[c]King Faisal University, Al Ahsa, Saudi Arabia
[d]California Public Utilities Commission, California 95834, USA

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*Corresponding author
arafiquzzaman@uob.edu.bh

Abstract

Sabkha is an inferior and indigenous type of soil which forms widely in the Arabian Gulf and in many parts of Saudi Arabia, especially in the coastal areas. Several studies over the last 25 years have been conducted to develop a better understanding and characterization of Sabkha soil and to improve its strength and durability. Different studies from different perspectives, different geographical locations, and particular types were discussed with specific treatment for its improvement. The main purpose of this study is to conclude Saudi Arabian Sabkha Soil characteristics, its associated problems, and to recapitulate the current technologies and practices for the improvement of it. The relative advantages and some of the drawbacks of currently available techniques have also been discussed. Scope and future development regarding this field have also been summarized. Preloading technique was found to be effective for stabilization and consolidation of Sabkha soil over longer period of time. Another study revealed characterizing Saudi Arabian Sabkha soil using seismic refraction technique. Other comparative research was studied which focused on the improvement of Sabkha soil for road construction using geotextile and cement additives. The results suggest that both of the techniques have similar effect on the improvement of subgrade but the geotextile application is more economical as compared to others. Geotextile (grade A-400) with greater strength and thickness exhibits higher load carrying capability which leads to less deformation settlement on the subgrade.

Keywords: Soil improvement, strength, geotextile, chemical agents

1.0 INTRODUCTION

In general, Sabkha soils are salt-encrusted, evaporative flats, which always contain a significant amount of organic materials. It is located along the coastlines or some interior of many arid climatic countries. In fact, Sabkha is an Arabic word which is known for this special type of soil; other names include: saline soils, evaporate soils etc. Indeed, the hot and arid environments, with more evaporation than the precipitation, are the most likely to produce Sabkha soils. This extreme water evaporation system promotes salt concentration in soil profile via precipitation. About 30% of the world's land surface is located within an arid climatic area. These areas are characterized by significant lack in water precipitation compared to the possible loss in moisture because of the evaporation process [7]. Sabkha Soils are present in many countries including India, Northern and Southern Africa, Australia, and United States, in addition to Saudi Arabia.

The properties of Sabkha Soil are very unique. It is normally loose, permeable and porous, and sandy to coarse textured. Sabkha surface also varies with the seasonal changes. For example, during the dry period of a year, it ranges from a very even crust to a weak polygonal shape as well as with flat irregular units. Its surface is strongly hygroscopic that becomes muddy and wet during the moist periods. Also, Sabkha Soils are well-known for their low bearing capacity in natural conditions. On the other hand, the water table in general is ranges from 0.30m and 1.15m below the top ground surface and it depends on the precipitation rate. Sometimes, there are non-uniform drops of 10-15 cm in the water table that happened because of both a vertical and lateral inhomogeneity of it [1]. These characteristics indicate that Sabkha Soils do not fulfill the regular required design criteria. Therefore, in its natural condition, Sabkha soil may be considered as for use as foundation material and improvement in its unfavorable properties is needed. The loose, low strength and low density, bulky structural arrangement as well as metastable fabric of Sabkha soil particles are the main elements that need to be stabilized. Moreover, the collapse potential of Sabkha Soil is considered as an unacceptable risk in normal practice and it needs improvement in its mechanical properties before any construction. However, some studies reveal that Sabkha is a highly variable material and there is a need for formulating a data bank by stabilizing as many Sabkha Soils as possible [7]. In general, several field stabilization techniques have been proposed and implemented for improving Sabkha properties which include: soil replacement, deep densification of soil using vibroflotation, vibratory compaction, stone columns, and dynamic compaction. On the contrary, geotextiles and geosynthetics have also been used to stabilize this particular Sabkha type of soils as resources of reinforcing it for drainage control, practicality & durability remain the critical factors. However, the chemical agent stabilization is considered to be relatively cheaper than many other existing techniques, and requires not as much of expertise than deep type of densification techniques that may requires particular experience & large scale equipment [2].

2.0 POTENTIAL PROBLEMS WITH SABKHA SOIL

Sabkha Soil has some complex engineering problems. It has also been attributed to a great diversity of origins, mostly of structural & erosion controls. These soils caused many geotechnical problems that appear mainly due to their high level of salt content & very much vulnerability to strength loss & failure. The main geotechnical problems including: primary or secondary settlement, corrosion, heaving for the salt in crystallized form & flood problems for the low infiltration rates [8]. For example, it is believed that one of the main problems in the roads construction along these coastal areas in the Arabian Gulf and the Red Sea is due to Sabkha Soils. Unavoidably, some engineering problems in pavement such as: raveling, cracking, permanent deformations, and formation of potholes, rutting and depressions as those pavement were located on Sabkha flats. Also, one of the main unique features of Sabkha is its concentrated ground-water brines and the changeability of its geotechnical properties for horizontal & vertical directions which can cause to unusual differential settlement. In fact, the vulnerability of Sabkha soils to the loss of strength and failure on soaking makes them risky and dangerous to use in construction. Some of this associated geotechnical problems are associated with its water sensitivity, low load-carrying capacity & chemical instability.

The main potential problems associated with Sabkha can be listed as:

- Rapid reduction of the strength of soil owing to water addition or flooding.
- Dissimilarity in the compressibility characteristics of the soil within a small distance that can cause major differential settlement.
- In hot & arid environment, gypsum ($CaSO_4.2H_2O$) cause irregular hydration and form anhydrite ($CaSO_4$) on the other hand it also cause dehydration to reform gypsum, the chemical progression that includes substantial volume changes.
- The salty waters within the Sabkha migrate towards surface by capillary action and increases the concentration of sulphate (SO_4) & chloride (Cl). These are corrosive for both concrete & steel and hence deteriorate the construction material even in construction stages.
- Reduced bearing capacity (q_{ult}) for Low water table, as we know bearing capacity depends upon depth of water table.
- Extreme evaporation and low precipitation increase the salt at the surface and in the hot environmental condition, the expansion of the salts originate small cracks in the road and pavements.

3.0 CHARACTERIZATION OF SABKHA SOIL

Characterization of the Sabkha is crucial to deals solving all related problems. This section describes their typology, formation, physical, chemical, and mechanical properties and response to some geotechnical field and laboratory tests.

3.1 Types of Sabkha within Saudi Arabia

There are two major types of Sabkha that have been classified as per their origin: Coastal Sabkha and Inland Sabkha (Figure 1). Two major sea coastal regions here are along the Red sea

(Western part of Saudi Arabia) and along the Gulf sea (Eastern part of Saudi Arabia), are largely covered by Sabkha. These have been studied and documented but Inland Sabkha has never been studied or documented yet. So, there is huge potential in this area for both types of Sabkha and their improvement.

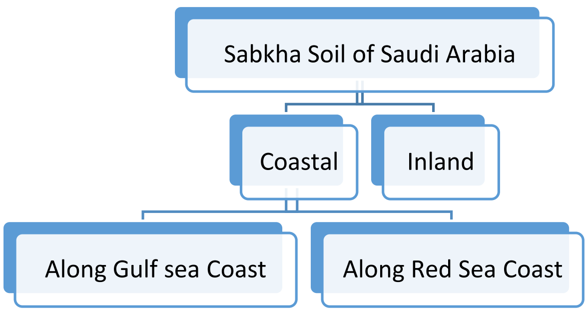

Figure 1 Types of Saudi Arabian Sabkha as per their source

3.2 Sabkha Distribution in Saudi Arabia

Distribution of Sabkha in Saudi Arabia is fairly wide specially in the well-populated cities and regions along the coast of Red sea & the Arabian Gulf Sea. The following Figure 2 shows the prevalence of Sabkha so far discovered within Saudi Arabia.

3.3 Formation of the Sabkha

The continuous interaction of brines with the sediment produces Sabkha [13]. Primary topographies are related to original framework of deposition, whereas the sedimentary topographies and minerals are among various characteristics of Sabkha deposits. The following Figure 3 clearly depicts the formation of Sabkha.

There are various factors that control the formation of Sabkha, which are:

1. Climate: it includes rainfall, temperature, and humidity as well as wind speed
2. Geochemical: includes both brine chemistry and minerals
3. Geomorphological: it includes surface gradient, groundwater table
4. Hydrological: this alone can be a one factor or may be a result of the above three factors
5. Biological: which includes the algal mats & burrowers

The collaboration and sometimes interaction of the above factors, may result in the reactions that characterize the Sabkha soil and its environment [17].

3.4 Chemistry in Sabkha Formation

Chemical analysis of Sabkha soil and brines are presented in Table 1. Varieties of cations and anions are present. Based on pH value the soil type can be described as neutral soil. Some studies reveal that on the consequence of salt precipitation from the direct evaporation of sea water (Figure 4), leads to the deposition of calcium carbonate (aragonite) first when sea water is evaporated to about half of its original volume, followed by calcium sulfate (gypsum) at 19% of the original volume. Next in succession, comes sodium chloride (halite), and at about 4% of the original volume, the highly soluble salts of potassium and magnesium (polyhalites) - start to develop as a co-precipitate with halite [14].

Heterogeneous matrix and chemical composition make Sabkha very unusual. In dry conditions, negative charges are balanced by exchangeable cations, and particles are held tighter by electromagnetic attractions [22]. So, their physical nature and structure are stiff as long as they are in dry conditions. On the other hand, when water comes inside polarity of water (H2O), plays a role to break that cationic bond. Thus, Sabkha Soil can be described as very much prone to water.

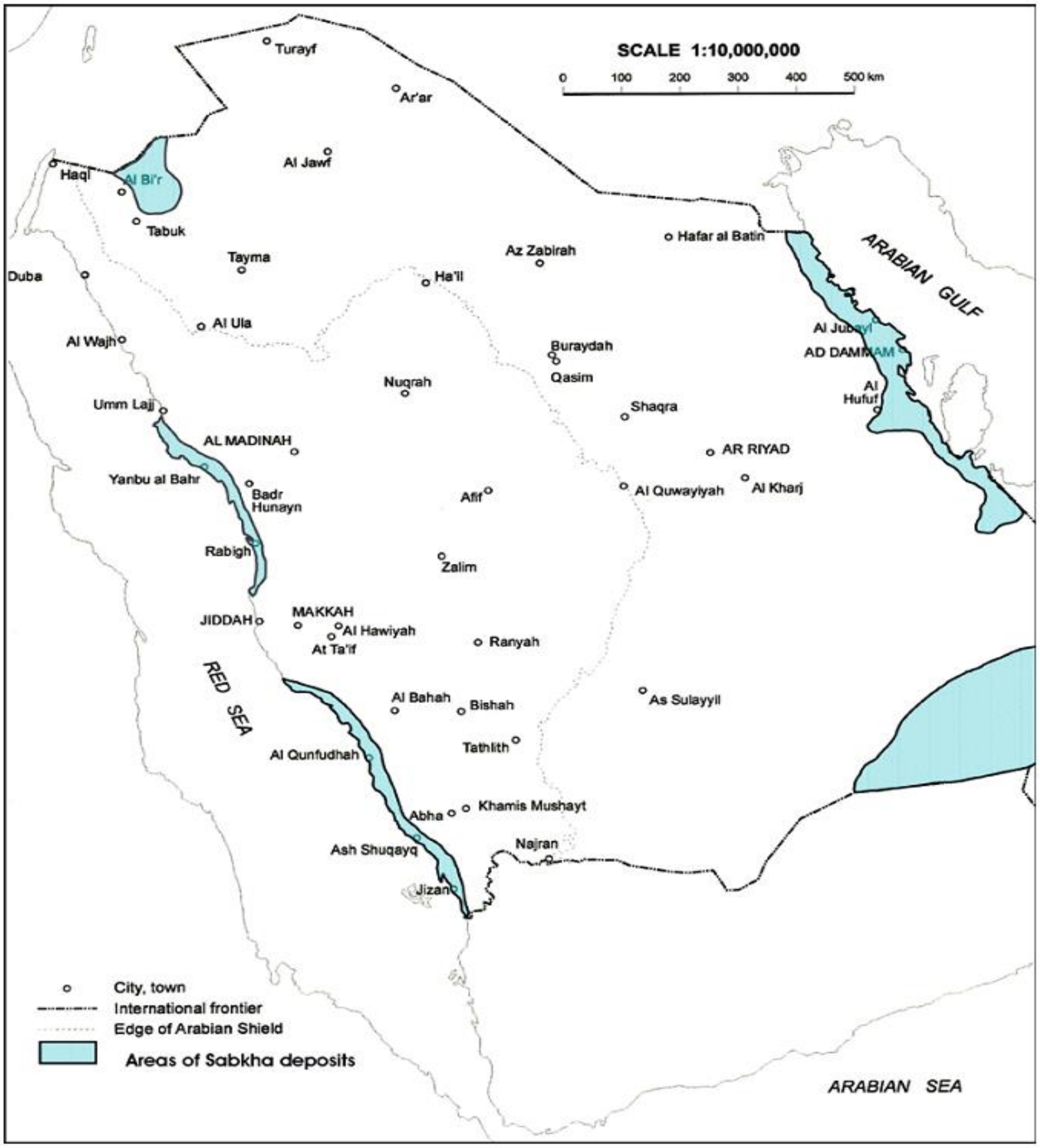

Figure 2 Distribution of Sabkha in Saudi Arabia [8]

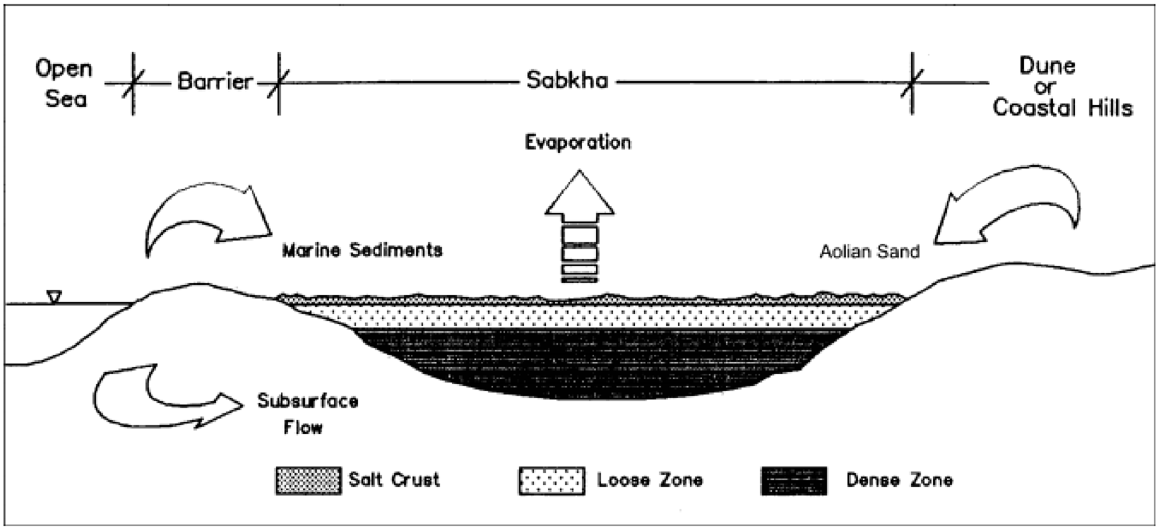

Figure 3 Formation of the Coastal Sabkha [8]

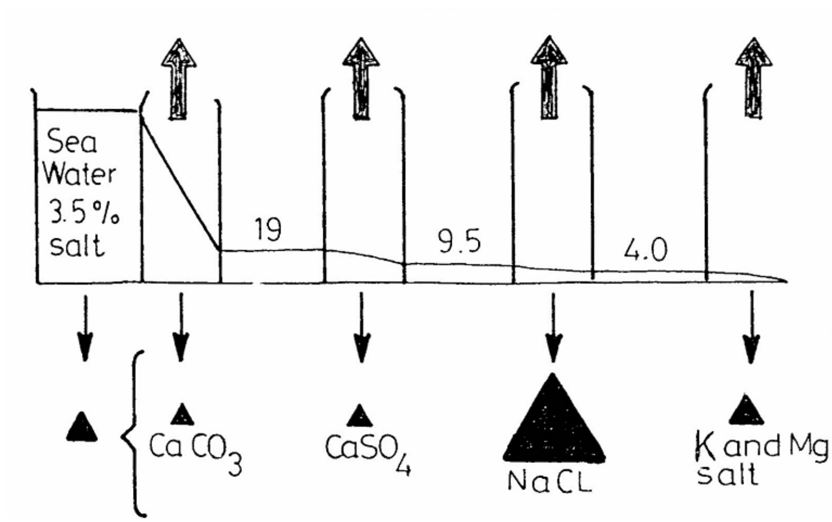

Figure 4 Precipitation of the Different Minerals from Evaporation of Sea Water [17]

3.5 Structural and Textural Character of Sabkha Formation

The structural and textural characteristics of the evaporite Sabkha sediments indicated the formation of the primary halite crystals at brine surface and floor of saline pans. The diagenetic formation of gypsum and anhydrite below the sediment surface as intra-sediment displacive, inclusive, and replacive growth in the wet sandflat and mudflat areas [17].

4.0 ENGINEERING PROPERTIES OF SABKHA

Several investigations have been conducted by researchers, including: field tests and laboratory tests. Here, some of the important results have been summarized.

4.1 Field Tests on Sabkha

In order to study the stratigraphy and subsurface condition, field tests like Standard Penetration Test (SPT or N) and California Bearing Ration (CBR) are very useful. CBR test conducted by Al-Amoudi *et al*. (1992) indicates that Sabkha is very weak and extremely vulnerable soil to failure on flooding by water. Naturally existing Sabkha soils had very low CBR values from 3 to 4 only, and these values were found to be reduced up to 50% when the Sabkha soil was flooded with water. It gives the indication that the susceptibility of Sabkha to failure when flooded with water. SPT values for Ras Al-Ghar has been found to be 8 (for the surface crust layer) which indicates the looseness of its nature. (As shown in Table 2). The physical and mechanical properties of Sabkha soil as shown in (Table 3) could be helpful for engineering analysis and construction purposes. The SPT, cohesion and angle of friction values indicates the weak nature of sabkha soil.

4.2 Laboratory Tests on Sabkha Soil

The classification of three different locations sabkha soil presented in Table 4. It shows the soil classification results according to AASHTO and USCS system. The results indicates the soil consists of mainly fines particles. Table 5 represents the specific gravity of this particular soil. The ranges varies from 2.52 to 2.73. The permeability values of two different sabkha soils are inserted in Table 6. The variation indicates the different nature of this soil while transferring water through it. It can help the engineers to design the roads/other structures over it or to modify then with different additives for the stabilization purposes.

Table 1 Chemical analysis result of Sabkha brines and seawater

Ions		Source of Sabkha and Reference					Seawater of KFUPM Beach (Arabian Gulf Sea)
		Ju'aymah Brine (1)	Ras Al-Ghar Brine(1)	Obhor Sabkha (8)(Average)	Al-Fasl Sabkha (8) (Average)	Avg. value from (20)	
pH	Unit	7.2	6.9	7.3	7.05	6.9	8.3
Na^{+}	Mg/L	41.4	78.8	57.5	61.5	79.8	20.7
Mg^{2+}	Mg/L	4.53	10.32	2.57	4.65	7.33	2.30
K^{+}	Mg/L	1.40	3.06	1.2	2	2.69	0.73
Ca^{2+}	Mg/L	1.34	1.45	1.1	1.7	1.86	0.76
Fe^{2+}	Mg/L	Noticed	Noticed	*	*	*	*
Sr^{2+}	Mg/L	0.031	0.029	*	*	*	0.013
Cl^{-}	Mg/L	76.8	157.2	36.05	112	158.2	36.9
Br^{-}	Mg/L	0.22	0.49	*	*	*	0.121
$(SO_4)^{2-}$	Mg/L	8.43	5.45	3.78	4.35	5.24	5.12
$(HCO_3)^{-}$	Mg/L	0.114	0.087	*	*	0.056	0.128

Table 2 Relative Density based on SPT [21]

Relative Density	SPT
Very loose	0 – 4
Loose	4 -10
Medium	10 – 30
Dense	30 – 50
Very Dense	Over 50

Table 3 Physical and Mechanical Properties of Sabkha [17]

Description	Maximum	Minimum
Passing Sieve No. 75, %	97	18
Natural Water Content, %	84.6	10
Liquid Limit, %	84	30
Plasticity Index, %	39	NP*
Bulk Density, g/cm3	1.89	1.34
Specific Gravity	2.82	2.51
SPT, blows/300 mm	6	0
Cohesion, kg/cm2	0.54	0
Angle of Friction,	22	0
Initial Void Ratio	2.16	1.08
Compression Index, Cc	0.95	0.39

Table 4 AASHTO and USCS Classifications of the Sabkha

AASHTO	USCS	Source Sample	Conducted By	Ref:
A-2-4	SW-SP	Eastern Province of Saudi Arabia	OSB Al-Amoudi	(2)
A-2-4	SM	Al-Qurayyah Sabkha	OSB Al-Amoudi	(7)
A-6	CL	Ar-Riyas	S.A. Aiban	(9)

Table 5 Specific Gravity of Sabkha

Specific Gravity	Source Sample	Conducted By	Ref:
2.73	Ar-Riyas, Eastearn Province of Saudi Arabia	OSB Al-Amoudi	(1)
2.73	Ras Al-Ghar	OSB Al-Amoudi	(4)
2.52	Al-Qurayyah sabkha	OSB Al-Amoudi	(7)

Table 6 Permeability of the Sabkha

Permeability (m/s)	Source Sample	Conducted By	Ref:
1.23×10^{-6} to 3.2×10^{-5}	Ras Al-Ghar	OSB Al-Amoudi	(4)
5.4×10^{-9}	Al-Lith Sabkha	Abdullah A. Sabtan & William M. Shehata	(11)

5.0 STABILIZATION OF SABKHA SOIL

Numerous field stabilization methods have been utilized for the improvement the properties of Sabkha soil. According to the review results, three stabilizations procedures have been used to stabilize Sabkha Soil in Saudi Arabia: (1) Chemical stabilization, (2) stabilization using Geotextiles and Cement (3) stabilization using Foamed asphalt.

5.1 Chemical Stabilization

Al-Amoudi *et al*. (1994) utilized two chemical stabilizing agents to investigate their effects on the density & compressive strength (unconfined) of Sabkha. Collected Sabkha Soil from eastern part of Saudi Arabia was treated with lime & cement. They used five different dosages (0%, 2.5%, 5%, 7.5% and 10%) with two moisture contents (16% & 22%) of soil specimens. The samples were prepared and standard compaction tests were carried out and its unconfined compressive strength were measuring at different stages of curing. Results show that there is no significant difference in the optimum moisture content between all mixes and the maximum dry density as increasing as the cement content is increasing. In contrast, the lime stabilized Sabkha mixtures did not show any significant improvement in maximum dry density. Also, results show that the strength of cement stabilized Sabkha mainly for 7.5 and 10% cement additions, increases even after 90 days of curing. They got highest strength for 90 days curing in case of lime Sabkha specimens that indicates that lime Sabkha mixtures need a long curing time to gain its strength. Results concluded that the cement is very much effective for the stabilization of Sabkha at natural water content. They found that the cement stabilized Sabkha achieved more strength over time.

Al-Amoudi *et al*. (1995) investigated the effect of limestone dust, lime and cement on the properties of saline and arid Sabkha. The sample was collected from the eastern Saudi Arabia. Unconfined compressive strength and standard compaction tests were conducted and the specimen were cured for seven days. Marl and limestone dust additives did not make any significant improvement whereas the lime and cement (from 2.5% and upward) helped gaining the soil strength much [18].

Aiban *et al*. (1995) evaluated the performance of lime stabilized Sabkha Soil in Ras Al-Ghar (Eastern Saudi Arabia). They collected soil samples from different layers and conducted laboratory experiment for soil characterization, compaction, unconfined and triaxial compression tests. They used different moisture and lime contents for washed and unwashed Sabkha soils. From their results, they found that 5% lime improves the strength of the soil even when the samples are compacted at moisture contents higher than the optimum value. Also, they found out that the strength of the particular soil is highly dependent on the molding moisture content, the curing regime and curing time, and the presence of salt. In addition, 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 soil samples. The unwashed Sabkha has higher strength compared to the washed Sabkha due to the presence of salt. In addition, the lower the moisture content at testing, the higher are the strength values. Also, they reported that the addition of small percentage of lime to Sabkha soils will improve the strength, and the strength increases with time even after 18 days of curing.

Al-Amoudi (2002) conducted his research to stabilize Sabkha soil of Al-Qurayyah in the Eastern Saudi Arabia with lime and cement. He used five different contents of lime and cement ranging from 0 to 10%. The study evaluated the load bearing capability of plain & stabilized Sabkha with different moisture contents. For this CBR, unconfined compressive strength, and Clegg impact value were used. Results show that the maximum dry density is increasing with the increase in cement content. However, there was a decrease in maximum dry density with the increase in the lime content. After adding cement in the range of 0 to 7% it has been found that there was no fundamental difference in optimum moisture content in those cement content. But, when 10% cement was used a slight increase of optimum moisture was found. In case of lime stabilized Sabkha, 17% increase of optimum moisture content was found with 0 and 3% lime contents, and almost 20% for 5, 7, and 10% lime contents. There was a substantial increment in strength when 3% cement was used to the Sabkha soil (from 809 with no cement to 2667kPa at 3% cement). This study also reveals that the addition of cement to Sabkha soil increases the unconfined compressive strength and CBR to its maximum value (5005kPa and 533%). For introduction of lime in Sabkha soil, the increment of strength and CBR was not significant. Strength and CBR values increased respectively from 809kPa & 111% (at 0% lime) to 1201kPa & 164% when 10% lime was added. So, the results indicated that cement much more positive effect on improvement of the performance of stabilized Sabkha than lime. Their study suggested the cement to be the suitable additive for the stabilization of Sabkha Soil of Al-Qurayyah area of Saudi Arabia.

5.2 Stabilization using Geotextiles and Cement

Abduljauwad *et al*. (1994) used conventional approach and Soil Fabric Aggregate (SFA) under the static and the dynamic loading conditions to investigate the performance of Sabkha subgrade in laboratory. The main goal of their study was to evaluate the influence of geotextiles on the performance of Sabkha subgrade. Different variables were investigated including, sub-base thickness, geotextile type, loading & moisture conditions. Sabkha soil from the Ras Tanura in Eastern part of Saudi Arabia were collected. They found that the geotextile incorporation with SFA systems for both the dry & saturated conditions increased the ultimate strength of Sabkha soil. The ultimate strength of the Sabkha soil increased from

1.5 kN & 5.0 kN (with no geotextile) to 3.0 kN & 21.0 kN (with geotextile) for saturated and dry specimens respectively under the same conditions. The results conclude that Sabkha with geotextile carry higher loads than Sabkha systems without geotextile for both dry and saturated conditions. It was significant improvement under dry conditions compared to that at saturated condition. Moreover, it also found that geotextile technique has significant effect to reduce the permanent deformation in Sabkha subgrade. For the determination of permanent deformation for SFA system they create a comparable model using all experimental data. The proposed regression model was:

$$PD = a_0 + a_1(\log N) + a_2(\log N)^2 + a_3(SDR) \quad [1]$$

Where, The permanent deformation (PD) depends on the number of cycles, N (number of load repetition), and the stress deformation ratio (SDR), that considers the effect of stress level, sub-base thickness and elastic deformation. a0, a1, a2 and a3 are the regression co-efficient. Values for these regression co-efficient for different tests condition are represented in the Table 7.

$$SDR = \frac{\text{Applied Stress}}{\text{Elastic Deformation}} \quad [2]$$

Table 7 Regression Co-efficient and Co-efficient of Determination for the model

Test Condition	R2	a0	a1	a2	a3
Saturated and without Geotextile	0.9890	-26.77	-42.1	20.28	0.00
Saturated and with Geotextile	0.9872	-25.81	22.05	-1.48	5.12
Dry and without Geotextile	0.9904	-10.37	14.5	-1.62	0.05
Dry and with Geotextile	0.9927	-5.26	7.35	-.75	0.02

Note: R2 is the Co-efficient of Determination for the model the geotextile they used here was Polyfelt TS-700.

Siddiqi (2000) also used geotextiles in his research to improve the load carrying capacity of pavements constructed on Sabkha Soil. He investigated the effect of geotextile grade, thickness of base, type of loading and moisture effect on the performance of SFA systems. He used three different dosages (5 percentage, 7 percentage and 10 percentage) of Portland cement as stabilizing agent. Load-carrying capacity was measured for permanent deformation of the base layer for both dry & soaked conditions and all systems were accessed. The results showed that the application of geotextile in road construction on Sabkha subgrades had improved load carrying capacities, specially under the soaked conditions. Also, the load-carrying capacity of Sabkha soil with 5% Portland cement was found less than that found applying A-400 geotextile. But inclusion of seven and ten percent of cement displayed better load carrying capacity than the application of geotextile [16].

Aiban *et al*. (2006) used geotextile and Portland cement for upgrading the load carrying capacity of Sabkha Soil which was used as subgrade material. They also investigated the impact of these two techniques on the performance of the SFA systems. They used non-woven and needle-punched, polypropylene geotextiles with three different grades of geotextile which have different tensile strength & unit weight. Three different dosages (5 percentage, 7 percentage and 10 percentage) of Portland cement was used as stabilizing agent. They investigated the soaking effect, effect of geotextile grade, effect of sub-base thickness and effect of different loading condition. They also found the almost similar findings that suggested the systems with geotextiles can carry more loads than the systems without geotextiles specially for the saturated conditions. Increasing the cement content and using the higher geotextile grade increased the load-carrying capacity of Sabkha Soil. On the other hand, their results show that, for SFA systems, the deformation (permanent) reduces with increasing base thickness for the same number of repeated loads. The findings suggested that using of geotextile can be inexpensive which cut down the base thickness in pavement design & construction. Their relative study found that application of due to the A-400 geotextile has increased the load-carrying capacity in Sabkha was almost same amount to the that achieved by adding 6.5% Portland cement. Geotextile (grade A-400) with greater strength and thickness exhibits higher load carrying capability which leads less deformation settlement on the subgrade.

5.3 Stabilization using Foamed Asphalt (FA)

Al-Amoudi *et al*. (1995) utilized emulsified asphalt despite the coarse grained nature of it. But there was no significant improvement resulted from their experiment [18].

But in general, FA stabilization has great advantages: it is less sensitive to severe weather conditions than application of the cement or emulsion treated mixes. Additionally FA permits more time for the compaction. In fact, stabilized mixes along with foamed asphalt deliver better fatigue properties.

Amin (2004) investigated the utilization of foam to improve local Sabkha Soil for using as base or sub-base material at high temperature conditions in Eastern Saudi Arabia [8]. He utilizes three treatment applications for the improvement of the Sabkha Soil. Foamed Asphalt (FA), emulsified asphalt, and sulfate-resisting (type V) Portland cement were those three treatments. He evaluated the properties of samples by conducting common testes like: Marshall Stability test, indirect tensile strength test and unconfined compressive strength test. The study found maximum soaked Indirect Tensile Strength (ITS) values and the maximum dry density for FA mixes by using 7% asphalt content. Unconfined Compressive Strength (UCS) test result showed that the maximum strength for both FA and FAC mixes was found at 7% to 8% asphalt content. The cement treatment of the asphalt mixes also improved the unconfined compressive strength. FA Sabkha Soil with 2% cement showed substantial improvement of the strength. Above all the best strength was found using FAC (FA + 2% cement) at 7% asphalt content. From the economical point of view the FA-Sabkha 2% cement mixture displayed a better result as comparison with the other stabilizing agents.

6.0 SUMMARY AND CONCLUSION

Sabkha is an inferior and indigenous type of soil which forms widely in the Arabian Gulf and in many other parts of Saudi Arabia, especially in the coastal areas. The hot and dry environments with excessive evaporation as compared to precipitation are most probable to formation of Sabkha soils. The properties of Sabkha Soil are very unique. It is loose, low density and low strength soil. As a result to these properties, Sabkha has some complex engineering problems that need to be improved. Several field stabilization techniques have been used to improve the weak properties of Sabkha in Saudi Arabia. Based on the results of this review, following results have been concluded:

- Several factors like climate, geochemical, hydrological and even some biological factors are liable for the formation of Sabkha and thus make that soil very heterogeneous characteristics.
- Chemical analysis of Sabkha of several sources reveals the predominant presence of salt content (more than the adjoining sea water) and thus they are very much sensitive to water.
- Physical and mechanical properties of Sabkha are also widely ranging, for example: Natural Water Content, from 10 to 84.6%, and Angle of Friction range from 0 to 30.
- Slandered Penetration Test of typical Sabkha Soil shows that it is very loose in nature (with SPT 8).
- Permeability of the Sabkha was found to be very low (1.24 x 10 -6 to 3.2 x 10 -5 m/s).
- For cement stabilization, the maximum dry density of Sabkha increases with cement content. The inclusion of cement to Sabkha increases the CBR maximum value. Also, cement stabilization improves the strength of Sabkha.
- For lime stabilization, there is no significant improvement on the maximum dry density of Sabkha. Also, lime Sabkha requires a long curing period to develop its strength.
- The strength of the Sabkha Soil is highly dependent on the molding moisture content, the curing regime and curing time, and the presence of salt in the Sabkha.
- Stabilization with different chemicals are considered to be relatively cheaper than many other available methods since the hydrated lime costs about 2.50 times higher than the Portland cement, in the local markets.
- Sabkha with geotextile can carry more loads than Sabkha without geotextile under dry and saturated conditions and it will increase with the improvement in the geotextile grade.
- The geotextile will also reduce the permanent deformation in Sabkha subgrade and the deformation decrease as the thickness of sub-base increases. Moreover, it can augment the stability of the Sabkha soil subgrades under existing soaked conditions.
- The use of geotextile and geosynthetics can be structurally & economically used in order to decrease the base thickness in pavement design and construction.
- Stabilization by foamed asphalt is one of the most effective stabilization procedures to improve strength of Sabkha from both engineering and economical view point.

Also, we found that none of the studies have been conducted for Inland Sabkha of Saudi Arabia. Due to day–to-day temperature and other climatic parameters changes, there is a huge potential of extensive research in this area. This will not only solve the existing problems economically but also will be efficient for sustainable development.

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References

[1] Al-Amoudi, O., S. Abduljauwad, Z. El-Naggar, and Rasheeduzzafar. 1992. Response Of Sabkha To *Laboratory* Tests: A Case Study. *Engineering Geology*. 33(2): 111-125.

[2] Al-Amoudi, O. 1993. Chemical Stabilization Of Sabkha Soils At *High* Moisture Contents. *Engineering Geology*. 36(3-4): 279-291.

[3] Abduljauwad, S., F. Bayomy, A. Al-Shaikh, and O. A-Amoudi. 1994. Influence Of Geotextiles On Performance Of Saline Sabkha Soils. *Journal of Geotechnical Engineering, ASCE*. 120(11): 1939-1960.

[4] Al-Amoudi, O., and S. Abduljauwad. 1995. Compressibility And *Collapse* Characteristics Of Arid Saline Sabkha Soils. *Engineering Geology*. 39(3-4): 185-202.

[5] Al-Shamrani, M. A., and A. Dhowia. 1997. Preloading For Reduction Of Compressibility Characteristics Of Sabkha Soil Profiles. *Engineering Geology*. 48: 19-41.

[6] Asi, I. M. 2001. Stabilization Of Sebkha Soil Using Foamed Asphalt. *Journal of Materials in Civil Engineering, ASCE*. 13(5): 325-331.

[7] Al-Amoudi, O. 2002. Characterization and Chemical Stabilization of Al-Qurayyah Sabkha Soil. *Journal of Materials in Civil Engineering, ASCE*. 14(6): 478-484.

[8] Amin, A. 2004. Comparative Study Of The Geotechnical Properties Of The Coastal Sabkhas Of Saudi *Arabia* And Their Hazardous Effects. *Bull Eng Geol Env*. 63(4): 309-314.

[9] Aiban, S., H. Al-Ahmadi, I. Asi, Z. Siddique, and O. *Al-Amoudi*. 2005. Effect Of Geotextile And Cement On The Performance Of Sabkha Subgrade. *Building and Environment*. 41(6): 807-820.

[10] Alsaaran, N. 2010. Origin And Geochemical Reaction Paths Of Sabkha Brines: Sabkha Jayb Uwayyid, Eastern Saudi Arabia. *Arab J Geosci*. 1(1): 63-74.

[11] Sabtan, A., and W. Shehata. 2002. Hydrogeology of Al-Lith Sabkha, Saudi Arabia. *Journal of Asian Earth Sciences*. 21(4): 423-429.

[12] Al-Shuhail, A., and A. Al-Shaibani. 2013. Characterization Of Sabkha Jayb Uwayyid, Eastern Saudi Arabia Using Seismic Refraction Profiling. *Arab J Geosci*. 6(3): 845-855.

[13] Dhowian, A. 1991. Secondary Compression Of Sabkha "Saline" Soils. *Engineering Geology*. 30(2): 155-169.

[14] Aiban, S., I. Asi, and O. Al-Amoudi. 1995. Stabilization Of Ras *Al*-Ghar Sabkha Soil With Lime. *The Fourth Saudi Engineering Conference*, Nov-1995, Vol-2.

[15] Al-Shamrani, A., and A. Dhowian. 1995. Rheological Behaviour of Jazan Sabkhas. *The Fourth Saudi Engineering Conference*, Nov-1995, Vol-2.

[16] Siddiqi, Z. U. 2000. Effects Of Geotextiles On The Load-Carrying Capacity Of Pavements On Sabkha. MS Dissertation, KFUPM.

[17] Al-Amoudi, O. 1992. Studies Of Soil Foundation Interaction In The Sabkha Environment Of Eastern Province Of Saudi Arabia. PhD Dissertation, KFUPM.

[18] Al-Amoudi, O., I. Asi and Z. El-Naggar. 1995. Stabilization Of An Arid, Saline Sabkha Soil Using Additives. *Quarterly Journal Of Engineering Geology And Hydrogeology*. 28(4): 369-379.

[19] Basyoni, M., and M. Aref. 2015. Sediment Characteristics And Microfacies Analysis Of Jizan Supratidal Sabkha, Red Sea Coast, Saudi Arabia. *Arabian Journal of Geosciences*. 8(11): 9973-9992.

[20] Johnson, D., M. Kamal, G. Pierson, and J. Ramsay. 1978. Sabkhas of Eastern Saudi Arabia, In: Al-Sayyari, S. S. and zotl, J. G. (ed.). *Quarternary Period In Saudi Arabia*. Springer-verlag, Berlin.

[21] Terzaghi, K., and R. Peck. 1967. *Soil Mechanics in Engineering Practice*. 2nd Edition. John Wiley, New York.

[22] Das, B. 2013. *Principles of Geotechnical Engineering*. 7th Edition, CL Engineering. New York.