Use of Geotextiles to Improve Sabka Subgrades for Low Volume Roads

S. N. Abduljauwad
King Fahd University of Petroluem & Minerals, Dhahran, Saudi Arabia

F. Bayomy
University of Idaho, ID, USA

A. M. Al-Shaikh
Isam Kabbani & Partners Co., Alkhobar, Saudi Arabia

ABSTRACT: One typical problem in the construction of low volume roads in the Eastern Province of Saudi Arabia and along the coast of the Gulf is the presence of sabkha soil. Sabkha is a saline, evaporative flat soil that forms under arid climates. It is generally associated with saturated watertables that are very close to the ground surface. Sabkha loses its strength when wet. Near the Gulf coast, the ground watertable is usually high and it can be higher than the pavement surface level in some locations. Hence, sabkha is considered very poor as a subgrade for road construction in the Gulf region. This study investigates the effectiveness of using geotextile fabrics on the top of sabkha subgrade under thin untreated bases that are typically used with low volume roads. The investigated parameters include: type of geotextile fabric, thickness of untreated base, sabkha subgrade moisture condition and the level of loading. Results of permanent deformation under repeated loads have shown that there is a great reduction in rutting susceptibility of the reinforced sabkha subgrade. This was more significant when comparing dry to wet conditions. Also, the bearing capacity of the sabkha subgrade soil has increased considerably by geotextile fabrics reinforcement. As the thickness of the untreated base increases, the effect of the geotextile reinforcement becomes ineffective. This indicates the importance of the use of the geotextiles in low volume roads where the base thickness is usually small.

1 INTRODUCTION

The expression "sabkha" is originally an Arabic term for the large, flat, evaporative areas, situated either along the coast (called coastal sabkha) or farther inland (called continental or inland sabkha). Along the western shores of the Arabian Gulf, sabkha soils extend intermittently for more than 1,700 km, with average inland extensions of 20 km. These soils normally have loose, rather permeable, sandy to gritty textures. Their salt-encrusted surface is usually composed of hygroscopic salts, which can render the normally-stable sabkha surface unstable when dampened.

Several techniques have been implemented to improve the inferior sabkha properties, with various degrees of success (Akili, 1981; Juillie and Sherwood, 1983). These have included soil replacement, vibratory rollers, deep soil densification using vibroflotation, stone columns and dynamic compaction. Control of both groundwater rise and inundation of sabkha with fresh water can be considered as a vital process for stabilized sabkha soils, because the cementing materials include aragonite, halite, gypsum, anhydrite and others. The dissolution of these salts, or part of them, particularly halite (i.e. NaCl), may significantly alter the stability of sabkha. Gravel layers have been recommended as horizontal drains to intercept the capillary fringe of sabkha soil. However, salt precipitation and sand-silt fines accumulation may block the gravel porosity thereby decreasing its efficiency. With the advent of geotextiles as efficient, versatile, multi-functional and cost-effective materials with many applications in the field of geotechnical engineering, such as reinforcement, drainage, etc. (Koerner, 1990), some trials on the use of geotextiles to arrest saline-water rise have been reported. Clough and French (1982) have shown the success of intercepting saline groundwater capillarity by geotextiles in cultivating the sabkha at the Al-Khobar Meridian Hotel. Similarly, French et al. (1982) have demonstrated, through laboratory experiments, the efficiency of the Filtram to prevent the rise of both salt and water and, furthermore, to prevent water infiltrating from above penetrating the fabric.

The purpose of this extensive laboratory program is to assess the influence of geotextiles on the performance of sabkha subgrade under static and cyclic loading conditions. A special cylindrical mould was fabricated to prepare the soil-fabric-aggregate (SFA) systems. Several variables were investigated, including subbase thickness, geotextile type, loading and moisture conditions.

2 EXPERIMENTAL PROGRAM

The common practice in the geotextile field is to clear and level the subgrade, spread the fabric out on the surface, generally unstrained, and cover the fabric with a suitable thickness of granular backfill compacted to a certain standard procedure (Greenwood and Brady, 1992); the system thus formed is called a soil-fabric-aggregate (SFA) system. In this laboratory investigation, the same methodology was used to conduct a broad-based two-series experimental investigation. In the first series, routine characterization tests were conducted on the sabkha subgrade soil and the subbase material used, in order to determine their basic properties. The second series consisted of testing the SFA systems under both static and repetitive loadings.

2.1 Materials

Sabkha was brought from the vicinity of Ras Tanura, eastern Saudi Arabia (where one of Saudi Arabia's largest oil refineries is located), from a depth of about one meter. The natural moisture content was 31%. The basic properties of sabkha have been briefly summarized in Table 1. These data, determined according to standard ASTM tests, show that the present subgrade sabkha contained a significant amount of fines, as the classification tests indicate, and this sabkha is highly susceptible to collapse. This can be observed from the significant reduction in CBR values from 9.0 to 2.2 due to soaking in water. The major compounds present in sabkha, as determined by semi-quantitative X-ray analysis (Al-Shaikh, 1989), were 60% aragonite, 17% calcite, 11% quartz, and 11% halite. This compositional data indicates a considerable presence of aragonite. Since aragonite is the principal mineral in maritime precipitation (Shearman, 1966), the 60% aragonite content indirectly proves that the present sabkha is coastal. Further, halite, constituting 11% of the sabkha weight and being highly soluble in water, is the clue for the high susceptibility of sabkha to collapse, as shown by the CBR test results. The subbase, granular material was brought from a local construction establishment that uses this material in the construction of roads in the Eastern Province of Saudi Arabia. The tests conducted on this material were grain-size analysis and compaction tests. The grain-size distribution of the granular subbase material is depicted in Fig. 1; its maximum dry unit weight $(\gamma_d)_{max}$ was 20.6 kN/m^3 and its optimum moisture content (w_{opt}) was 7.5%. Three different types of non-woven geotextiles were used in this investigation; Polyfelt TS-800, Polyfelt TS-700 and Typar 3407. The most important characteristics of these geotextiles, as determined by the manufacturers, are listed in Table 2. The data shown in this table indicate that the TS-800 geotextile has more weight, thickness and strength as well as less elongation, cone resistance and permeability than the other two types of geotextile.

Table 1 Properties of subgrade sabkha soil

Parameter	Value
Uniformity Coefficient, C_u	80
Curvature Coefficient, C_c	9.8
AASHTO Classification	A-6(7)
USCS Classification	CL
w_L	29.4
w_p	18.4
I_p	11.0
w_{opt} (%)	14.5
$(\gamma_d)_{max}$ (kN/^{2})	1.88
CBR (soaked)	2.2
CBR (unsoaked)	9.0

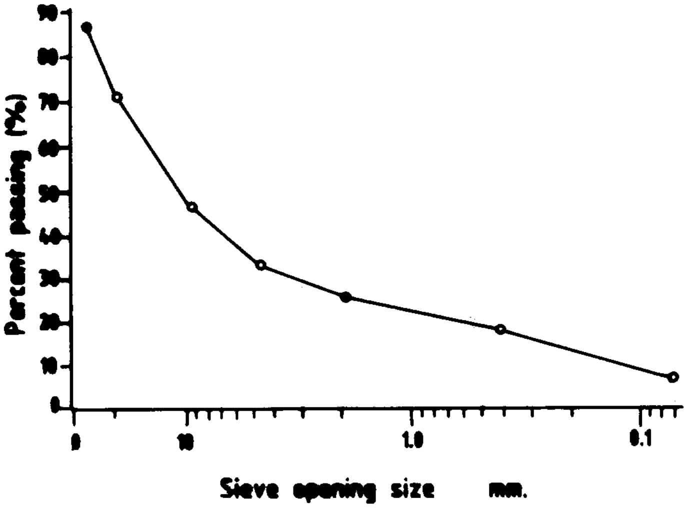

Fig. 1 Grain size distribution of granular subbase material

Table 2 Technical specifications of the three geotextiles used in these investigations

Property	Standard	Dimension	TS-700	TS-800	Typar 3407
Weight	ASTM D 3776	g/m^2	280	400	136
Thickness under Pressure of 200 kN/m^2	ASTM D 3777	mm	2.6	3.3	0.46
Strip Tensile Strength	ASTM D 4595	kN/m	18	24	7.6
Grab Tensile Strength	ASTM D 4632	N	1080	1550	680
Elongation	ASTM D 1682	%	50-80	50-80	>60
Cone Drop Resistance	TRC, SF	mm	10	7	29
Permeability Coefficient, K	Francius Institute	10^{-4} ms^{-1}	90	80	7

2.2 Soil-fabric-aggregate (SFA) loading tests

The factorial design, shown in Table 3, involved testing 28 specimens. Each of these specimens was given a notation code (legend) to specify the various test conditions. For example, specimen number "S2G2H2W" means the sample was tested under stress level 2 (S2) of 380 kPa (55 psi) using a type 2 (G2) TS-700 geotextile and the thickness of the subbase was 5 cm (H2) under a saturated condition (W). In the case of static tests, the legend starts with (ST). In each test, the sabkha, geotextile and granular material had to be placed in a special mould. Two cylindrical (32×42 cm) moulds were specially prepared from a PVC pipe with a 2 cm wall thickness. A perforated circular base of 42 cm diameter was attached to the cylindrical moulds via a circular groove and an O-ring. When saturation was investigated, the cylindrical mould was placed in a circular tank of about 60 cm diameter with 5 cm clearance from the base, as shown in Fig. 2. It should be mentioned that a sheet of Polyfelt TS-500 filter was placed at the bottom of the subgrade to prevent clogging of the holes at the base, and the saturation process took at least 24 hours to ensure proper soaking of the SFA systems.

The lower 20 cm of the mould invariably contained compacted sabkha subgrade. Compaction of sabkha at $(\gamma_d)_{max}$ and w_{opt} was achieved by mixing the required amounts of air-dry sabkha with water, compacting the material in four equal lifts using a mechanical automatic compactor. Each layer needed 25 blows of the modified hammer (6.0 kg weight) falling freely from 46 cm to obtain the required $(\gamma_d)_{max}$. Each geotextile was first cut into circular pieces of 35 cm diameter and then placed on top of the compacted subgrade in the mould. The granular material was thereafter placed in a way more or less similar to that followed when the sabkha subgrade was compacted. The granular material was compacted at its $(\gamma_d)_{max}$ and w_{opt} and placed either directly on the sabkha subgrade or on the geotextile.

2.3 Loading systems

Two types of loading were performed: static and repeated loading systems. Static loading was applied using a universal compression tester Strassentest machine, which has a maximum press travel of 130 mm and a maximum load of 50 kN. Static loads were conducted at a rate of 0.5 kN/min and both displacement and load were automatically recorded on a data sheet every 0.5 kN.

The main features of this system are shown in Fig. 2 (Abduljauwad et al., 1994). Permanent deformation (i.e. rutting) was measured with a dial gauge at a selected number of cycles. The gage was held by a magnetic holder to the top of the stand of the loading system. The gage was fixed to the load cell and had an accuracy of 0.01 mm. Elastic (resilient) deformation was measured by means of an LVDT and a chart recorder (Fig. 2). Normally, the LVDT readings were taken simultaneously with the permanent deformation at the same number of load repetitions.

3 RESULTS AND DISCUSSION

3.1 Static loading results

Figure 3 indicates that the ultimate strength was significantly increased when geotextile was incorporated in the SFA systems for both dry and saturated conditions; the ultimate strength of the geotextile systems was 3.0 and 21 kN for saturated and dry specimens, respectively, compared to 1.5 and 5.0 kN for the "no geotextile" specimens under the same conditions. These results indicate that systems of sabkha with geotextile can carry higher loads than sabkha systems without geotextile under both dry and saturated conditions. The improvement, however, was greater under dry conditions when compared to the saturated ones.

Table 3 Factorial design and designated specimen codes for various test conditions

Condition of Test	Thickness of Subbase	H1 = 2.5 cm	H2 = 5.0 cm				H3 = 10 cm
	Type of Geotextile \ Applied Stress	Repeated (kN/m^2)	Repeated (kN/m^2)			Static	Repeated (kN/m^2)
		σ_2 380	σ_1 240	σ_2 380	σ_3 520		σ_2 380
Dry (D)	NONE (G0)	S2G0H1D	S1G0H2D	S2G0H2D	S3G0H2D	STG0H2D	S2G0H3D
	G1		S1G1H2D	S2G1H2D	S3G1H2D	STG1H2D	
	G2	S2G2H1D		S2G2H2D			S2G2H3D
	G3			S2G3H2D			
Saturated (W)	NONE (G0)	S2G0H1W	S1G0H2W	S2G0H2W	S3G0H2W	STG0H2W	S2G0H3W
	G1		S1G1H2W	S2G1H2W	S3G1H2W	STG1H2W	
	G2	H2G2H1W		S2G2H2W			S2G2H3W
	G3			S2G3H2W			

Type: G1 = Polyfelt TS-800
S1 = Stress Level 1 (240 kPa)
ST = Static Test
G2 = Polyfelt TS-700
S2 = Stress Level 2 (380 kPa)
D = Dry
G3 = Typar 3702
S3 = Stress Level 3 (520 kPa)
W = Saturated

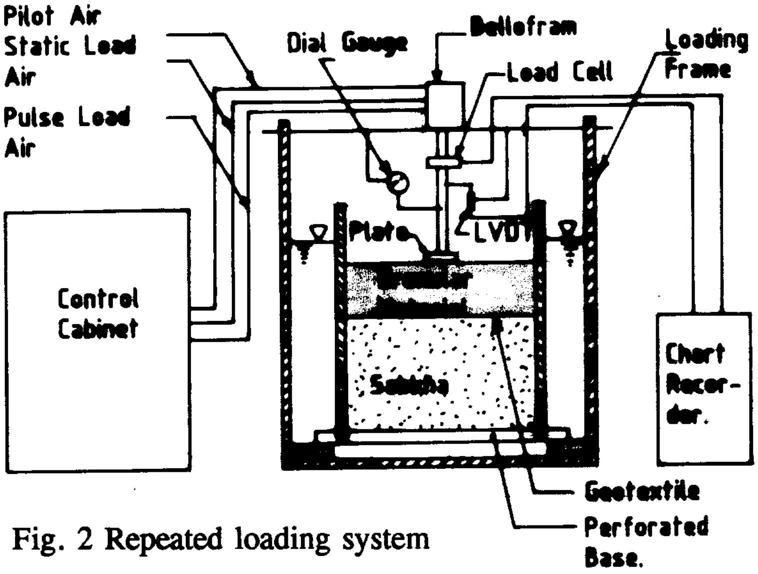

Fig. 2 Repeated loading system

3.2 Dynamic load results

3.2.1 Effect of saturation

Figure 4 indicates that the deformation in saturated specimens was much more extensive than in the dry specimens under identical conditions of load and subbase thickness. When geotextile Polyfelt TS-700 (G2) was used, the deformation did not exceed 13 mm after 150,000 load repetitions in dry conditions (S2G2H2D) compared to a saturated sample deformation of 47 mm after the same number of load repetitions (S2G2H2W). These results, as well as those presented in the static loading conditions, illustrate the unsatisfactory performance of wet sabkha. This behavior is attributable to the presence of a significant amount of soluble salts in the sabkha matrix. The X-ray data presented earlier indicated that halite comprised 11% of the weight of sabkha and constitutes one of the primary cementing agents, and consequently its dissolution is expected to result in significant deformation.

3.2.2 Effect of subbase thickness

Figure 5 signifies the influence of subbase thickness on sabkha under saturated condition under a load of 380 kPa (S2) and with and without G2 geotextile. It was observed from these figures that geotextile tended to decrease the deformation in SFA systems with 2.5 and 5.0 cm subbases. These data indicate that the deformation decreased with increasing the thickness of subbase. This is attributed to the enhanced capability of the subbase to spread the load, thereby reducing the peak stress on the subgrade and thus increasing the stability of the system. These data clarify the significant influence of geotextile at low subbase thicknesses (H1 = 2.5 cm), as discussed earlier.

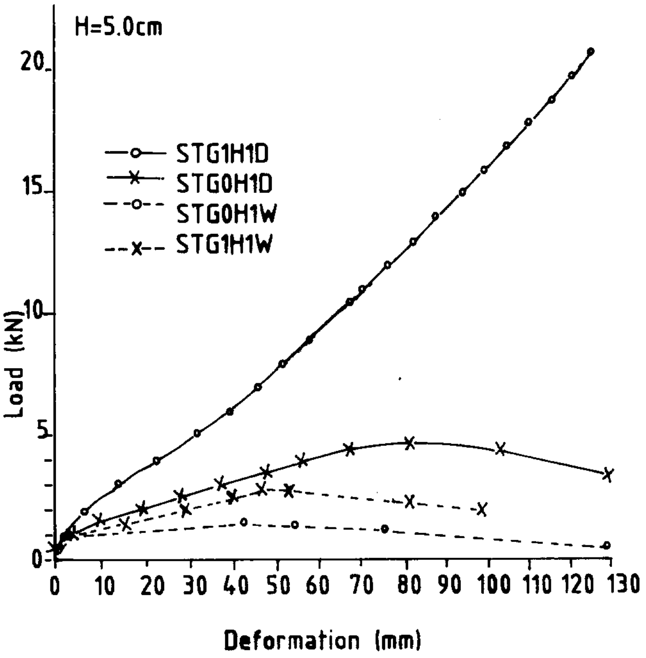

Fig. 3 Deformation versus static loads of dry and saturated samples

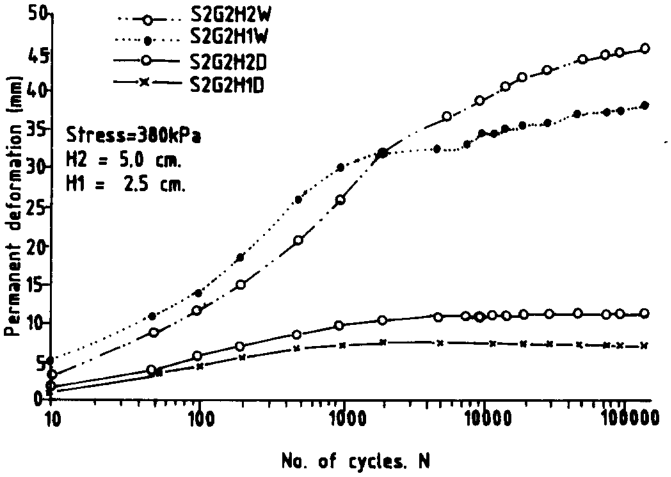

Fig. 4 Effect of saturation on permanent deformation of samples with geotextiles

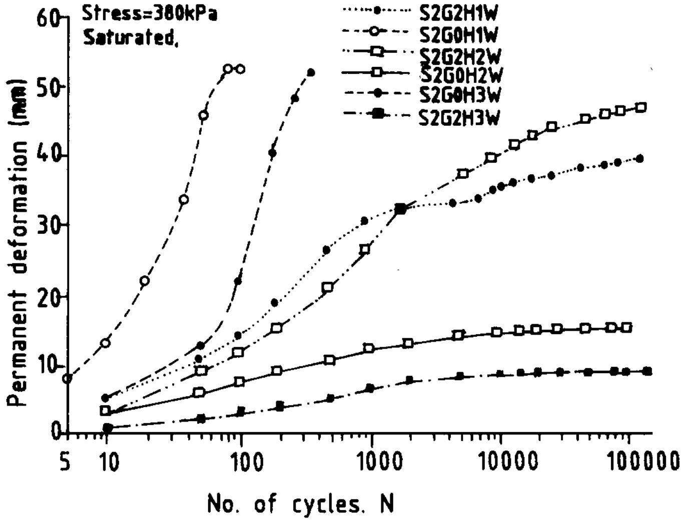

Fig. 5 Permanent deformation versus number of load cycles of saturated samples of different subbase thicknesses

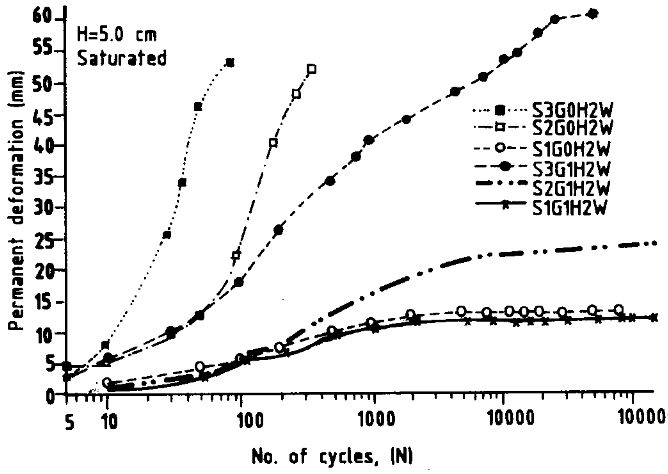

Fig. 6 Permanent deformation versus number of load cycles of saturated samples subjected to different stresses

3.2.3 Effect of stress level

Three stress levels were selected to test identical specimens made with a subbase thickness of 5 cm and with or without geotextile G1 (Polyfelt TS-800). These specimens were tested either under dry or saturated conditions. It can be clearly observed from Fig. 6 that geotextile incorporation in the SFA systems decreased permanent deformation in specimens subjected to large stresses, i.e. 380 and 520 kPa; this effect was not significant, however, when the stress was reduced to 240 kPa. This finding was attributed to the fact that since low stresses induce insignificant deformation; hence the role of geotextile will be minor. Results indicate that the reduction in permanent deformation due to geotextile incorporation under saturated conditions was much higher than that under dry conditions. This again signifies the important role that geotextiles can play in mitigating the instability of sabkha once it is flooded. The increase in deformation would also be aggravated by increasing the load repetition, particularly when geotextile was not present. For example, when specimens were tested without geotextile at a stress level of 520 kPa, permanent deformation attained a maximum depth of 53 mm compared to only 18 mm when geotextile was used under the same test conditions.

3.2.4 Effect of geotextile type

The influence of geotextile type on the performance of SFA systems was investigated under dry and saturated conditions by testing identical specimens with a 5 cm subbase and under 380 kPa of repeated stress. The effect of geotextile type on the permanent deformation for the saturated condition is illustrated in Table 4.

Results indicate that all geotextile types significantly reduced the permanent deformation in sabkha subgrade when compared to specimens with no geotextile. However, each geotextile produced different levels of reduction. The best performance was attained by the TS-800 geotextile (G1) which produced a permanent deformation that did not exceed 22 mm after more than 150,000 cycles. Typar 3407 (G3) recorded the lowest degree of improvement, producing a deformation that reached 52 mm after about 1,300 cycles. These different levels of performance are attributed entirely to the structure of these geotextiles, i.e. their physical and mechanical properties, as presented in Table 2. Consequently, the characteristics of geotextile to be used in any field improvement, such as improving sabkha subgrade or otherwise, should be well investigated in order to predict the future performance of SFA systems.

Table 4 Effect of geotextile type on permanent deformation

No. of Cycles (N)		10	50	100	200
Permanent Deformation (mm) of	G0	5.32	12.36	22.12	40.44
	G1	1.93	3.45	5.38	7.41
	G2	3.2	9.0	11.92	15.34
	G3	3.5	9.5	12.65	17.71

4 CONCLUSION

1) The incorporation of geotextiles in SFA sabkha subgrade systems produced a much higher resistance to static loads than similar systems without geotextiles under both saturated and dry conditions.
2) The incorporation of geotextiles in SFA sabkha subgrade systems significantly improved the behavior of sabkha, particularly when the specimens were saturated.
3) The efficiency of geotextiles in reducing the permanent deformation in SFA systems diminished with an increase in subbase thickness or with a decreased level of stress.
4) Geotextiles with different physical and mechanical properties exhibited different levels of performance.

ACKNOWLEDGEMENT

The authors gratefully acknowledge the support provided by the Department of Civil Engineering, King Fahd University of Petroleum and Minerals. The support of Isam Kabbani & Partners (UNITECH) for providing the geotextile material is greatly appreciated. Appreciation is also extended to Mr. Solano Cruz for typing the manuscript.

REFERENCES

Abduljauwad, S. N., Bayomy, F., Al-Shaikh, A. M. and Al-Amoudi, O. S. B. (1994) The influence of geotextiles on the performance of saline 'sabkha' soils, *Geotechnical Engineering Journal,* ASCE, in press.

Akili, W. (1981) On sabkha sands of Eastern Saudi Arabia, *Proceedings of Symposium on Geotechnical Problems in Saudi Arabia,* Riyadh, 2:775-791.

Al-Shaikh, A. M. (1989) *Effect of using geotextile on behavior of sabkha subgrade,* M.S. Thesis, Dept. of Civil Engineering, King Fahd University of Petroleum and Minerals, Dhahran, Saudi Arabia.

Clough, I. R. and French, W. J. (1982) Laboratory and field work relating to the use of geotextiles in arid regions, *Proceedings of 2nd Conference on Geotextile,* Las Vegas, Session 5B:447-452.

French, W. J., Poole, A. B., Ravenscroft, P. and Khiabani, M. (1982) Results of preliminary experiments on the influence of fabrics on the migration of groundwater and water-soluble minerals in the capillary fringe, *Quarterly Journal of Engineering Geology,* 15:187-199.

Greenwood, J. H. and Brady, K. C. (1992) Geotextiles in aggressive soils, *Construction & Building Materials,* 6(1):15-18.

Juillie, Y. and Sherwood, D. E. (1983) Improvement of sabkha soil of the Arabian Gulf Coast, *Proceedings of 8th European Conference on Soil Mechanics and Foundation Engineering,* Helsinki, Vol. 2, Session 7-12:781-788.

Koerner, R. M. (1990) *Designing with geosynthetics,* 2nd ed., Prentice-Hall, New Jersey.

Shearman, D. J. (1966) Origin and marine evaporites by diagenesis, *Transactions of Institution of Mining and Metallurgy,* 75(717):B208-B215.