Building Roads on Sabkha Soils with Geosynthetic Systems

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Summary

Road engineers often face the challange to design a solid road foundation on top of very soft soils which are characterized by sabkha soils. With the help of geosynthetics innovative solutions can be offered to several situations. This paper gives an overview of these several solutions and the design principles behind these options. Also, the paper give some new insight on which properties of geosynthetics are important for designing road structures on sabkha soils. Furthermore, the paper will present the geosynthetic products which can be used into these roadstructures.

Keywords: Road design, sabkha, unpaved road, paved road, geogrid, geotextile, high modulus geogrid composite, piling, traffic intensity, axle loading,

1. Introduction

Sabkha is an Arabic expression to describe recent coastal sediments with a high salt content and are characterised by very low bearing capacities and low SPT values. Sabkha soils are widely distributed in the Arabian Peninsula. Sabkha soils are not only found in the Middle East but are also widely distributed over the world, like in India, Australia, USA and Southern Africa where sabkha soils have different expressions [1]. The geotechnical problems caused by sabkhas are now well defined and although several standard soil improvement techniques are still extensively used, more economical and long-lasting soil improvement methods are playing an increasing role in foundation work of roads and highways. One of the most economical soil improvement solution is the use of geosynthetics. Not only are geosynthetics used as a reinforcement or as a separators, they more and more are using in combinations with other foundation technologies. This paper presents several standard possible stabilisation methods used in sabkha soils with geosynthetic systems and reveals the benefits of using geosynthetics.

2. Geotechnical properties of Sabkha Soils

Although several papers have been published about the sabkha characteristics, a rough distinction between muddy and sandy sabkhas can be made [2].

- *Muddy sabkhas:* These soils are generally found between +2m and -6m related to present sea level and are all near the coast (Fig. 1). These sabkha soils are relatively young.
- *Sandy sabkhas:* Sandy sabkhas are often sandy layers interbedded with sandy mud. These ancient soils can be found as far as 50 km inland (Fig.2).

Fig. 1 Muddy Sabkha Areas along the Arabian Gulf Coast

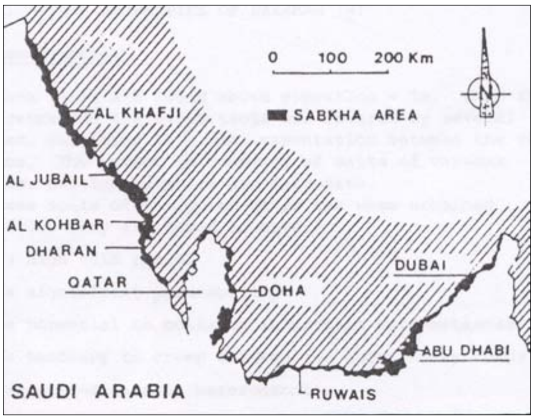


Fig. 2 Sandy Sabkha Areas Inland

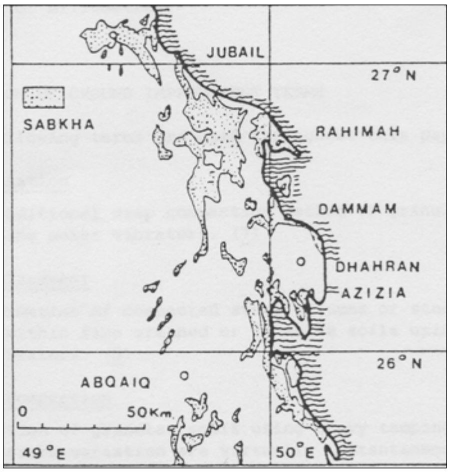


Table 1 highlights the physical characteristics of both sabkha types. Clearly, the muddy sabkhas are the worst to construct your road on. This paper will continue with these muddy sabkhas since these are the most critical of the two.

Table 1. Typical soil properties of muddy and sandy sabkhas [2]

Properties	**Muddy Sabkhas**	**Sandy Sabkhas**
Percentage Fines	25 to 95	5 to 25
Salt content (%)	2 to 18	2 to 15
Water content (%)	25 to 90	4 to 40
In-situ density	1.0 to 1.35	1.3 to 1.85
Internal friction	0^0 to 22^0	20^0 to 35^0
Percentage of Ca CO_3 (%)	20 to 90	> 30
Plasticity index	0 to 40	Non plastic
Cohesion (kN/m^2)	0 to 55	Zero
Compression index	0.4 to 0.95	Zero
S.P.T. values (blows)	0 to 4	2 to 10
Static cone resistance (MN/m^2)	0.2 to 2	1 to 6
Bearing capacity (kN/m2)	15 to 30	30 to 60

3. Possible Stabilisation Methods

Before building infrastructure on sabkha soils, a stabilisation method has to be selected to improve the bearing capacity of the soils. There have been many different stabilisation methods discussed. The main methods are:

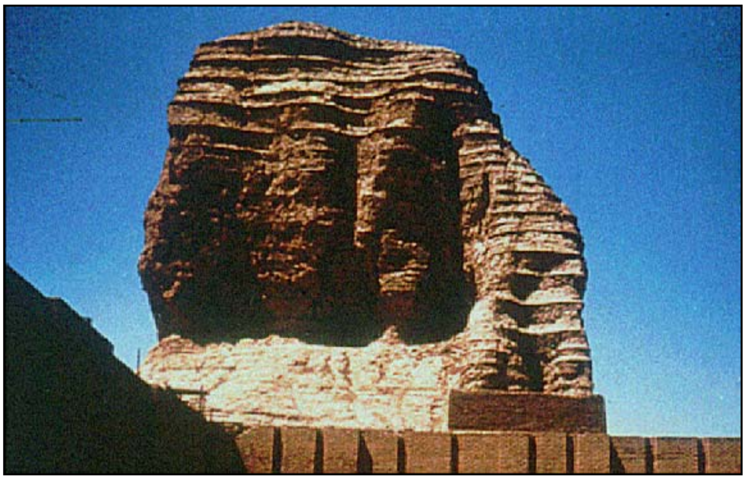
- Filling the sabkha soils with different stone gradings, from large diameters down to smaller ones, untill the minimum required bearing capacity is reached.
- Pre-loading with an embankment to incresae the consolidation of the natural soil
- Installing chemical additives
- Mechanical soil improvement techniques like vibroflotation, heavy tamping related methods, sand columns and piling.
- Geosynthetics

Each of these methods has its advantages and disadvantages. This paper goes into the possibility of using geosynthetics. Their use is becoming more and more common as they usually present an economic advantage to the more traditional methods.

4. Geosynthetics for Sabkha

Geosynthetics to stabilize soil have been used over a long period. Already thousands of years ago special pressed paper was used as soil reinforcement (Fig.3). Later the Romans have used organic materials like strawmats to stabilize road structures. Only the past century other materials have been used, first products out of steel and later polymer reinforcement products, to stabilize and reinforce structures to take away the restriction of the natural friction angle of the soil used.

Fig. 3 Soil Reinforcement with pressed paper along the Eufraat



In principle there are two main geosynthetic products used in the road foundation for sabkha soils:

- Geotextiles (Fig.4): a planar, permeable, polymeric nonwoven textile material [3]
- Geogrids (Fig.5): a planar, polymeric structure consisting of a regular, open network of connected tensile elements and whose openings are much larger than its constituents [3]

Furthermore, there are geogrid+geotextile composites which provide a 2-in-1 solution (Fig. 6).

Fig.4 Geotextile

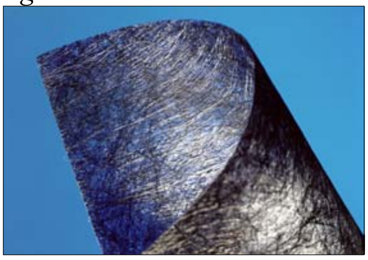


Fig.5 Geogrid

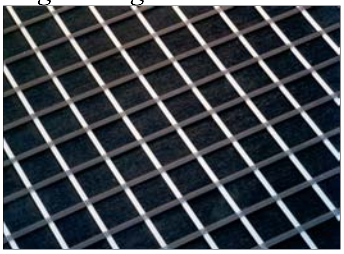
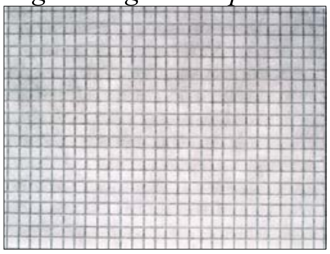


Fig.6 Geogrid composite



The main geosynthetic characteristics which are important to function on sabkha soils are mentioned below (Table 2) and are based on the EN standard for roads and the trafficed areas [4].

Table 2. Important geosynthetic characteristics for sabkha soil

Geotextile Function: filtration + separation		**Geogrid** Function: reinforcement		**Geogrid composite** Function: reinforcement + filtration + separation	
Characteristic	**Unit**	**Characteristic**	**Unit**	**Characteristic**	**Unit**
Tensile strength in both directions	kN/m	Tensile strength in both directions	kN/m	Tensile strength in both directions	kN/m
Resistance to static puncture	kN	Elongation at break	%	Elongation at break	%
Dynamic perforation resistance	mm	Durability	-	Resistance to static puncture	kN
Opening size	µm			Dynamic perforation resistance	mm
Water permeability	m/s			Opening size	µm
Durability	-			Water permeability	m/s
				Durability	-

The Durability aspect covers the assessment on weathering and service life. The weathering test indicates the maximum exposure time on site before the geosynthetics have to be covered by soil. The service life is reviewed after several tests and is based on the type of material used in relation to the conditions of use. For example, the oxidation resistancy for polypropylene and the resistance to hydrolysis for polyester.

The above characteristics have to be measured according to EN or ASTM standards. However, the European standards (EN) and the American standards (ASTM) are not equal and can therefore show different values. One example is for the geotextile where the measurement of the Opening Size should be done with standard seives. Since the ASTM seives are different than the EN seives, there will be different results for the same geotextile. An other example is for the geogrid . The speed of the ASTM tensile test is slower than the EN test. This can result in different tensile test results for the same geogrid. When needed to compare between EN and ASTM results for product comparisons, it is advised to consult an independent expert or to go to product manufacturers which have both ASTM and EN testresults.

5. Geosynthetic Systems for Sabkha Soil

5.1 Introduction

Based on the axle loading and the traffic intensity, a rough indication can be made which geosynthetic system can be selected to build on sabkha soil. Both criteria are more discussed on the next section. The other sections show the different geosynthetic systems.

5.2 Axle Loading and Traffic Intensity

The axle loading is based on the maximum axle load of a vehicle, either truck or a car. Table 3 shows how the axle loading is characterized in this paper. The traffic intensity is based on the number of axle passes per year. The axle passes are used instead of the number of vehicles because first it is difficult to make a difference between the number of cars and trucks. Second, the road is being attacked during each axle pass and each pass has to be absorbed by the roadstructure. Table 4 shows a rough indication of several traffic intensity levels. The fact that there are many other possibilities to make such a selection for both criteria is recognized, however, these tables give a tool for the geosynthetic systems presented in this paper and are based on best practises of using geosynthetics in roads worldwide.

Table 3. Axle loading (max. kN per axle per vehicle)

< 50 kN (5 tons)	Small
50 kN – 100 kN (5 – 10 tons)	Medium
> 100 kN (10 tons)	High

Table 4. Traffic intensity (number of axle passes per year)

< 100,000	Small
100,000 – 1,000,000	Medium
> 1,000,000	High

5.3 Selection of Geosynthetic System

With the axle loading and traffic intensity defined, a guideline can be given of which geosynthetic system has to be used on top of low bearing capacity sabkha soils and is presented in Table 5. This table refers to the appropriate paragraph of Chapter 5 which discusses the system in more detail.

Table 5 also shows the type of road surface. In most cases the road surface is selected on the basis of the expected axle loading and traffic intensity during the life-time of the structure. For Table 5, only the unpaved and paved surface are selected. Further detail of the surface layer itself is often based on the applicable national standards on road design and construction to which is refered if more information is necessary.

Table 5. Selection of the Geosynthetic System for Muddy Sabhkas

Input		**Output**			
Axle loading	**Traffic Intensity**	**Road surface**	**Geosynthetic system**	**Single or multi geogrid layers**	**Paragraph**
Low	Low	Unpaved	Geotextile	-	5.4
Low	Medium	Unpaved	Geogrid + geotextile	Single	5.5
Medium	Medium	Unpaved	Geogrid (high modulus) + geotextile	Single	5.6
Medium	Medium	Paved	Geogrid + geotextile	Single	5.7
Medium	High	Paved	Geogrid + geotextile	Multi	5.8
High	High	Paved	Geogrid (high modulus) + geotextile	Multi	5.9

5.4 Unpaved Road for Low Axle Loading + Low Traffic Intensity

Building an unpaved road for low axle loading and low traffic intensity on sabkha soils only need a geotextile layer. The geotextile will prevent mixing of the good gravel layer with the small muddy particles of the sabkha which is called the 'pumping effect'. This pumping effect is created by the constant dynamic wheel loads creating wateroverpressure in the sabkha soil. The wateroverpressures create water travelling upwards to the gravel layers. With the geotextile as the filter, no small muddy particles will get into the gravel layer. This results in a clean subbase layer which remains its stiffness during the road life. Although some rutting may appear at the roadsurface, this is often not very critical. Figure 7 shows the cross-section of the lay-out. If rutting appears, this is often during the first installation phase. The rutting can be filled with new gravel (see Fig. 8).

Fig. 7 Unpaved Road for Low Axle Loading+Low Traffic Intensity

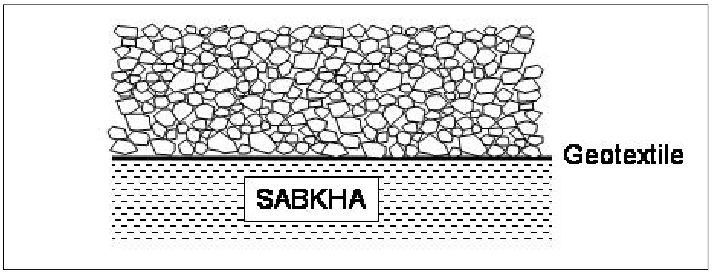
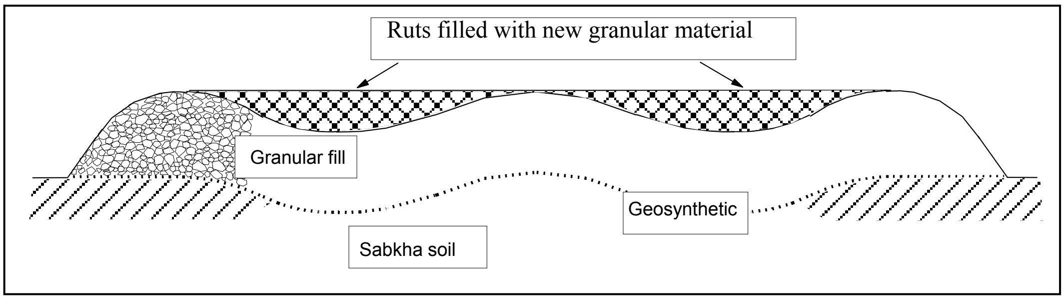


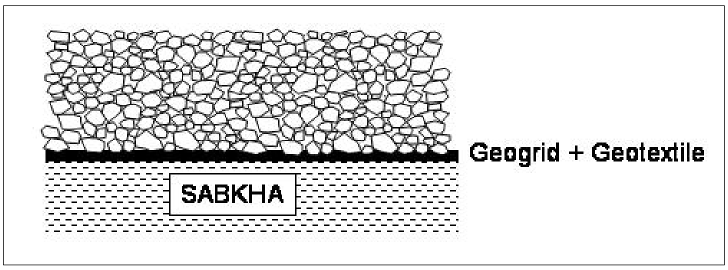
Fig. 8 Filling up the rutting shortly after installation.



5.5 Unpaved Road for Low Axle Loading + Medium Traffic Intensity

In this case a reinforcement layer is needed to increase the stiffness of the foundation. Although the axle loading can be up to 100 kN, a geogrid + geotextile (or a geogrid composite) can be used to create a solid foundation (Fig. 9). The geogrid will increase the stiffness, while the geotextile will separate the soiltypes and filter out any wateroverpressures in the sabkha to prevent the pumping effect. Still some minimum rutting may appear but this is not critical. The rutting results in the mobilisation of the geogrid which is therefore creating the additional stiffness in the foundation. This is explained in Chapter 6. Again, if rutting appears, it should be filled up with new gravel shortly after installation.

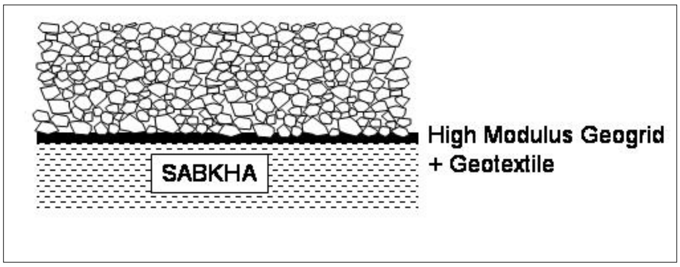
Fig. 9 Unpaved Road for Low Axle Loading+Medium Traffic Intensity



5.6 Unpaved Road for Medium Axle Loading + Medium Traffic Intensity

Increasing the traffic intensity will have impact on the required stiffness. More and more dynamic loads will be taken up by the foundation layer which is resulting in some higher requirements for the reinforcement layer. The geogrid should have a higher modulus than the previous geogrid layer in paragraph 5.5. This can be measured by the 2% modulus of the geogrid. An example is the Enkagrid TRC which has been assessed by the Ministry of Communication in Saudi Arabia for sabkha soils [5]. Figure 10 presents the proposed cross-section.

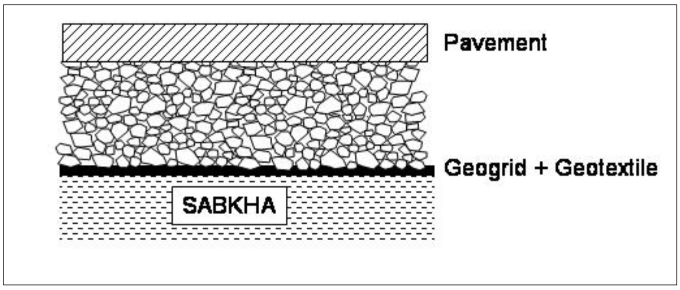
Fig. 10 Unpaved Road for Medium Axle Loading + Medium Traffic Intensity



5.7 Paved Road for Medium Axle Loading + Medium Traffic Intensity

When the road engineer selects to design a paved road structure on top of muddy sabkha, the use of the geogrid and geotextile is helpful for a longer road life. The geogrid for reinforcement and the geotextile for the separation effect (Fig. 11).

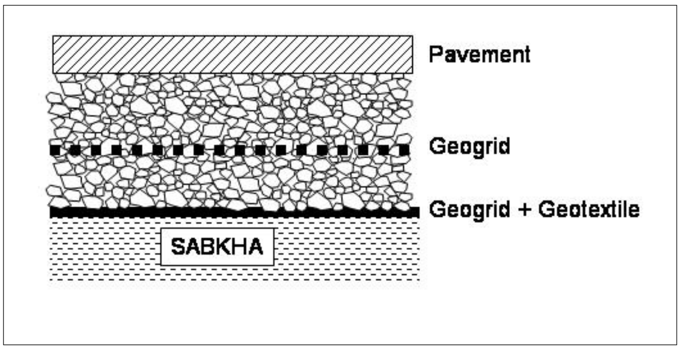
Fig. 11 Paved Road for Medium Axle Loading + Medium Traffic Intensity



5.8 Paved Road for Medium Axle Loading + High Traffic Intensity

The more traffic intensity, again the higher the stiffness should be to hold the dynamic loading. In this case, a multiple geogrid layer is used to create a stiff raft (or reinforced mattrass) underneath the bitumen and base layers. The top layer geogrid is spreading the loads over a wider area, while the bottom geogrid layer is taking up the horizontal forces. Still a geotextile is needed to prevent the mixing of the different soil types (Fig.12).

Fig. 12 Paved Road for Medium Axle Loading + High Traffic Intensity



5.9 Paved Road for High Axle Loading + High Traffic Intensity

This ultimate situation requires the combination of a high modulus geogrid together with a geotextile. Furthermore, additional geogrid layers should be used to spread the high axle load over a wide area. The more loadspreading within the foundation layer, the more the foundation will act as a working platform or a stiff matrass. Figure 13 provides the cross section of the situation. Figure 14 is showing a design for a project in the UAE where all elements in the total road layer are presented. More information about this design and its principles are presented in Chapter 6.

Fig. 13 Paved Road for High Axle Loading + High Traffic Intensity

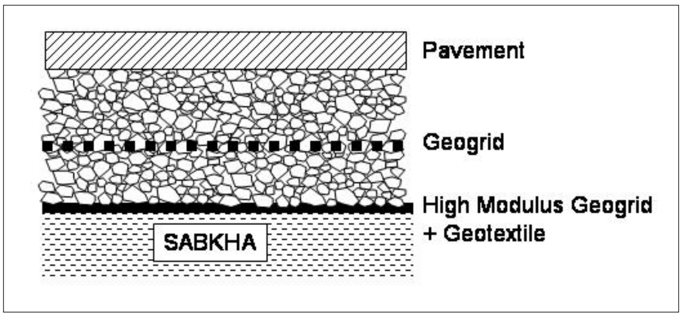
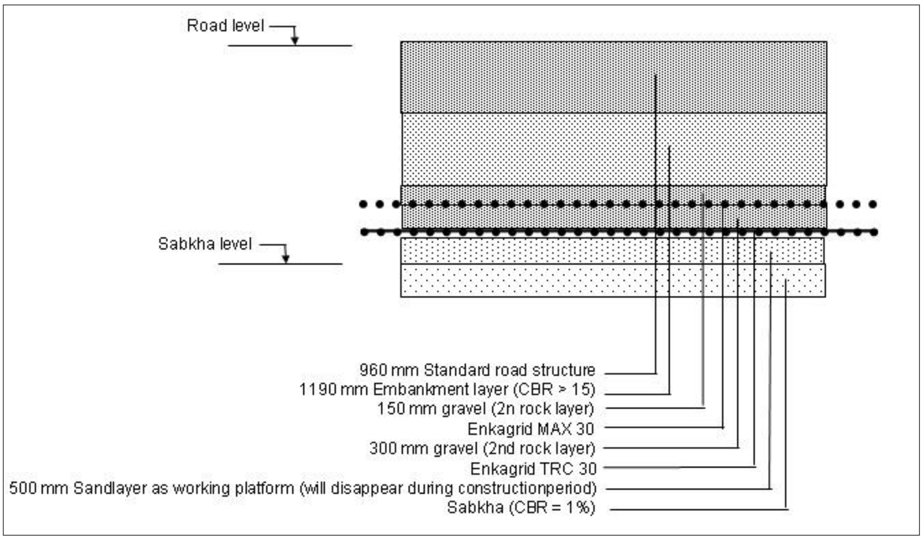


Fig. 14 Design for a High Axle Loading + High Traffic Intensity Paved Road



5.10 Reinforced Embankments on Sabkha Soil

Often, roads are build on embankments. When the dynamic loads are not traffeling down into the sabkha soil, the foundation can be expressed as an embankment. This paper uses the minimum thickness of an embankment of 2.0 m which is based on historical experiences with reinforced embankments and stabilized roads.

For all embankment structures, a multi-layer geogrid lay-out is suggested. The multi-layers are creating a stiff sandwich on top of which the road can be built. Table 6 presents the different geosynthetic systems.

Table 6. Reinforced Embankments with Geosynthetics on Sabkha Soils

Embankment	Geosynthetic system	Single or multi geogrid layers	Figure
2.0 m – 3.0 m high	Geogrid + geotextile	Multi	Figure 15
≥ 3.0 m high	Geogrid + geotextile	Multi	Figure 16
On piles	Geogrid + geotextile	Multi	Figure 17

The higher the embankment, the more load has to be spread over the sabkha soil. Calculation methods are able to design the exact lay-out and the number of geogrid layers for each type of embankment. More attention is given to a special system, the reinforced embankment on piles (Fig. 17), in the next paragraph.

Fig. 15 Reinforced Embankment 2-3 m height

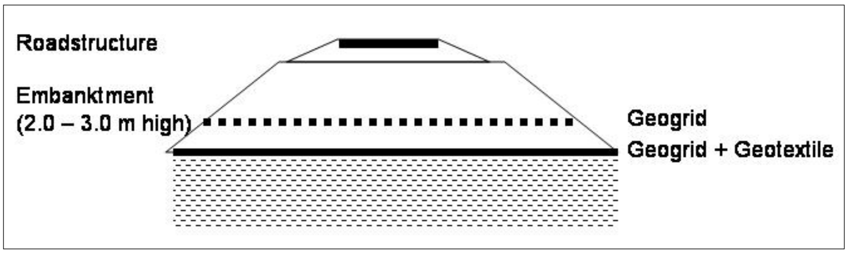


Fig. 16 Reinforced Embankment ≥ 3 m height

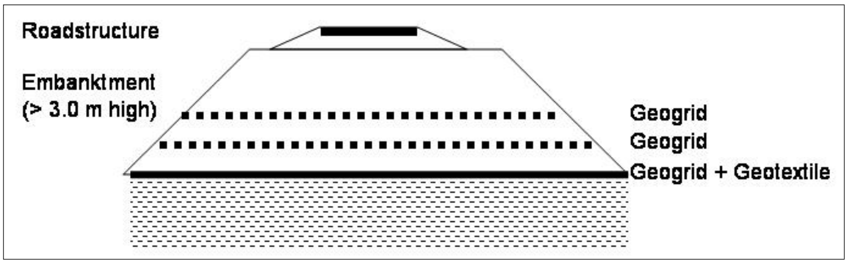
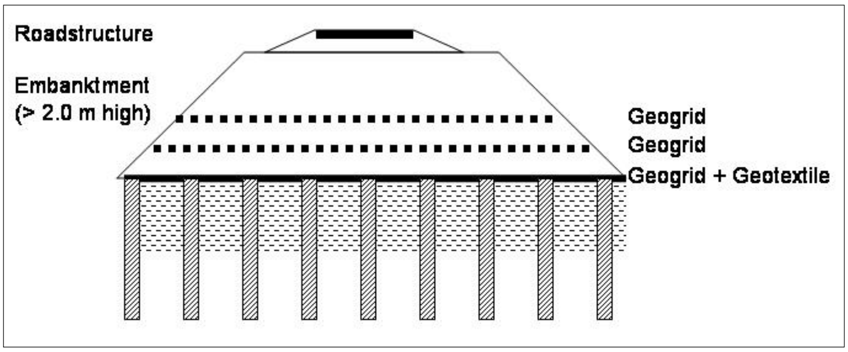


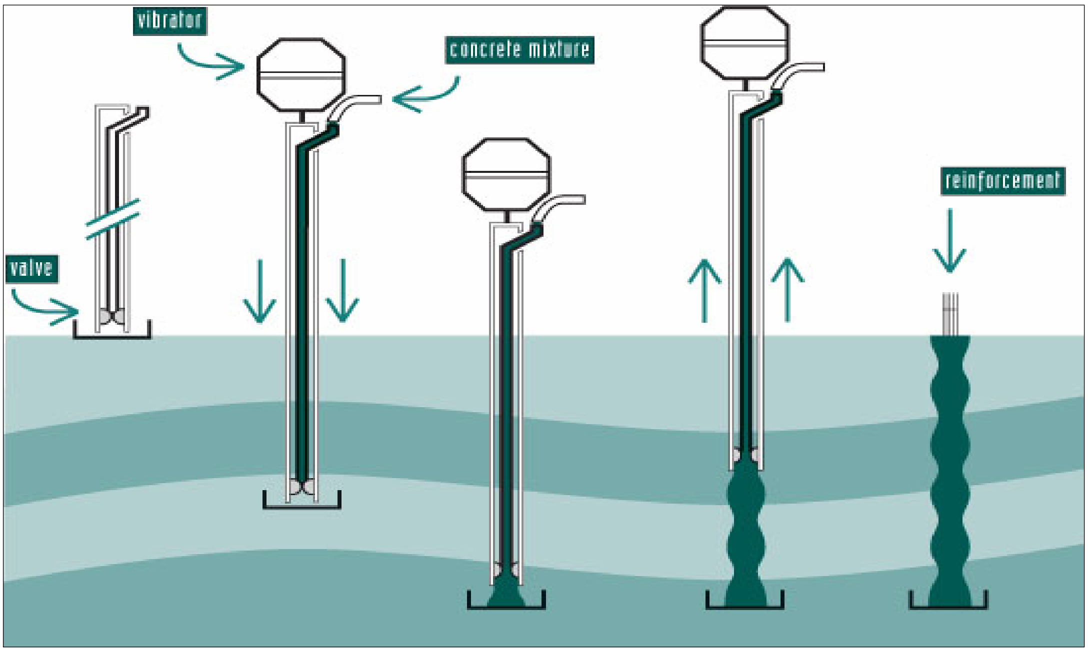
Fig. 17 Reinforced Embankment on Piles



5.11 Reinforced Embankments on Piles

It is important to realize that all systems discussed till now in Chapter 5, are all preventing differential and local settlements. When the natural subsoil is likely to consolidate, different systems come into play which can prevent the consolidation settlements. When a foundation is needed and allowing for zero settlement during construction and service life, a reinforced embankment on piles is a very feasible and practical solution. Although there are additional costs compared to the other presented geosynthetic systems, a new cost-effective system has been developed and approved in The Netherlands for railway systems [6]. The combination of a low-cost piling system and the geogrid layered reinforcement is very interesting to take into account when looking into the different options to stabilize the sabkha soil before starting the construction. The piles are in-situ formed piles installed at a very high speed. The maximum depth can be upto 17 m. This system is preventing any consolidation settlement because each pile is installed till it reached the good bearing capacity layer (normally a sandlayer). Figure 18 shows the installation procedure of this piling system.

Fig. 18 Installing the piling system for an embankment on piles [6]



6. Design principles

6.1 Introduction

Till today, a final design code for geosynthetics in roads has not been established. However, several design philosophies have proven themselves over the past years. This chapter starts with the status-quo on the combination of a design with a geosynthetic and the existing national road design standard which is mostly used for the surface layer. Then, the chapter goes into the two important and accepted design philosophies for using geosynthetics as a reinforcement in roads on soft soils. The first philosophy is for the unpaved road, the second philosophy is for the paved road situation. Also, some references for the reinforced embankments are discussed. For all these calculation methods, design software has been developed which allows the engineer to make the first step towards the final design.

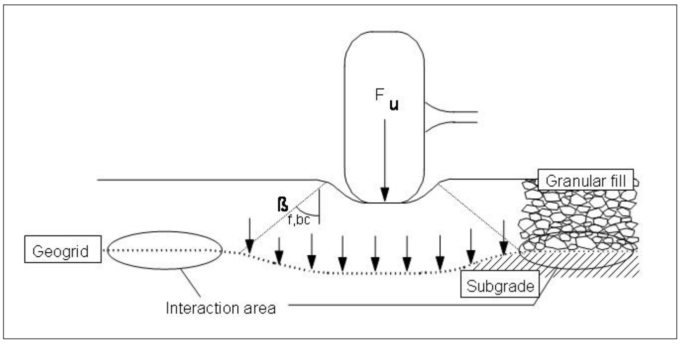
6.2 Current practise of road design with geosynthetics

Although no final design code is currently available which covers the total road design including geosynthetics, major contributions have been made by several research programs to combine the existing road design codes with geosynthetics base/subbase stabilisation. An example is the AASHTO Committee 4E which has created a base for further reseach into this subject [7]. In most of the cases, the standard practise is to use the geosynthetic as a increased bearing capacity layer which improves the base/subbase (see section 6.3 and 6.4) before applying the standard national road design code, like AASHTO, AUSTROADS.

6.3 Unpaved Roads

The unpaved reinforced road design philosophy is based on the membrane method [8]. When some small rutting appears the reinforcement is acting as a membrane which creates tension. This tensioned geogrid membrane will create an upward force to resist further rutting at the top of the surface (Fig. 19). The stiffness of the geogrid reinforcement is an important input parameter. Special design tools are available in the market to calculate the minimum thickness of the roadfoundation for unpaved roads.

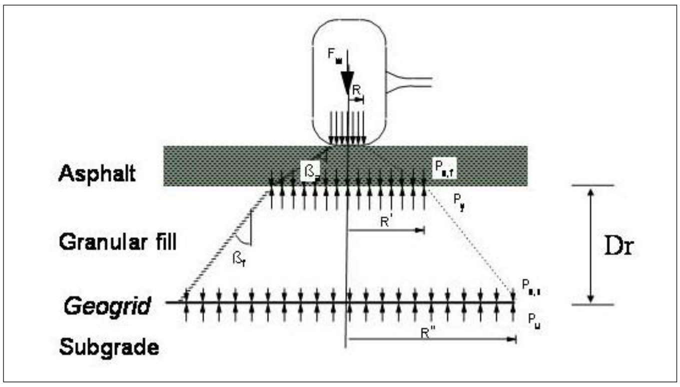
Fig. 19 Unpaved Road Design Model



6.4 Paved Roads

For paved roads, the available method is based on the combination membrane method [8] and the bearing capacity method [9], [10]. The wheel load is spread down through the road foundation. The stiffer the foundation layer is, the more loadspreading will appear. Using geogrids will increase the stiffness of the foundation and therefore will also increase the loadspreading (Fig.20). The bearing capacity of the sabkha soil is calculated and based on the CBR value. This bearing capacity is checked with the load on top of the sabkha soil. When the bearing capacity is higher than the load, the factor of safety will be greater than 1.0. The same check can be done with the bearing capacity of the base and subbase layer.

Fig. 20 Paved Road Design Model



6.3 Reinforced Embankments

Designing reinforced embankments are based on the global stability calculation of which the Bishop method is the most common. Reference is made to [11] where the accepted calculation methods for both reinforced embankments and the reinforced embankment on piles are presented.

7. Conclusion

Very low bearing capacity muddy sabkha soils are often around the coasts of the Middle Eastern Peninsula. New stabilization methodologies are currently available to construct infrastructural works on these sabkha soils. A very cost-effective way of stabilization is the use of geosynthetics. Three types of geosynthetics have been presented and all three can work together to provide the most benefitial solution per project. A indicative design tool has been given which is based on the maximum axle loads and the number of axle passes per year. This tool provides the engineer to select an appropriate geosynthetic system for his/her project circumstances. Based on this selection, the first design step can be made which is based on the presented design models. The second step is to incorporate the national requirements for the remaining part of the total road structure, like the surface layer.

8. References

1. AIBAN S.A., AL-AMOUDI O.S.B., AHMED I. and AL-ABDUB WAHHAB, “Reinforcement of a Saudi Sabkha Soil Using Geotextiles”, *Sixth International Conference on Geosynthetics*, Altanta, 1998

2. JUILLIE Y. and SHERWOOD D.E., “Improvement of Sabkha Soil of the Arabian Gulf Coast”, *Eighth European Conference on Soil Mechanics and Foundation Engineering*, Helsinki, 1983

3. GEVERS W.A., DEN HOEDT G. and VOSKAMP W., “Geosynthetics, Terms and Definitions”, *IGS News*, Vol. 8, No. 2, July 1992, pp. 5-7

4. EN 13249, Geotextiles and geotextile-related products – Characteristics required for use in the construction of roads and other trafficced areas (excluding railways and asphalt inclusion), 2001

5. MINISTRY OF COMMUNICATION SAUDI ARABIA, “Enkagrid TRC assessment for Sabkha Soils”, Riyadh, Saudi Arabia, 1999

6. VOORBIJ FUNDERINGSTECHNIEK and HEIBEDRIJF HYLKEMA ., “Voton HSP Palen”, The Netherlands, 2002

7. AASHTO COMMITTEE 4E and GMA (Geosynthetic Materials Association), “Geosynthetic Reinforcement of the Aggregate Base/Subbase Courses of Pavement Structures”, GMA White Paper II, July 2000

8. GIROUD J.P. and NOIRAY L., “Geotextile-Reinforced Paved Road Design”, *Journal of the Geotechnical Engineering Division*, American Society of Civil Engineers, Vol.107, No. GT9, pp. 1233 – 1254, 1981

9. HOUSLY G.T. and JEWELL R.A., “Design of Reinforced Unpaved Roads for Small Rut Depths”, *Geotextiles, Geomembranes and Related Products*, ed. G. den Hoedt, Balkema, Rotterdam, The Netherlands, pp. 171 – 176, 1990

10. MEIJER N. and ELIAS J.M., “Design Methods for Roads Reinforced with Multifunctional Geogrid Composites for Subbase Stabilization”, *Kunststoffe in de Geotechnik*, Technical University Munich, Germany, 1999

11. BS 8006, “Code of Practice for Strengthened/Reinforced Soils and Other Fills”, *British Standards Institution*, London, UK, 1995 / 1999.