Numerical analysis of embankment reinforced by geosynthetics on sabkha soil

Naima Benmebarek
Numerical Modeling and Instrumentation Laboratory, Biskra University, Algeria, *benmebarekn@yahoo.fr*

Berrabah Fouad
Numerical Modeling and Instrumentation Laboratory, Biskra University, Algeria, fouad.berrabah@yahoo.fr

Benmebarek Sadok
Numerical Modeling and Instrumentation Laboratory, Biskra University, Algeria, benmebareks@yahoo.fr

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ABSTRACT: Sabkha soils are coastal and inland saline deposits of arid climates consisting mainly of loosely cemented sandy silt to silty clay particles. Accordingly, they are characterized by being highly compressible, and hence considered among the poorest of foundation materials. One of the most economical soil improvement solutions is the use of geosynthetics. This paper presents a numerical simulation using the PLAXIS software of the geosynthetic reinforced road embankment constructed on sabkha of Chott El Hodna in the north middle of Algeria. Due to the poor bearing capacity sabkha surface and the arising water table over the soil surface serious difficulties were faced during the investigation of the subsurface soil and the construction of the road embankment. The visual observation of the sabkha site and analysis of geotechnical test results show that the sabkha soil is characterized by poor mechanical properties and high compressibility. The main objective of this study was to assess the effect of reinforcement by geosynthetic on the construction embankment layer quality, the settlement and stability of the embankment. The results of the study indicate that the reinforcement does not have a significant influence on the absolute settlement of the embankment but, improves the conditions of implementation and the quality of the embankment, especially under wet conditions. In addition, the use of reinforcement in embankment construction may allow for an increase in the design factor of safety and, an increase in the height of the embankment. Moreover, the reinforcement may also reduce horizontal displacements of the underlying soil.

1 INTRODUCTION

Salt flats or sabkhas are salt bearing arid climate deposits that cover vast areas on the coasts of Middle Eastern and North African countries. They developed by the erosion of coastal deposits both by wind and extreme storm tides followed by a period of sedimentation (Fookes, 1978; Akili, 1981; James and Little, 1994). Sabkha soils are associated with many geotechnical problems, due to the presence of digenetic salts of different sizes, shapes and compositions; and the shallow saline ground waters. Therefore, sabkha soil is considered to be an inferior construction material. Because of these characteristics, roads constructed on sabkha terrains are subjected to deterioration in the form of raveling, cracking, rutting, formation of potholes and depressions. The sabkha soils are highly variable in lateral and vertical extent; various soil types, primarily composed of clays, silts and fine sands (Akili and Torrance, 1981). Furthermore, the susceptibility of these soils to strength loss and collapse upon wetting makes their use in construction very risky and hazardous (Al-Amoudi and Abduljauwad, 1995). In its natural state, sabkha soil is considered very poor, even if it is used as a subgrade layer for road construction. Since sabkha in its present condition may be inadequate to be used as a foundation material and cannot support most of the common engineering structures, this necessitates that the soil is to be treated to enhance its engineering properties prior to structural loading. Several field stabilization techniques have been implemented to improve the inferior sabkha properties, with various degrees of success (Juillie and Sherwood, 1983). However, it has generally been found that the use of geosynthetics as reinforcement has the advantages of being practical, economical, and easy to apply.

Sabkha soil is extensively distributed along the inland regions of the Algeria. The susceptibility of these soils to strength loss and collapse upon wetting makes their use in construction very risky, particularly if proper treatment has not been undertaken. The purpose of this study is to upgrade the bearing capacity of sabkha soil as a subgrade, using geosynthetic and investigate the impact of this stabilizing technique on the performance of the road embankment crossing the sabkha.

This paper, after description of the site and geotechnical characteristics of sabkha soil, is interested in the numerical modelling using software PLAXIS, of the geosynthetic reinforced road embankment constructed on sabkha of Chott El Hodna in the north middle of Algeria. The results of this study show the effect of reinforcement on the settlement and stability of the embankment.

2 PRESENTATION OF SABKHA SITE

The project consists of the realization of a road connecting the village of M'Cif with Ain El Khadra (Town of M'sila) by crossing the Sabkha of Chott El Hodna on 11 Km (Figure 1). This road reduces the current distance from two towns by 140 km and improves considerably the commercial and agriculture activities. The in situ observations show that in summer surface soil is partially dry and soft enough where only a very small weight vehicle can cross the Sabkha. However, in winter the sabkha is inundated where water table may arise up to 60 cm over soil surface.

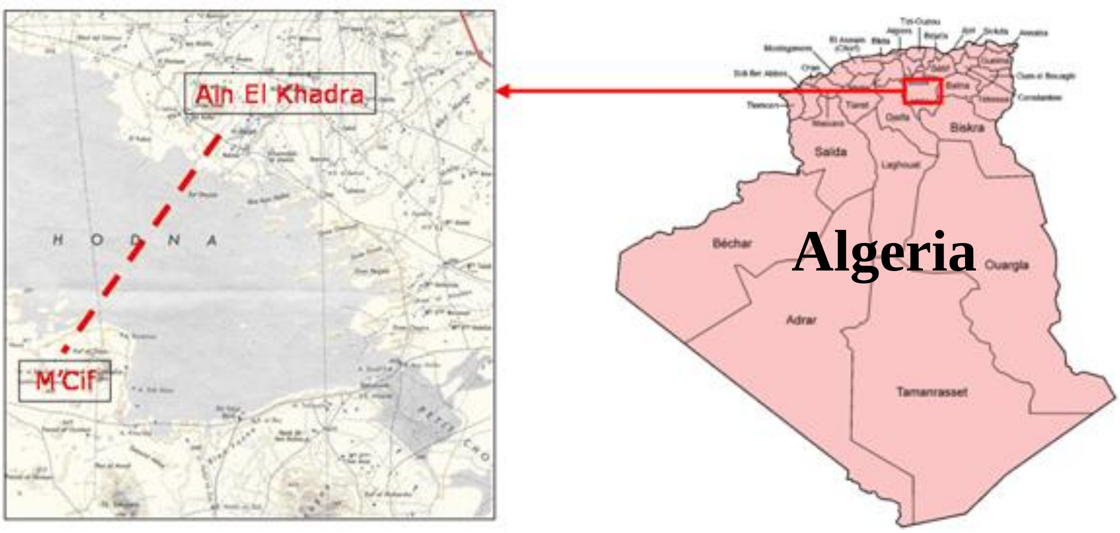

Figure 1. Situation of the project.

The sabkha of Chott El Hodna in the middle north of Algeria is a large closed flat of 26000 km² developed where surface runoff converges from the Saharian Atlas in the South and the Tellien Atlas in the North and also by soil infiltration. In summer, the surface is encrusted with salt. The embankment road devises the sabkha in two parts. The hydrological study shows the maximum water level which may reach 1.40 m over soil surface for a one period of thousand-year-old return.

3 CHARACTERIZATION OF SABKHA SOIL

The program of sabkha subsurface investigations contains boring hole and cone penetration test every 300 m of the embankment length.

Subsurface state conditions at the middle of the Sabkha consists of a brown muddy clay layer with thickness varying from 3 m to 5 m, underlain by grey muddy marl and gypsum concretions with traces fine sand with thickness varying from 5 m to 7 m. Near the edges of the sabkha the thickness of the soft layers decreases.

Once the soil was brought to the geotechnical laboratory, the whole soil was thoroughly and homogeneously mixed and preserved in plastic drums until testing. Some general tests were conducted to determine the geotechnical properties of the sabkha soil. The laboratory testing results show that the compression index C_c varying from 0.31 to 0.56, the plasticity index I_p varying from 27.5 to 48.5 and the dry density varying between 1.38 and 1.64 indicating high soil compressibility. The undrained shear strength of the layers brown muddy clay and grey muddy marl reaches 9 KPa. In the sabkha centre, the thickness of the very soft layers may reach 10 m. These results are in good agreement with the static cone penetration test results showing no point resistance for this depth.

In the present project, the construction of the road embankment on sabkha soil needs the use of geosynthetic system (Figure 2). The geogrid will increase the stiffness of the foundation, while the geotextile will prevent mixing of the first aggregate lift with the small muddy particles of the sabkha. The most important properties of these geosynthetics are summarized in Table 1.

(a) Laying of geotextile (b) Laying of geogrid

Figure 2. Installation of geosynthetic in the sabkha.

Table 1. Summary of the characteristics of geosynthetic.

Characteristics	Geosynthetic type	
	Geotextile TS 60	Geogrid GX 55/55
Axial stiffness (KN/m)	50	550

The sabkha soils are highly variable in both the horizontal and vertical directions. The idealized cross-section of sabkha terrain is shown in Figure 3. However layering usually is not distinctively conspicuous since a variety of materials are often randomly interlayered without a delineated real stratification. The embankment is 2 m high above the existing ground surface, with 11 m crest width. The geotechnical properties, for the different layers, are presented in Table 2.

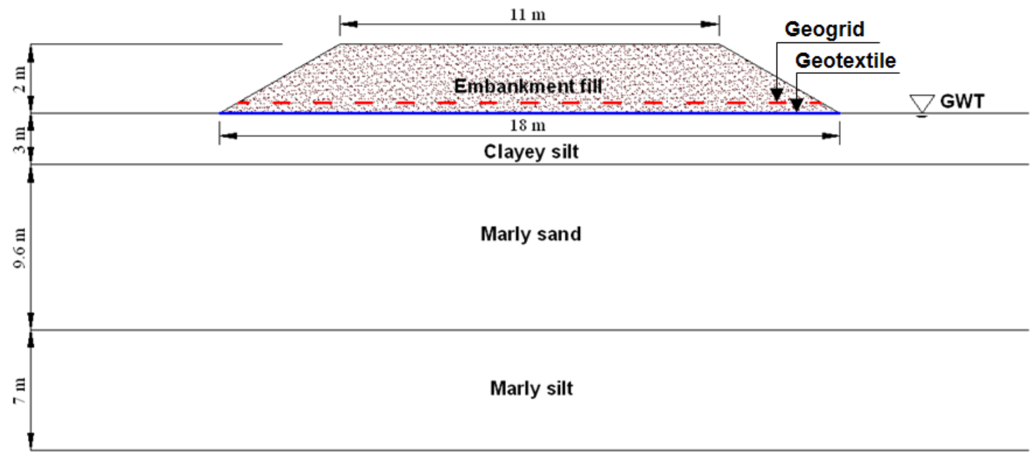

Figure 3. Generalized embankment geometry and foundation soil stratigraphy.

Table 2. Summary of the geotechnical properties of embankment fill and foundation soil.

Soils layers	Embankment fill	Clayey silt	Marly silt	Marly sand
Unit weight (KN/m^3)	20	18	18	17
Elastic modulus (KN/m²)	30000	8000	8000	20000
Poisson ratio	0.3	0.3	0.3	0.3
Cohesion (KN/m²)	1	10	10	2
Friction angle (^{o})	35	20	20	30
Dilatancy angle (^{o})	0	0	0	0
Compression index	--	0.35	0.3	--
Swelling index	--	0.035	0.03	--
Horizontal permeability (m/day)	1	1x10^{-5}	1x10^{-5}	1
Vertical permeability (m/day)	1	1x10^{-5}	1x10^{-5}	1

4 NUMERICAL ANALYSIS OF THE REINFORCED EMBANKMENT

In this present study, the construction of a road embankment on soft soil was examined. The discretization of the reinforced embankment-foundation along with the boundary conditions is shown in Figure 4. 15-node triangular elements were used to discretize the embankment and foundation soil. The soft foundation was taken to be 19.6 m deep and underlain by a rigid and relatively permeable soil, which constitutes the lower boundary. The horizontal displacements in the centreline of the embankment (a line of symmetry) and the far field lateral boundary are assumed to be zero with the lateral boundary located 36 m from the centreline. Taking into account the high permeability characteristics of the geosynthetic and of the embankment fill, the upper foundation surface is a drainage boundary. The water table was assumed to be at ground surface and the initial pore pressures prior to embankment construction were taken to be hydrostatic. The mechanism of displacement of the embankment is considered a plane strain problem. The embankment construction was simulated by activating the different embankment layers (Chai and Bergado, 1993).

The clayey silt and marly silt layers has been modelled with soft soil model. A non-linear elastic- perfectly plastic model with a Mohr–Coulomb failure surface was adopted for the marly sand layer. The behaviour of the embankment fill consisting of a purely frictional material has been represented by an elastic-perfectly plastic material with Mohr-Coulomb yield criterion. The geosynthetic reinforcement has been characterized with elasto-plastic behaviour using Mohr-Coulomb yield criterion.

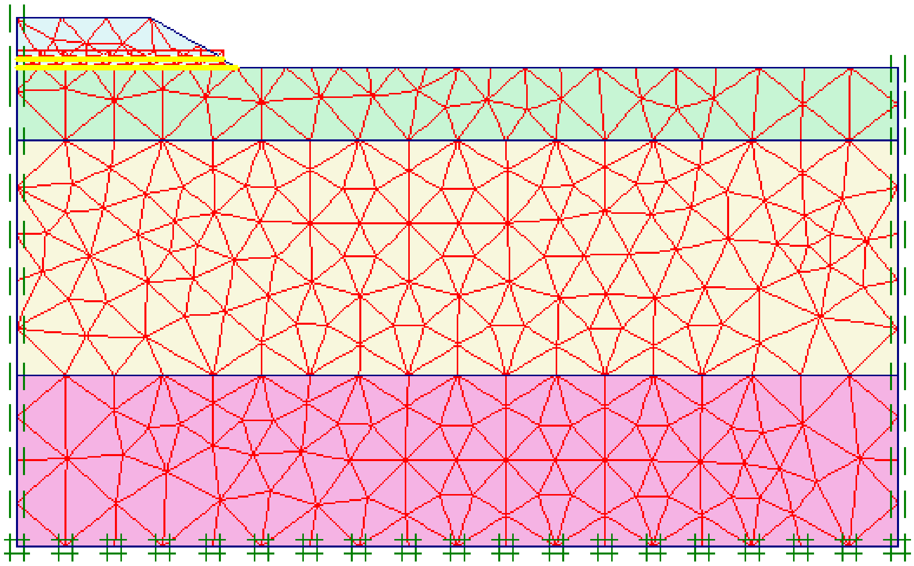

Figure 4. Finite element mesh of the embankment and foundation soil.

After initialization of the geometry (calculation of stress states, pore pressure and deformation), the calculation is carried out in three stages, respectively corresponding to the placement of the geotextile separation layer and the construction of the first lift of embankment, the placement of the geogrid reinforcement layer, the construction of the embankment through lifts, the consolidation of the soil under the effect of the stress caused by the embankment and then to the estimation of safety factor after the construction of the embankment.

5 RESULTS AND DISCUSSIONS

The results of the numerical analysis show the effect of reinforcement by geosynthetics on the settlement and stability of the embankment.

Figures 5 and 6 summarise the comparison of both unreinforced and reinforced embankments, expressing the effect of reinforcement on horizontal and vertical displacements of the embankment at the end of consolidation.

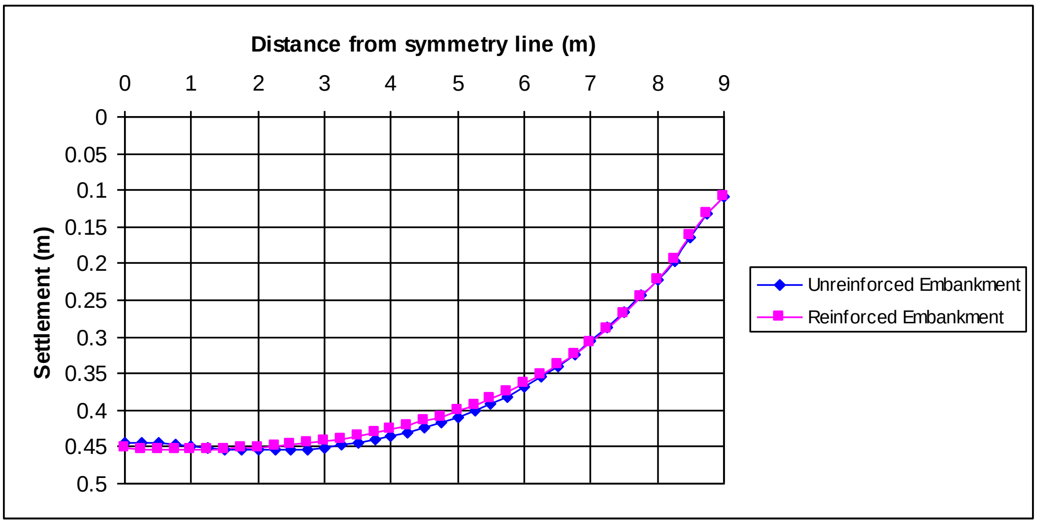

Figure 5. Effect of reinforcement on the settlement.

One can see that the reinforcement does not decrease absolute settlement at the embankment base. It is noted that the reinforcement clearly determines the reduction of horizontal displacements in the soil nearby the reinforcement. The maximum effect of reinforcement on the horizontal displacement is noted near the embankment toe.

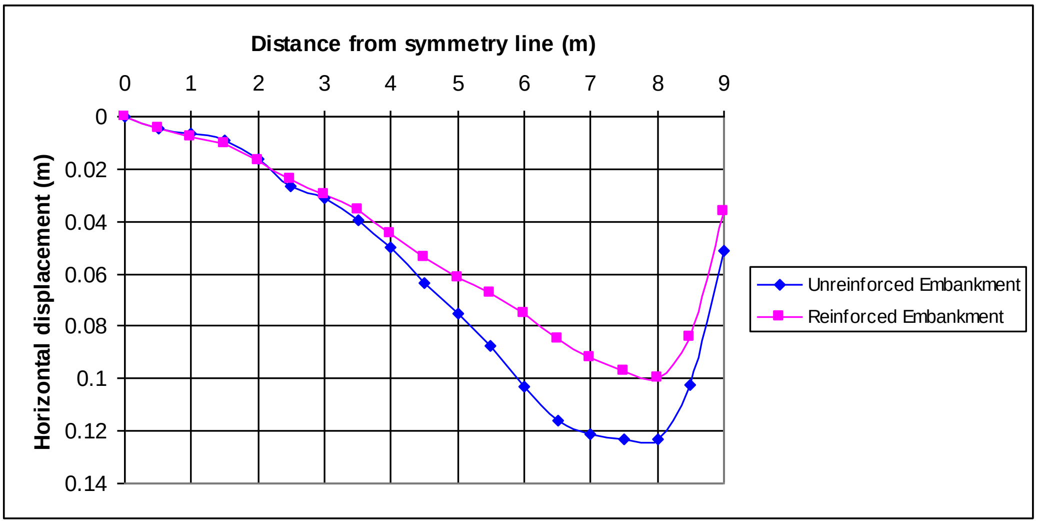

Figure 6. Effect of reinforcement on the horizontal displacement.

Figure 7 shows factors of safety for unreinforced and reinforced embankments, at the end of construction. It is clearly seen that in the case of reinforced embankment, overall stability significantly increases. These simulations show an improvement about 33 % of the safety factor of reinforced embankment.

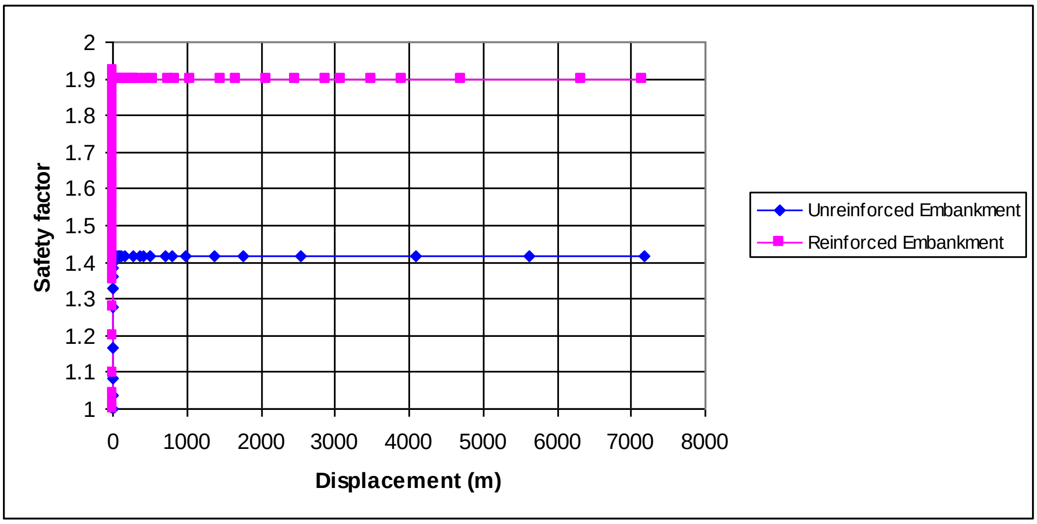

Figure 7. Safety factor of the embankment at the end of construction.

Figure 8 shows the failures height of both unreinforced and reinforced embankments. Firstly, the failure height of the embankment corresponds to a safety factor lower than 1. It is observed that the unreinforced embankment failed when it reached a height of 3 m, while the reinforced embankment reached a height of 3 m without failure for a safety factor equal to 1.7.

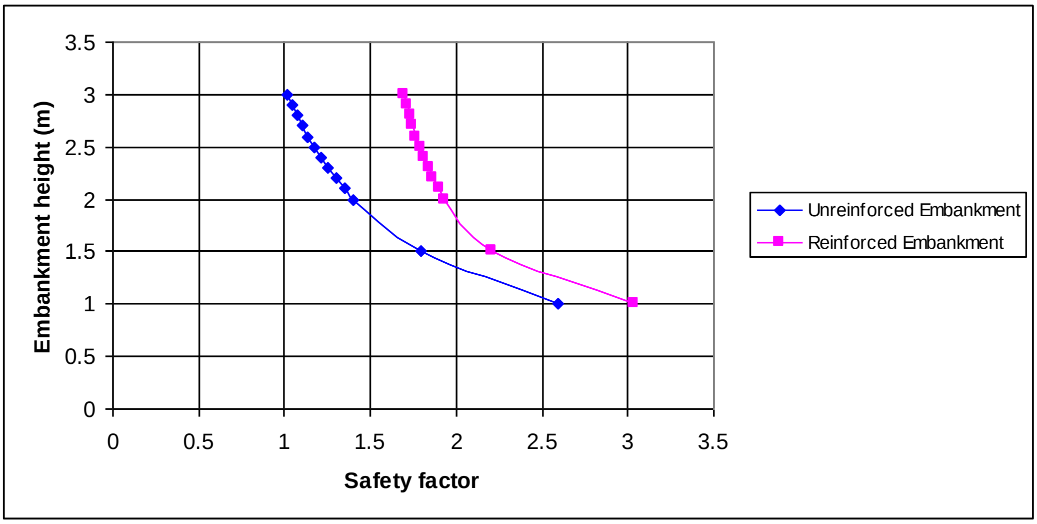

Figure 8. Effect of reinforcement on the embankment height.

6 CONCLUSIONS

This study allowed to show the effect of the reinforcement by geosynthetic layers on the settlement and stability of the embankment constructed on soft foundation that characterized by sabkha soil. The following conclusions are drawn from the study.

- The presence of the reinforcement does not have a significant influence on the absolute settlement of the embankment;
- The reinforcement improves the stability of the embankment at the end of construction;
- The reinforcement decreases the horizontal displacements at the embankment base;
- The reinforcement by geosynthetic of the base of embankments allows building of embankments of height greater than the failure height without reinforcement;
- The use of geosynthetic materials in the construction of embankment on sabkha soil improves the conditions of implementation, especially under wet conditions.

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