Building Road Embankments on Algeria Sabkha Soils with Geosynthetics

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ABSTRACT

With the help of geosynthetics innovative, economic and durable solutions can be offered to several situations where standard soil improvement techniques are still extensively used. This paper is interested by the design and the construction of the road with reinforced embankment crossing the sabkha of Chott El Hodna on 11 km length 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. After the project description and soil investigation, the need of reinforced embankment by geosynthetic was well highlighted by numerical modelling and confirmed by the difficulty reencountered in the placement of the two first embankment lift and the compaction performance.

1. INTRODUCTION

Sabkha is originally an Arabic name for saline flats that are characterised by very low bearing capacities and underlain by sand, silt and clay, and often encrusted with salt. Sabkha soils are very sensitive to moisture whereby complete collapse and large reduction in the bearing capacity are anticipated when these soils are in contact with water (Al-Amoudi et al. 1992). Such behaviour is attributed to the fact that some of the cementing materials that bond the mineral grains of sabkha together, such as halite, are highly soluble in water, while others, such as gypsum, aragonite, and calcite are less soluble. The work done by Aiban et al. (1998) on different sabkha soils confirms the acute water sensitivity and chemical aggressiveness of sabkhas. The CBR values can easily exceed 50 when the sabkha is tested at low moisture contents; however, upon soaking the CBR may not exceed a value of 4, regardless of the dry density or the moulding moisture content of the sabkha.

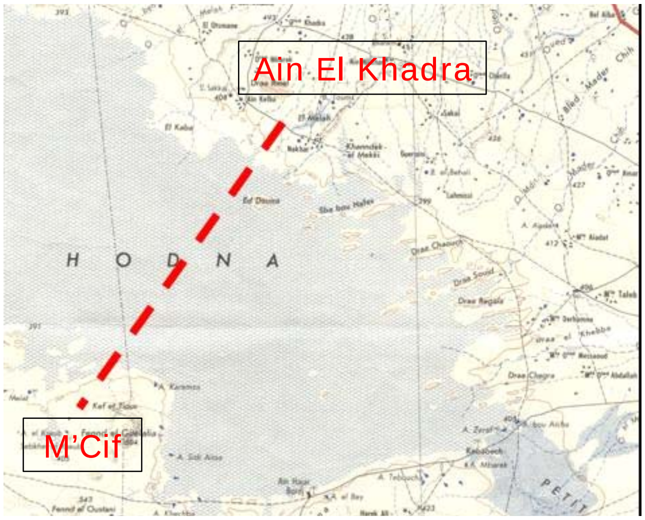


Figure 1. Site project.

Road engineers in Algeria like Tunisia, Arabi Saoudit, USA, India and Australia often face the challenge to design a solid road foundation on top of very soft soils which are characterized by sabkha soils.
In the present paper, the proposed road with reinforced embankment which crosses the sabkha of Chott El Hodna on 11 km is located in the M'Sila department in the north middle of Algeria (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 vehicles can cross the Sabkha. However, in winter the sabkha is inundated where water table may arise up to 60 cm over soil surface.
Figure 2 presents two photographs showing the sabkha surface state taken respectively in July and December 2005.

In this paper, after the description of the project and soil investigation, the need of reinforced embankment by geosynthetic was well highlighted by numerical modelling using an explicit finite difference code and confirmed by the difficulty reencountered in the placement of the first embankment lift and the compaction performance.

(a) Sabkha surface state in summer (18.07.2005) (b) Sabkha inundation in winter (19.12.2005)

Figure 2. Subsurface state of the project road.

2. HYDROLOGICAL AND SUBSURFACE SOIL INVESTIGATIONS

The sabkha of Chott El-hodna in the middle north of Algeria is a large closed flat of 26000 km^2 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. The program of sabkha subsurface investigations contains boring hole, cone penetration test and vane shear test every 300 m of the embankment length.
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. Therefore, the subsurface investigations were accomplished with the advancement of the two first lifts reinforced by geosynthetic of the embankment.
Subsurface state conditions at the middle of the Sabkha consists of a brown muddy clay layer with thickness varying from 3m to 5m, underlain by grey muddy marl and gypsum concretions with traces fine sand with thickness varying from 5m to 7m. Near the edges of the sabkha the thickness of the soft layers decreases.

The partially 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.

3. REINFORCED EMBANKMENT AND SLOPE PROTECTION

In the conventional method of embankment construction over soft subsurface, the soft soil is replaced by a suitable soil or it is improved (by preloading, dynamic consolidation, lime/cement mixing or grouting) prior to the placement of the embankment. The weak bearing capacity and the often surface inundation of the present sabkha soil limit the use of the conventional construction method where serious difficulties arise for the embankment construction. The alternate solution is to place a geosynthetic (geotextile, geogrid, or geocomposite) layer over the soft foundation soil and construct the embankment directly over it. More than one geosynthetic layer may be required, if the foundation soil has weak zones.

In the present case the geotextile is used to separate the subsoil and the embankment aggregate, while the reinforcement by geogrid layer is used to increase the stiffness of the foundation and to increase the compaction quality. For the embankment, a sandy gravel material was chosen to allow free drainage of the foundation soils and reducing the pore pressure build-up below the embankment;

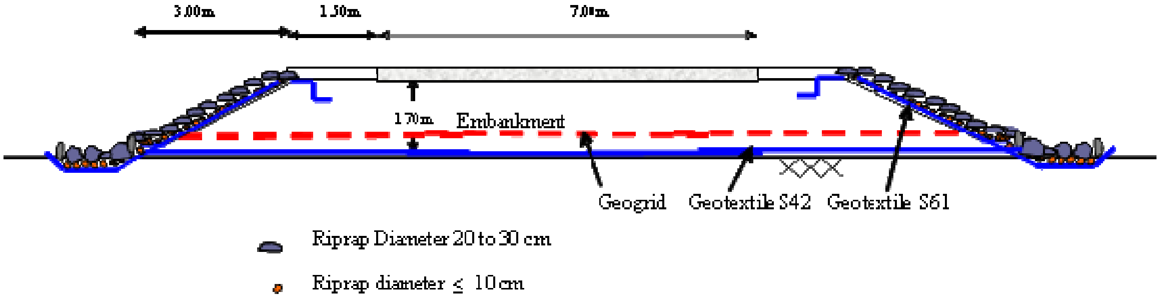


Figure 3. Reinforcement and protection of the embankment.

Figure 4. Laying directly over sabkha surface a nonwoven geotextile GT 1

Figure 5. Laying the geogrid over the first lift of the embankment

The construction steps used as showing in Figure 3 can be summarised as following:

- Laying directly over sabkha surface corresponding to embankment base a nonwoven geotextile layer as separator/filter to prevent contamination of embankment material (Figure 4). From the in situ observations, without this separating geotextile it was not possible to prevent the mixing of the first aggregate lift and the soft subgrade;
- Construction of the first lift of 30 cm thickness compacted to obtain plane surface;
- Laying the geogrid over the surface to uplift the tensile strength to the embankment base (Figure 5);
- Construction the embankment layer by sub-layers with compaction control;
- After reaching the embankment height 1.70m, the hydraulic PEHD reinforced tubes were installed (figure 6). These tubes are inert to sabkha soil aggressively;
- Protection of embankment slopes with separate geotextile GT 2 placed under rock ripraps (figure 7).

Figure 6. PEHD reinforced tubes installation

Figure 7. Protection of embankment slopes

4. NUMERICAL ANALYSIS OF THE EMBANKMENT REINFORCEMENT

For reinforcement applications, solutions have been proposed for situations where the tensioned-membrane reinforcement function will be realized and for situations where the lateral base course restraint mechanism is appropriate. Since separation is typically an integral part of the tensioned-membrane reinforcement function, design solutions for this geosynthetic function generally lump these two functions together.

Designs incorporating the tensioned-membrane reinforcement function are applicable for unpaved roads and situations where relatively large rut depths in the roadway can be tolerated and where the traffic is mainly canalized. This approach was recommended by Holtz et al. (1995) for temporary unpaved roads. However, incorporation of the lateral base course restraint mechanism is applicable for roadways where rut depth needs to be limited to 25 mm. The performance of the road and embankment base reinforcement over soft subsurface depends on several factors particularly the geogrid stiffness, characteristic of the subsurface and parameters of the interface ground-reinforcement (Rowe and Ho 1997, Alfaro and Al 1997). This area of research is very favourable to numerical computations.

The present work interests with the numerical simulation of reinforced embankment base over soft subsurface in order to improve the bearing capacity. The improvement of the bearing capacity is evaluated by comparing the wheel load-displacement response corresponding. The analysis was carried out using the computer code FLAC^{-2D} (Fast Lagrangian Analysis of Continua) which is a commercially available finite difference explicit program.

The embankment material and the soil behavior were modeled by the elastic-perfectly plastic Mohr-Coulomb model encoded in this code. The embankment material was characterized by a unit weight γ=20 kN/m^3 angle of friction φ=35° and a null cohesion. The sabkha soil was characterized by the undrained cohesion C_u =9kPa.

The geogrid, modelled by beam element without flexural strength, is connected to embankment material via interface elements obeying the criterion of Mohr-Coulomb and characterized by a null cohesion and a friction angle δ representing the angle of friction of the contact geogrid-embankment material. For the reason of the lack of the laboratory tests, the friction angle δ was taken equal to the 2/3 of the friction angle of the embankment (φ=35°).

The wheel load-displacement response was determined by this study in large strain analysis for embankment first layers with and without reinforcement. Using a FISH function, the bearing capacity can be calculated as the integral of stress components for all soil zones in contact with the footing area or by the reaction force resultant in the vertical direction at footing nodes. From these simulations it was deduced the improvement made by the reinforcement. A cross section of the embankment was modelled in two dimensions assuming plane strain conditions. The procedure of simulation used in the present analysis was based on the two following steps:

A mechanical calculation of the geostatic stresses : These were computed assuming the material to be elastic;

A mechanical calculation of the improvement of the bearing capacity: the bearing capacity was modeled by a downward velocity applied to the area representing the wheel load until obtaining tolerable rut. The value of the velocity applied to the footing area was 2.5 × 10^{-6} m/step for this analysis. This value was sufficiently small to minimize any inertial effects in the present conditions.

Figure 8 visualizes the vectors of displacement (yellow vectors) and tensile effort (red curve) mobilized in the biaxial geogrid with tensile strength 58 KN/m in the two directions for a lengthening of 12% for the simulation of the bearing capacity for the two first lifts of the embankment by indenting the tires of an axle.

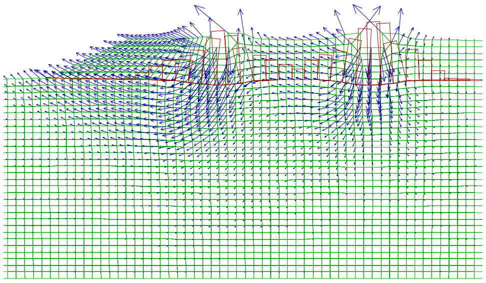
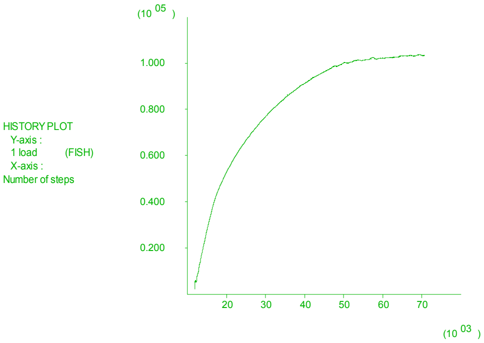
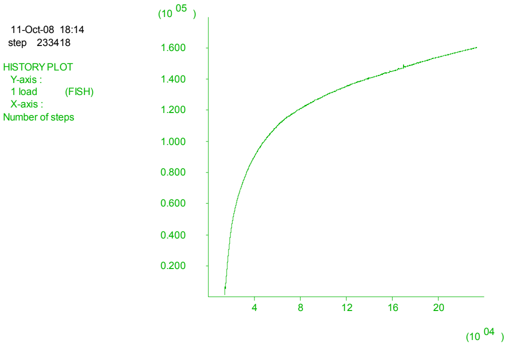


Figure 8. Visualisation of the field displacement and the geogrid tensile due to wheel indentation



(a) Without reinforcement



(b) With reinforcement

Figure 9. Reinforcement Influence on soft subsurface bearing capacity

A typical plot of the load-displacement curve is shown in fig 9-a without reinforcement and in fig 9-b with reinforcement by this geogrid. The asymptotic limiting value corresponds to the ultimate bearing capacity for the first case (fig 9-a). However the bearing capacity increases with displacement for the second case (reinforced by geogrid fig 9-b). These simulations show an improvement of the bearing capacity about 60% for a tolerable rut limited to 10 cm (Figure 9).

5. CONCLUSIONS

In light of the work observations and the numerical computation results, the following conclusions may be drawn:

- From soil investigation the present sabkha subsurface is dominated by a muddy clay very sensitive in wet conditions;
- In the present project, without separating geotextile it was not possible to prevent the mixing of the first aggregate lift and the soft subgrade;
- The need of reinforced embankment by geotextile separation and geogrid was well highlighted by numerical computation and confirmed by the difficulty reencountered in the placement of the first embankment lift and the amelioration of the compaction performance;
- Numerical computations of the present project show an improvement about 60% of the bearing capacity of reinforced embankment.

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