Overview of Geosynthetics Applications in Northern Africa Through Case Histories

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ABSTRACT
This paper presents recent applications of geosynthetics in Northern Africa through case histories. Each case is presented in a standard descriptive form giving information about the application, function of geosynthetics, technical data and design methods. It highlights the importance of considering geosynthetics solutions to address some of the technical difficulties inherent to the region.

1. INTRODUCTION

The diversity in functions that geosynthetics can offer combined with the possibility of speeding up project completions and the challenge to design and construct more economical structures with limited resources have resulted in an increasing uptake and acceptance of geosynthetics in Northern Africa. One needs to acknowledge that the increasing use of geosynthetics is also driven by major programs of infrastructure development funded either through international institutions or local governments, for which project delivery time is of paramount importance because of the impact on the local population. The stages of development in the use of geosynthetics in Northern Africa may be described as undeveloped and developing. General features of these two stages are given in table 1. It should be noted that for the purposes of this paper Northern Africa is considered to cover some of the Sahelian countries. Lawson and Cowland (2000) indicated the demand for geosynthetics is in most cases driven by the state of the nation's economy. This is particularly true for Northern African countries as indicated in Table 1. It is interesting to note that Group 1 represents countries with a state of economy in the developing stage and therefore financial resources are available for infrastructure and resource development leading to increased demand for geosynthetics. Whereas Group2 (exception of Libya), the state of economy is undeveloped and opportunities for development projects are limited unless funding is provided by international institutions (e.g., NGOs, World Bank, etc.).

Table 1. Some general features of developing and undeveloped geosynthetics stages (modified from Lawson and Cowland, 2000)

Features	Stage of geosynthetics use	
	Developing (Group 1)	Undeveloped (Group 2)
Countries	Algeria, Egypt, Morocco, Tunisia	Burkina Faso, Libya, Mali, Mauritania, Niger, Senegal, Tchad
Time of activity	10-20 years	<10 years
Relative acceptance of geosynthetics	Fair	Poor
Information infrastructure	Developing	None
Recognised standards/procedures	Use of others or none	None

This paper aims to give a snapshot of major projects or cases (not widely known or documented) which show a variety of applications in Northern Africa as described in Table 2 in some cases these are first time applications. Furthermore, the paper intends to contribute to the start of the establishment of a useful data base of projects related to geosynthetics earthworks in Africa. It will also highlight some of the issues typical to Northern Africa which probably are similar to the rest of the continent.

Table 2. List of selected cases

N°	Application	Gosynthetic function	Location	Country
B1	Bridge Abutment, Segmental wall	Reinforcement	Msila	Algeria
B2	Bridge Abutment, Concrete Screen	Reinforcement	Dakar	Senegal
S1	Steep slopes, Subvertical facing	Reinforcement	Bejaia	Algeria
S3	Steep slopes, Vertical facing	Reinforcement	El Jebha	Morocco
E1	Embankment on soil of poor bearing capacity	Reinforcement	Chott El-Hodna	Algeria
E2	Embankment on soil prone to subsidence (Karst)	Reinforcement		Tunisia
E3	Embankment on soil of poor bearing capacity	Reinforcement	Kabale & Kimimba swamp	Uganda
A1	Airfield rehabilitation	Reinforcement	Djanet	Algeria
D1	Dam	Filtration	Dzoumougné	Mayotte
D2	Dam	Barrier	Rabat	Morocco
W1	Waste containment (MSW)	Barrier	Pesoglo	Burkina Faso
W2	Waste containment (MSW)	Barrier	Sidi Rached	Algeria

2. GEOSYNTHETICS: SHORT BACKGROUND

Nowadays, geosynthetics applications are very diverse and are usually defined by the primary or principal function. They are widely used in geotechnical, environmental and hydraulic applications due to their versatility and their ability to perform a variety of functions. These functions include not only primary traditional functions such as reinforcement, filtration, drainage, separation and fluid (liquid or gas) barriers (table 3, Bouazza et al., 2002) but also other functions (non-traditional or specialised) such as protection or cushion for geomembranes, minimisation of reflective cracking in road pavements, micro-confinement of soil particles in erosion control applications, confinement of soils or wastes through the use of geocells or geocontainers. Geosynthetics may perform one or more secondary functions, which must also be considered when selecting the geosynthetic characteristics for optimum performance (for example, a geocomposite layer that serves as a drainage means can also be a protection layer for an underlying geomembrane).

Table 3. Types and functions of various geosynthetics. ● main function; ■ secondary function

	Function					
Geosynthetic types	Separation	Drainage	Filtration	Reinforcement	Hydraulique/ gas barrier	Protection
Non woven geotextile	●	■	●		●[1]	●
Woven geotextile	●		■	●		
Geogrids				●		
Geomembranes					●	
Geocells	●			●		
Geosynthetic clay liners					●	■
Geocomposites	■	●	■	■	●	●
Geonet		●				
Geopipe		●				

1=asphalt-saturated geotextiles

As with other engineering materials, there are several design approaches that could be used during the selection process of geosynthetic products (Zornberg and Christopher, 2007). The most common methods are design by experience, by specification, or by function (Koerner, 2005). However, the design-by-function approach tends to be the general approach followed in the majority of the projects. In this paper, the presentation of the case histories will be based on functions as shown in table 3.

3. EARTH REINFORCED STRUCTURES

Geosynthetic inclusions within a soil mass can provide a reinforcement function by developing tensile forces that contribute to the stability of the geosynthetic-soil composite (a reinforced soil structure) and will also allow soil to carry greater shear loading than would otherwise be possible. Geosynthetic products typically used as reinforcement elements are geotextiles and geogrids. Additional products include geocells and fiber reinforcement. Design and construction of stable steep slopes, bridge abutments, retaining walls and embankments within space constrains are major economical considerations in geotechnical engineering projects. As a result of this, the uptake of the geosynthetic solution has become very appealing to a number of North African countries. It is the objective of this section to present a selected number of case histories which will show the breadth of applications that this part of the African continent has experienced in the past few years and highlight the challenges faced by local engineers.

3.1 Bridge Abutments, Retaining Walls

3.1.1 Case B1, Bridge Access Embankment, M'sila, Algeria

The revival of a railway link project between the cities of Bordj-BouArreridj and Ain Touta, via the city of M'sila (East of Algeria) has forced the national railway company to resume work on the flyover that crosses the railway line at the entrance of the city of M'sila. The structure was constructed in the 1980's but was never completed because the railway project was abandoned due to economical constraints (Figure 1). Given the urgency of the railway project, the local administration launched a consultation for the construction of the access ramps to the road bridge in order to avoid any disturbance to road traffic during the construction of the railway track and complete the flyover structure for the benefit of the road users.

Figure 1. View of the unfinished bridge structure.

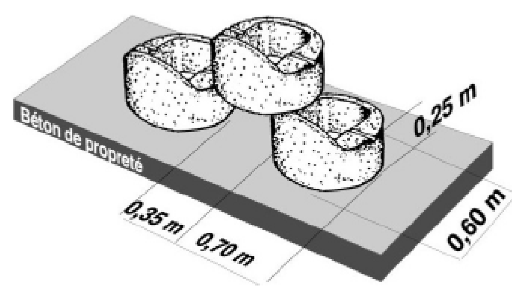

Figure 2. Segmental blocks.

The classical embankment solution was excluded because of the proximity of farmland and a housing complex for which the expropriation process would have taken long time to complete. The contracting authority sought a solution that would stiffen the embankment fill, reduce the footprint and construction time. The solution adopted for the stiffening of the access ramps was to use segmental walls (Figure 2), inclined at 74^{o}, reinforced with high tensile strength geotextiles. Backfill material (alluvial material) was sourced locally and structure was completed in 2005 (Figure 3).

The calculation method used for the design of the structure was based on the software CARTAGE, and followed French guidelines for earthen structures (Delmas et al., 1986). This method determines the efforts mobilised in the reinforcement and takes into account the extensible nature of the geotextiles, the mechanical properties of the backfill material and the geometry of the structure.

Figure 3. Completed structure.

3.1.2 Case B2 , Bridge Access Embankments, Dakar, Senegal

The highway which constitutes the main access to the peninsula of Dakar supports a very large flow of vehicles. Poorly designed intersections resulted in persistent bottlenecks leading to continuous and lengthy traffic jams. Under the improvement of urban mobility project launched by the local authorities, two major junctions “Malick SY” and “Cyrnos” have been rearranged to improve traffic fluidity. These improvements included the construction of overpasses and access embankments. Lack of space, cost for crushed materials and the presence of soft clayey-sand subsoil were critical issues which had to be solved and made the construction of access reinforced embankments very attractive. The use of geosynthetic reinforced fills allowed the construction of vertical embankments and minimized the need to use concrete compared to traditional retaining walls. Dune sand, cheap and abundantly available locally, was used as backfill material. It was confined at the facing by geotextiles and laterite. The embankments were completed before the facing was installed, in order to allow consolidation of the clayey-sand subsoil.

The bridge-access embankments (Figure 4 and 5) were constituted of:

- a geosynthetic reinforced fill: alternate layers of high strength geotextiles and fill material were used. The geotextiles were wrapped round the fill at the facing to obtain a vertical, stable embankment with as maximum height of 5.2 m.
- prefabricated-concrete panel facing, 20 to 25 cm distant from the reinforced embankment. This facing was totally independent of the fill and did not support any earth pressure. It was founded on the ground in place or on a geosynthetic reinforced fill for the particular case of the northern side of “Cyrnos” junction. The abutments were founded on piles.

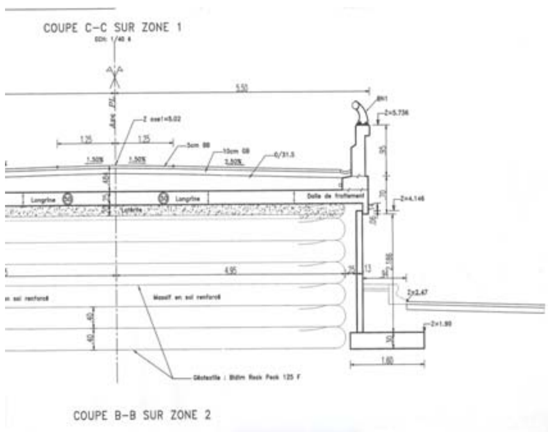

Figure 4. Transversal cross section (Malick Sy, Junction).

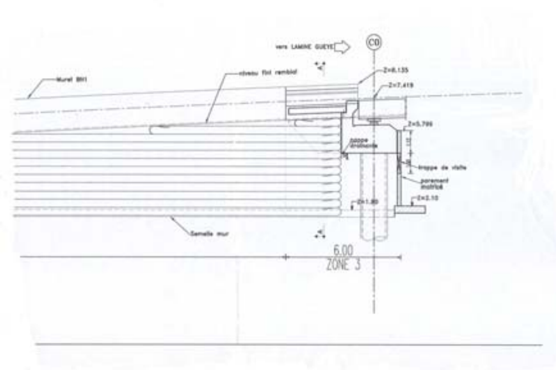

Figure 5. Partial longitudinal cross section near abutment (Malick Sy junction).

Short and long term internal and global stability of the reinforced fills were verified numerically using the conventional Bishop's method. For the particular case of the northern side of "Cyrnos" junction where prefabricated concrete panels were directly founded on reinforced fills, the calculation was supplemented by an approach based on the use of the software CARTAGE (see case B1).

A monitoring system using optic fibers (Geodetect®) has been installed on each embankment to monitor the deformations within the fills during the working life of the embankments. Monitoring measurements taken during installation and after construction completion showed very small deformations (average was around 0.5%).

It is worth noting that with this project (Figure 6) geosynthetic-reinforced wall technology was used for the first time in this part of Africa. Despite the absence of local experience on geosynthetic-reinforced wall construction, the project was easily completed. Furthermore, it illustrates how using local materials and a geosynthetic solution could provide sustainable growth.

Figure 6. View of the completed structure.

3.2 Slopes, Roads, Airfields

3.2.1 Case S1, Tifra Landslide Repair, Bejaia, Algeria

The Tifra landslide (Bejaia, East of Algeria) occurred in a mountainous area following a heavy rainfall event and badly damaged a mountainside road over a length of 80 m (figure 7). The geology of the Tifra region is constituted of sandstone formations in which marls and schistose marls are inter-stratified. Geotechnical site investigations have revealed the following layering from top to bottom (figure 8):

- a layer of sandstone boulders, 5 m thick;
- soft schistose marls, 0.5 m thick;
- weathered sandstone benches, 1.10 m thick;
- beyond 6.60 m depth, alternating layers of compact schistose marl and sandstone.

Geotechnical studies indicated that the slip occurred due to infiltration of water on the upstream side of the slope and the total absence of drainage. The slip failure was located in the soft schistose marl layer of limited thickness and the layer of weathered sandstone benches

Figure 7. View of the damaged road and slope failure

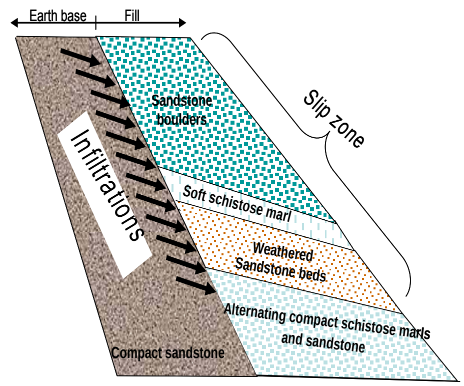

Figure 8. Soil profile at the location of the slip

Several technical solutions were proposed to the local authorities to repair the slope and reconstruct the road. The initial solution implemented was to clear away the entire slip zone and reconstruct the embankment with a slope of 3H/2V using a clean coarse fill material, compacted in successive layers of 0.3 m and with drainage upstream provided by a granular drain. However, during construction, longitudinal cracks appeared at the top and at the foot of the slope of the new embankment before reaching the final level. (Figure 9). This prompted the contractor and the owner to stop work and to consider alternative solutions. The solution adopted, because of ease and rapidity of construction, was a wrap around geotextile retaining wall with a vegetation facing and coupled to a geocomposite drain equipped with mini-drains.

Figure 9. Longitudinal cracks caused by soil surcharge

Figure 10. View of the geocomposite drain and drain trench.

The work took place in several phases. After a total clean up of the slip zone (again) and excavating to the bedrock, a drainage trench was constructed at the foot of the slope. The geocomposite drain was installed directly on the side slope and was linked up to the drainage trench at the foot of the slope to evacuate the collected water (figure 10). The backfill was compacted at optimum Proctor in 0.4 m thick layers using fill material from the slip zone. A high strength geotextile was used for the wrap around reinforcement. The seeding of the vegetation on the surface of the wall was achieved by applying a layer of top soil held in place with a geonet (Geotalus).

The structure was designed based on the guidelines of the French Geosynthetics Committee for reinforced earthen structures using CARTAGE, a software developed by the LCPC and LIRIGM (Delmas et al., 1986). It was used to size the structure, and enabled, based on possible surface rupture studies, to determine the forces applied to the reinforcement taking into consideration their extendable nature, the physical characteristics of the fill material and the construction geometry. This allowed determining the number, resistance, length and spacing of the geotextile sheets. The construction cross-section and reinforcement density are illustrated in Figure 11. Figure 12 shows the completed facility which allowed the reconstruction of the roadway in 4 months in a sustainable way.

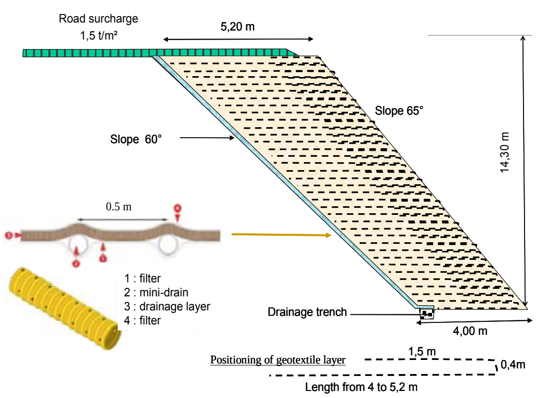

Figure 11. Cross section of the repaired slope

Figure 12. View of the completed wrap around geotextile wall.

3.2.2 Case S2, Mediterranean bypass, El Jebha, Morocoo

Northern Morocco is characterised by a poor road network. To open up the region, the Mediterranean bypass project was launched by the local authorities. It includes the rearrangement of 250 km of existing roads and the construction of 300 kms of new roads. Reinforced earth structures played an important role in this major “open up” project. This case is in relation to the redevelopment of a mountainside road along the Moroccan Riff which is often on unstable slopes. The aim of the project was to stabilise the road as part of its widening on the section El Jebha/Beni Boufrah. The project involved the construction of 21 reinforced walls with height ranging from 8 to 16 m and length from 100 to 500 m, for a total area of 15 800 m². GeoStrap reinforcements, made from high tenacity fiber polyester encased in a polyethylene casing, were used in all the walls following Terre Armee concept (Figure 13 and 14).

Figure 13. View of the geostrap reinforcement

Figure 14. View of the completed structure

3.2.3 Case E1, Road Embankment, Chott El Hodna, Algeria

The Chott El-Hodna project involves the construction of a 11 km long road through a salt lake (Chott El-Hodna, East of Algeria) linking the cities of M'Cif and Ain El-Khadra. The new road has opened up the salt lake for the inhabitants, who formerly had to make a 75 km detour, reducing the distance between the two cities to 16 km.

The salt lake is located at the extreme east of the highlands and is 220 Km long and 90 km wide. It is hydrologically a closed lake of more than 26.000 km^2. It was created by waters descending from the Atlas Tellien to the North and the Saharian Atlas to the South. The road will divide the lake in two parts, eastern lake and western lake with the eastern lake ending up with the largest area.

The salt lake is characterised by a very poor sub-grade (soft soil, undrained strength, C_u=9 kPa), Figure 15. During the winter it has a depth of 1 m, and remains filled with water 8 months of the year, Figure 16. In the summer it dries up due to evaporation and the bottom is completely covered with a layer of salt.

Figure 15. Site conditions.

Figure 16. View of the partially inundated pilot road route test (prior to reinforcement solution).

The initial solution that was advocated was to dig two metres deep (carrier layer) over the entire length of the road and then fill the excavated area with a good quality fill material before building the road. However, this solution proved to be inadequate after a pilot test was conducted which indicated that it was difficult to conduct earthworks in very low bearing capacity soils and to find a suitable material in sufficient quantity and acceptable quality. After additional geotechnical investigations, a solution integrating the use of geosynthetics has been accepted by the local authority. It consisted of a shallow embankment which comprised from bottom to top of a separation/filtration geotextile, a compacted layer of fill material 0.40 thick, a bidirectional geogrid and a compacted 1.3 m of fill material (Figure 17). Furthermore, HDPE pipes with a diameter of 1000 mm were installed at regular intervals to ensure the continuity of natural flow between the two parts of the lake. Protection of the embankment slope consisted of a separation / filtration geotextile and rockfill shell.

Figure 17. Installation of filtration geotextile, fill material and geogrid.

3.2.4 Case E2, Motorway Embankment, Tunis, Tunisia

Recently, karstic cavities have been observed on a section of about two kilometres during the construction of a motorway in Tunisia (Jamei et al., 2006). The geotechnical and geological data showed that the detected cavities were randomly distributed, and have varied shapes and depths. Two types of anomalies were indexed: (1) Collapses related to the presence of karstic cavities, in general from 2 to 3 m in diameter (Figure 18), but being able to reach in certain cases 4 m to 5 m length by 2 m width. The collapse phenomenon is complex and very randomly (slowly collapse or collapse of blocks). (2) Old chimneys (slow collapse), filled by argillaceous and marly materials (Figure 19). In these areas the soil is composed by gypsum of Triassic and marled clay with 30 m thickness, where heavy water activities were developed, which have a high acid concentration that induce the dissolutions of the gypsum and generate the formation of sub soil cavities.

Figure 18. Karstic Cavities (from Jamei et al., 2006)

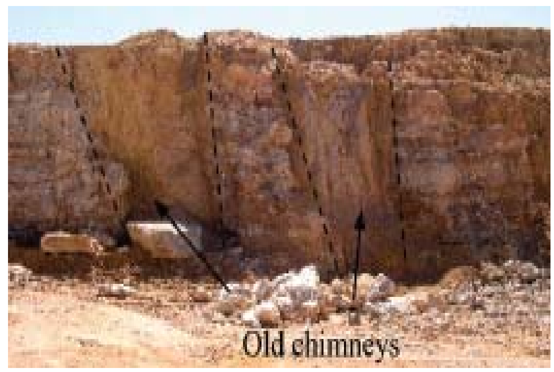

Figure 19. Old chimneys filed by filling material (from Jamei et al., 2006)

The solution adopted for this project was to treat the cavities by injection of filling materials to slow down their evolution. This was combined with the use of a high tensile geotextile positioned at the base of the embankment to detect the presence of cavities, through the vertical movements obtained at the surface, and to limit the surface settlement to permissible values allowing traffic until repair works can be carried out. The geotextile was a non woven fitted with high tenacity polyester fibres (reinforcement was needed to support the required tensile force) in the traffic direction. The embankment was constituted of a 0.8 m thick layer of granular material. The thickness of the pavement road layer was about 0.35 m. For this project, the purpose of the designing method was to obtain in serviceability limit state a maximal surface settlement of 0.10 m for diameters of cavities of 2 m (maximal strain acting on the geosynthetic less than 5 %). The British Standard for reinforced fills and the French method (Villard et al. 2002) were used in this project. The major difference between the two methods is on the assumption of the collapse area over the cavity. Design methods allowed the selection of a geotextile with a the maximum average tensile strength of 260 kN/m corresponding to 8% of strain

3.2.5 Case E3, Kabale-Kutana road, Uganda

The Kabale-Kutana road is the final link into Rwanda from Uganda. For much of its length the road runs along or close, to the interface between a swamp and sidelong ground. It is built either on embankment, or in half cutting and half embankment. Following extensive rainfall, two sections of embankment collapsed into the swamp with deep openings and cracks extending into the carriageway (Figures 21 and 21). This necessitated that the road be restricted to one lane for the use of light vehicles and closed completely to heavy vehicles.

The repair work involved the use of a geocell mattress and geogrid reinforced soil. A 60° wrap-around 5 meter high embankment was used to provide a stable structure on which the highway could be rebuilt. This minimised the embankment foot print, which would otherwise have meant extending the side slopes further onto the swamp areas with the continual risk of further failures. Soil filled bags were used to form the face angle of 60° with uniaxial geogrids wrapped around the bag work face and connected to the layer above using bodkins (Figures 22 and 23).

Figure 20. Deep tension cracks in surfacing.

Figure 21. slip failure.

Locally fill was used in the embankment construction. The embankment fill was placed and compacted in accordance with local standards. The use of the geocell mattress was to provide a free draining, stable platform over very soft ground and to minimise differential settlement. It also allows water, percolating under the road, to escape without undermining the foundation between the existing cut half of the road, formed on a stable foundation, and the part of the road founded on swamp. It was rapidly assembled on site to form a deep, open cellular structure which is then filled with granular material. The filled geocell creates a rigid, high strength foundation for the embankment, a construction platform for earthwork plant and, in addition, it acts as a drainage layer. The design method was based on British Standards for earth reinforced fills. Ten years after its reconstruction, the road remains intact to the extent that the Ministry of Works removed it from its maintenance list.

Figure 22. Construction of Geocell foundation mattress

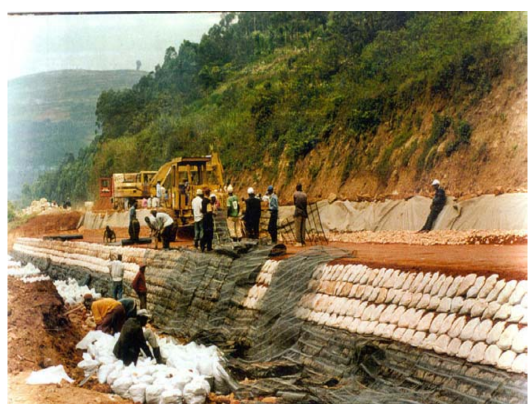

Figure 23. Construction of steep embankment slope.

3.2.6 Case A1, Airfield Rehabilitation, Djanet Airport, Algeria

Djanet airport was built in 1984. It is located 30 km south of the town of Djanet, near the Algerian-Libyan border, at the extreme south east of Algeria, 2200 kms from the Mediterranean coast. Djanet is characterised by a desert-type climate. The difference between day and night temperatures can be as high as 30^{o}C, leading to high thermal gradients. Given the harsh climatic conditions and high temperature gradients, widespread reflective cracks have appeared in the main runway ten years after the opening of the airport leading to a high level of degradation of its surface. Visual observation indicated that the cracks were of two types: Transversal and longitudinal cracks, Figure 12 and 13, respectively. Transversal cracks covered the entire surface of the runway, with openings reaching a width of 3 cm at some locations. The transversal cracks are shrinkage cracks caused by very high thermal gradients typically encountered in the Djanet region. Longitudinal cracks were cracks of the longitudinal joints on all of the asphalt strips bands. Depth of the cracks reached 5 cm at some locations. The formation of this type of crack is due to poor adhesion between two strips of asphalt installed at different ages (at different temperatures) and insufficient compaction at the edge of the strip.

Figure 24. Transversal cracks due to thermal stresses

Figure 25. Longitudinal cracks along the asphalt strip joint

The various sealing programs performed on this runaway proved to be ineffective. The phenomenon of reflective cracking kept reappearing which prompted the local authority to adopt a different alternative to their standard approach based on replacement of existing pavement which necessitates very significant financial resources and was becoming difficult to justify due to the low volume of traffic experienced by the airport. The solution adopted was based on the use of a geogrid (fibreglass type, tensile resistance 50 Kn/m) as a strengthening measure of the runway and to minimise the presence of reflective cracking (Figure 26).

This project completed in 2005 (Figure 27) allowed the use, for the first time in Algeria, of a geogrid to minimise or retard reflective cracking in runways. The experience gained from this project will serve, without any doubt, other airports in Southern Algeria which suffer from the same problem (i.e., thermal stress) and will help to reduce at the same time the costs of rehabilitation and maintenance.

Figure 26. Installation of geogrid

Figure 27. Rehabilitated runway

4. HYDRAULIC STRUCTURES

Hydraulic structures comprise dams and canals. Hydraulic structures interact with water, which can be one of the more destructive forces in the environment. Geosynthetics are often used to limit the interaction between the structure and water. Geosynthetics can increase the stability of the hydraulic structures. For hydraulic structures, geosynthetics can be used to: (1) Reduce or prevent water infiltration through the use of geomembranes, (2) Reduce or prevent bank erosion of canals through the use of geomembrane liners, (3) Provide drainage and/or filtration through the use of geotextiles and geonets, (4) Provide reinforcement for the structure's foundation or the structure itself.

4.1 Dams

4.1.1 Case D1, Filtration, Dzoumogne Dam, Mayotte Island

The filtration function involves movement of liquid through the geosynthetic and, at the same time, retention of soil on its upstream side. Geotextiles are the product generally used for the function of filtration. Applications include geotextile filters for trench drains, blanket drains, interceptor drains, structural drains, toe drains in dams, filters for hard armor (e.g., rip-rap, gabions, fabric-form) erosion control systems, silt fences, and silt curtains.

The Dzoumogne earth dam was built in 2000 for the storage of drinking water. The maximum storage capacity is 2.8 million m^3 corresponding to a volume of embankment of about 250 000m^3, a total height of 24.5 m and a crest of 300 m. The dam is designed with an overflow in its central part and a 60 cm thick spillway made with 200/400 kg stones mixed with bituminous concrete, Figure 28. The earth embankment built behind the spillway is covered with a thick layer of rockfill.

The dam is made of homogeneous clayey soil. The upstream slope is protected with a 60 cm thick rip-rap with a secondary layer of 0/100 kg stone and a primary layer of 150/500 kg. A two layer filtration geotextile GT2 was installed between the rip rap layer and the embankment. Soil that has to be filtrated is a homogeneous clayey soil with d_{85} < 80 µm. The drainage system consists of :

- A layer inclined 1V/1H downstream to intercept the stream lines inside the body of the dam;
- Drainage trenches and blankets at the bottom to direct infiltrated water to a gutter at the upstream toe of the dam. The granular (gravel) drainage system built with gravels is protected by a mono layer filtration geotextile GT1 (Figure 30).

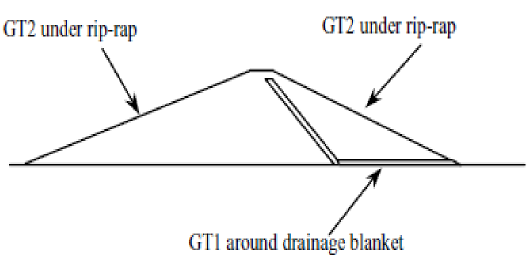

Figure 28. Dzoumogne Dam cross section

Figure 29. Top view of the dam during construction (filtration geotextile in white)

Filtration geotextiles are particularly adapted to fines soils that can be observed in many parts of Africa. When used instead of granular layers, they contribute to a sustainable development. Completed structure is shown in Figure 31.

Figure 30. Drainage blanket with stone and filtration geotextile

Figure 31. View of the completed dam.

4.1.2 Case D2, Geotubes and Waterproofing, Temporary Dam, Rabat, Morocco

Geotextile containments are increasingly used in hydraulic and marine, foundations and environmental applications (Lawson, 2006). There are three fundamental types of geotextile containment units, differentiated by geometrical shape and volume. These are geotextile tubes, geotextile containers and geotextile bags (Lawson, 2006).

The dam in Rabat was needed as a temporary barrier so that the existing dam could be renovated. The dam could not be emptied to carry out the renovation because it was the supply source of drinking water to the city of Rabat. For this project, three geotextile tube systems with a diameter of 5 meter where used to construct a temporary dam in 6 meter deep water. Geotextile tubes are tubular containers that are formed in-situ on land or in water. The tubes were made of woven polypropylene uniaxial geotextiles and were filled with sand ($D_{50} > 250\ \mu$) . They were stacked on a rock foundation as shown in Figure 32 to form a temporary dam. A woven biaxial polypropylene geotextile was used at the interface between the bottom two tubes and the upper tube as an erosion material. The construction was covered with a reinforced geomembrane to waterproof it. The geomembrane was made from a woven textile laminated on both sides with thin continuous polyethylene sheets. The geotextile tubes solution was chosen because of the difficulty in bringing large quantities of rock for constructing the temporary dam coupled to accessibility constraints (presence of high rock walls and access not easy for boats, Figure 33). By pumping sandy material directly into the geotextile tube systems the dam was easier and quicker to construct. It should be noted that the geotextile containment is required only for temporary use, therefore the requirements of the geotextile container is fairly basic as it only has a short life over which it has to perform.

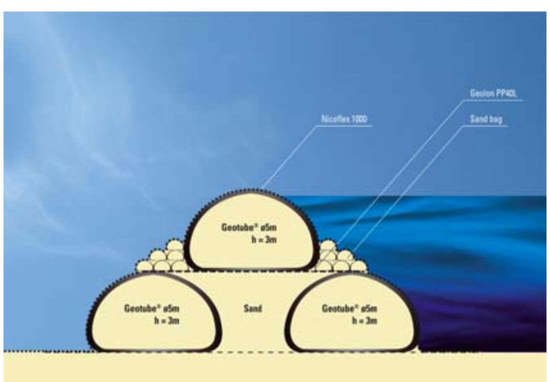

Figure 32. Cross section of the temporary dam

Figure 33. Overview of the site where the systems are being installed in the water. The walls have a height of around 50 meters.

There was no specific design methodology used in this project since the sub base was rock and no slip circle failures could occur. The only aspect which was of a concern was the sliding resistance of the structure. In the performance situation the temporary dam had to resist the horizontal water pressure of 6 meter. Calculations were done on the friction between the sub base and the geotextile tube system. It was found that if the water was pumped away on one side of the dam there was still a factor of safety of around 1.5 against sliding. The system was installed in 2004 (Figures 34 and 35) and was removed in 2006 upon completion of the renovation of the existing dam.

Figure 34. Dam in place and covered with the geomembrane.

Figure 35. View of the dam with the geotextile tubes in place

5. WASTE CONTAINMENT FACILITIES

Waste containment facilities are constructed to retain various types of waste (municipal solid waste, hazardous waste, mining waste, etc.). Containment is achieved with individual barriers that, together, provide a system of engineered control. It is accomplished using physical, hydraulic, or chemical barriers that prevent or control the outward migration of contaminants into the surrounding environment to levels that will result in negligible impact and can provide a safe and highly cost-effective mechanism for environmental protection. Geosynthetics and related products have found wide application in the design and construction of these containment facilities because of the economical and technical advantages that geosynthetics can offer in relation to more traditional materials. There are numerous types of geosynthetics, which can be used in waste containment applications and each can perform a specific function as indicated in Table 3. The focus of this section will be solely on the barrier function.

5.1 Barriers

The barrier function can be performed by geosynthetic products that have adequately low hydraulic conductivity as to provide containment to liquid or vapour. The barrier function may be provided by several types of geosynthetics, namely, geomembranes, geosynthetic clay liners (GCLs) and in some cases asphalt-impregnated geotextiles. They are commonly used as liner for surface impoundments storing hazardous and non-hazardous liquids, and at base and covers of landfills in combination with other materials.

5.1.1 Case W1, Polesgo Landfill, Ougadougou, Burkina Faso

The Polesgo landfill is located 50 km north of Ouagadougou, capital city of Burkina Faso. It is designed to receive 5.700.000 m^3 of municipal solid waste and 441.000 m^3 of special industrial waste including medical waste (Aina, 2006). Six cells of approximately 100 ha each were provided for storage of municipal solid waste (MSW) and four cells for the industrial waste (IW). The cells differ in their lining design, the MSW cells rely solely on 0.6 m compacted clay liner with a hydraulic conductivity of 10^{-6} m/s. A geotextile is used at the interface between waste and the drainage layer for the purpose of filtration. On the other hand the IW cells are lined with a double composite liner comprising from top to bottom: 0.5 m granular drainage layer, geotextile cushion, 1.5 mm HDPE geomembrane, 0.3 m granular drainage layer acting as leak detection layer, 1 mm HDPE geomembrane, and finally 0.6 m compacted clay liner with a hydraulic conductivity of 10^{-6} m/s. Although, the MSW cells are not lined, the leachate ponds (2 for MSW and 2 for IW) are!. The leachate ponds are lined with a double composite liner consisting from top to bottom of 1 mm HDPE geomembrane, a geocomposite, 1 mm HDPE geomembrane and 0.6 compacted clay liner with a hydraulic conductivity of 10^{-6} m/s.

5.1.2 Case W2, Sidi Rached Landfill, Tipaza, Algeria

The amount of municipal waste produced in Algeria is estimated to 10 million tonnes / year, in which more than 1.5 million tonnes are of industrial waste type. This waste is mostly dumped into uncontrolled landfills. A recent survey conducted by the Algerian Ministry of Land and Environment (MATE) showed that more than 3200 uncontrolled landfills are located throughout the country, occupying more than 150.000 hectares of agricultural land. Considering the environmental impact of such practice, it is not surprising that a large program of construction of controlled landfills has been launched by the local authorities with the aim of providing major towns with means of disposing of their waste in a safely manner. The aim was also to transform the uncontrolled sites into controlled sites to phase out the practice of dumping of waste with no control. The Sidi Rached Landfill, located in Tipaza, about 80 km west of Algiers, is such type of site (Figure 36).

Figure 36. View of Sidi Rached landfill before rehabilitation.

The site occupies an area of about 17 hectares and caters for the surrounding regional towns. It has been designed for an operation of 18 years with initially two cells. The two cells are located on a thick deposit of marls characterised by a low hydraulic conductivity. This has been taken into account to engineer the soil base of the cells. In addition to the soil liner, the cells liner comprises a 2 mm HDPE geomembrane (Figure 37), a polypropylene geotextile cushion and 0.5 m thick granular drainage layer. On the side wall, the geomembrane is protected by a geocomposite which acts also as drainage medium (Figure 38).

Figure 37. Geomembrane liner for a new cell

Figure 38. Geocomposite on side wall and granular drainage layer at the bottom of the cell

6. CONCLUSIONS

Given the increased use of geosynthetics in various applications observed in the Northern African region over the past few years, it is interesting to speculate how the practice will develop in future. It is clear that with ever increasing focus on sustainable development geotechnical engineers will be called upon to solve a multitude of problems linked to infrastructure and resources development and environmental protection. In this respect, geosynthetics will have a major role to play in this process. However, one should not lose sight of the need to adapt any transfer of technologies to local conditions and more importantly to tailor the selected solutions to the local specific needs of a country. Failure to acknowledge this aspect will result in the construction of too sophisticated structures or facilities that do not meet the local realities. Based on the cases reported in this paper, it is quite obvious that the use of geosynthetics is controlled by the rate of national economical development; similar conclusions were drawn by Lawson and Cowland (2000) on the future of geosynthetics in Asia.

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