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Waterproofing by PVC geomembrane of two ponds at the pumped storage station of Afourer (Morocco)

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ABSTRACT: The Afourer pumped-storage station project in Morocco involves the construction and waterproofing of two ponds and the construction of two reversible plants. The new pumped-storage plants, UR1 and UR2 at Afourer will represent 10 percent of the total installed capacity in Morocco and will produce enough energy for peak and high demand period, producing 5.8% of the Moroccan energy production.

The reservoirs, which have a useable capacity of 1,260,000 m^3 each, were installed on very permeable foundations and needed artificial waterproofing. The waterproofing solution chosen for both reservoirs is composed of a 1.5 mm-thick PVC geomembrane, between two polypropylene continuous filament needle-punched non-woven geotextiles 500 g/m^2, laid on a granular layer (gravel 5/16 mm) and draining pipes. These are protected by gravel on the bottom and gravel and rip-rap on slopes. The work started in 2001 and was completed in 2004 (geomembrane installation: 2003/2004).

This paper presents the characteristics of the work, the general design of the geomembrane lining system, installation and quality control procedures. In particular, several field tests have been carried out on a very large area (from 5×30 m to 18×55 m) to verify the behavior of complex geotextile geomembrane during tipping of the upper granular layers, taking into account the granulometry and angularity of the gravel in the draining and protective layers, the thickness of upper layer, as well as the characteristics of vehicles used for installation and the slopes of the area (horizontal, 5/1 an 3/1).

1 DESCRIPTION OF PUMPED STORAGE STATION (STEP) OF AFOURER

The project at the Afourer pumped-storage station in Morocco involves the construction and waterproofing of two ponds and the construction of two reversible plants and was recently completed. The Afourer site is at the bottom of the Middle Atlas, near river Oum er Rbia, between Marrakech and Meknès. The new pumped storage complex is composed of an upper and a lower reservoir with a difference of level of 800 m and of two reversible plants, UR1 (364 MW), installed 200 meters above the lower reservoir and UR2 (120 MW), close to the lower reservoir. It is connected to an existing classical gravitary complex composed of the Bin El Ouidane Dam (with a plant of 135 MW), and the Aït Ouarda dam (with a plant of 92 MW at Afourer). Both complexes are used for electric power generation and for irrigation. Water for the pumped storage is taken out of the gallery existing between Aït Ouarda and Afourer, at the level of UR1. Water is pumped to the reservoir 600 m higher, and is turbined to the lower reservoir 800 m below. Depending on the need for irrigation, water of the lower reservoir can be injected into irrigation canals or pumped to the higher reservoir

The topography of the site is very favorable, but the realization of the reservoirs is difficult, due to karstic limestone in the foundations of both reservoirs.

Owner of the project: Office National d'Electricité (ONE), the national electric utility. Conceptual design of the project: EDF-CIH.

Main contractors: Alstom (France) and SGTM (La Société Générale des Travaux du Maroc) for the civil engineering and earth works.

The subcontractor for the supply and installation of the geomembrane was Alkor Draka, who subcontracted the geomembrane design and the installation supervision to Appligeo (and, partially, also to BAST for installation supervision), and the geomembrane installation to two Moroccan companies, Valmont Maroc and Sofima Etanchéité.

2 THE WATERPROOFING OF RESERVOIRS

The reservoirs, which have each a useable capacity of 1,260,000 m^3, needed artificial waterproofing because they were installed on very permeable foundations. Foundation of the upper reservoir is a calcareous karstic layer with ponors and lapiaz, and for the lower reservoir, it is calcareous breccia with clay. Table 1 gives the main characteristics of both reservoirs.

Table 1. Characteristics of reservoirs of AFOURER.

	Upper water-reservoir	Lower water reservoir
Spot height of top of dam/slopes: m	1284.50	492.00
Spot height of bottom of dam	1268.5	476.
Length of dam	~360 m	~ 1000 m
Internal Slope Excavated area Dam:	 5H/1V 3H/1V	 3H/1V 3H/1V
External slope of dam:	1.5/1	2.5H/1V
Bottom of reservoir: m	1270.93	477.5
Higher water level: m	1283.65	490.72
Max. water depth, m	12,72	13.22
Range of water level during power production: m	1283.55 to 1273.20	490.60 to 479.95
Area : m^2	~ 180 000	~ 160 000
Foundation:	Karstic	Calc.breccia

2.1 *Choice of geomembrane*

The waterproofing solution for the two reservoirs involved the use of a 1.5 mm-thick PVC geomembrane, (Table 2).

Table 2. Characteristics of PVC geomembrane ALKORPLAN 35053.

Characteristics	Norms	Units	Nominal Values
Density	DIN 53479	g/cm^3	1,24 ± 0,02
Thickness		mm	1.5 mm ± 5%
Tensile strength	DIN 53455	N/mm^2	L: ≥ 15 T: ≥ 15
Elongation at the failure	DIN 53455	%	L: ≥ 300 T: ≥ 300
Tear strength	DIN 53363	N/mm	≥ 80
Hardness	DIN 53505	Shore A; 10 s	75 ± 2
Cold crack temperature	DIN 53372	° C	– 20 °C, no cracks
Cold mandrel test	DIN 53361	° C	– 20 °C, no cracks
Dimensional stability	DIN 53377 6 hours/80°C	%	L: ≤ 2 T: ≤ 2

This geomembrane was chosen for the following reasons:

- Higher resistance to puncturing during installation of protective layer and service; confirmed by laboratory tests and in situ tests.
- Higher friction coefficient (about 26 degrees between geotextile and geomembrane). This is very important for the stability of the protective layer on slopes (in static and seismic conditions).
- Formula containing only virgin resin, without any regenerated product. The K-Wert of PVC resin is >70, conferring to the final product the best durability and a good behavior to creeps.

The thickness of 1.5 mm was chosen, taking into account:

- Moderate maximal water depth (13.22 m).
- Need of very long durability.
- Risk of puncturing during installation of protective layer (see below).
- Economical considerations.

The geomembrane is slightly protected against UV, due to the planed protective layer poured shortly after installation.

Figure 1. Upper reservoir of Afourer.

Figure 2. Lower reservoir of Afourer.

2.2 *Choice of protected geomembrane*

The suitability of a protective layer was carefully examined before beginning the work.

Both sites are very exposed to wind effect, and both reservoirs are empty and filled twice a day. Their

maximal length, at the water level, is 660 m for the lower reservoir, which is elongated, and 465 m for the upper reservoir, more or less circular.

Empty, wind forces may destroy the geomembrane if it is not protected, regularly ballasted or anchored. Filled, the wind may induce heavy waves. For instance, the height of the specific wave for the upper reservoir is 0.85 m for a wind speed of 150 km/h, (Bretschneider formula). Therefore, to avoid problems due to such waves, it is necessary either to protect the geomembrane with a granular or concrete layer, or to reinforce the cohesion of the supporting layer of the geomembrane (for example, treatment with cement, etc).

A protective layer avoid any risk of human and animal vandalism, and increases the durability of the geomembrane (about five time or more). Thinking in long-term and taking into account the operating losses occurring during the waterproofing repair or renewal, the cost of a protected layer is significantly offset by its advantages.

Therefore, it was decided to keep the solution of protecting the geomembrane by granular layers: gravel on the bottom and gravel and rip-rap on slopes, as planed in the first design by EDF-CIH.

After field tests carried out to verify all material parameters, installation equipment characteristics and procedures, the chosen structure was as describe in Table 3.

Table 3. Composition of lining system.

	Bottom	Slopes
Rip-rap		Crushed stones 100/200
Transition layer	Semi crushed gravel 16/32, or 8/31.5, 0.30 m thick	Crushed gravel 5/16, 0.20 m thick
Anti-puncturing geotextile	Non woven 500 g/m^2	Non woven 500 g/m^2
Geomembrane	PVC 1.5 mm thick	PVC 1.5 mm thick
Anti-puncturing geotextile	Non woven 500 g/m^2	Non woven 500 g/m^2
Draining supporting layer	Semi crushed gravel 5/16, 0.20 m thick	Semi crushed gravel 5/16, 0.20 m thick
Foundation level	Regularized and compacted	

The geotextile, on both sides of the geomembrane, is a 100% polypropylene continuous filament needle-punched non-woven geotextile. (see Table 4).

3 FIELD TESTS

Several field tests were carried out on very large areas (from 5 × 30 m to 18 × 55 m) to verify the behavior of complex geotextile geomembrane during tipping of upper granular layers, taking into account the granulometry and angularity of the gravel for the draining and protective layers, the thickness of the upper layer, the characteristics of vehicles used for installation and slopes of the area (horizontal, 5/1 an 3/1). The purpose of those tests was to avoid any puncturing of the geomembrane and any sliding of the protective layer on slopes during installation. Even a puncturing mark 1/10 mm deep was enough to reject the solution. Results are summarized on Table 5. The preliminary test has been carried out with 1.2 mm thick geomembrane, as 1.5 mm thick was not available on site at this time. The other tests and the work itself have been done using a 1.5 mm thick geomembrane.

Table 4. Characteristics of BIDIM P50 geotextile.

Characteristic	Unit	Symbol	Value
Tensile strength EN ISO 10319 – md & cmd*	kN/m	T^{max}	30
Elongation EN ISO 10319 md & cmd*	%	$å^{max}$	85/75
Dynamic perforation (cone drop test) – EN 918	mm	P_d	10,5
Mass EN 965	g/m^2	μ_{GT}	500
Thickness EN 964-1 2 kPa	mm	P_d	4.2
CBR puncture resistance EN ISO 12236	kN	$P_{s(x)}$	5400

4 WATERPROOFING INSTALLATION

The geotextile under the geomembrane is installed on a draining layer with an overlap of 30 cm. Rolls of geomembrane, 2.05 m wide and 150 m in length are unrolled from a sling bar hanging on a backhoe loader; and welded with automatic welding device making a double welding, allowing a control by air pressure test. (Without prefabrication). The geotextile on the geomembrane is sewed to avoid any opening risk of the junction, either by wind or during pouring of gravel for the protective layer.

The protective layer is installed on slopes with a hydraulic excavator, spreading first the gravel that was poured on top of the slope and in a second step, spreading the rip-rap stones also tipped on the crest. On the bottom, material 16/32 or 8/31.5 is tipped from a dumper 405, driving on a gravel layer minimum 0.3 cm thick. Spreading of material is done by the loader 554 or the motor grader.

5 QUALITY CONTROL SYSTEM

The quality control procedure is at the highest level, with a full traceability of each component of the flexible lining system: topography, granulometry and surface aspect of the draining layer, verification of each geosynthetics delivery which are supplied with the results of factory quality control. The number of

Table 5. Field test results.

Date	Granulometry 1 supporting layer	Granulometry 2 protective layer	Thickness (m) layer on GMB	Vehicle	Weight/ wheel ton	σ_{GMB} MPa	Résult	Slope m/1	T_{gmb}
12/06 2003	4/10-R	5/16-C	0,2	1	10	0,48	OK	5/1	1,2
	5/16-R	5/16 C	0,2	1	10	0,48	OK	5/1	1,2
	5/16-R	5/16-C	0,2	1	10	0,48	OK	5/1	1,2
	5/16-C	5/16-C	0,2	1	10	0,48	OK	5/1	1,2
			0,7***	1	10	0,48	OK	5/1	1,2
22/11 2003	5/16-R	5/16-C	0,2	8			OK	3/1	1,5
	5/16-R	5/16-C	0,2	9			OK*	3/1	1,5
	5/16-R	16/32-R	0,3	1		0,32	OK	0	1,5
19/01 2004	5/16-R	10/25-C	0,3	1	10	0,48	N	0	1,5
20/01 2004	5/16-R	8/16-C	0,3	1	10	0,48	N**	0	1,5
	5/16-R	8/16-C	0,3	4	6	0,19	OK	0	1,5
	5/16-R	8/16-C	0,2	2	2,8	0,24	OK	0	1,5
23/03 2004	5/16-R	8/31,5-R	0,3	1	10	0,48	OK	0	1,5
15/4 2004	5/10-R	5/16-C	0,2	8		<,05	OK	43/1	1,5

Legend of Table 5:
OK : no mark on geomembrane
N: puncturing mark ≥ 1/10 mm deep
- Characteristics of the vehicles

1 Dumper 405, weight 48 ton, tire pressure (t.p.): 0.7 MPa
2 Motor Grader, weight 17 ton, t.p.: 0.35 MPa
4 Loader 554 weight/wheel 6 ton, t.p. 0.4 MPa
8 Hydraulic excavator Hitachi EX 235 weight 23.5 ton, pressure under track 0.05 MPa
9 Track dozer Cat D5
*Track shoes of the D5 track dozer have high grousers. On slope 3/1, and with a thin gravel layer (10 cm) on geosynthetics, gravel is pushed by the tracks and moves on the geosynthetics. We observe some attrition of upper geotextile, but the geomembrane is absolutely intact. This solution was rejected due to the difficulty to obtain a constant thickness and the risk to produce a failure of the waterproofing system.
** Puncturing marks are very small, 1/10 or 2/10 mm deep. Solution was rejected.
***; Preliminary test, gravel 0.20 m thick + 100/200 pebble layer 0.50 mm thick
σ_{GMB} Stress at the level of geomembrane determined by Boussinesq method.

production order of the geomembrane and number of roll is physically written on each panel and reported on the final plan. Each welding is fully tested. The name of the welder, results of tests, and name of the controller and its approval for the welding are written on the geomembrane and reported on a specific document. Each welding machine is tested (destructive test on welding sample) twice a day, in normal ambient climatic condition and destructive tests are carried out each 1000 m^2 on slopes and each 2000 m^2 on the bottom. A first reception is done for each area of about 3000 to 5000 m^2 of welded geomembrane. A second reception is done, for the same area, after laying and sewing the upper geotextile, and before pouring the protective layer.

6 CONCLUSION

Use of protected PVC geomembrane was the right solution for those large reservoirs in karstic area, for environmental, economical and durability considerations. The choice of a 1.5 mm thick PVC geomembrane combined with high performance geotextiles, the realization of numerous large scale field tests and the application of a stringent quality control system have allowed the very high level of performance of the waterproofing system that is essential for this type of project.

Figure 3. Field test on slope 3/1; laying of protective layer.

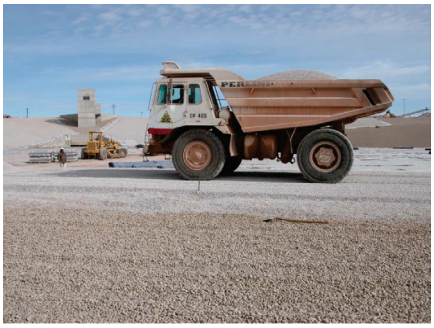

Figure 4. Field test on bottom (dumper goes past 80 times on gravel 0.30 m thick).