Geosynthetics Applications at Boussiaba Dam in Algeria

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ABSTRACT
Boussiaba is a 51 m high Rolled Compacted Concrete (RCC) dam under construction in Algeria. Owned by ANBT (Agence National des Barrages et Transfers), the dam will increase water supply to Beni Haroun Transfer and to the people of El Milia region. EDF – CIH (Centre for Hydraulic Engineering of Electricité de France) are the designers. The dam, of the low cementitious content type, has an upstream exposed drained geomembrane system to provide watertightness. The barrier system includes an impervious PVC geocomposite and a drainage geonet. The drainage system is divided in six compartments that will allow monitoring the behaviour of the impervious PVC geocomposite. The paper describes the details of the system selected by ANBT, the results of the tests performed at CESI on the impervious geocomposite, and the phases of installation that have been completed by the waterproofing contractor Carpi Tech at the time of preparation of the paper.

1. INTRODUCTION

1.1 Project Background

Boussiaba is one of the RCC dams at present under construction in Algeria. The dam, which is part of the Beni Haroun – Boussiaba system, is located 10 km north east of El Milia, and about 400 km east of Algiers. Owned by ANBT, Agence National des Barrages et Transfers, the dam will form a reservoir having a capacity of 120 million m^3, and a regulating volume of 80 million m^3. The regulating volume will be used to increase the capacity of the Beni Haroun Transfer and the supply of water to the 226,700 people of the El Milia region: 69 million m^3 will be transferred to the Beni Haroun reservoir, and 11 million m^3 to the population. EDF-CIH, Centre Ingénierie Hydraulique (Hydraulic Engineering Centre) of Electricité de France, are the designers of the project.

The dam will be approximately 51m high and 310m long, with a 100m long spillway section. Crest elevation is 79.65m, spillway elevation 74.40m. The drainage gallery has the invert at elevation 29m. The concrete intake tower is positioned at the right abutment. The upstream plinth from where the grout curtain is injected is positioned all along the bottom perimeter.

Design by EDF-CIH is based on an RCC mix of the low cementitious content type and fines. A 0.5m thick upstream layer of enriched vibrated RCC has the purpose of making the process of forming the upstream face easier. On top of the enriched vibrated RCC layer, an exposed drained geomembrane sealing system provides watertightness to the dam. The barrier system covers the entire upstream face, with the exclusion of the concrete intake tower, from crest down to the plinth.

An international tender awarded the construction of the dam to Zagope Construçoes & Ingenharia and the installation of the geomembrane system to Carpi Tech, who also holds the patent of the tensioning system adopted. RSW International is the Engineer, Socotec provides the technical assistance to the owner.

1.2 Precedents of the Selected Geomembrane System

The selected system is an evolution of the geomembrane system developed and used since the 1950s in Europe both for concrete and embankment dams. First adopted in 1990 at Riou RCC dam in France, it accounts at present for 14 successful applications in 11 countries, as listed in Table 1. The climatic conditions in which it has been applied are quite different, ranging from humid equatorial climates (Colombia), to very cold climates with temperatures down to -50°C and high temperature excursion (Mongolia). At present it holds the record for the highest RCC dam in the world with a waterproofing geomembrane (Miel I, Colombia, 188 m) and for the highest RCC dam in USA (Olivenhain, 97 m). The geomembrane adopted at Boussiaba is the same used in covered position on 8 large RCC dams in Australia and USA, also listed in Table 1. Both exposed and covered geomembrane systems in RCC dams are widely discussed in international literature up to date (Scuero and Vaschetti 2008).

Table 1. PVC geomembrane systems on RCC dams (in chronological order).

Dam	Country	Year	Geomembrane is
Boussiaba	Algeria	2009	Exposed
Meander	Australia	2007	Exposed
Taishir	Mongolia	2007	Exposed
Elkwater Fork	USA	2007	Covered
Hickory Log	USA	2007	Covered
Blalock	USA	2007	Covered
Eidsvold Main Weir[1]	Australia	2004	Exposed
Burnett River (Paradise)	Australia	2004	Covered
Olivenhain	USA	2003	Exposed
Mujib	Jordan	2003	Exposed
Miel I	Colombia	2002	Exposed
Platanovryssi[2]	Greece	2002	Exposed
Hunting Run	USA	2001	Covered
Hughes River	USA	2001	Covered
Dona Francisca[2]	Brazil	2000	Exposed
Porce II[1]	Colombia	2000	Exposed
Balambano	Indonesia	1999	Exposed
Platanovryssi[1]	Greece	1998	Exposed
Buckhorn	USA	1998	Covered
Penn Forest	USA	1998	Covered
Nacaome	Honduras	1995	Exposed
Concepcion	Honduras	1991	Exposed
Riou	France	1990	Exposed

[1]waterproofing of contraction joints
[2]waterproofing of cracks

The same exposed geomembrane system has been installed as a rehabilitation measure since 1976 on 55 large dams of all types (ICOLD 2009).

Using a geomembrane system in an RCC dam allows taking advantage of the doubtless benefits that a low cementitious content RCC mix can provide. As reported by Tarbox et al. I(2005), the advantages of exposed drained geomembrane systems in RCC dams are related to seepage reduction that can be significantly below the expected design values, to the reduction of the internal uplift pressure, to the added simplification of construction, with associated schedule and cost benefits, and to seismic performance.

2. THE EXPOSED GEOMEMBRANE BARRIER SYSTEM

2.1 Waterproofing Liner

The waterproofing liner is a geocomposite consisting of a 2.5mm thick PVC geomembrane coupled during fabrication to a 500g/m^2 anti-puncturing geotextile. The cover strips waterproofing the tensioning profiles consist of a 2.5mm thick PVC geomembrane of the same material forming the geocomposite, but without geotextile. The formulation of the geomembrane has been engineered to resist the local conditions.

The geosynthetics were manufactured in Italy under ISO 9001 certification. The specified characteristics were tested in the internal laboratory of the manufacturers. In addition to the Quality Control testing made by the manufacturers, the selected geosynthetics have been tested in the Geo Laboratory at CESI in Milano, Italy, for all properties prescribed by tender specifications, including the physical tests (nominal thickness, density, and mass per unit area), the mechanical tests (tensile, tear, puncture, and hydrostatic pressure), and the durability tests (flexibility at low temperature, dimensional stability, thermal ageing in water, and UV resistance). In particular, it is important to emphasize the very good results obtained in terms of UV resistance behaviour: in fact, no practical variation of the tensile properties was registered after laboratory testing.

2.2 Face Anchorage

To anchor the PVC geocomposite against wind and waves uplift, a well known patented tensioning profiles assembly has been selected. The tensioning system has been adopted because of its capability to avoid formation of slack areas and folds, which are zones of concentration of stresses that can be prejudicial to the durability of geomembranes.

The tensioning system consists of two steel profiles. The first profile, U shaped, is fastened to the upstream face of the dam and is then covered by the PVC geocomposite; the second profile, Ω shaped, is placed over the PVC geocomposite and is then fastened to the first profile by a special connector. The geometry of the two profiles forces the PVC geocomposite clamped between them into a position that achieves tensioning.

In RCC dams, there are two possible configurations for the U profile that is fastened to the upstream face: the profile can be can be installed when the upstream face has been completed (external U profile, as pictured at left in Figure 1), or it can be embedded by the main contractor in the dam face as it is being constructed (embedded U profile, at right in Figure 1).

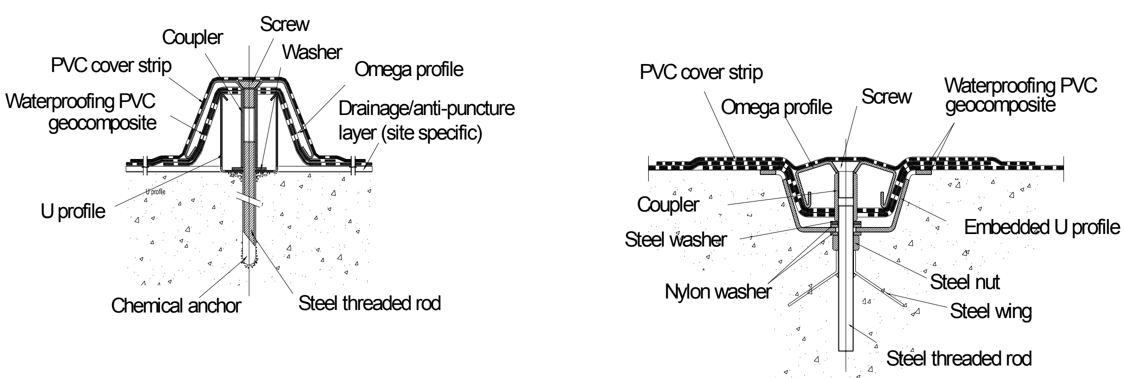


Figure 1. The two possible configurations of the tensioning system in RCC dams.

The two options are technically equivalent. In the external configuration the time for installation of the entire waterproofing system is under the full control and responsibility of waterproofing contractor, it is less dependent on the skills and production rate of the main contractor, and less quality control on the civil works is required. In the embedded configuration the time for embedding the U profiles may be subject to uncertainties: if the main contractor embeds the profiles in the RCC in a proper way the total time for installation of the entire waterproofing system may be lower, but if on the contrary the profiles are not embedded in a proper way, additional time and cost may be needed to make the necessary corrective actions.

The configuration with external U profiles (see left part of Figure 1) was selected for Boussiaba. The spacing between adjacent lines of profiles, calculated based on foreseen local conditions, is 5.7m.

2.3 Drainage System

EDF-CIH designed a drained system with a face drainage layer, a bottom longitudinal collector and six separate drainage compartments. The face drainage layer consists of a drainage geonet having hydraulic flow rate of 0.41l/m/s with a gradient of 1 and σ_v = 500kPa. The waterproofing contractor proposed to modify the bottom collector taking advantage of the characteristics of geosynthetics: instead of the embedded box drain foreseen by the original design, a 1m high strip of drainage geonet, of the same type of the one constituting the drainage layer, was placed along the bottom perimeter of the waterproofing system, as a second geonet layer. This modification was accepted as it simplified construction because the only embedment required was related to the six transverse pipes.

Also the face anchorage system developed by the waterproofing contractor allowed improving the efficiency of the drainage system. The tensioning profiles forming parallel vertical box drains at 5.7m spacing are an extremely efficient and high-capacity system to collect water intercepted by the drainage geonet and to convey it to the bottom collector. No seepage water will thus enter the lifts between joints, no increase in uplift will be possible, and the safety of the dam will be safeguarded.

The six compartments discharge into the gallery by means of six transverse discharge pipes. Where the elevation of the gallery is lower than the elevation of the transverse pipe, sub-vertical holes are drilled to reach the gallery. A stainless steel drainage plate is placed in front of each pipe, to avoid that the PVC geocomposite intrudes in the pipe under the water head.

Seepage or condensation water will travel by gravity in the drainage geonet layer and in the vertical tensioning profiles, will reach the longitudinal drainage geonet band and from there the transverse pipes to the gallery. The drainage system will allow monitoring the efficiency of the synthetic liner by measuring the drained flow in each of the six compartments.

On the lowest part of the dam, the excavation of the foundation rock reached elevation 26m and, due to the fact that the inspection gallery invert is higher, there is a small portion of the upstream waterproofed surface which is not possible to drain. This situation will not affect the functionality of the waterproofing system because the lowest part of the reservoir from elevation of the bottom outlet (40m) to elevation 26m will be always submerged.

2.4 Perimeter Sealing

Watertight perimeter seal is made at the boundaries of the lined area, to impede water infiltration behind the waterproofing liner. At the boundaries that can be submerged, that is along the plinth, the spillway, and at the sides of the intake tower, the seal is watertight against water in pressure and is made by stainless steel flat batten strips, 80 x 8mm, fastened to the concrete by stainless steel anchor rods embedded in chemical anchors placed at 0.15m spacing. Bedding resin mortar, rubber gaskets and splice plates provide the adequate distribution of stresses that is necessary to achieve watertightness.

At crest, the seal is watertight against rain and is made by stainless steel flat batten strips, 50 x 3mm, fastened to the concrete by impact anchors at 0.20m spacing.

3. INSTALLATION UP TO DATE OF PRESENTATION OF PAPER

Boussiaba dam is being constructed in blocks starting from the left abutment. Installation of the waterproofing system is being carried out following the availability of the surface from the main contractor. The waterproofing system has been installed up to date only on the left abutment, which was completed in January 2009. The spillway section should be completed within the first half of March and installation of the waterproofing system should be resumed on March 20 2009. The completion of the waterproofing system, for a total of 8315 m^2, is expected in summer 2009.

Installation was carried out by crews working from three travelling platforms and performing tasks in succession. One crew prepared the surface, the second crew installed the U profiles, the geonet and the geocomposite, and the third crew installed and waterproofed the omega profiles. The bottom seal was executed working on the plinth, after the previous operations had been completed. The last days were dedicated to the preparation of the surface for the interruption of works.

The crews started positioning the installation platforms on January 22 2009. Installation of the waterproofing system on the entire left abutment (from tensioning profiles 1 to tensioning profiles 17), for a total of about 1800 m^2, was carried out in 21 days including 5 complete days of bad weather. The crews demobilised on February 12 2009.

3.1 Surface Preparation

Preparation consisted in cleaning of the finished enriched vibrated RCC surface, in inspection of the cleaned surface, and in some local repair with cement mortar. These works were executed by the main contractor under the instruction and supervision of the waterproofing contractor.

While the main contractor was performing local repair in the left section of the left abutment, the waterproofing crews started installing the geomembrane system on the right part that did not require civil works.

3.2 Drainage System

After drilling the holes and positioning the pipes for drainage discharge, the crews have placed the U profiles that form the vertical drains on the face of the dam, the geonet in the space between the profiles, and the additional band of geonet as longitudinal collector at the heel of the dam.

Figures 2 and 3. Placement of the geonet on the upstream face between adjacent anchorage profiles, and the additional band of drainage geonet acting as longitudinal collector at heel.

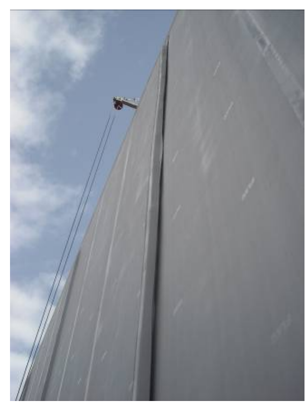
3.3 Placement and Anchorage of the Waterproofing Liner

Placement of the PVC geocomposite started on January the 30th. The PVC geocomposite, produced in 2.10 m wide rolled sheets, has been deployed from the crest and temporarily anchored at top. The top seal is at elevation 79.50m on the abutments, and at elevation 70m in the spillway section. The geocomposite lines the dam on its entire height, down to the plinth.

Joining of adjacent sheets has been made by watertight heat welding, with manual one track welding machines. All welds exposed to the water have been checked on their entire length according to the mechanical point stressing method of ASTM standard D 4437.

Figures 4 and 5. Placement and welding of the geocomposite sheets.

The PVC geocomposite has been punctured over the threaded rods anchoring the U profile, to expose the rods and allow coupling the tensioning profiles. The Ω profiles. have been placed over the punctured holes, and the connection with the U profiles has been made. Lastly, the Ω profiles have been waterproofed with PVC geomembrane cover strips.

Figures 6 and 7. Placement of the Ω profiles on the punctured PVC geocomposite, and the PVC geomembrane cover strip waterproofing the profiles.

3.4 Perimeter Sealing

The top perimeter seals have been completed over the entire waterproofed area, following placement and welding of the PVC geocomposite sheets. The bottom perimeter seal on the plinth has been executed as last task of the waterproofing works.

The main contractor requested to stop the perimeter seal at the twelfth tensioning profile, to allow treating a crack on the plinth. A temporary fixation has been placed along the remaining part of the plinth, from profile 12 to profile 17, to provide a seal watertight against rain and wind until waterproofing works are resumed in March 2009.

Figures 8 and 9. At left, the components of the watertight seals: bedding resin, PVC geocomposite, rubber gasket, stainless steel splice plate, stainless steel batten strip. At right, the watertight bottom an side sea, and the top seal, at the end of the left abutment.

To protect the installed waterproofing system seal from wind gusts until installation is resumed, the external tensioning profiles have been put in place at the last tensioning line facing the spillway (profiles 17).

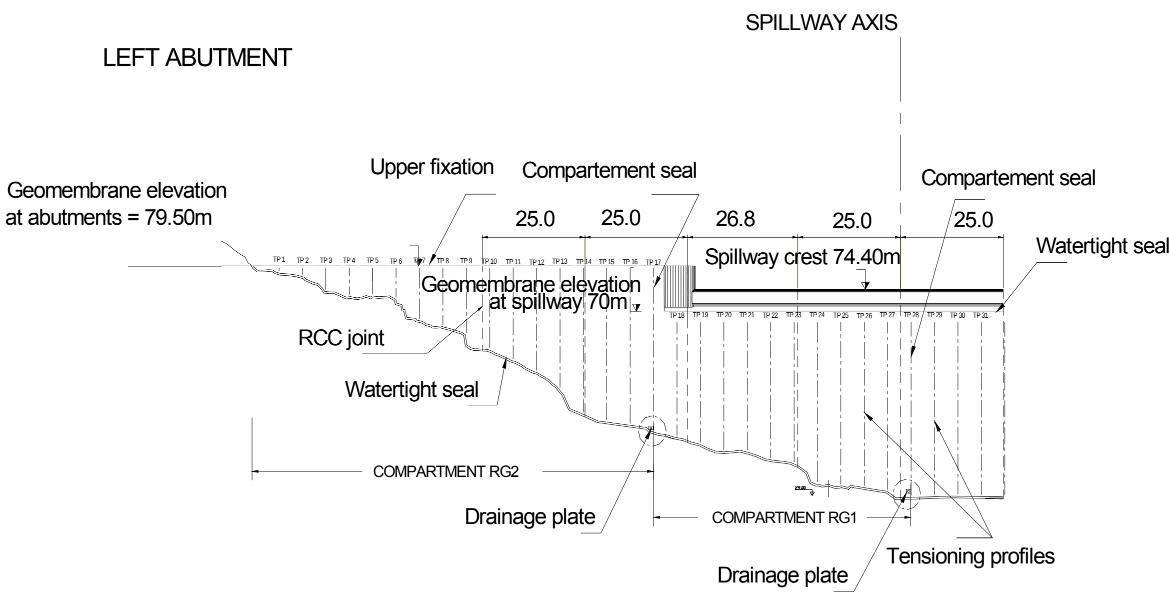


Figure 10. At the time of preparation of the paper the waterproofing system has been installed from the end of the left abutment to profile 17 (compartment seal at left of spillway).

4. CONCLUSIONS

The use of geosynthetics as adopted in the final design has achieved the objectives of simplifying the construction of the dam and of its waterproofing system. The external U profiles configuration has allowed carrying out waterproofing works without affecting the construction works that were ongoing at spillway, has reduced construction constraints and quality control, and has kept installation times and costs within those announced.

The waterproofing works on the left abutment have been completed on schedule, notwithstanding more than 20% days of bad weather. It is foreseen that the complete installation of the waterproofing system will be achieved in the foreseen times.

Figure 11. Boussiaba dam at completion of waterproofing works on the left abutment, while construction is ongoing at spillway.

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