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# WATERPROOFING BY A BITUMINOUS GEOMEMBRANE OF THE RIBEROLE RESERVOIR AT 1625 M. ALTITUDE

# DICHTUNG DES RIBEROLE SPEICHERS IN 1625 m HÖHE MIT EINER BITUMINÖSEN GEOMEMBRANE

# L'ETANCHEITE PAR UNE GEOMEMBRANE BITUMINEUSE DU BASSIN DE LA RIBEROLE A 1625 m D'ALTITUDE

The storage reservoir of the Riberole hydro-electric mini powerstation (Eastern Pyrenees) has the following waterproofing system :
- a reinforced bituminous geomembrane Coletanche NTP 2
- an anti-punch geotextile
- a blanket of material extracted from the site
- a rockfill in the wave action zone.

This system is :
- very longlasting under the service conditions of a reservoir located at 1 625 m altitude, covered with ice in winter, having a daily drawdown range of 3 to 4 m and possible fall of boulders into the basin,
- capable of supporting the circulation of the vehicles used for taking away the gravels that will accumulate in the basin during service,
- cheap to lay, considering the difficult access conditions of the site.

## 1. HYDROELECTRIC EQUIPMENT OF THE VALLEY OT THE TET

The "Societe Hydro-Electrique du Midi (SHEM)"subsidiary owned 80 % by the SNCF obtained in 1965 the concession for the project and operating of one hydro electric power station to complement the French National Railway (SNCF) ones on the Tet river (Eastern Pyrénées). More recently in 1982 SHEM was authorised to equip the Riberole, a tributary of the Tet. An intake on the Riberole brings the waters to the direct supply reservoir of a mini power station located at Prats-Balaguer on the right bank of the Tet at 10 km from Mont Louis and upstream from the Fontpedrouse power station intake structure (Figure 1).
The following lines examine the project for this mini power station using the waters of the Riberole and especially the waterproofing of its reservoir.
This provides for the generation of electricity at peak hours especially in the spring time (table 1).
Very often the water will have to be stored before use.
Note that the valley of the Tet from Prades to Mont Louis contains a 1 metre gauge electric railway line some of whose constructive works built by Sejourné at the end of the 19th century are outstanding for their beauty and daring.

## 2. RIBEROLE SCHEME

This scheme consists of :
2,1 - A main intake located at level 1632 NGF (scheduled flow rate 0.84 m3/s) comprising :
- the intake structures (screens, top sluice, desilter),
- a system regulating the flow rate whatever the water level,
- two auxiliary intake structures on two small adjacent streams, level 1635 NGF.

2,2 - A dia. 0.80 m metal pipe buried in the forest and conveying the water to the reservoir located on the Aumet plateau.
2,3 - The water reservoir located at level 1625 NGF, useful volume 20,000 $m^3$ with its accessoiries (bottom outlet, 8 m3/s spillway and an intake structure protected by a screen).
2,4 - a dia. 0.75 m metal pipe conveying the water from the reservoir to the power station. On its route a water point supplies water for irrigation. This penstock, is also buried.
2,5 - The Power Station. The power station whose concrete structure building with hollow brick walls has an area of 100 m2 and a height of 15 m consists of :
- a single jet and horizontal axis Pelton turbine (flow rate 0.8 m3/s waterfall height 432 m, 375 rpm), power 3,000 kW.
- a Jeumont alternator with 10 to 20 kV step-up, a circuit breaker and auxiliary services designed for the safety and monitoring of the generator.

This station is operated automatically with no human intervention, maintenance being provided by the staff of the nearby Cassagne power station. The turbined water is rejected into the Riberole river where it flows into the Tet.

## 3. STUDY OF THE RESERVOIR

### 3,1 - Characteristics

This reservoir accumulates the water from the stream and restores it at constant flow rate during periods in which the electricity must be produced. The volume stored is 20,000 m3 and the surface in contact with the water, which must therefore be waterproof, is 12,000 m2 (8,000 for the apron and 4,000 for the banks).

Table 1 : Riberole monthly flow in m3/s (August 1981 Study)

| Month | January | February | March | April | May | June | July | August | Septemb. | October | Novemb. | Decemb. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Flow | 0.1 | 0.13 | 0.5 | 1 | 2.6 | 2.4 | 0.9 | 0.35 | 0.35 | 0.35 | 0.35 | 0.35 |

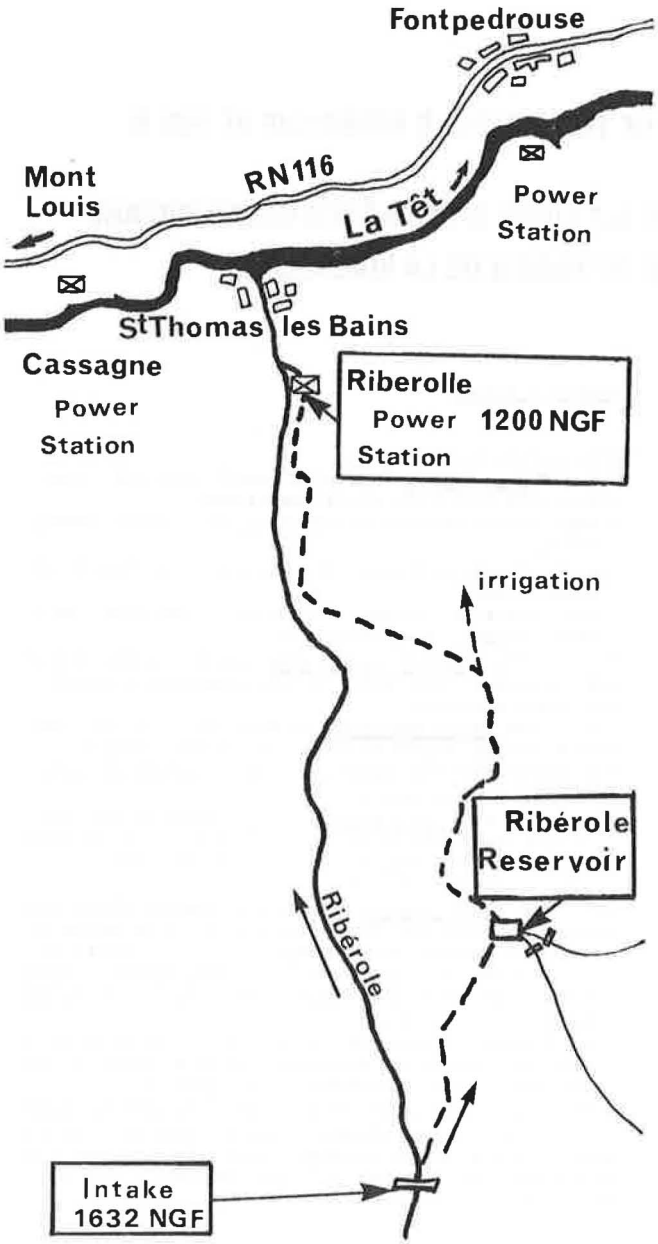



Figure 1 - Location of the Riberole reservoir

The required waterproofing must therefore meet the following characteristics :
- be waterproof (permeability $\ll 10^{-6}$ m/s)
- be very longlasting in operating conditions at an altitude of 1625 m, i.e. resistant to freezing, sun ice, daily drawdown, tearing, and possible fall of boulders into the basin,
- be capable of supporting the circulation of the trucks used for taking away the gravels that will accumulate in the basin during service,
- be cheap and easy to lay and to maintain considering the difficult access conditions of the site.

3.2 - Feasibility Study

This study was performed prior to the works by the company FTM (FONDATIONS & TRAVAUX MINIERS) with a view to :
- defining the nature of the soils in line with the dike and the basin
- characterizing the rocky substratum
- calculating the permeability of the soil
- knowing whether the ground was suited to the construction of the basin.

It commenced by making four core-drills 10 to 30 m deep two of which were equipped with piezometers. After being drilled "Lefranc" type water injection tests were made.

All these measurements produce the following results

Geology : the subsoil contains (Figure 2) :
- surface formations consisting of rocky elements of variable diameter (agglomerated sands, gravel, pebbles) bond by 30 to 70 % of clay matter. These aggregates come from the stream's slopes and silt deposits ;
- a rocky substratum of rich micaceous gray schists and seams of quartz to be found around-5 metres. The schists are inclined 50 to 70° to the horizontal.

Physical state : the rocks are intensively fractured.

Very high permeability of the soils : water circulations are observed on the surface and down several metres, fed by the stream, whose upper level oscillates between the surface and less than 1 metre, then in depth at the level of the rock, water circulation exist in the fractures. Thus the soils and rock are highly permeable (respectively $K = 5 \times 10^{-4}$ and $10^{-3}$ m/s), the permeability increasing with the depth.

Workability of the soils : these are loose over 5 m depth with a small percentage of clay : they are therefore easy to move so that traditional civil engineering equipment can be used (shovels, bulldozers).

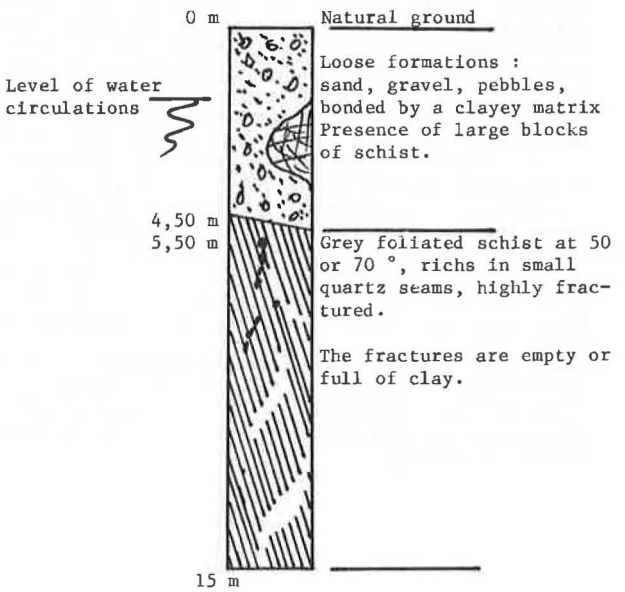



Figure 2 - Cross section of soil at the basin location

3.3 - Recommendations

These results produce the following recommendations
- the earthworks and dikes (core in clayey material with schist rip-rap) will be easy to build;
- in the absence of clay of sufficient quality it will be necessary to apply a waterproof sheet onto the 12,000 m2 surface of the basin.
- a land drainage network will be installed on the bottom of the reservoir to collect the water circulation. The drainage collector will go through the dike into a downstream pond, from where the collected waters will be pumped back into the reservoir. In wet periods of the year the throughput of water in the drain may reach 50 l/s.

## 4. CHOICE OF WATERPROOFING SYSTEM

Different types of waterproofing systems are available : FTM recommended a bituminous geomembrane applied in situe with two or three layers of 3 to 5 kg/m2 each of Shell Mexphalte SM3 bitumen sprayed at 180 °C onto a polyester geotextile. A bituminous geomembrane (delivered from the works or made in situ) offers the following intrinsic advantages :
- resistance to water which does not impair bitumen
- maintenance of the flexibility of the geomembrane when exposed to ultraviolet rays
- resistance to microorganisms and most chemicals,
- capacity to match the movements of the soil
- stability versus cold or hot temperatures
- very high mechanical resistance
- welding, fitting and repairs easy
- no folds in the laying thus facilitating welding operations (in case of geomembrane delivered in rolls from works).

There are numerous references covering bituminous waterproofing : without going as far as reminding the structures in Mesopotamia over 30 centuries old, and still visible today, the reinforced bituminous geomembranes produced in situ or manufactured in a plant (more than 2 million m2 in France in the past 10 years) have considerably developed. In particular the application of these geomembranes to the Avoriaz water basin in the French Alps with similar dimensions and at the same altitude as the Riberole reservoir was a highly instructive precedent.
Nevertheless after a thorough study it was decided to apply a prefabricated reinforced bituminous geomembrane rather than the reinforced bituminous geomembrane prepared in situ. In fact the application in situ of hot bitumen depends on atmospheric conditions : now the climate in the Eastern Pyrenees is featured by very heavy rainfalls in altitude : heavy daily storms are frequent in the fine season which should be chosen for these works in the mountains.

## 5. CHARACTERISTICS OF THE SELECTED WATERPROOFING SYSTEM

The reinforced bituminous geomembrane must naturally be covered with a protective layer of earth so as to be :
- protected against accidental impacts, dropping of stones, movements of ice and also against ageing due to the sunshine ;
- weighted so as to withstand the underpressures observed on the spot ;
- insentitive to turbulence of the water and action of ferreting animals ;
- open to traffic to allow the passing of machines and trucks required to clean and maintain the basin.

5.1 - Waterproofing Support

The surface supporting the waterproofing system is stripped if required to remove the vegetable earth, graded roughly rounding off the differences in level and reducing the sharp edges, then compacted.

5.2 - Structure of the Waterproofing System

This consists of :
- a Coletanche type NTP 2 reinforced bituminous geomembrane 3.9 mm thick
- a Geofelt MT 500 geotextile 5 mm thick, protecting the membrane against punching by the stones of the overlaying embankment
- a 50 cm thick fill extracted locally, and covered on the facing of the dike and the bank slopes by a 100/400 mm schist rip-rap.

5,3 - Prefabricated Reinforced bituminous geomembrane

These Coletanche prefabricated geomembranes produced in a plant in strips 4 m wide, are highly homogeneous. Their composition, starting from the bottom side is as follows :
- a perforation-proof film to avoid the possible rising of vegetation through the geomembrane. This film may be surmounted by a fibre glass fabric,
- a polyester geotextile impregnated and coated with a 100/40 fillerised bitumen containing a percentage of $<$ 0.1 mm filler not over 25 %
- sand layer on the top of the geomembrane to protect the bitumen from sunshine and reduce the sticking,
- an anti-adherence film.

Table 2 shows the characteristics of the Coletanche NTP 2 geomembrane applied.
From reading this table it is clear that the Coletanche NTP 2 has qualities perfectly suited to the Riberole site :
- high tensile strength in all directions
- considerable elongation at break
- perfect waterproofing ($K < 10^{-13}$ m/s)
- high resistance to tearing, punching and cracking
- excellent resistance to ageing, to creeping on slope, to natural agents (sun, ozone, cold, vegetation)
- easy to apply, to weld thus giving reliable joints.

5,4 - Geofelt geotextile

The Geofelt MT 500 is an antipunch geotextile composed of 400 g/m2 of 100 % polypropylene fibres of 50 mm long spunbonded onto a 100 g/m2 woven polypropylene reinforcing fabric.

Table 2 - Prefabricated Reinforced Bituminous Geomembrane COLETANCHE NTP 2

| | | |
|---|---|---|
| Mass per unit area | (kg/m2) | 4.5 |
| Thickness | (mm) | 3.9 |
| Roll length | (m ) | 80 |
| Traction test NFG 07001 20 °C - Vitesse 1.6 mm/s | | |
| - Force per unit width at failure | (kN/m) | |
| Length direction | | 20 |
| Width direction | | 15 |
| - Elongation at failure in | (%) | |
| Length direction | | 35 to 45 |
| Width direction | | 35 to 45 |
| Permeability coefficient K | | |
| Water Pressure | (kPa) | K (m/s) |
| 50 | | $8.5\ 10^{-14}$ |
| 100 | | $7.4\ 10^{-14}$ |
| 250 | | $2.7\ 10^{-14}$ |
| 500 | | $1.3\ 10^{-14}$ |
| 750 | | $9.8\ 10^{-15}$ |

Geofelt MT 500 has the following characteristics :
- punch-proof : by protecting the underlaying geomembrane against the sharp edges of the aggregates of the embankment up to pressures of 1300 kPa thus higher than the inflation of heavy vehicle tires
- rot-proof and resisting most chemicals
- mechanical qualities : the Geofelt MT 500, in the NFG 07001 traction test offers a breaking strength
  . in the lengthwise direction of 10 k N/m dry and
  . 9.6 k N/m wetted
  . in the transverse direction of 8 k N/m dry and 7 kN/m wetted.

  The elongation at break is 50 % in the production or transverse direction, so that high continuous or momentary localized loads are distributed.
- compressibility : owing to its thickness, the strength and elongation possibilities of the support, this geotextile absorbs impacts and distributes local or widespread strains
- easy to handle : it is supplied in rolls 50 m long and 2 m wide weighing only 48 kg : easy to install by unwinding, cheap to purchase, transport and install.

5,5 - Protective Embankment

In view of the intrinsic qualities of the Coletanche NTP 2 and the Geofelt MT 500 the embankment does not have any special qualities. It uses the ungraded earth found locally and will be covered along the dike and on the slopes by a rip-rap (100-400 mm local schist rock). A punch test was carried out on the site by unloading the embankment material onto the Coletanche geomembrane protected by the Geofelt geotextile and making a ramp of increasing thickness from 0.05 m to 0.50 m supporting the load of a truck (View 1).
This trial showed no punching of the geomembrane as soon as the thickness of the embankment reaches 0.10 m. To take a safety factor the thickness of the embankment applied will be 0.5 m. This embankment will be compacted in full thickness before the application of the rip-rap.

## 6. DESCRIPTION OF THE WORKS

6,1 - The main earthworks and construction of the dike were to a great extent completed during the fine season of 1983. They only required very standard equipment (3 axle trucks with 15 000 kg load, crawler shovels, loaders, bulldozers and single roller compactors).
The body of the dike (Figure 2) was built in ungraded clayey material with successive compacted passes. It is protected, downstream side, by a rock fill with a 2/1 slope and upstream, by the geomembrane covered with the geotextile and the protective embankment and rock fill.
The works required to install the waterproofing and the finishing were performed in a very short term (a few weeks in the summer of 1984).
6,2 - The Coletanche NTP 2 supplied from the works in rolls 4 m wide and 80 m long (weight 1500 kg) is easy to apply : the rolls are unwound by a hydraulic shovel equipped with a reel, resulting in a high rate of application. The joints are obtained by overlapping the sheets to at least 0.20 m and bonding them together by heating the bitumen with a blow torch (View 2).
6,3 - The very light Geofelt geotextile is easily unwound, being 2 m wide and 50 m long, with also an overlap of 0.20 m over the adjacent strip.

View 1 - Punching trial

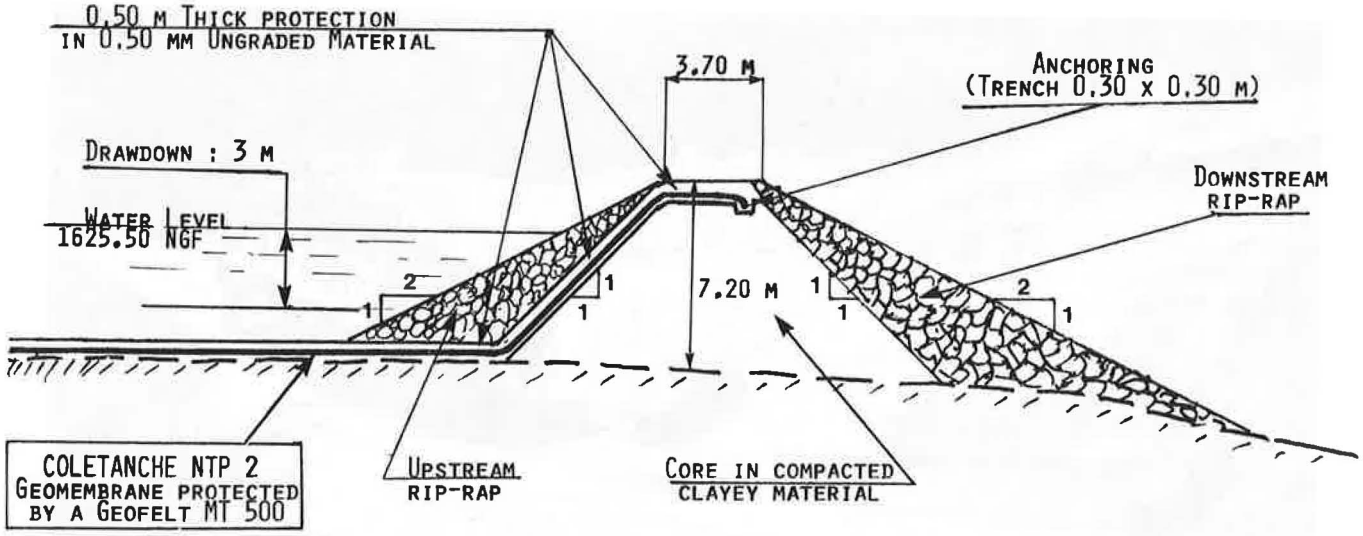
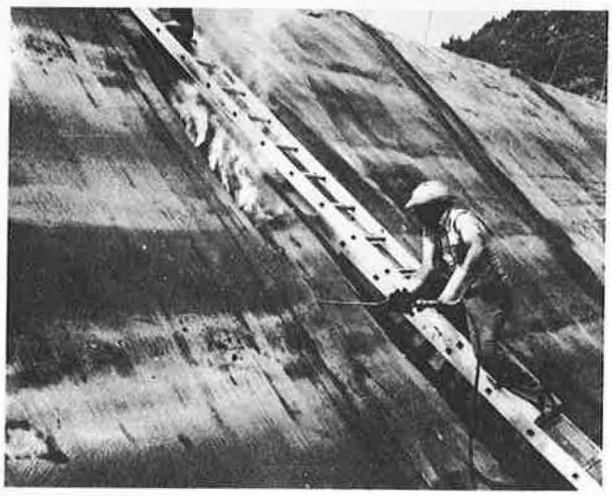



Figure 2 - Cross section of the Riberole reservoir dike

6,4 - The application of the ungraded embankment material offers no difficulties : it is unloaded in front of the wheels of the trucks (View 3), installed to a thickness of 0.50 m and compacted before the possible application of rock fill to the slopes. View 4 shows the reservoir before the waterfilling, which was carried out in 1985 with no problem.

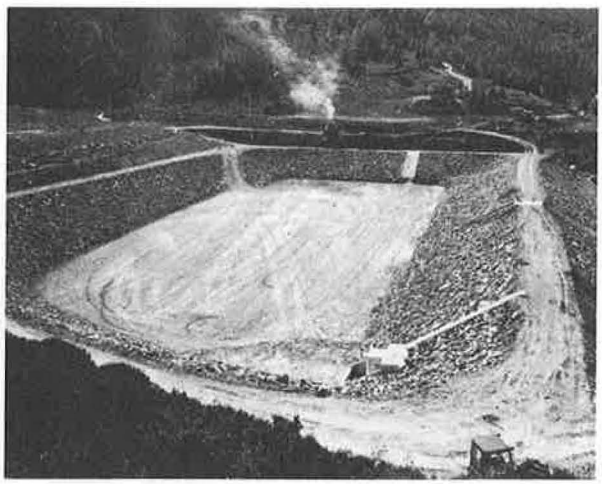
## 7. CONCLUSION

The waterproofing system applied to the reservoir of the Riberole mino-power station, consisting of a bituminous geomembrane protected by a geotextile and an embankment, provides an effective answer to the criteria imposed. It is interesting to stress the fact that the works required to install this waterproofing were performed economically, in a very short time and on a site at altitude, certainly highly enchanting and touristic, but very rainy and with difficult access.
These works, which are one of the numerous references ot the Coletanche prefabricated reinforced bituminous geomembrane is, owing to the special difficulties encountered, amongst the most original and interesting ones.



View 2 - Welding of two geomembrane strips on the dike

View 3 - Application of the antipunch geotextile on the geomembrane and delivery of the embankment material



View 4 - Riberole reservoir before water filling