A record height in dam waterproofing with bituminous geomembrane: La Galaube dam on Alzeau river.

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ABSTRACT: A bituminous geomembrane was used in 2000 for the construction of the upstream waterproofing face of La Galaube dam on Alzeau river in the south of France. This paper will describe the different phases of the project, the specific techniques and equipment that were required to carry out in a short time the construction of 23.000 square meters of impervious structure, and will insist on the quality management that was applied to achieve a record height for upstream impervious face based upon a bituminous geomembrane.

1 THE ORIGINS OF THE PROJECT

Already envisaged before 1680 by Pierre Paul Riquet, Designer and Engineer of the "Canal du Midi", the dam of La Galaube completes the hydraulic system of the Montagne Noire area, above the city of Carcassonne in the south of France.

This system, which already includes the dams of Saint Ferréol, Lampy, and Cammazes builds up a storage capacity of more than 35 million cubic meters, in order to supply drinkable and irrigation water within three departments of the south of France, Aude, Haute-Garonne and Tarn, and regulate the flow of the Canal du Midi.

This project of a dam on the Alzeau river was once again studied in 1940, but it's only in 1990 that the Interdepartmental Office for Hydraulic Equipment of the Montagne Noire, in charge of production and distribution of drinkable and irrigation water for 185 municipalities, made up the decision of building the dam of La Galaube.

This dam will have a capacity of 8 million cubic meters and the lake will cover an area of 68 hectares, at an altitude of more than 700 metres.

The amount of the whole project is higher than 100 million French Francs, i.e. 15 million Euros.

2 DESCRIPTION OF THE PROJECT

2.1 *General presentation*

Design and supervision of works for this project were carried out by two Consulting Engineers I.S.L. and B.R.L..

A technical solution based on a rockfill embankment with an upstream geomembrane waterproofing was selected. The stability of the dam is ensured by the weight of the rocks, which consist in about 800,000 cubic meters of micaschistes excavated on the site. The embankment is based upstream on a reinforced concrete plinth, founded on fresh or slightly weathered granite.

The dam is 380 meter long at its ridge and the slopes have a gradient of 2 horizontal to 1 vertical, i.e. an angle of about 26°. The maximum height above the foundations is 43 metres.

The dam waterproofing is prolonged inside the foundation by an injection wall through the upstream plinth.

In addition, the project includes:

- a side spillway able to sustain a flow of 80 cubic meters per second
- an upstream intake tower,
- an under-embankment tunnel, including an hydraulic tunnel and a monitoring tunnel,
- a downstream outlet structure.

Construction works were divided into 4 independent contracts:

- earthworks and civil engineering,
- grouting,
- equipment,
- upstream waterproofing face,

COLAS Midi Méditerranée teams were awarded the contract for upstream waterproofing face construction, which began in July 2000, with 23,000 square meters to be waterproofed.

2.2 *Cross section of the waterproofing structure*

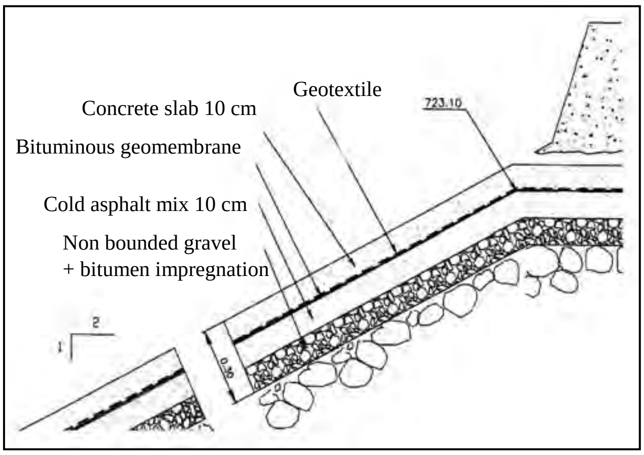

Figure 1. Typical cross-section of the water-proofing structure

The upstream waterproofing structure consists in:

- a 10 cm layer of non bounded material, with a 0/20 mm grading, impregnated with bitumen emulsion,
- a 10 cm layer of cold asphalt mix, with a 0/10 mm grading,
- a bituminous geomembrane,
- a 10 cm layer fibrous concrete laid upon a geotextile.

3 THE PREPARATORY WORKS

3.1 *Compaction of the slope*

First of all, the upstream slope was compacted with two 4 tons static rollers.

Those compactors, specially designed and manufactured by the equipment division of the company were pulled from the dam crest by two hydraulic excavators equipped with winches.

3.2 *Non bounded material*

Then a layer of non-bounded material, with a 0/20 mm grading was laid, with a minimum thickness of 20 cm. The purpose of this layer is to regulate the surface of the slope and close it before the next layer. Therefore, 5,000 tons of limestone crushed material were hauled by trailers form the Saint-Amancet quarry.

Once stored and humidified, the gravel material was carried by dumpers, which unloaded it from the crest along the slope.

Laying and fine grading was then carried out with 2 bulldozers.

Figure 2. Laying the 0/20 non-bounded gravel as first layer of the waterproofing structure

They were guided by a rotating laser, which beam was parallel to the theoretical plane of the upstream face. The bulldozers were equipped with sensors, which indicated to the drivers the position of their blade compared to the theoretical one, and guided them into a fine trimming.

Compaction was followed by a permanent check of densities through measurements with gamma-densimeters.

Areas that could not be reached by 4 tons rollers, mainly around the foot of the intake tower were compacted by a vibrating plate mounted on a hydraulic excavator.

3.3 *Bitumen emulsion impregnation*

An impregnation layer with bitumen emulsion was then hand-spread, with a rate of 1.5 kg per square meter. In some areas, flexible hoses between the emulsion storage on the crest and the spraying head were more than 100 meter long.

3.4 *Cold asphalt mix*

The next layer is then a 10 cm thick cold asphalt mix, with a 0/10 cm grading, which main purposes are to

- Ensure the fine trimming of the upstream face before laying the geomembrane,
- Build up semi-impervious layer that will reduce leakage flow through the waterproofing structure in case of tears of the geomembrane, or if the storage happened to be accidentally flooded as it happened in 1996 on another dam waterproofed by the company in Corsica.[Hyunh et al., 1998], [Tisserand et al., 1997].

A specific laboratory study was carried out to define the recipe of the asphalt cold mix, in order to reach a permeability around 10^{-6} m/s, with a specific care to the controlled breaking behaviour of the emulsion, so that the cold asphalt mix maniability was ensured throughout the laying and compaction phases.

This study allowed establishing a correlation between asphalt density and permeability. Therefore, laboratory tests carried out on site that included compliance of the aggregates with the defined grading curve, asphalt content and in-situ densities allowed to reach the desired permeability.

5,000 tons of cold asphalt mix were manufactured on site with a 200 tons per hour mixing plant. Three gradation cut-offs 0/2, 2/6 and 6/10 coming from the same limestone quarry were used.

Figure 3. Compaction on the slopes by specially designed equipment

Laying conditions were similar to the non-bounded materials, except for the compactors, which needed to always keep their drums wet, to avoid sticking to the asphalt mix.

An accuracy of plus or minus 2 cm could be reached at the end of this stage.

4 WATERPROOFING BY REINFORCED BITUMINOUS GEOMEMBRANE

4.1 *The bituminous geomembrane*

A COLETANCHE NTP 3 bituminous geomembrane, with a mass per unit area of 5.5 kg/m², and a 5 mm thickness was used. This geomembrane is manufactured by COLAS in its Galway plant in Ireland, in 5.15 meter wide rolls.

As no transversal welds could be accepted along the slope, it was therefore required to manufacture each individual roll with respect to its final position. Some of the rolls were longer than 100 meters, with a weight above 3 tons.

Among the properties of this geomembrane, which is based upon a non-woven polyester geotextile impregnated with 100/40 blown bitumen, one can notice:

- A high tensile strength in both directions (28 KN/m in longitudinal direction, 20 in transverse direction, together with more than 70 % deformation at break, according to French standard NF P 84.501)
- A high resistance to punching (500 N according to French standard NF P 84.507)
- A good ageing behaviour based on more than 20-year-old references, including the field of dam waterproofing. [Bianchi et al., 1979]

4.2 *Laying and welding operations*

Rolls were lifted and unrolled with a hydraulic beam carried by a track excavator adapted therefore. The beams were here also specifically designed and manufactured by the equipment division of the company.

Figure 4. Laying beam and geomembrane roll carried by a 20 tons excavator

The geomembrane strips were laid side by side, with a 20-cm cover for the future weld.

The rather high mass per unit area of the geomembrane reduced the risks of uplifting by the wind, and the creation of creases, which therefore eased up the welding operations.

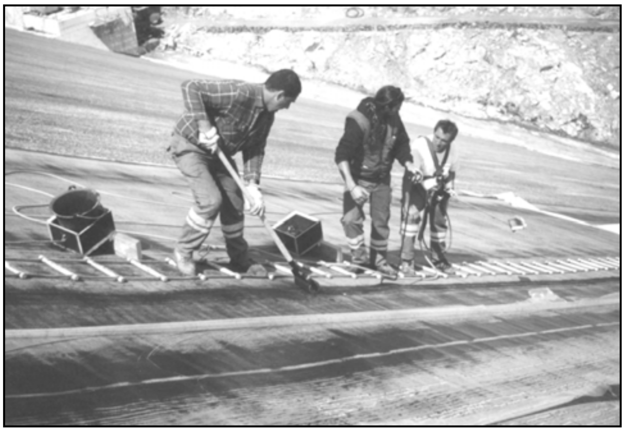

Figure 5. Welding and rolling the joints along the slope

After removing the kraft paper that protected the edge of the strips, welds were carried out with a gas burner, which heated the bitumen until fusion of both geomembranes' surface. This operation was then followed, within two meters from the flame, by the rolling of the welded strips, to ensure a proper contact between the two geomembranes.

To avoid any risk of geomembrane slipping along the slope, it was temporarily anchored by steel pins and loaded by gravel material upon the crest of the dam.

Figure 6. Up to 110-meter long strips of geomembrane to avoid transversal seams

4.3 *Construction details*

At the foot of the slope and along the whole periphery of the impervious face, the geomembrane was fastened to the reinforced concrete plinth, which is anchored into the rock foundation. The geomembrane was hot-welded on the concrete surface, which had been previously covered with a tack-primer, then anchored with stainless steel plates bolted into the plinth.

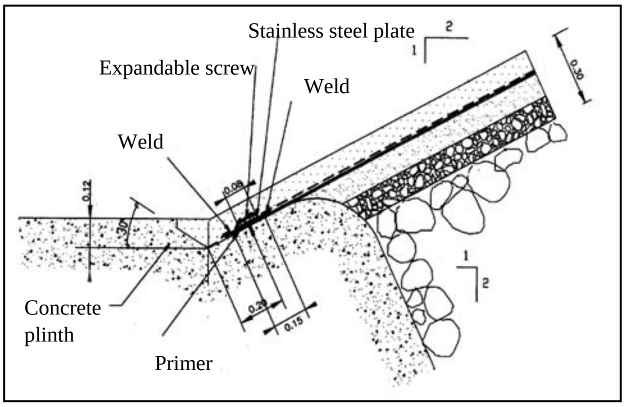

Figure 7. Details of the connection of the geomembrane to the concrete plinth

A 1-meter wide strip of geomembrane was then welded above the steel plates.

4.4 *Quality control*

The weld quality was checked by a continuous non-destructive device called CAC 94. [Breul et al., 1998]

This machine is based upon a measure wheel, which includes 24 ultrasonic sensors that can detect flaws of a minimum surface of 0.8 x 0.5 cm at the interface between the two geomembranes, on a 21-cm wide strip. Data of each sensor are transferred to a PC computer, and a specific software allows printing a global view of the weld, as well as an enlarged view of flaw areas.

If a section of welds actually showed some defects, a wider patch with at least 20 cm around the flaw was then applied, hot-welded and checked again.

Figure 8. Ultrasonic control by CAC94 equipment

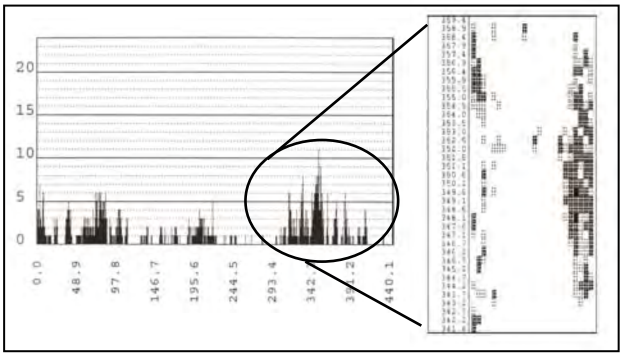

Figure 9. Histogram of cumulated defects versus distance (left) – Detailed mapping of defects (right)

5 MECHANICAL PROTECTION OF THE GEOGEOMEMBRANE

A mechanical protection is necessary to guarantee a good behaviour of the geomembrane towards any kind of aggression, such as ice or vandalism.

This protection was made of in-situ cast concrete slabs, on a non-woven geotextile acting as a protection against punching.

The minimum thickness of the slabs was 10 cm, and polypropylene fibres were added to the concrete to prevent cracking.

Large slabs (5 m x 10 m) with open joints have the following advantages:

- From an aesthetic point of view, with a nice visual aspect of the slabs in staggered rows,
- Drainage under the slabs is made easier within the geotextile and through the open joints ,
- Slabs in staggered rows allow limited concrete demolition in case of intervention on the waterproofing geomembrane.

Concrete was pumped to the slabs, with a maximal distance of 60 metres. Fluidity of the concrete was checked permanently, to keep a compromise between its behaviour on the slope, and the ability to pump.

The slabs were cast alternately in specific aluminium forms, and the concrete was laid with a vibrating drum pulled from the top of the slope. Through a hydraulic engine, this drum rotated in the opposite direction to its movement, which compacted and smoothened the surface.

The joints between the concrete slabs in the water variation range were filled with an elastomeric binder, added with solvents to allow a cold application on vertical surfaces, even under wet conditions.

6 CONCLUSION

Despite difficult site conditions due to autumn rains, the short five-month delay was respected to carry out the project.

The waterproofing structure was delivered in November 2000, which allowed the Owner to start the flooding of the dam before winter.

The dam of La Galaube is up to now, with a height of more than 40 meters, the highest dam in the world which upstream impervious face is based upon a bituminous geomembrane.

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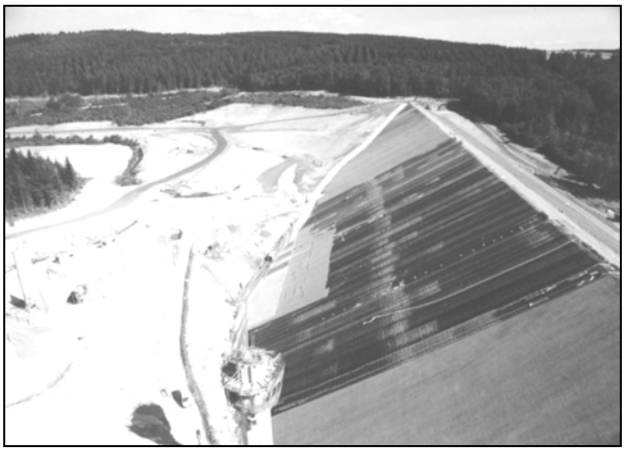

Figure 10. General view of the dam during the construction of the waterproofing structure