REVIEW OF A DAM CONSTRUCTED USING A BGM AFTER 15 YEARS OF SERVICE

Bernard Breul, Coletanche Technical Director
Robert McIlwraith General Manager Coletanche - Australia and NZ

ABSTRACT

A bituminous geomembrane (BGM) was used in 2000 for the construction of the upstream waterproofing face of La Galaube dam in the south of France. The BGM was selected for this application after a technical comparison with other options including an impervious clay core, asphalt concrete and a PVC solution. This paper will describe the different phases of the project, the specific techniques and equipment that were required to carry out the rapid construction (in 4 months) of 23,000 square meters of impervious structure, and will detail the quality management. Storage capacity of this dam is more than 35 million cubic meters, in order to supply potable and irrigation water (BGM has NSF 61 Certificate for potable water).

The stability of the dam is ensured by the weight of the rocks, which consist in about 800,000 cubic meters of mica-schist 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 on the crest and the slope is 2 H to 1 V. The maximum height above the foundations is 43 meters. The dam has been in service for 15 years and the watertightness has been carefully monitored by the asset owner EDF (French Electricity Corporation).

We will also refer to some other dams waterproofed with a bituminous geomembrane:

In France, Ortolo (37m high) in Corsica waterproofed with a bituminous geomembrane. We will discuss the practical challenges on site with strong winds and flooding during construction and how these were overcome. Ospédale (25m high) a 37 years old ICOLD dam which was the first high dam waterproofed with a geomembrane. We will discuss the Ministry of Agriculture’s complete survey of this dam.

In Chile, El Mauro dam in 2006, a RCC dam with an upstream face using a BGM on a slope of 0.7 H to 1 V.

In Peru, Cerro Lindo, which was subjected to and survived an earthquake of 8.1 magnitude. We will give the results of the audit done by Golder Associates on Cerro Lindo after the earthquake.

KEYWORDS

Bituminous geomembrane, watertightness, backfilling and RCC dams, potability, 30 and 15 years old, autumnal weather conditions, earthquake

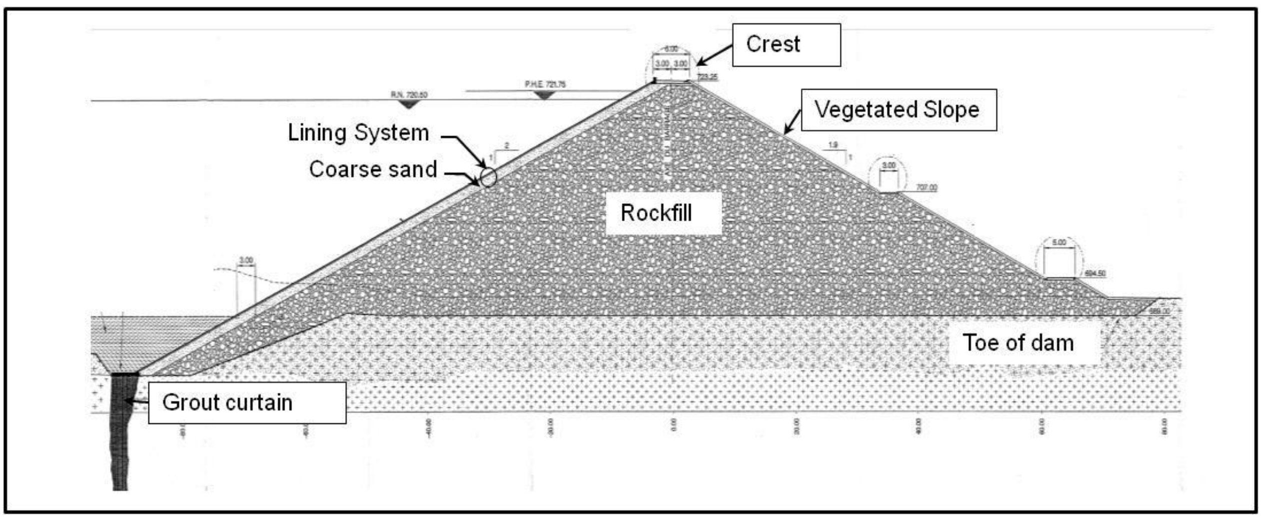
1. INTRODUCTION

Background: The dam La Galaube dam completes the hydraulic system of the Montagne Noire area, above the city of Carcassonne in the south of France, to provide a total storage capacity of in excess of 35 million cubic meters, in order to supply potable water to three provinces and 185 municipalities in the south of France, Aude, Haute-Garonne and Tarn, and regulates the flow of the Canal du Midi, classified as UNESCO World Heritage site. The La Galaube dam has a capacity of 8 million cubic meters and covers an area of 68 hectares, at an altitude of more than 700 metres. The cost of the whole project was in excess of 20 million US $.

Description: Design and supervision of works for the La Galaube dam project was carried out by two Consulting Engineers, namely I.S.L. and B.R.L. A design of a rockfill embankment with an upstream geomembrane waterproofing was selected because it was the most economical and also had the least environmental impact. A large amount of the work could be performed within the footprint of the project. The mica schist excavated on the site was used to build the embankment and therefore minimum amount of material had to be imported. By contrast some of the other options considered for the embankment such as Roller-Compacted Concrete (RCC) or zoned embankment with cores and shells would have required large amount of material import and truck traffic in a pristine area of southern France

The La Galaube dam is a gravity embankment dam and its stability is ensured by the weight of the rocks, which consist of about 800,000 cubic meters of mica schist excavated on the site. The embankment is rests upstream on a reinforced concrete plinth, founded on fresh or slightly weathered granite. The La Galaube dam is 380 meter long at the crest with slopes inclined at 2:1(2 horizontal to 1 vertical). The maximum height above the foundations is 43 meters. A typical cross section of the dam is shown on Figure 1.

Figure 1: Cross Section of the La Galaube Dam



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.

Waterproofing of the la Galaube dam included lining the upstream face grouting the foundation. The lining system installed on the upstream face consists of:
A 20 cm layer of unbound material, with a 0/20 mm grading natural material, impregnated with bitumen emulsion,
a 10 cm layer of cold asphalt mix, with a 0/10 mm grading natural material,
a bituminous geomembrane, ES 3
a 10 cm layer fibrous concrete laid upon a geotextile.

Installation of the 23,000 square meters of the lining system began in July 2000.

2. SUBGRADE PREPARATION

2.1 Compaction of the slope

The upstream slope was compacted with two 4 ton static rollers. Those compactors were pulled from the dam crest by two hydraulic excavators equipped with winches as shown on Figure 2

Figure 2: Compaction of the rockfill

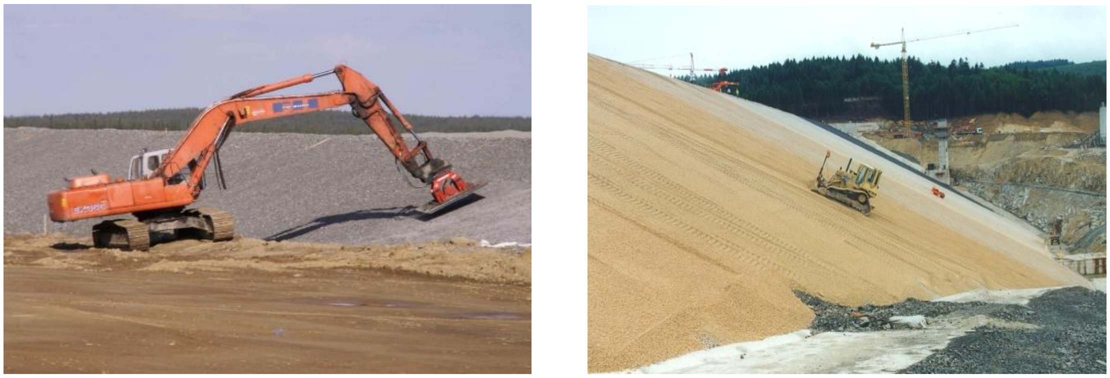
2.2 Unbound material

A layer of unbound material consisting of a crushed limestone of 0/20 mm of grain size, was laid down. The minimum thickness of this layer was 20 cm. Applied directly on the rockfill, it filled up the voids in the coarse rock and provided for a smooth working surface with minimum size protrusions. A total of 5,000 tons of the crushed limestone was imported by trucks from a nearby quarry.

The material was moisture conditioned and the transported with rear dump truck and unloaded at the crest along the slope and pushed down the slope and graded to the desired thickness and grade lines using bulldozers as shown of Figure 3 and 4. The bulldozers were equipped with lasers. The material was compacted using a 4 ton roller. In areas difficult to reach, such as the foot of the intake tower a vibrating plate mounted on a hydraulic excavator was used.

Figure 3: Laser- equipped dozer pushing limesto

Figure 4: Placing the aggregate layer and vibrating plate



2.3 Bitumen emulsion impregnation

An impregnation layer with bitumen emulsion was then hand spread, at a rate of 1.5 kg/m2. The purpose of the layer is to facilitate the laying of the asphalt mix and the intimate contact (glue) between unbound natural material and cold asphalt mix.

2.4 Cold asphalt mix

The 10 cm thick layer cold asphalt mix, with a 0/10 cm aggregates was then laid on top of the bitumen emulsion impregnated crushed limestone. The purposes of the layer of asphalt are:
To provide a smooth surface for laying and attaching the BGM,
To create a semi-impervious layer that will reduce leakage flow into the rockfill in case of tears of the geomembrane, or if the storage happened to be accidentally flooded under construction as it happened in 1996 at the Ortolo dam in Corsica where only a geomembrane had been used as the waterproofing element of the upstream face. [Huynh et al., 1998], [Tisserand et al., 1997].

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

Laboratory tests were carried out on site to confirm that the aggregates met the specified gradation curve. The asphalt content and in-situ densities were checked as there is a correlation between asphalt density and permeability. A total of 5,000 tons of cold asphalt mix were manufactured on site with a 200 tons per hour mixing plant. The aggregate were obtained from the same limestone quarry as that used for the unbound material layer. Three gradation cut-offs 0/2 mm, 2/6 mm and 6/10 mm were used during placement and compaction it was critical to keep the rollers wet so they would not stick to the asphalt mix.

Figure 5: Cold asphalt plant on site

The allowable tolerance of the finished asphalt surface that included the irregularities in the crushed limestone layer was set a plus or minus 2 cm and was achieved.

Asphalt-cold mix was chosen as a very light equipment is required for manufacturing.

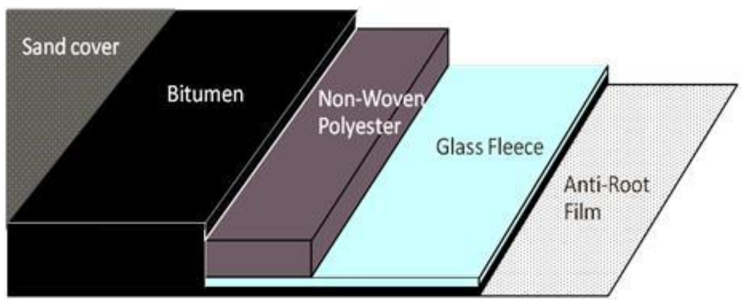
The plant was installed on site to minimize transport cost and CO_2 emissions.

3. SUBGRADE PREPARATION

3.1 The bituminous geomembrane

The bituminous geomembrane is manufactured by impregnating a non-woven polyester geotextile with elastomeric bitumen. In addition, the geomembrane is coated with sand on one side and an anti-root film on the other side. Usually the sandy side is placed facing upwards to the exposed face and the anti-root film is placed against the subgrade. The sandy side has a friction angle of 34° and the anti-root side has a friction angle of 16°. The BGM can also be supplied without the anti-root film on special request where a high interface shear resistance is required on both sides. A typical cross section of a bituminous geomembrane is shown on Figure 6.

Figure 6: Cross section of bituminous geomembrane



Coletanche ES 3 grade bituminous geomembrane was used on this project. These BGM grade was selected due to some to its properties which include:
A high tensile strength in both directions (28 kN/m in longitudinal direction, 20 kN/m in transverse direction, together with more than 70 % deformation at break).
A high resistance to puncture (500 N)
A good ageing behaviour based on other project references, [Bianchi et al., 1979, and memo of French Ministry of Agriculture about Ospédale Dam in Corsica.)
To avoid any transversal seams on the slope, rolls of more than 100m were specifically manufactured for this project. Each roll weighed in excess of 3 tons.

3.2 Laying and welding operations

Rolls were lifted and unrolled with a hydraulic beam carried by 20-ton track excavator. The hydraulic beam allows the excavator driver to precisely control the unrolling of the membrane.

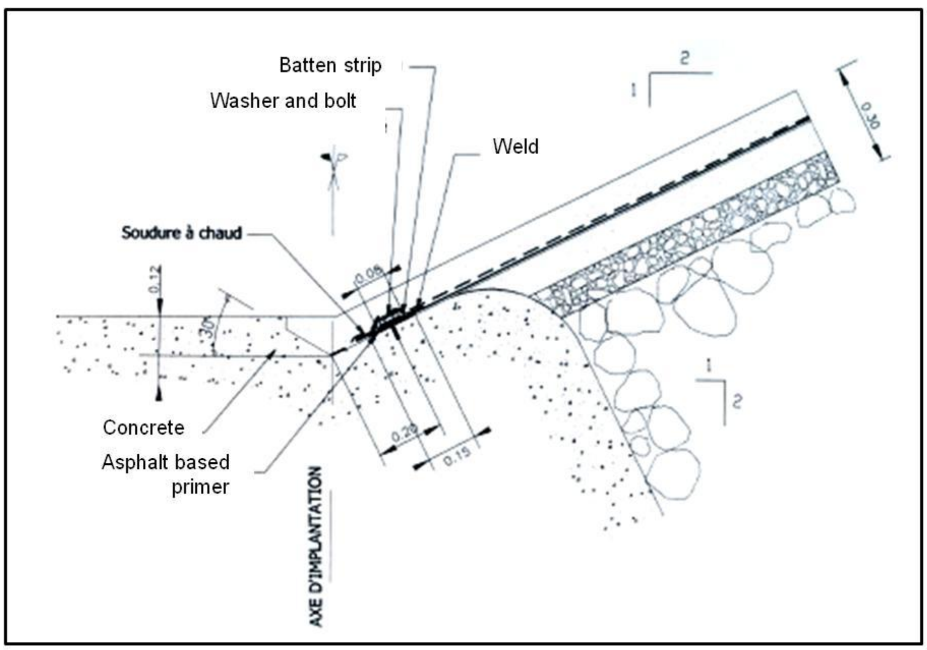
Figure 7: Deployment of bituminous geomembrane

The BGM rolls were laid side by side, with a 20-cm overlap for the seam. The high mass per unit area of the geomembrane reduced the risks of wind uplift and any resultant creases. This facilitated an efficient seam welding process.

3.3 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 onto the concrete surface, which had been previously covered with a tack-primer, then anchored with stainless steel plates bolted into the plinth as shown on Figure 8.

Figure 8: Detail of connection to concrete at toe of slope



At the top of the slope, the BGM was anchored into a trench. The trench was designed to take the total tangential force along the slope.

3.4 Quality control

Quality control included three operations:
Observations of the welding operations. Monitoring that the geomembrane overlap was at least 20 cm, verifying the bitumen is melted enough to flow out of the seam and leave a bead at least 2 cm wide,
Monitoring the finish of the seams whereby a second crew melts the bitumen bead and smooth it with a trowel to ensure that there the edge of the top geomembrane is welded and cannot be lifted.

Monitoring the seams with an ultrasound machine to verify that the weld extend across the 20 cm of overlap. Normally for this operation there are two options are available as outlined below. (For this dam Option 2 was selected).
Option 1: spot control, a portable unit is sued to control the weld on a random manner. Typically a 1 meter long segment of the seam is checked. In general each seam is checked with no length greater than 35 meters is left unchecked. In addition the CQA monitor will check any area that he feels may be imperfect. He will look for wrinkles, fishmouth and other external indication
Option 2: continuous control using the CAC 94. [Breul et al., 1998] machine shown on Figure 8. The machine is based upon a measuring wheel, which includes 24 ultrasonic sensors that can detect gaps in the weld as little as 0.8 x 0.5 cm at the interface between the two geomembranes,

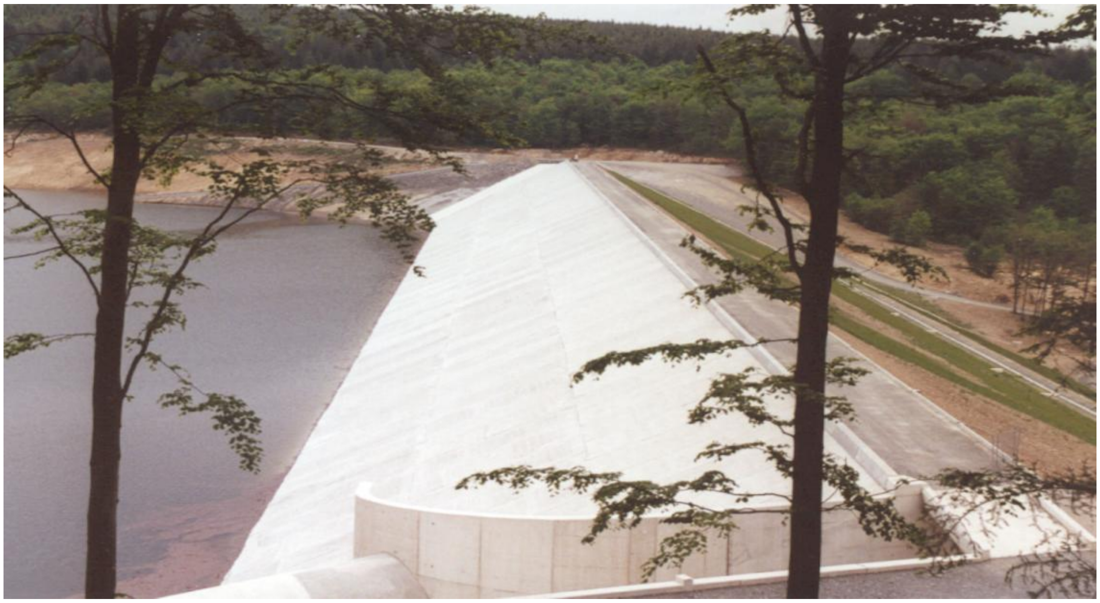
If a section of welds actually shows some defects, a patch extending at least 20 cm beyond the limits of defect is welded and checked again. Figure 8 shows the testing of the seams on the slope using the CAC 94 machine.

Figure 9: Ultrasonic control by CAC94 equipment

4. SUBGRADE PREPARATION

A mechanical covering was deemed necessary to protect the geomembrane against damage that could be caused by floating tree trunks (from the forests in the area).
This protection consisted on cast in-pace concrete slabs. Rectangular slabs 5 metres wide, 10 metres long and 10 cm thick were used. The concrete was reinforced with polypropylene fibres to prevent cracking.
The choice of individual slabs with open joints was guided by:
Aesthetic consideration: the checker pattern of the slabs provides a better appearance when the reservoir is low.
Drainage consideration, flow under the slabs and along the geomembrane is easier and better controlled.
Maintenance consideration, less concrete demolition in case of intervention on the waterproofing geomembrane.
The joints between the concrete slabs within the range of the water level in the reservoir were filled with an elastomeric binder.
Despite difficult site conditions due to autumn rains, the short five-month construction schedule was achieved on time.
The waterproofing structure was delivered in November 2000, which allowed the Owner to start the filling of the reservoir before winter as shown on Figure 9. The La Galaube Dam is one of the tallest dam in the world which upstream impervious face is based upon a bituminous geomembrane.

Figure 10: La Galaube dam with reservoir full



Below are some other examples of dams waterproofed with a BGM. BGMs have been used successfully for dam construction for more than 35 years.

4.1 In France

Ortolo (37m high) and Ospédale (26m high) dams in Corsica. The Corsican river development authority OEHC built their first geomembrane-faced embankment dam in 1979 (Ospédale) and has since been pursuing to waterproof dams with the same liner.

Figure 11a: Ospédale dam

Figure 11b: Ortolo dam

Table 1: Design information of dams

Dam	OSPEDALE	ORTOLO
Year completed	1979	1996
Height (m)	26	37
Length at crest (m)	135	157
Upstream face/slope (HIV)	1.7H/1V	1.7H/1V
Downstream face/slope (I-1/V)	1.5H/1V	1.5H/1V
Geomembrane	4.8 mm	4.8 mm
Res. capacity (Mm^3)	2.8	3

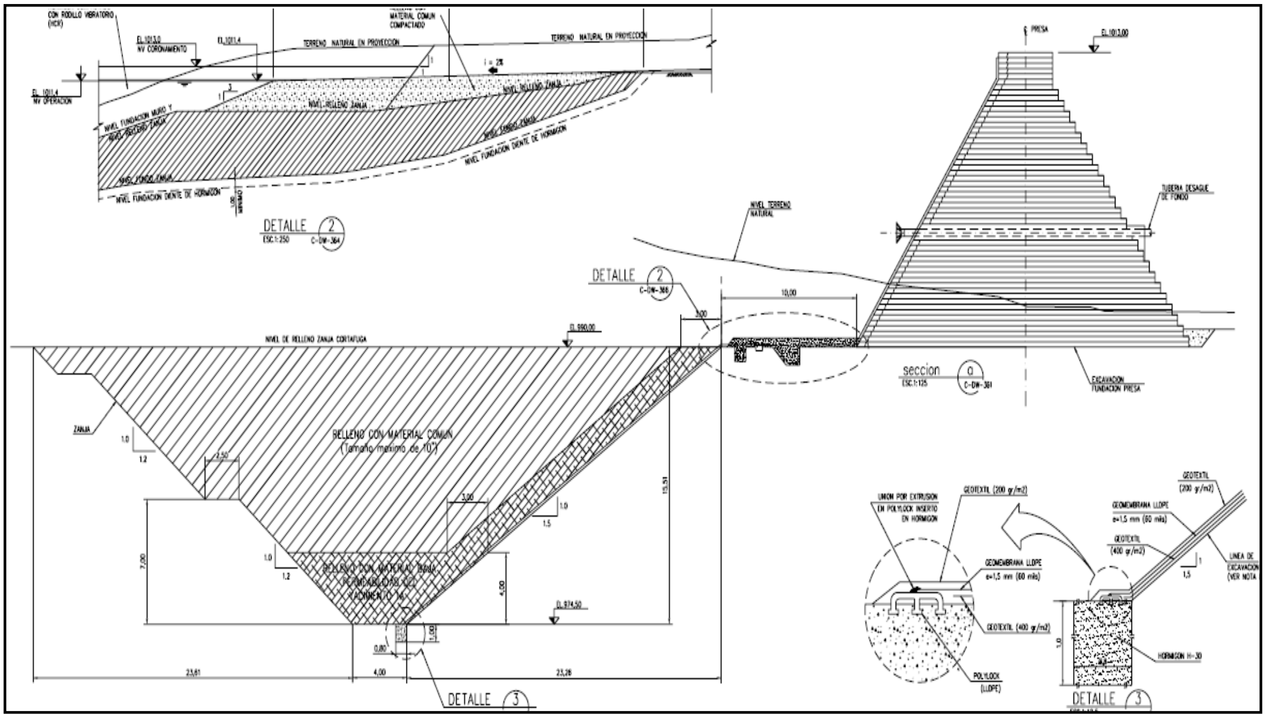
4.2 In Chile

El Mauro dam (Chile) BGM exposed. A roller compacted concrete clear water supply dam was constructed in Chile to provide water for agriculture activities downstream of a mine.

It is a 23 m high, roller-compacted concrete dam with a water supply capacity close to 600,000 m3. It is located in a region with an altitude of approximately 1,000 m and a temperature range between –5°C and 35°C.
This dam contains both a BGM and an LLDPE, which were used to ensure a waterproof upstream face and also to prevent underground seepage.

A BGM was used as the low permeability, upstream-face element to control seepage through the dam. A deep cut-off trench with an LLDPE liner has been built to control seepage beneath the dam and through its abutments. The cut-off trench was excavated down to the weathered bedrock found at a depth of 15 m under the dam foundation.

Figure 12: El Mauro dam cross section



The upstream and downstream faces of the dam have the same slope: 1V; 0.7H). The middle section of the dam comprises discharge piping as required for maintenance operations.

Figure 13a and Figure 13b: El Mauro dam under construction

Downstream, a spillway and an open channel convey water by a long canal to agricultural areas.
The dam´s upstream toe comprises an LLDPE lined, cut-off trench filled with random material at the top and impermeable material at the bottom.
At 10 m, from the upstream dam toe and in front of the dam and parallel to the structure, a small trench hosts the special joint between the LLDPE and BGM liners.
The dam foundation rests on fluvial ground, and the excavation work required for its construction reached the watertight horizon, where fluvial granular soil of raised strength and density was identified.
A complete sealing BGM with concrete was done by impregnation of a primer (mixture of bitumen and solvent) and torching to part the watertightness in independent panels like this it is easier to identify the panel where there is an eventual defect.
The dam was checked by Golder Associates office in Santiago in 2014 and the BGM was performing without problems.

4.3 In Peru, BGM exposed

Cerro-Lindo tailing dam: It is a 30 m high, earth and rockfill dam built with a capacity close to 67,000 m^3 for the purpose of controlling process water. It is located in a region with an altitude of approximately 2,000 m and a temperature range between 10 and 35°C.

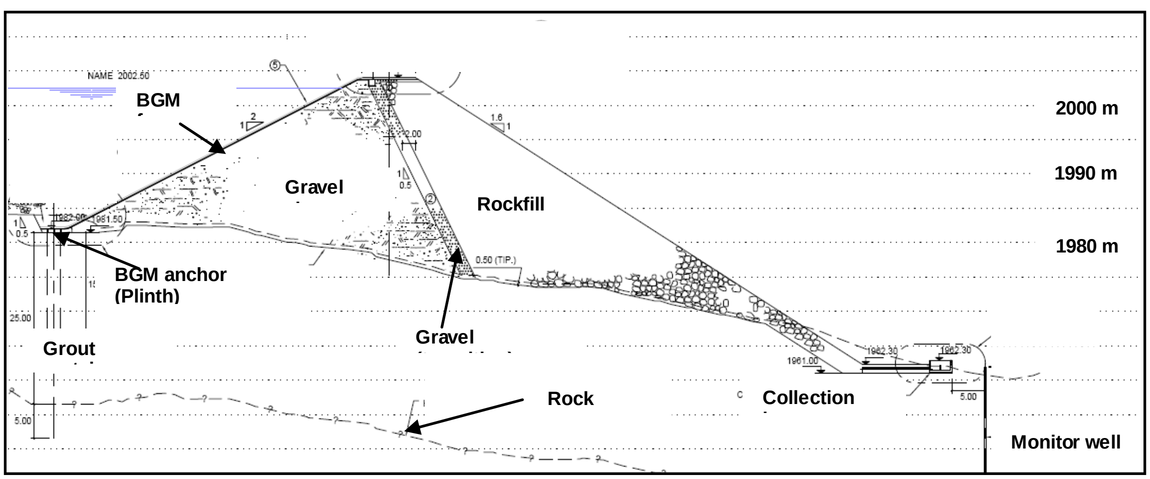
This dam is waterproofed against contaminated water by means of a BGM.

Figure 14a: Upstream face before BGM installation

Figure 14b: Upstream face after BGM installation

The here-under figure shows a typical cross section of the dam:

Figure 15: Typical cross section of the dam



All joints (100%) between the BGM liner panels were field-tested by means of manual ultrasound equipment and the results obtained were used to determine the need for joint repairs. Taking into account the size of the job, the number of repairs actually required were very few.

In 2007 and earthquake hit the site. The earthquake had an epicenter at Chincha (40km from the site) with a magnitude of 8.1. There was no damage to the BGM and this was confirmed by laboratory testing in California. (Interface Friction Testing Between Soil and a Bituminous Geomembrane, Lew et al 2013).

5. CONCLUSION

The La Galaube dam was completed on time within the short five-month construction schedule, despite difficult site conditions due to autumn rains.

These dams discussed are all inspected on a regular basis and the BGMs continue to perform well, some of them after more than 35 years of service.

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