Twenty five years experience using bituminous geomembranes as upstream waterproofing for structures

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SYNOPSIS.
Since 1978, with minor variations in the structure details, more than twenty rockfill or earthfill dams have been constructed over the last 25 years using a thin bituminous geomembrane for the upstream waterproof facing. This paper illustrates, using the examples of the last two dams built in France, the 38 metre high "L'Ortolo" dam in 1996 in Corsica and the 43 metre high "La Galaube" dam in 2000 near Carcassonne, the details of this construction technique which proves to be an efficient and economical alternative to dense asphalt or clay waterproofing structures.

INTRODUCTION

The modern use of bitumen as a geomembrane waterproofing layer for dam facings commenced in the early 1970's with the *in-situ* impregnation of a synthetic geotextile placed onto a prepared substrate, and impregnated with bitumen sprayed onto the material at a high temperature – typically in excess of 180°C. The first application of this form of sprayed geomembrane was in lining ponds in 1973-74 and around the same time, on small dams such as the dam of "Les Bimes" (9 metres high) or the dam of "Pierrefeu" (8 metres high), both of them located in the south east of France.
This, although an effective method of producing a waterproof and seamless geomembrane layer, had major inherent drawbacks both in terms of operator safety and quality control. The process was sensitive to moisture, and the bitumen usage was difficult to control leading to variations in thickness. The introduction of prefabricated geomembranes manufactured using bitumen impregnated geotextile under quality-controlled factory conditions removed these failings, leading to greater confidence in their use. There was a transition to the use of the prefabricated geomembranes in the mid 1970's.

Long-term benefits and performance of dams. Thomas Telford, London, 2004

THE PREFABRICATED GEOMEMBRANE

The factory production of a prefabricated geomembrane of bitumen impregnated geotextile, reinforced with glass fleece, addressed the safety and quality problems. Initially, rolls of material 4.0m wide were produced on a small factory-production plant and laid on site in strips. These strips were overlapped at the edges and joined by forming seams in the material using propane gas torches to heat-weld the overlap. A few small dams were waterproofed according to this technique such as “Locmine” in Brittany, (7 metres high) in 1977 and “Gardel” in Guadeloupe, (14 metres high) in 1978.

The geomembrane today

The bituminous geomembrane liner in use by Colas today, Coletanche, is manufactured in a state-of-the-art factory in Galway, Eire, commissioned by the company in 2000. The facility enables a more versatile approach to production of wider rolls (5.15m) available in several thickness grades impregnated with either Oxidised (NTP grade) or Elastomeric (ES Grade) modified bitumen; typically the “NTP” 3 grade is used for dam lining.

Table 1: Physical characteristics of Coletanche NTP3

Characteristic:	Property:
Roll length	65m
Roll Width	5.15m
Material thickness	4.8
Mass per unit area	5.5kg/m^2

The structure of the geomembrane

The base structure of the geomembrane is illustrated in Figure 1 and comprises:

- A non-woven polyester geotextile, whose weight per m^2 determines the ultimate thickness of the geomembrane – between 3.5 to 5.6mm. Coletanche NTP3 is 4.8mm thick with a mass of 5.5kg/m^2.
- A glass fleece reinforcement (which contributes to the strength of the geomembrane and stability during fabrication).
- Total impregnation with a compound including a blown bitumen of 100/40 pen plus filler (NTP grade), or an elastomeric modified bitumen (ES grade)
- The underside is coated with a Terphane film bonded when the membrane is hot, and designed to give resistance to penetration from tree roots.
- Finally the upper surface is coated with a fine sand to a) provide greater traction on a slope, giving greater operator safety and security from slipping, and b) to give protection from the degrading effects of UV radiation.

Among the properties of this geomembrane the significant mechanical characteristics are shown below in table 2.
The material is now used for a wide variety of environmental and hydraulic applications from lining canals and watercourses, groundwater protection, landfill lining and capping as well as for the waterproofing of dams.

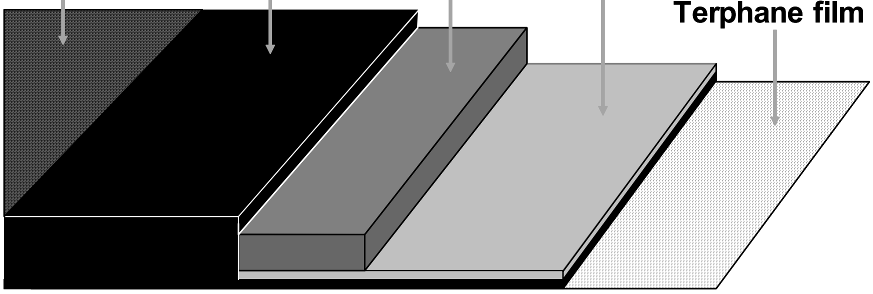

Figure 1: Typical structure of the geomembrane

Table 2: Mechanical characteristics of Coletanche NTP3

Characteristic:	Property:	Test Method:
Tensile strength at break	25,000kN/m	ISO 10319
Strain at break	70%	ISO 10319
Tear resistance	90N	NF G 07-112
Puncture resistance (Static)	500N	NF P 84-507
Puncture resistance (Dynamic)	22J	NF-p 84 502
Permeability (at 0.1 MPa)	7×10^{-14}	Darcy's Coefficient
Conventional watertightness level	$<10^{-4}$ $m^3/m^2/j$	NF-P 84515
Flexibility when cold	0°C	NF P 84-350
Maximum friction angle	35°	

Application of the geomembrane

The rolls of geomembrane are lifted and unrolled using a purpose-designed hydraulically controlled beam, carried by a tracked excavator. Lining the face of a dam, the material is unrolled down the face of the structure with the excavator remaining at the top.
The geomembrane is laid with a 20 cm overlap which is used to form a welded seam, utilising a propane gas torch to liquefy the bitumen prior to pressing and fusing the two liner sections together to form a watertight seam. This method is also used when fixing to structures, and forming round pipe-work, etc after first coating the surface with a primer.

Testing the seams

Quality control of the seams is undertaken non-destructively using ultrasound to check the integrity of the welded area, either using a single hand-held transducer for small areas or a machine known as “CAC 94”, which automatically tests the full seam width using 24 ultrasound sensors arranged in a staggered row to completely cover the seam width, downloading the data onto a computer. Software designed for the machine allows a printout to be produced showing a global view of the weld and any defects: a 20cm weld is required to have a minimum 75% width continuously welded for acceptance.

PROJECTS USING REINFORCED BITUMINOUS GEOMEMBRANE:

Ospedale dam

The first reference project using a prefabricated bituminous geomembrane took place in 1978, with the “Ospedale” dam, located in a remote area of southern Corsica at an altitude of 1,000 metres. This was constructed as a rock fill dam with a length of 135 metres and a height of 25 metres, a 70,000 m^3 embankment volume, with slopes 1.7 to 1 upstream, 1.5 to 1 downstream, and designed to have a capacity of 3 million m^3.

An alternative design proposal

The initial design for the dam was based upon an upstream waterproof facing of a 3 layer hot bituminous-mix, making a total thickness of 24 cm. This would have proved difficult to build, due to the remoteness of the construction project and the subsequent long transportation distances for the hot mix. As an alternative to this design, a proposal was put forward based upon the following structure:

- Two regulating layers of a gravel material impregnated with bitumen emulsion to provide stability, in order to improve the profile of the rock fill embankment,
- A 5 cm thick 3/6 mm open graded cold asphalt mix with a permeability of 10^{-4} m/s, to ensure an efficient under-drainage layer and prevent back-pressure under the waterproof geomembrane in the unlikely event of damage to the membrane layer leading to leakage. This cold-mix material was manufactured on site in a purpose-designed mobile plant, laid using small hoppers lowered on hawsers.
- A 4.8mm thick bituminous geomembrane, Coletanche NTP 3, laid between two geotextiles.
- Finally a mechanical protection made of unbound interlocking pre-cast concrete blocks to reduce risk of under-pressure

There were, additionally, other considerations; the membrane must not slip under its own weight down the face of the dam, and the concrete blocks were to be able to move independent of the membrane.

In order to meet these requirements, the membrane was laid with its smooth Terphane-faced side uppermost, as the friction angle on this side varies from 20 to 28°, compared with 30 to 42° on the sanded side. This proved effective in 1983 when during a huge storm, a large section of the concrete paving slipped away, without the slightest damage to the membrane.
The geomembrane was bonded to a concrete plinth at the foot of the dam using a bituminous primer painted onto the concrete to enable the membrane to be heat-welded. A thin stainless steel strip 5 to 6cm wide was fixed into the concrete through the membrane and covered with one additional thickness of membrane for additional protection.
This alternate design was accepted by the "French Committee on Large Dams", and a paper presented during the 13th International Congress on Large Dams in New-Delhi [Bianchi et al, 1979].

<u>Projects carried out during the '80s and '90s</u>
Following the success of the Ospedale dam project, over twenty further lining projects were undertaken with bituminous geomembranes, based upon either oxidised or polymer modified bitumen, with only minor variations in the design, among which can be noted: "La Riberole" dam, for a reservoir to feed a hydroelectric power plant, with a small height of only 8 metres, but at an altitude of 1,625 metres in the Pyrenees; at "Verney" in the French Alps where the membrane is used for a different purpose, to improve the water tightness of the upstream drainage bed; the dam of "Gachet", on the island of Guadeloupe, 14metres high, where the membrane is protected by unbound pre-cast concrete block protection, and still showing very good behaviour despite the tropical weather conditions; the dam of "Mauriac", in the centre of France, which is a constant level reservoir where therefore only the upper part of the upstream facing is protected with precast concrete slabs, anchored by stainless steel cables in the upper part of the dam [Clérin et al, 1991]. Finally the last two large dams built in France, which show the use of a bituminous geomembrane on a quite different scale: "L'Ortolo" dam, in Corsica in 1996, and La Galaube" dam, near Carcassonne in Southern France in 2000, which are described in more detail below.

"L'ORTOLO" DAM
A rock fill dam of 155,000 m^3, 157 metres long, a width at the foot of 120 metres, and 38 metres in height from the base. With slopes of 1.7 to 1 upstream and 1.5 to 1 downstream it has created a reservoir of 3 million m^3. [Tisserand et al, 1997]

<u>The design:</u>

The upstream waterproofing

- 10 cm 25/50 ballast impregnated with bitumen emulsion at 3 kg/m^2

- 10 cm cold asphalt mix 4/10, with a 7 to 8 % void content and a permeability between 10^{-4} and 10^{-5} m/s, manufactured on site
- Coletanche NTP 3, covered by a 400 g/m^2 geotextile fixed at the base with a 6 mm thick and 60 mm wide stainless steel plate, bolted every 15 cm into the plinth, covered with a double thickness of membrane. The geomembrane was fixed at the crest of the dam.

The protection layer

- Fibrous in-situ cast concrete slabs 14 cm thick, 3 metres wide

Comments

Two major events occurred during the construction of this project, which delayed the completion for several months, and which led to changes in the design of the next dam. Storms and strong winds on January 10th 1996 lifted 1,500 m^2 of membrane during its installation phase. The effect of the wind was amplified by the venturi effect above the crest, and under pressure generated through the dam which was permeable to downstream winds.
This storm was followed, on February 2nd, by a 100 year flood of 270m^3/s that led to a 0.5 m high flow of water through the spillway. The dam filled up in one night, and began to leak, with a flow of 5 to 6 m^3/s through the rock fill (i.e. 2litres/s/m^2), and then emptied within 48 hours through the dam and outlet. No damage was noticed to the embankment, with only slight movement of a few rocks, and a minor settlement of 6 cm on top. However, several weeks were then needed to clean the whole area, and remove the mud and all the debris carried by the flood.
The main conclusion from this project was that the permeability of the asphalt layer below the geomembrane needed to be reduced, both to increase the suction effect in case of strong winds, and to decrease flow rates in case of flood during construction before the membrane is completely installed [Tisserand et al, 1998].

"LA GALAUBE" DAM

This rock fill dam is constructed of 800,000 m^3 of mica schists excavated from the site, on a foundation of granite and a reinforced concrete plinth upstream. With a length of 380 metres, a height of 43 metres above the foundations and slopes of 2 to 1, (26°) it is the highest dam in the world with a bituminous geomembrane as an upstream impervious face and was built in 2000 on the Alzeau River in the south of France. The reservoir created is at an altitude of 700 metres with a 68 ha surface, and a capacity of 8 million m^3. [Gautier et al, 2002]

The design

The upstream waterproofing

- 10 cm layer of non-bound material, with a 0/20 mm grading, impregnated with bitumen emulsion, to regulate the slope. This required 5,000 tonnes of limestone from a nearby quarry, deposited from the crest and leveled using 2 laser-guided bulldozers.
- 10 cm layer of cold asphalt mix, with a 0/10 mm grading, to ensure the final regulating of the upstream face before laying the geomembrane. This was to be a semi-impervious layer designed to a) reduce leakage flow through the waterproofing structure in case of accidental damage to the geomembrane, and b) to overcome the problems experienced in Corsica, of premature flooding prior to completion. Laboratory studies were carried out to determine the recipe of the cold mix asphalt required in order to achieve permeability around 10^{-6} m/s, as well as ensuring that a workable mix could be achieved.

Figure 2: Work in progress at La Galaube

- as with the previous dam at L'Ortolo, 4.8mm thick Coletanche NTP3 geomembrane was used, protected by a geotextile above to reduce the effect of underpressure in case of rapid emptying of the reservoir. As it was important to have no transverse seams in the geomembrane on the slope of the structure each individual roll was manufactured to the required length to match its final position on the dam face, with a unique reference number allocated to its position. A roll of this grade of membrane is normally 65m; some rolls, required to be in excess of 100 metres, had an ensuing weight of over 3 tonnes.

The protection layer

- Fibrous concrete manufactured on site was cast into aluminium formwork to produce 10cm thick slabs 5 m x 10 m with open joints.

The completed structure was delivered in November 2000, after less than a five month period for the waterproofing phase, and a cost of €1,500,000 (£1,050,000) for an impervious surface of more than 22,000 m^2. This allowed the owner to start the filling of the dam before winter, leading to the first outflow through the spillway 18months later.

CONCLUSION

The continuous monitoring of dams with the upstream face waterproofed using a prefabricated bituminous geomembrane, some of them for more than 25 years, has demonstrated a good performance over this period. The behaviour of these structures over the period since lining has shown no reduction in watertightness with for example constant flow rates of 2.4 $l/hour/m^2$ at l'Ospedale dam, or 0.9 $l/hour/m^2$ at Mauriac dam through the liner into to the drainage layer beneath, results that are very acceptable to he clients. [Tisserand et al, 2002].

Through this knowledge and the experience gained along all these projects, the use of a bituminous geomembrane as an upstream waterproofing facing on earth fill or rock fill dams has now proved an efficient alternative solution to inner clay barriers or dense bituminous mix facings, with installation costs that can be comparable and even more interesting in remote locations.

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