Bituminous geomembranes in hydraulic construction

Robert McIlwraith
Axter Coletanche, Australia

Bertrand Breul & Bernard Breul
Axter Coletanche, France

ABSTRACT: The paper will review briefly the key characteristics of BGM that make it a great option for waterproofing dams, reservoirs, and irrigation canals.
For illustrating the use of BGM in hydraulic construction, the paper will review case studies where a bituminous geomembrane (BGM) was used.
In dam applications, the paper will review a 30-m high earth and rock fill dam in Peru, a 23-m high concrete dam in Chile, two earth and rock filled dams (42-m and 37-m high, respectively) in France. These dams are classified as high dams, per the definition established by the International Commission on Large Dams, ICOLD.
In reservoir applications, the paper will mention two water reservoirs, the Mannes reservoir at the Bayard pass in the French Alps that provides water for irrigation and potable water for the city of Gap and the Waste Way 5 Re-Regulation Reservoir Project, Roza Irrigation District reservoir in Washington state, USA.
In canal lining, the paper will mention different case studies in the United States, Canada, and France - how the bituminous geomembrane (BGM) is a very viable technical and economical option for lining canals of different widths.
This paper will describe the projects mentioned above, the specific techniques and equipment used to build the impervious structures, and will detail the quality management that was applied.
Finally, for giving an idea about the longevity of the BGM, the paper will present the results of the survey done by the French Ministry of Agriculture on the condition of the BGM on a dam in Corsica after 30 years of service.

Keywords: Bituminous geomembrane, Dams, Reservoir, Canals, Manning coefficient, longevity

1 INTRODUCTION

Approximately five thousand years ago, ancient people in the Middle East started using bitumen, which came out from deep fissures in the ground, for its waterproofing properties. Since those early times, it has been used to build and repair wells, reservoirs, canals and consolidate irrigation canal embankments. Many of these constructions are still in good condition today.

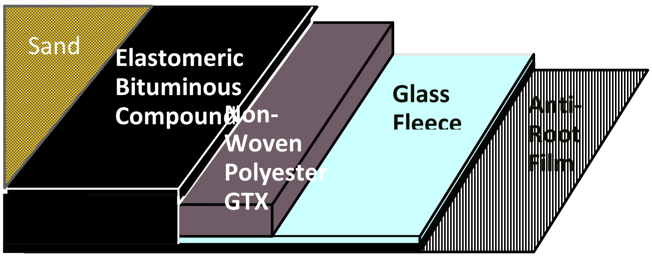
2 GENERAL PRESENTATION OF A BGM AND ITS KEY CHARACTERISTICS

The first application of a Bituminous Geomembrane (BGM) was in France in 1975 near Grenoble where it was used for potable water storage reservoirs in the Alps at an altitude around 2000m. This work was done by Professor Jean-Pierre Giroud, from the Grenoble University France who is now a world renown expert on geosynthetics.

The structure of a BGM is a multi-layered composite including: a highly resistant anti-root film able to withstand puncturing by vegetation or rough substrates; a glass fleece which ensures dimensional stability; a non-woven geotextile which is highly resistant to tearing and puncturing; a elastomeric bitumen binder that ensures that the geotextile is waterproof and resistant to ageing; and a coating of sand ensures that workers can walk on the surface in all weather conditions to carry out maintenance work. It also provides a rough surface which allows coverage of the membrane on slopes with soil.

Manufacturing is done under strict quality control procedures certified under an ISO 9002 quality assurance scheme, under a French and European ASQUAL certification and it is CE marked (European marked).

The factory operates with an ISO 14001 environmental certification.



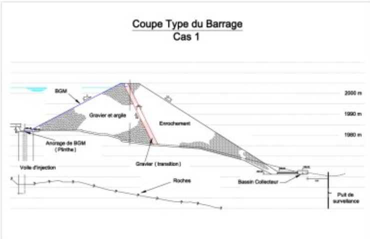
The technical characteristics of a BGM, which gives it advantages for use in hydraulic applications, are:

- Very low permeability (6 x 10^{-14} m/sec),
- Its surface mass prevents wind uplift. A BGM is the most suitable membrane to use in high wind zones,
- Highly resistant to tearing and puncturing, allowing the traffic of heavy equipment during installation and maintenance, and may be safely covered by large stones without being damaged,

- Compatible with asphalt and concrete layers directly above the membrane for additional abrasion or load carrying capacity,
- BGMs have excellent dimensional stability due to their extremely low co-efficient of thermal expansion. So they are not affected by large changes in temperature which can be problematic for other membranes which suffer from temperature induced wrinkles. Wrinkles can have an adverse effect on the long term performance of a membrane.
- The sand surface of a BGM imparts a frictional surface to the geomembrane. The interface friction angle depends on the material in contact with the sanded surface, but it is in the order of 34°. This provides a non-slip surface which is a safety factor against slippage of workers, public and animals into canals and water reservoirs. It also allows soil or aggregate veneer cover layers to be used over the BGM if required.
- A BGM can be used to store potable water in reservoirs greater than 150,000 gallons, as approved by the international water quality certificate NSF 61.
- Due to the internal reinforcement and the elastomeric bitumen, a BGM has a very high resistance to earthquakes. This has been demonstrated in real life when the Milpo dam in Peru, which was built using a BGM, survived an earthquake of a magnitude of 8.1.
- The specific gravity of a BGM is 1.22 which means it is heavier than water, unlike other polymeric membranes that are less dense than water and tend to float upwards.
- The 200mm overlap seams of a BGM provide a watertight seal with full tensile strength. The seams can be tested by variety of means on site according to ASTM D7700. On site seam tests can be selected from a combination of destructive tensile testing, non-destructive air lance testing, vacuum chamber testing, mechanical point stressing, spark testing, ultrasonic testing or electrical leak location.

3 CASE STUDIES OF BGMS IN HYDRAULIC CONSTRUCTION: DAMS

A 30-m high BGM, earth and rock fill dam in Peru for process water.
At the Cerro Lindo mine in Peru, a BGM was used to construct a 30-m high, earth and rockfill dam to store and control process water. It is located near Chincha at an altitude of approximately 2,000 m in a region characterized by strong winds. This upstream face of the dam was waterproofed by means of a BGM. At the downstream toe, an infiltration-water collection box and monitoring wells were installed to allow a permanent control of watertightness. The dam was hit by an 8.1 magnitude earthquake in 2007, and although there was incredible devastation in the area, the dam was inspected by independent engineers and found to be in perfect working order. The BGM dam continue to function to this day.

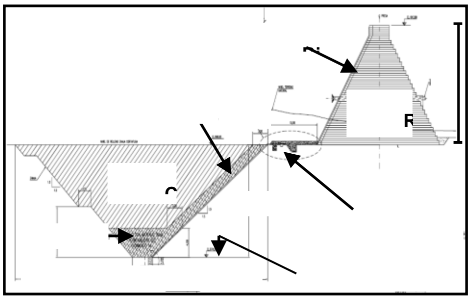


Typical cross section

Work finished

Dam in use

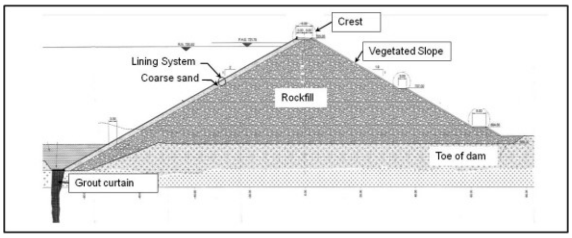
A 23-m high concrete and BGM dam in Chile for agricultural water storage,
A roller compacted concrete water supply dam was constructed in Chile to provide water for agriculture activities downstream a copper mine, during the dry season. The 23-m high dam has a very steep face of 1V:0.7H and it used a BGM to control seepage through the dam. An ultrasonic apparatus was used as part of the quality control on the BGM seams.



Two earth and rock filled dams in France.
These two BGM dams discussed below are classified as "High Dams" as per the definition established by the International Commission on Large Dams – ICOLD.

A - La Galaube dam: A design on a rockfill embankment with an upstream BGM was selected because it was the most economical and 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. This meant a cost saving for the project as well as a good environmental outcome. By contrast, the other options considered for the embankment such as Roller-Compacted Concrete (RCC) or zoned embankment with cores and shells were 20% more expensive.

The La Galaube dam is 380-meter-long at the crest with slopes inclined at 2H:1V. The maximum height above the foundations is 43 meters



Cross Section of the La Galaube Dam

Work in progress

The dam and reservoir after 15 yrs

B – Ortolo dam: 37m high, rock filled dam with BGM upstream face, Bastia, Corsica, France.
The three main objectives of this dam were: to provide irrigation water; to provide reserve drinking water; and to produce electricity by means of a micropower plant managed by EDF (Electricity of France).

The upstream face has a slope of 1.7H:1V and was waterproofed using a 4.8mm thick BGM. Above the BGM there was an upstream protection layer consisting of a layer of rocks with size 25/120 mm. The BGM was sealed onto a concrete plinth on the abutments.

The construction of the dam was completed in 6 months. The client was happy that local people from this remote area could be trained to do the installation and welding of the BGM for this project.

4 REVIEW OF BGMS IN RESERVOIR APPLICATIONS

In France, the Mannes reservoir, at the Bayard pass in the French Alps, provides water for irrigation and potable water for the city of Gap. This reservoir was rendered watertight with a 4mm BGM that was left exposed. It's an interesting example due to its simplicity and low cost.

In USA: State of Washington
The Wasteway 5 Re-Regulation Reservoir project was a joint venture equalization pond conceived and funded through the US Bureau of Reclamation, State of Washington Department of Ecology. The BGM choice received the approval of the Dam Safety Commission of the Washington State. A BGM was chosen as it represented a cost efficient and effective method to line the reservoir as an exposed option. This resulted in significant revenue savings without compromising quality and longevity of the project.
The reservoir is located on a 17-hectare land parcel and has an average depth of 32 m. The project installation began in March of 2017 and was completed in September 2017

The reservoir is permanently monitored by piezometers along the perimeter of the reservoir.

Start of the work : May 2017

September 2017

5 BGMS FOR WATERPROOFING CANALS

Naches Selah Irrigation District, Washington State USA (2006 to present)

The Naches Selah Irrigation District (NSID) provides irrigation via canals to the area ranchers in Yakima and Naches, Washington State. Several lining systems for these irrigation canals (including concrete and asphalt) were used in the NSID area over the years. Since 2006 the NSID has on a yearly basis continually selected a 4mm thick BGM to line their canals. This is due to the puncture resistance of the BGM and the ability of the irrigation teams to install the BGM themselves according to their schedule.

Ochocco Canal, Oregon USA

In 1990, the United States Bureau of Reclamation (USBR) put into place a study into the performance of various alternative Canal Lining Systems. Particular attention was given to geomembrane based solutions, one of which being a BGM. After several tests and a cost comparison of a BGM to the other solutions, a BGM was selected and installed for these canals in the year 2000. Due to the excellent puncture resistance of the BGM, the BGM was able to be laid over a rough subgrade with minimum preparation. This allowed the installation to proceed at a faster pace without delays from subgrade preparation issues. As a routine procedure, the USBR conducts an inspection on this canal every year. No major problems have been found since the installation of the BGM and these canals have been in good working order since then.

Northern Chile is a very dry area where water is a scarce resource and canals need to be lined to avoid water losses. The Rio Choapa and the Rio Elqui irrigation districts decided to look for alternatives to concrete liners to reduce costs. As part of these efforts, more than 62,000 m2 of irrigation canals in these two districts were lined with 2.2 and 3.5 mm thick BGM in 2012 to 2014. These canals were lined at a cost about 30% less than that of a concrete lining and have been operating since without any issue.

Shipping canals: Lancaster Canal in UK,
British Waterways identified the section known as “Miliness Cutting" on the Lancaster Canal (Cumbria -U.K.) as an "urgent repair scheme" after severe leaks were detected in their canals bed and embankments. After several comparison studies, they decided to use a 4mm thick BGM as the most suitable liner.

The BGM was advantageous to use since it could be installed during harsh and humid weather.

Artaix Canal, Nevers, France
For many years, a BGM has been the sole type of geomembrane used for annual repairs and upgrading on parts of the French canal network. These canals are designed and maintained by Voies Navigables de France (VNF). The usual design for these canals is: a geotextile on the subgrade; the above the geotextile a 4mm thick BGM; then an upper layer geotextile with riprap above (to prevent damage from boat traffic).

The most recent project completed in 2017 was on the Artaix canal near Nevers, which links the Rhone River and the Loire River. Approximately 20,000 m2 of BGM was installed.

The installation was in winter, as there is usually less traffic of boats (goods and tourism), than the rest of the year as well as a low level of water. The ability to install the BGM in this winter season under harsh weather conditions is another reason why it is the preferred choice by the canal authority.

Sankt Dionysen Canal in Austria (1999) for a hydro-electric plant
In 1999, the electricity provider STEWEAG (Graz region) decided to repair and upgrade the upstream water canal of the Sankt Dionysen hydro-electrical plant. After a technical and cost comparison study between a PVC liner and a 4mm thick BGM, the BGM was chosen for this project based on its technical advantages subsequent overall project savings. The low Manning coefficient factor of the BGM meant that more water would be available for the turbine producing electricity. After cleaning the existing canal, 100 000 m² of BGM was installed at a rate of 5 000 m² per day with two crews. The seams were torch bonded on a slope of 3H:2V and checked using an ultrasonic machine. An asphalt layer was placed directly on the BGM on the base of the canal which enabled an annual clean of the canal during the

spring time to maintain the same yearly flow.



A transversal anchorage was done every 50 meters to prevent any drag effect on the membrane. The flexibility of a BGM makes these transverse anchors possible.

Sealing of a 30 year old concrete canal in Alberta, Canada.

A BGM was used to seal a 30 year old concrete canal, which was used for supplying water for a coal power plant. The advantage of a BGM is that it can be heat bonded directly onto bitumen primed concrete. This allows the BGM to be secured transversally and longitudinally to the concrete in the canal.



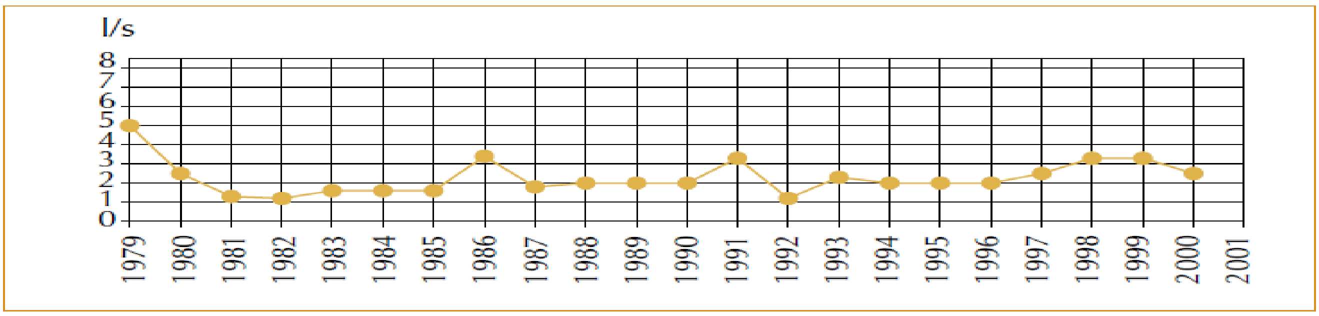
6 LONGEVITY OF BGMS IN HYDRAULIC APPLICATIONS

The International Commission on Large Dams (ICOLD, 2010) presented an overview of various types of dams around the world including 23 dams using a BGM. The oldest application of a rockfill dam with a BGM for the upstream face is the Banegon dam in France. It was built in 1973 and had an exposed face without a protective layer. Only superficial micro-cracks affecting the physical appearance were observed but according to (ICOLD, 2010) this phenomenon remains limited to the surface without altering the permeability of the geomembrane.

(Alonso et al. 1990), (Royet et al. 2002) presented a report related to French earth dams incorporating watertight geomembranes. All these French dams are to this day in service with the original geomembrane. The Ospédale rockfill dam (1978) which is now 40 years-old is 26m high, with a BGM on the upstream face which is sandwiched between two layers of non-woven geotextile and protected by interlocking concrete blocks.

Ospédale dam (1978)

Sample of BGM in 2009



No reduction of watertightness was observed during the monitoring of a moderate constant flow from the construction (average value of 2 l/s). Recent retrieving of samples show a slight loss of flexibility, probably due to oxidation of the bituminous binder, a slight alteration of the tensile strength but still excellent watertightness (hydraulic conductivity 10^{-13}m/s) which is 100 times above the value specified in the French standard NF P 84500(1998).

In 2009, hydraulic conductivity (NF EN 14150) was also evaluated from a retrieved sample of oxidized BGM (non-exposed), more than 30 years after installation (Touze et al.,2011). No superficial damage and no variation of the hydraulic conductivity were observed.

Through this knowledge and the experience gained from many projects over the last 35 years, the use of a BGM as an upstream waterproofing facing has now proved its long-term efficiency.

7 CONCLUSIONS

BGM possesses high physical and mechanical properties allowing them to be left exposed in hydraulic applications.

Installation is relatively straight forward using a propane torch for welding that requires equipment commonly found all over the world (torch and propane gas bottle). Maintenance and repairs are easy to execute and can be performed by local on-site labour (e.g., personnel from the irrigation district) previously trained by the manufacturer's monitors.

Its high unit weight allows a BGM to be installed in the presence of high speed winds (up 50 km/h). This property is very useful since dams, reservoirs and channels are often located in remote regions in open areas with no trees or vegetation to curb the effect of the wind. Channels are subject to the Venturi effect which increases wind speed in narrow places.

Subgrade preparation for this liner is reduced to the minimum and the defect rate is low due to the internal reinforcement in the BGM. On site coordination between the excavation contractor and the BGM installer is easy thus delays are minimized.

For a safety point of view, the sanded surface of the BGM gives a high angle of friction (34°) and this helps people or animals that accidently fall into a canal or reservoir to get out.

Irrigation districts usually face increased water demands from their users. Lining an earthen channel with a BGM with its very low Manning coefficient (0,012) will allow a larger water flow within the same cross section, as well a substantially reducing water loss through the soil. The benefit from achieving a watertight canal usually return the investment within a 3 to 5 year period.

BGMs have proven to be a tough and effective waterproofing membrane on a wide range of hydraulic projects over the past 35 years.

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