Bituminous Geomembranes (BGM), 15 years of presence in Latin America for Hydraulic Applications

Natalie Daly, Coletanche Business Manager North America/Axter Coletanche, Canada
Emilio Escobar, Coletanche Business Manager Latin America/ Axter Ibérica, Chile
Bertrand Breul, Technical Manager, Civil Engineering/Axter, France

ABSTRACT

The paper will overview the reinforced structure of bituminous geomembranes (BGM) and its specific characteristics that make it a valuable option for waterproofing hydraulic applications such as dams, reservoirs and canals. An overview of the properties will be described such as its low coefficient of permeability, its low thermal expansion coefficient that allows the installation of the BGM under almost any weather condition without wrinkling, its high friction angle allowing the use of steeper slopes that minimize earthmoving requirements, its large unit mass that allows handling and installation under heavy wind conditions and under water, its ability to be fixed to concrete, its strong resistance to weathering especially when exposed to UV radiation, its high puncture resistance promotes eliminating the need to use additional geotextiles for protection, and its suitability to store potable water that is certified by an international institute. Various case studies in South America will be illustrated. In dam applications, there is a 23-m high roller-compacted concrete (RCC) dam in Chile. The paper will describe a water reservoir at the Toromocho mine in Peru in the Andes mountains at an altitude of 4,800 meters and the raw water storage ponds in Pirque, near Santiago de Chile to feed the water treatment plant of the Santiago potable water system. This work includes a layer of asphalt and a concrete slab directly on top of the BGM allowing the periodic cleanup and removal of sediments from the ponds. Finally, the paper will mention different cases in Chile where BGM was used to waterproof irrigation canals, a canal to handle rainfall and surface drainage around the spoil dump at the Pelambres Mine.

1. INTRODUCTION

1.1 General comments on BGM,

About five thousand years ago, ancient people started using natural bitumen from the ground to waterproof wells, reservoirs, canals. Many of these constructions are still operating today.

The first application of an in-situ bituminous geomembrane was done by US engineers during the Second World War to construct aprons for airplanes in 1944 and for capping radioactive wastes in Texas. The first application of a factory manufactured bituminous geomembrane (BGM) was in France in 1975 near Grenoble where it was used for potable water storage reservoirs in a ski resort in the Alps at an altitude around 2000m. This work was done by Professor Jean-Pierre Giroud. This evolution from in-situ to factory manufacturing was essentially driven by the need for the ability to control the quality of the product and to have a better independence from the weather conditions which is the main concern with the use of clay and even GCL.
The structure of BGM is multi-layered including mainly: a polyester geotextile (providing the mechanical resistance and especially the high puncture resistance) with an elastomeric bitumen compound providing the waterproofing properties and ensuring its longevity by impregnating the geotextile totally. The glass fleece provides the dimensional stability, while the sand coating improves the resistance to UV and increases the angle of friction. The anti-root film prevents puncturing from roots and vegetation (Figure 1).

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

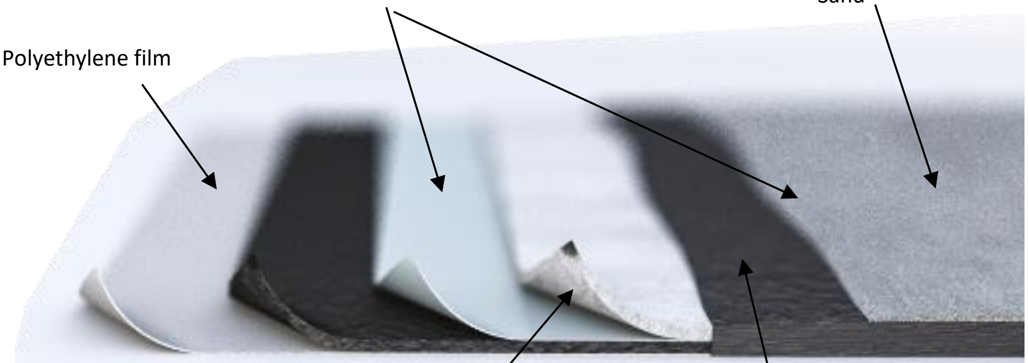

Figure 1: Composition of BGM

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

- Very low and permanent permeability (6 x 10^{-14} m/sec, Darcy's law).
- High puncture resistance (from 450 N to 650 N for static puncture following standard ASTM D 4833) allowing the traffic of heavy equipment during installation and maintenance as well as the placement of coarse material directly above BGM without additional protection (Figure 2).
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a) Gravel cover b) Rip Rap cover c) Direct trafficability

Figure 2: Puncture resistance of BGM

- Highest unit mass of any other type of geomembrane (from 4,2 kg/m² to 6,4 kg/m² following standard ASTM D 3776) reducing installation restrictions due to weather compared to polymeric geomembranes. BGM can be installed in extreme conditions (rain, wind, low temperatures below zero till -40°C).
- Compatible with asphalt and concrete layers directly above the membrane to allow for maintenance cleanup of the lined surface or additional load carrying capacity,
- BGMs have excellent dimensional stability due to their extremely low coefficient of thermal expansion ($0,22.10^{-2}$ mm/m/°C following ASTM D 696), i.e., 100 times less than HDPE. BGM high dimensional stability minimizes the heat-induced wrinkles on the surface and allows continuous installation over a higher

temperature range than polymeric membranes.

- In general, bituminous compounds have a high friction angle (minimum 34° with crushed gravel following standard NF EN ISO 12957-2). The sanded surface of a BGM gives a higher frictional angle and it provides a non-slip surface reducing slippage of people and animals into canals and water reservoirs,
- BGM can be used to store potable water in reservoirs greater than 283,9 m^3 (75,000 gallons), as approved by the international water quality certificate NSF/ANSI 61,
- BGM has a very high resistance to earthquakes as demonstrated in real life when the Cerro Lindo dam (work detailed here-under) in Peru, which was lined with a BGM, survived an earthquake of a magnitude of 8.1 with reviews proven in laboratory by Precision Lab before placing BGM at a large water reservoir for Los Angeles Department of Water and Power,
- The specific gravity of a BGM is 1.22, i.e. it will sink under water. This feature has been used to repair polymeric membranes under water,
- Longevity of the product in exposed conditions
- Ability to be connected to concrete to provide a watertight link with any concrete structure.

2. 15 YEARS OF PRESENCE IN LATIN AMERICA IN HYDRAULIC CONSTRUCTION

2.1 Dams

2.1.1 Chile; El Mauro Dam

Owner: Minera Los Pelambres, Designer: Golder Associates Santiago

The Los Pelambres mine is a large open-pit copper mine located 200km north of Santiago in the Choapa Province, at an altitude around 3,100m above sea level.

The mine built a 23-m high roller compacted concrete dam to store water for agricultural purposes and used a BGM to waterproof the upstream face of the dam. The upstream face has a very steep face of 1V:0.7H. The BGM was fully welded to previously primed strips on the concrete surface and it was mechanically anchored to the concrete with horizontal steel plates and expansion bolts.

Figure 3. El Mauro dam, Chile

Reasons for choice of BGM:

- Resistance to UV and longevity in exposed conditions,
- Ability to be fixed to concrete, easy to detect incident panel by panel.

2.1.2 Peru, Chuspiri dam

Owner: MMG

The Las Bambas copper mine, property of the Chinese company MMG, is a large copper open pit mine located at an altitude around 4,000 m above sea level between the provinces of Cotabambas and Grau, in Apurímac region, approximately 72 km southeast of Cusco in Peru. MMG built the Chuspiri dam to store water for usage at the mine. Chuspiri is a large earth dam with a maximum height of 41,5 meters. The upstream face of the dam has a slope of 2H: 1V and it was waterproofed with a BGM. The project was developed by MWH Engineering in Santiago de Chile (Figure 4).

a) Site overview b) Start of filling

Figure 4. Chuspiri dam, Peru

Reasons for choice of BGM:

- Resistance to UV and longevity in exposed conditions,
- Large unit mass thus providing large resistance to wind uplift.

2.1.2 Peru, Cerro Lindo dam

Owner: Minera Milpo

The Cerro Lindo mine is an underground polymetallic mine located near the town of Chincha in Central Peru that belongs to Minera Milpo. Cerro Lindo built a 30-m high, earth and rockfill dam to store and control process water. The dam was built on a competent substratum reached through shallow excavations in natural soil. It is located at an altitude of approximately 2,000 m in a region characterized by strong winds. The upstream face of the dam was built with compacted soil consisting of gravelly clay with a 2H:1V slope face waterproofed with a BGM. After completion of the construction there was a large earthquake in the area (magnitude 8.1 in the Richter scale) and neither the dam nor the BGM suffered any damage, reviewed after laboratory testing.

a) Work completed b) Dam in use after earthquake

Figure 5. Cerro Lindo dam

Reasons for choice of BGM:

- Resistance to UV and longevity in exposed conditions
- Large unit mass thus providing large resistance to wind uplift.

2.2 Reservoirs

2.2.1 Chile, Estanques Pirque water storage facility

Owner: Aguas Andinas

High turbidity events in the Maipo river – which provides a large percentage of the water required by the Santiago de Chile metropolitan area – usually requires the suspension of operations of the Vizcachas water treatment plant, thus causing water service cuts in the city.

Aguas Andinas, Santiago's water utility, undertook the construction of the Estanques Pirque project to store 1.5 million m3 of raw water from the Maipo river into 6 ponds. The water stored in these ponds will be used to feed the Vizcachas water treatment plant mainly when there are high turbidity events in the Maipo river. This storage capability is enough to supply water to the entire metropolitan area of Santiago for up to 34 hours.

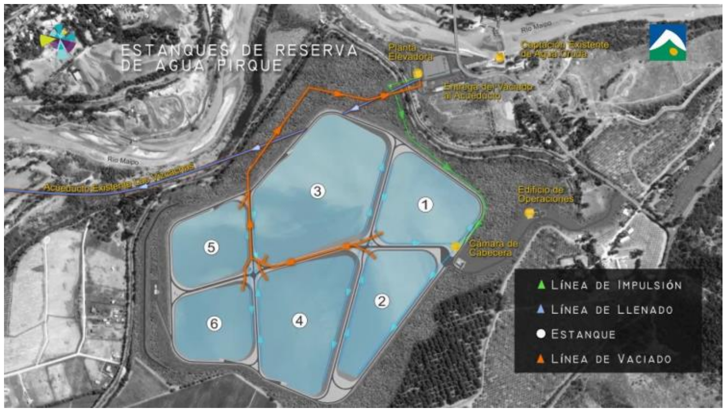

Figure 6: Estanques Pirque, Chile – Plan view

The ponds (see Figure 6) will have a maximum depth of 6 meters and will have a free border of 1 meter between the crest of the walls and the maximum water level in the ponds to prevent accidental overflowing. Wall slope is 2,5H: 1V. Sedimentation from the raw water is expected to take place and thus mechanical cleanup of the bottom will have to be done from time to time. This requirement, along with the need to have the capability to store water for human consumption, lead the consultant AMEC to select BGM of 4 mm thick (ASTM D 5199) and with a unit mass of 4,85 Kg/m² (ASTM D 3776). The quantity of BGM supplied was approximately 440,000 m2. The lining structure for the bottom of the pond is more complex and entails several layers as listed below (from bottom to top).

- 5 cm leveling asphalt layer
- 5 cm drainage asphalt layer
- BGM 4 mm thick
- 5 cm asphalt pavement directly on top of BGM
- 15 cm concrete slab

Figure 7: Estanques Pirque - Work details

Reasons for choice of BGM:

- The NSF/ANSI 61 certification to store water for drinking water systems.
- The only geomembrane able to support laying asphalt concrete directly above at a temperature of 140°C, allowing sediment removal with mechanical methods.

2.2.2 Peru, Water Reservoir, Toromocho

Owner: Chinalco

Toromocho, property of Chinese company Chinalco, is a large open pit copper mine located in the province of Junin, Perú at an altitude of 4,600 meters above sea level. Water was used throughout the production chain of the mine. The reservoir is used to contain polluted water, this water is then recycled (Figure 8).

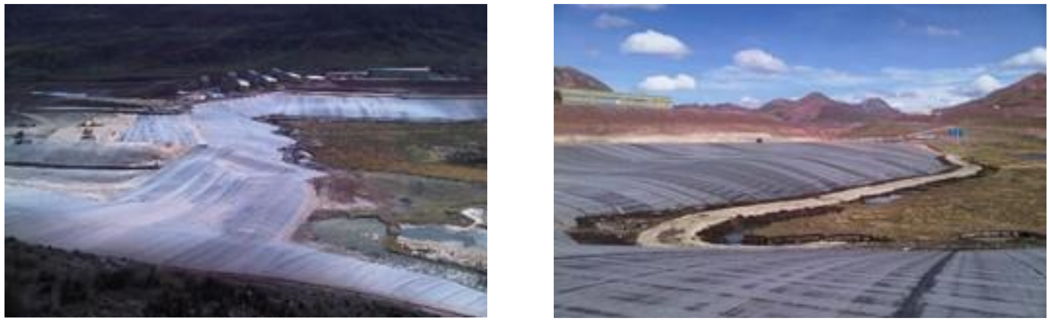

Figure 8. Water Reservoir at Toromocho Copper Mine, Peru

Reasons for choice of BGM:

- Resistance to UV and longevity in exposed conditions,
- Installation could be done by local workers able to work at this altitude,
- The installation is possible in extreme weather conditions (rainfall, heavy wind at this altitude),
- The low thermal expansion coefficient allows large temperature variations during the day without wrinkling, thus allowing welding during the entire day.

2.2.3 Guatemala, retention ponds and basins

El Escobal, owner: Pan American Silver

The Escobal mine is a large underground silver mine located in the Santa Rosa Department about 70 km southeast of Guatemala city, at an altitude of about 1,300 meters above sea level.

One of the most important management considerations of this mining project, located in tropical climate, is surface runoff control. A series of channels, retention ponds and basins have been built around the site. Guatemala is a highly volcanic and seismic active country and the site is underlain by liquefiable soils. Consequently, the stormwater control system was designed to reduce infiltration as much as possible, so the ponds were lined with various geomembranes. The pond lined with BGM was installed at the toe of the excavated volcanic ash stockpile.

Some characteristics:

- The pond is approximately 100m by 25m and 10 meters deep with a 1:1 slope.
- The subgrade is native volcanic ash material.
- the pond stored stormwater and is emptied after big storms if needed.

Reasons for choice of BGM:

- High resistance to wind uplift in a region subject to large storms. HDPE in the first ponds was routinely lifted by the wind and there was concern about its eventual failure due to a fatigue phenomenon,
  Low thermal expansion coefficient; Figure 9 below shows two liners being laid in a pond in Guatemala during a sunny day with an ambient temperature of 39°C. The BGM lays flat on the support soil with no wrinkles, while the polymeric geomembrane shows many wrinkles under the same temperature.

a) BGM b) PE membrane

Figure 9: Escobal Mine: Comparison between a pond done with BGM and HDPE same hour same day

- The possibility to accommodate larger protrusions under the geomembrane. The volcanic formation contains large amount of gravel size particles and - due to the steep slope of the pond walls – it was not possible to install a fine-grained material as a bedding support for the membrane.
- Ease of installation and repair by a local firm after receiving training from a factory monitor.

2.2.4 Mexico, The Palmarejo Mine, Fresh Water Diversion Dam

Owner: Coeur d'Alene

The Palmarejo Mine is a silver and gold mine located in Northern Mexico in the municipality of Chínipas, within the State of Chihuahua, at an altitude of 1,000 meters above sea level. The mine consists of open pit and underground operations.

Figure 10: Palmarejo Dam, Mexico

Reasons for choice of BGM:

- Resistance to UV and longevity in exposed conditions,
- Ability to be fixed to concrete and rocks

2.3 Canals

2.3.1 Chile, Irrigation canal

Owner: The Rio Choapa and the Rio Elqui irrigation districts

The Elqui River and Tributaries Board of Control (Junta de Vigilancia del Río Elqui y sus Afluentes, JVRE), administers 121 irrigation canals in Elqui Province in north-central Chile to irrigate an area in the order of 200 km^2. The Rio Choapa Board of Control (Junta de Vigilancia del Rio Choapa) administers more than 660 km of canals to irrigate more than 220 km^2 of land in central Chile. The area covered by these districts – which produce grapes, citrus fruits, avocados, and vegetables for export - is a very dry area where water is a scarce resource, so canals need to be lined to avoid water loss. 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 a 2.2 and 3.5 mm thick BGM in 2012, 2013 and 2014. These canals were lined at a cost of about 30% less than that of a concrete lining and have been operating since without any issue.

a) Rio Elqui b) Rio Choapa

Figure 11. Irrigation canals in Chile

It is worth noting that in smaller canals where the perimeter is less or equal than the width of the BGM roll, construction joints are much less frequent and thus the deployment of the liner is very fast.

Reasons for choice of BGM:

- Resistance to UV and longevity in exposed conditions,
- Ability to be fixed to concrete,
- High friction angle permitting animals to walk across,
- Low Manning coefficient,
- Less expansive and faster to deploy than a conventional concrete lining.

2.3.2 Contour Canal – Pelambres mine

Owner: Minera Los Pelambres

As a part of its social responsibility, Minera Los Pelambres (same owner as EL Mauro Dam) has undertaken a series of projects for the benefit of the township of Caimanes, near the mine site. Part of these projects included the waterproofing of existing concrete and masonry canals totaling about 18 km, which required around 26,500 m2 of a 4,0 mm thick BGM. Figure 12 shows a typical cross section. The BGM restored the waterproofing of these canals and it has been working without issues since its installation.

Figure 12. Contour canals, typical section

3. CONCLUSION

Experience with BGM for hydraulic construction in Latin America dates back to only about 15 years, which is relatively short when compared to the 40+ years in which BGM has been successfully used for hydraulic construction in Europe. However, in these 15 years of experience in hydraulic projects in Latin America, BGM has demonstrated its versatility and usefulness.

BGM possesses excellent physical and mechanical properties allowing it to remain exposed with a long service life. Its installation is straightforward, using a propane torch for welding which can be done by local installers trained by manufacturer's monitors on site. Its high unit weight conveys for a high resistance against wind uplift and rough weather conditions; and its thermal stability allows it to be installed in a large ambient temperature range without interruption, thus reducing the required installation time. Finally, subgrade preparation for this liner is reduced, permitting large cost and time reductions.

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