Bituminous Geomembrane (BGM) in hot climates for hydraulic construction

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Abstract. This paper will explain the reinforced structure and key characteristics that make bituminous geomembranes (BGM) an interesting option for waterproofing hydraulic works in hot climate areas. For illustrating this, the paper will review some case studies where BGM was chosen due to its characteristics. In dam application, a project for a waterproofing of a dike in Saday (Djibouti) and a rock fill dam (42-m high) in France will be explained. For irrigation in reservoir and canal lining, a work in Goudel and a canal on laterite soil in Niamey (both in Niger) will described proving use of BGM in dry tropical climates. This paper will also review the construction of raw water storage ponds in Pirque (Chile) for the city of Santiago's potable water system. A last project will be described on a large irrigation canal in Nagpur (India) where the Pench canal, located in the center of India, convey water from the Pench River to the surrounding agricultural areas. The old canal, originally made of concrete, collapsed due to the water seepage and the swelling clay underneath.

1 Introduction

Bitumen is a natural product and, like clay, has been used since around five thousand years for its waterproofing properties. Coming out from fissures in the ground, the first known applications where in Middle East: canals and embarkments in Mesopotamia and ancient Egypt (Schwartz, 2000 [1]), reservoirs, wells, roofs, and many other applications have been found with the use of this product. This paper will briefly present the structure of bituminous geomembrane (BGM) which integrates its own reinforcement by a geotextile inside the membrane. The key properties for waterproofing hydraulic structures will be analyzed to demonstrate the use in these applications. All of these will be presented through examples in different projects all over the world.

2 Characteristics and advantages

The structure of BGM is multi-layered, which includes a non-woven polyester geotextile at the core, providing the mechanical and high puncture resistance. This geotextile is impregnated by an elastomeric bituminous blend that provides the waterproofing properties

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and ensures the product's longevity by totally impregnating the geotextile. The glass fleece, also fully impregnated by the bitumen, provides the dimensional stability during the manufacturing process. Finally, an upper sand coating layer improves the resistance to UV and secures people and animals to walk on the surface providing grip properties, especially interesting on the slopes. The anti-perforation film on the below layer prevents puncturing from roots and vegetation (Fig. 1).

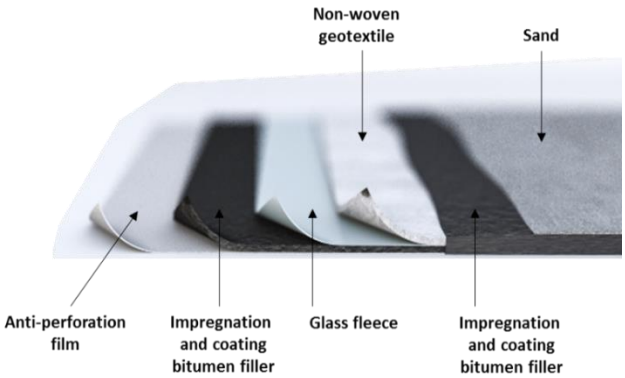

Fig. 1. Typical structure of a bituminous geomembrane (Source: Axter)

The manufacturing process is done under strict quality control procedures certified by ISO 9002 quality assurance and following 14001 quality environmental procedure scheme. The product is CE marked (European marked).

The technical characteristics of BGM, which provide advantages for use in hydraulic applications, are the following:

- Very low permeability, at the same level of any other type of PE geomembrane: 6 x 10^{-14} m/sec (ASTM E96).
- High puncture resistance, up to 650 N for static puncture (ASTM D4833) allowing traffic of heavy equipment during installation and maintenance as well as the placement of coarse material directly above without additional protection (Fig. 2), and hydrostatic puncture resistance (ASTM D5147) between 501 and 564 kPa for the range of 4,00-mm and 4,80-mm thickness geomembranes.

Gravel cover Riprap cover Direct trafficability

Fig. 2. Examples of BGM high puncture resistance (Source: Axter)

- High unit mass, up to 6.4 kg/m² (ASTM D3776) preventing wind uplift and reducing installation restrictions for weather constraints. BGM is a suitable membrane to be installed in high wind areas.

- Compatible with asphalt and concrete layers directly above the membrane (without any intermediate layer) for allowing additional abrasion or load capacity on the membrane (i.e., machinery for regular clean-up maintenance).
- Excellent dimensional stability due to the extremely low thermal expansion coefficient of BGM (0.22 x 10^{-2} mm/m/°C following ASTM D696). This is around 100 times less than high density polyethylene membranes (HDPE). BGMs do not suffer from heat-induced wrinkles with variations in temperature and its installation can take place on a wide range of temperatures meaning less interruptions due to weather constraints.
- High friction angle of 34° with crushed gravel according to NF EN ISO 12957-2 (Afnor, 2005 [2]). The sanded surface of BGM provides a non-slip surface reducing slippage of people and animals into canals and water reservoirs. It also allows soil or aggregate cover layers to be used over the BGM if required. Designers can use BGM in slopes steeper than 2H:1V (i.e., upstream face of a dam or the banks of reservoir).
- BGM can be used to store potable water following the NSF/ANSI 61 (international water quality certificate).
- The seams of BGM (200 mm) provide a fully watertight seal with good mechanical strength. These seams can be tested by variety of means according to ASTM D7700. On site QC (quality control) can be selected from a combination of destructive and non-destructive tests.
- The specific density of a BGM is 1.22 meaning that, unlike other polymeric membranes, it does not tend to float on water (saving on ballasting in water projects). Underwater repairs are possible with BGM using a with a special bituminous mastic.

3 Case studies

3.1 Dams

3.1.1 Spillway in Saday, Republic of Djibouti (Year 2014)

Djibouti faces a general lack of water resources with no permanent source of surface water. The annual total use of water is around 19 million m^3, including 2.5 million m^3 (13%) for irrigation and 0.5 million m^3 (3%) for livestock. The remaining (84%) is used for household and municipal purposes. It is estimated that over the 70% of rural population and its flocks do not have access to water at a reasonable distance, and about 95% of the water use comes from deep aquifers that are recharged by infiltration of rainwater from wadis. The Government is strongly committed to the promotion of rural development: The project "Mobilization of water for domestic and agricultural use in rural areas" aims to contribute to the provision sustainable services of drinking water supply, irrigation, and livestock watering for all rural populations in the Digri and Obock regions. The purpose is to allow a better knowledge of the water resources in the country by making available a bank of water management projects to the local authorities.

In 2014, a project of a spillway dike was waterproofed using 20,000 m² of BGM in Saday, Republic of Djibouti. The dike from 1.30m to 4.60m (Fig. 3) was designed by MCG Engineering (Mauritanian Engineering firm).

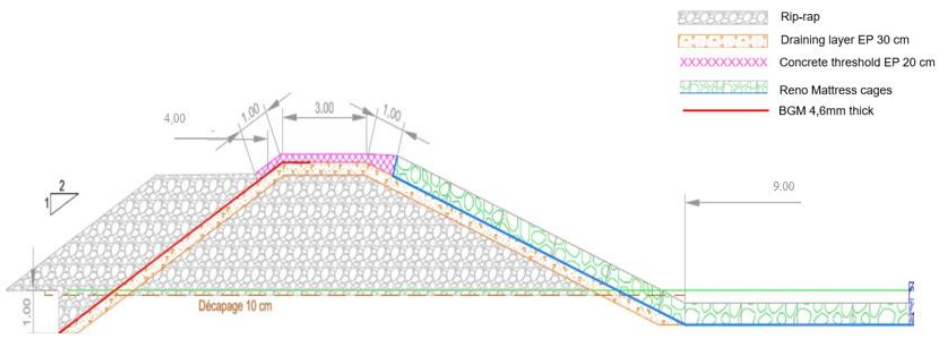

Fig. 3. Cross-section of the Saday Dyke (Source: Colas)

A BGM 4.6 mm thick (ASTM D5199) and 5.8 kg/m² of surface mass (ASTM D5261) was selected for the project conditions and height of the dam (Fig. 4). The geomembrane could resist the aggressive abrasion conditions of the sand-laden water of the surroundings.

Fig. 4. Installation of BGM in Saday dike (Source: Axter)

An installation rate of 1,500 m² per day was achieved with the use of a hydraulic excavator and a spreader bar. The manufacturer provided an installation training at the beginning of the work. The geomembrane was placed on 2H/1V (26°) slopes. This could be achieved due to the high friction angle of BGM (34°), giving a safety factor of 1.25. A riprap layer was placed directly on top of the membrane, protecting it against puncturing elements such as big rocks.

3.1.2 Rockfill dam (42-m high) in France for Electricity of France (Year 2000)

La Galaube dam supplies potable water to 185 municipalities and regulates the flow of a shipping canal. The reservoir in front of the dam has a capacity of 8 million m^3 and covers an area of 68 hectares. A design on a rockfill embankment with an upstream geomembrane waterproofing was selected as it was the most economical solution and with less environmental impact. The mica schist excavated on the site was used to build the embankment, therefore minimum amount of material had to be imported. Other considered options such as Roller-Compacted Concrete (RCC) or zoned embankment with cores and shells resulted 20% more expensive and would have required large amount of material import to the remote area in the South of France (thus increasing CO_2 emissions).

La Galaube is a rock-fill embankment dam. Its stability is ensured by the weight of the rocks, which consist of about 800,000 m^3 of mica schist obtained from the excavation on the site. The embankment rests upstream on a reinforced concrete plinth, founded on fresh or

slightly weathered granite. The dam is 380 meter long at the crest with 2H:1V slopes and its maximum height is 43 meters. A typical cross section is shown on Fig. 5.

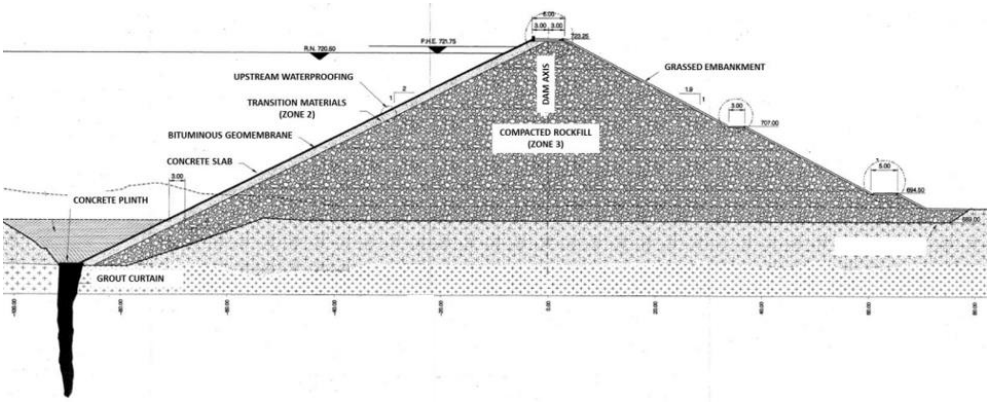

Fig. 5. Typical cross-section of La Galaube dam (Source: ISL)

The waterproofing of the La Galaube dam included the lining of the upstream face and the grouting of the foundation. The lining system (Fig. 6) installed on the upstream face consists of:
- 10 cm layer of material bounded with bitumen emulsion (0/20 mm grade).
- 10 cm layer of cold asphalt mix (0/10 mm grade).
- BGM 4.80 mm thick (5.80 kg/m² of unit mass).
- 10 cm layer fibrous concrete laid on a geotextile.

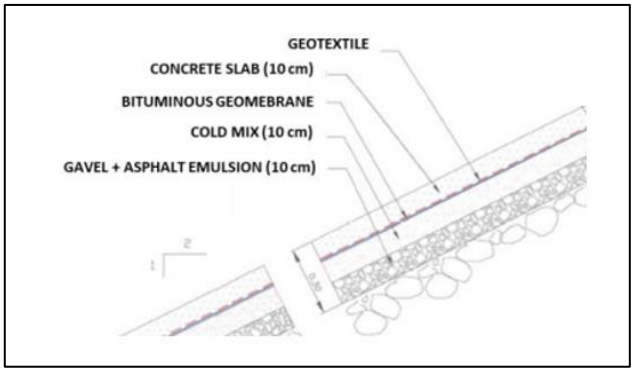

Fig. 6. Cross-section of the upstream face of La Galaube dam (Source: ISL)

The installation of the 23,000 m² used for the lining system began in July 2000. The upstream slope was compacted with two static rollers. Those compactors were pulled from the dam crest by two hydraulic excavators equipped with winches as shown on Figure 5. BGM rolls were lifted and unrolled with a hydraulic beam carried by 20-ton track excavator. Geomembrane panels were laid side by side, with a 20-cm seam overlap. The high mass of the BGM reduced the risks of uplifting by the wind, and the very low thermal expansion coefficient of the membrane avoided the creation of wrinkles, which facilitated the welding operations on the installation.

Since the beginning of the work, a drain in the bottom of the upstream face of La Galaube measures the quantity of seepage. Twenty-one years later, the drainpipe stays still empty confirming there's been no loss of water since then (except loss by evaporation).

3.2 Reservoir

3.2.1 Irrigation complex (reservoir and canals) in Goudel, Niger (Year 1991)

In Goudel, a water reservoir and canals (Fig. 7) from the Niger river were lined with 4,500 m^2 of BGM in 1981. The work remains in good condition after more than 40 years of its installation. Only few tears at junctions with the concrete structures had to be repaired in a simple way, welding a patch of BGM on the top. Ten years later in 1991, a canal network built on laterite soil was lined using 20,000 m^2 BGM in Niamey. These canals were used to feed water to the livestock and farming areas of the surroundings. Some years after the installation, various details were observed:
- Canals in vegetable-growing areas were in good condition.
- Canals close to livestock farming areas had been damaged only at cattle crossings.
- In some stretches of the canal residents had taken the geomembrane.

In Niger as in other African countries it is said that the material of bituminous geomembrane is used for re-soling shoes. This means that special measures are needed to face damage of animal and human origin: such as fencing, thorn hedges or concrete cattle crossings.

3.2.2 Raw water storage reservoirs in Santiago, Chile (Year 2020)

The Estanques Pirque project is approximately 75 km away from the city of Santiago in Chile. The project consists of six ponds to store 1.5 million m^3 of raw water from the Maipo river. The water stored in the ponds is used to feed the Las Vizcachas treatment plant during the cut off for high-turbidity events caused by high rainfall and the rapid melting of the snow from the Andes mountains of the Maipo River. Santiago's water utility (Aguas Andinas) undertook the construction of the project. The project has a capacity to store enough water for the supply up to 34 hours to the metropolitan area of Santiago

The six ponds have a maximum depth of 6 meters and a wall slope of 2.5H: 1V. A total of 440,000 m^2 of BGM 4.0 mm thick was used to line the entire project. Fig. 8 shows the cross section of the structure. The bottom of the pond consists of five different layers from bottom to top:
- A 5 cm levelling asphalt concrete layer.
- A 5 cm draining asphalt layer.
- A 4 mm thick BGM following ASTM D5199.
- A 5 cm thick asphalt pavement directly on BGM.
- A 15 cm thick concrete slab.

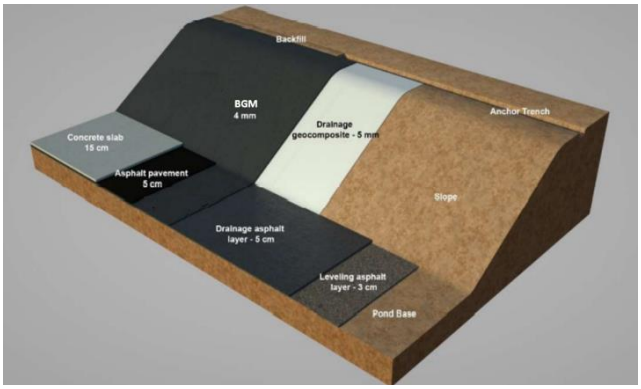

Fig. 8. Cross section of the adopted solution (Source: Axter)

A periodic clean-up of the solids settled in the bottom of the ponds was required due to the raw water sedimentation. Therefore, a protection of the membrane was needed to allow maintenance vehicles over it. It was solved with 5cm asphalt layer directly on BGM and a 15cm concrete slab over the asphalt. Like this, trucks and loaders could operate regularly for the cleaning of the ponds.

The main reasons of BGM choice on this project were:
- ANSI/NSF 61 certification for the use in drinking water systems.
- Hot asphalt mix can be directly poured on top of BGM without any intermediate layer.
- High resistance to weathering and UV. Part of BGM on the slopes remained exposed without any additional protection.
- Durability compatible with the expected life of the project.

3.3 Canals

3.3.1 Irrigation of a Large Canal in Nagpur, India (Year 2018, 2022)

The Pench canal network, located in central India, brings water from the Pench dam to the agricultural crops in the region. Divided in two main canals - Pench Left Bank Canal and Right Bank Canal - it supplies water to 83,000 hectares in Nagpur city (with 6 million inhabitants) and 21,400 hectares in Bhandara district. The network has around 1,800 km of big and small canals. The two main canals, constructed almost 40 years ago, were sealed using concrete lining, a common solution at that time. Over the years, the condition of the concrete deteriorated, and many dikes broke inducing many loses of water by seepage (Fig. 9). The Department of Water Resources of Maharashtra state (WRD) together with the local Vidarbha Irrigation Development Corporation of Nagpur (VIDC) took the decision to reline the canal with a flexible bituminous geomembrane.

Fig. 9. Canal before and after renovation work - Pench Left Canal, India (Source: Axter)

The swelling clay under the concrete was the main reason of the canal deterioration. The water, filtered through the concrete joints, caused the contraction and expansion of the clay creating soil movements. The concrete slabs along the canal did not have enough flexibility to withstand the stresses generated by soil movements below the concrete. As a result, the canal had a shorter service life than initially expected.

The WRD studied different possibilities for a long-term solution. After some studies, they decided to waterproof the canal with a bituminous geomembrane. The project involved the

renovation of 1km of the canal in 2019. The most damaged parts of the old concrete were removed and compacted to re-profile the canal. A BGM 4mm thick with a surface mass of 4.85 kg/m² was placed directly on the ground and anchored on top. A strong and flexible membrane capable of responding to the basement movements was needed. The high temperatures of that region in Central India (around 45ºC) were not an issue for BGM during installation.

The execution work began in June and it was completed before rainy season in less than one month. An onsite training by the manufacturer allowed a quick installation at a very affordable cost by local manpower. The complete installation could be achieved in just 15 days, with an average of 2,500 m²/day.

After 3 years, in June 2022, given the success of the adopted solution, the local authorities decided to reline a second 800 linear meter stretch of the same canal with BGM.

4 Conclusions

BGM has been used successfully as a waterproofing membrane in hot climate areas over the last 40 years.

Its high physical and mechanical properties allow BGM to remain exposed. Thanks to its good dimensional stability BGMs do not suffer from heat-induced wrinkles, permitting the installation in a wide range of temperatures and at any daytime (avoiding interruptions and delays in the project). Its high surface mass allows it to be installed in high wind areas (up to 50 km/h) requiring less ballasting during installation. With the use of BGM, subgrade preparation is also reduced, minimizing this cost. Some layers on the design (such as protective geotextiles) can be eventually saved thanks to the high puncture resistance of the membrane.

Installation of BGM is very straightforward using a propane torch and can be done by local labor previously trained by the manufacturer (e.g., personnel from the irrigation district). Maintenance and repairs are also easy to execute. This is an advantage in remote places where skilled labor difficult to obtain.

The case histories in tropical climates described in this paper show examples of BGM used in different challenging applications. Through them, BGM have proofed to be a consistent and effective waterproofing solution on a wide range of hydraulic projects.

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