4th PAN AMERICAN CONFERENCE ON GEOSYNTHETICS
26-29 APRIL 2020 • RIO DE JANEIRO • BRAZIL

Bituminous Geomembranes (BGM), 15 years of presence in Mine construction in Latin America

N. Daly, BGM Business Manager North America, Axter BGM, Canada
E. Escobar, BGM Business Manager Latin America, Axter Ibérica, Chile
B. Breul, Technical Manager, Civil Engineering, Axter, France

ABSTRACT

BGM is manufactured by impregnating a polyester geotextile and a fiberglass layer with an elastomeric bitumen compound. The geotextile provides the mechanical resistance and the high puncture resistance (thus eliminating the need to use outside geotextiles for protection) and permits the traffic of tire-mounted equipment, during construction. The bitumen provides the waterproofing properties of the geomembrane and ensures the longevity of BGM by protecting the geotextile fibers over the long run. BGM has a higher friction angle than other types of geomembranes. This contributes to the stability of the heap leach pile and it helps reduce earthmoving costs in the construction of reservoirs for storage of solids or liquids by allowing the use of steeper slopes.
The paper describes examples of application in mining operations in Latin America where BGM was selected in lieu of the usual polymeric geomembranes, due to BGM's high puncture resistance, its ability to be installed in very harsh weather conditions (wind, warm, cold…) and its ease of installation, ability to be deployed on a coarser subgrade and tolerance to extreme atmospheric conditions. The projects to be described are for applications in: Containment of solids and liquids: Waste rock dump for PAG rocks cap test at Antamina copper mine in Peru, a heap leach pad at Dolores silver mine in Mexico, a lithium evaporation ponds at the Atacama salar in Chile, the Barahona spoil dump at Codelco's Teniente mine in Chile and a storage of solid waste at a niobium mine in Brazil. Capping of solid waste: Capping of sulfite waste at La Granja mine in Peru and capping of mine spoil dumps at Furioso mine in Chile. Tailings storage facilities: Tailings dams at the Cerro Lindo mine in Peru and the Cerro Negro gold mine in Argentina. We will also describe the underwater repairs of HDPE liner using BGM at the tailing's reservoir of the Antamina mine copper mine in Peru.

1. INTRODUCTION

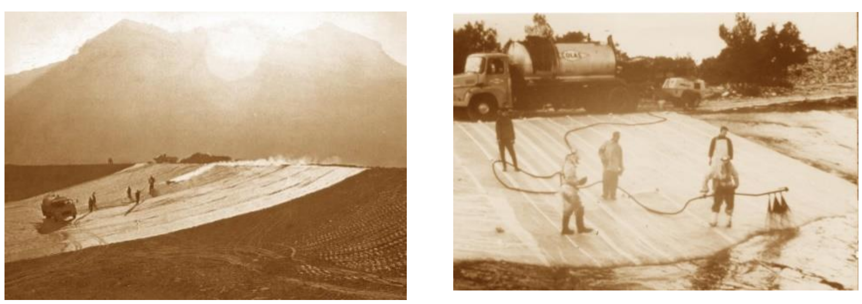

Figure 1. The first BGM applications

Mining operations and processes generate solid and liquid wastes that need to be properly confined during operation to appropriately safeguard the environment. After the life of the mine is achieved, appropriate measures should be taken to prevent the aerial contamination of the environment by encapsulating tailings. The fact that mine operations are usually located in remote locations with harsh weather conditions only increase the difficulty of achieving the above tasks. To solve this problematic by a geomembrane, this paper will suggest the use of a bituminous geomembrane (BGM) knowing that bitumen has been used as a construction and a watertight product for centuries. From the fourth millennium BC, the Sumerians, the Babylonians and the Assyrians exploited bitumen as hydraulic mortar for the construction of terraces, canals, dams, etc., including the famed hanging gardens of Babylon. Bitumen emerged again as a standard 20th century waterproofing material in civil and water engineering in the form of bituminous concrete, asphalt and bituminous geomembrane (BGM). In-situ BGM was invented by US engineers during World War II to build temporary runways for airplanes by spraying bitumen on top a geotextile laid down on the ground and in USA, to cover low and medium radioactive wastes in Texas. This technique was introduced in France in 1974 by the large French road contractor COLAS in association with the oil company Royal Dutch Shell, for some industrial applications near Grenoble and for potable water storage reservoirs in the Alps (see Figure 1) under the supervision of the world renowned Geosynthetics expert Jean-Pierre Giroud. This paper will present the original and innovative structure of BGM which leads to certain technical advantages in comparison with other type of geomembranes more usually used. The other target of this paper is show that for a construction the consultant has to consider the cost of a global solution (including delay in spite of weather conditions, grain size of material able to be directly in contact with the geomembrane, ability to be installed and welded by local contractor with equipment available locally…), and not only the cost of the geomembrane.

2. STRUCTURE

BGM is a geomembrane manufactured by impregnating a non-woven long fiber polyester geotextile with an elastomeric bitumen compound in a factory to avoid hazards. The geotextile provides the mechanical resistance and especially the high puncture resistance. The bitumen compound provides the waterproofing properties of the geomembrane and ensure its longevity by impregnating totally the geotextile and protecting it from ageing.

BGM is manufactured in a thickness range from 3.50 mm to 5.60 mm following ASTM D 5199, and a large surface mass ranging from 4.20 to 6.40 kg/m² following ASTM D 3776. This makes BGM a thick geomembrane compared to others on the market.

BGM is a composite of a different materials, as follows:

- A long-fiber, non-woven polyester geotextile ranging from 200 to 400 g/m²,
- A glass fiber fleece of 50 g/m²,
- An elastomeric bitumen, which impregnates the geotextile and the glass fleece,
- Sand on the upper surface of BGM improves the safety of the workers during installation and maintenance,
- A polyethylene anti-perforation film is on the bottom of the geomembrane.

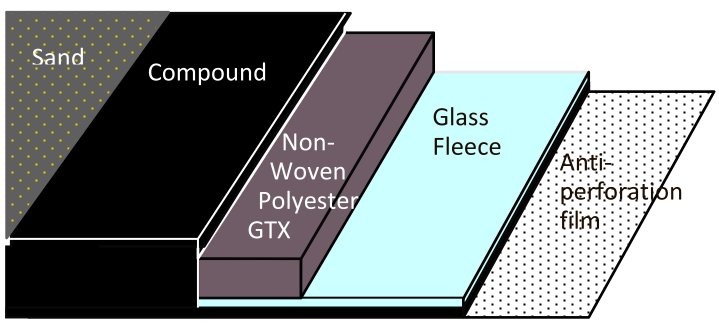

Figure 2. Composite structure of BGM

3. PARTICULAR PROPERTIES

The combination of the above components provides the BGM with exceptional properties compared to other geomembranes available on the market.

3.1 - *Permeability*

- Water, 6×10^{-14} m/s following standard ASTM E 96,
- Methane Gas, 2.10^{-4} $m^3/(m^2/day/atm)$ according to ASTM D 1434-82

3.2 -Physical Properties

- The BGM surface mass ranges between 4.20 and 6.40 kg/m². This is more than three times the surface mass of a 2 mm polymeric liner and four times the surface mass of a 1.5 mm polymeric liner. The larger unit mass makes BGM much less susceptible to wind uplift thus making it easier and safer to install in windy weather.
- Thermal Performance: the low thermal expansion and good dimensional stability of BGM makes it more insensitive to variations in temperature during installation and service regardless of the hour of the day or

the period of the year. With this, BGM suffers less of the fatigue phenomenon compared to other geomembranes, where fatigue appears from the generation of stresses due to temperature variations. This advantage helps achieving a longer service life to BGM.

Figure 3. BGM remains flat regardless of the ambient temperature.

Figure 3 shows two different sites in Chile and Argentina with ambient temperatures ranging from 30 to 40°C and the BGM remains flat with no wrinkles. The absence of wrinkles allows welding to be done continuously during the entire work shift. Also, placement of cover material on top of BGM (if required by the project design) can be done regardless the hour of the day. Furthermore, Giroud (2001) notes that thermal properties of BGM helps ensuring a good and uniform contact with the support material underneath. Typical polymeric geomembranes, because of their thermal properties and for other reasons presented by Giroud and Morel (1992), exhibit more wrinkles than a BGM. This results in less contact with the support material which could cause increased flow under the membrane when the membrane gets punctured, especially if there is a geotextile installed between the membrane and the support material.

3.3 - ***Mechanical Properties***

3.3.1 Tensile Properties

The tensile properties of BGM are derived primarily from the geotextile at the core of the product. When stressed, BGM shows an approximately linear response, typical of a non-woven geotextile, up to failure. There is no yield point. This contrasts with polymeric geomembranes that have a defined yield point at a strain around 12%. Past their yield point, polymeric membranes exhibit a plastic deformation up to the point of failure. Design procedures for polymeric normally dictate that strains in service should not exceed about 4% in order to reduce the likelihood of environmental stress cracking. On the contrary, BGM can operate safely at much greater strains without risk of failure until 35 or 40% for J.P Giroud.

3.3.2 Puncture Resistance

3.3.2.1 Aggregate Puncture Test

Tests have been performed on BGM using 20 – 40 mm crushed stone on the geomembrane applying a pressure equivalent to 40 m of water head without puncturing the membrane (measured by the laboratory of the French Agriculture Ministry (IRSTEA) using NF 84515 standard).

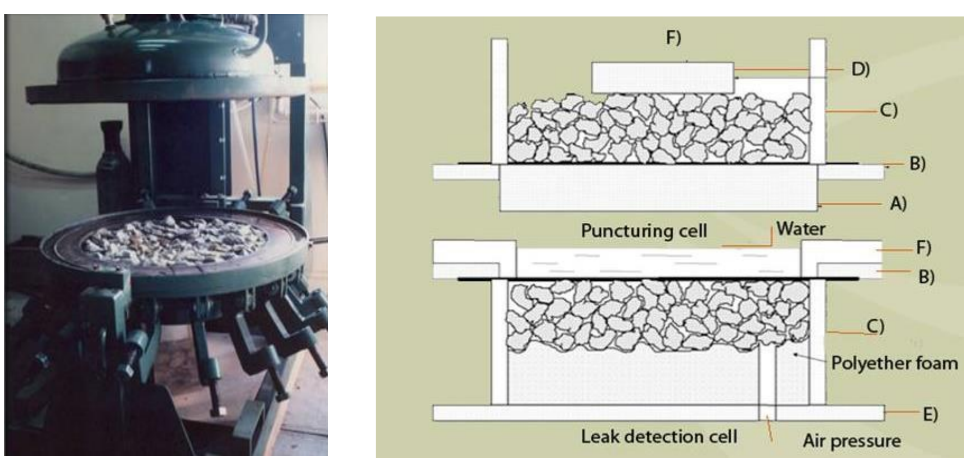

Figure 4. Equipment for measuring puncture resistance by aggregates, NF P 84510

3.3.2.2 - Field Puncture

It is possible that a geomembrane gets punctured when personnel or equipment traverse on top of it during installation, inspections, and during placement of subsequent layers (e.g., geotextile, drainage medium). Being a sturdy and thick material, BGM is capable of withstanding severe point pressures on its surface without being punctured.

3.3.2.3 - High friction angle

BGM offers a large friction angle on its sanded surface. Following are the test results for friction angle done by the INSA University in Lyon following the European Standard NF EN 495-2 and by Sageos in Quebec following standard ASTM D5321-02 which permits a storage above with a higher angle than polymeric geomembrane which needs a geotextile to obtain a similar angle of storage.

Anchored geomembrane		Maximal slope
Rolled sand	39,5°	
Crushed gravel	40°	
Earth dry	35 °	1V\1,5H
Wet clay soil	20 °	1V \ 3H
Aggregates of alluvial origin dry	35 °	1V \ 1,5H
Aggregates of alluvial origin saturated	25 °	1V \ 2H
Dry or wet materials of quarry	45 °	1V \ 1H
Bound or coated materials	45 °	1V \ 1H
Precast concrete – paved	45 °	1V \ 1H

Table.1 Friction angle of BGM with various materials

3.3.3 Density

BGM has a density of approximately 1.26 g/cm^3 following ASTM D 792. With its density larger than that of water, BGM does not float and can repair holes under water.

4. BGM MINING APPLICATIONS IN LATIN AMERICA

BGM has been successfully used in several mining application in Latin America. Examples are described below, indicating why BGM was the preferred geomembrane.

4.1 Containment of solids and liquids:

- Waste rock pad at Antamina copper mine in Peru

Figure 5. Antamina test waste rock pad at altitude 4,000 m

The location of the mine is 400 km from Lima, at an altitude of 4000 m. Temperatures range between -2ºC and 20ºC, with a rainy season (altiplano winter) and dry season (seasonal winter).
In the Antamina copper mine , a BGM, the most resistant to puncture of 5,6 mm of thickness following standard ASTM D 5199, unit mass of 6,40 kg/m² following ASTM D 3776, was used to line a waste rock pad due to the superior puncture resistance of 650 N following standard ASTM D 4833 and 35 kN following the French standard NFP 84523 for puncture by aggregates, permitted the use of a single layer of BGM without protection geotextiles. This enabled a faster installation schedule in these extreme conditions, as only one geomembrane was required to be installed rather than a thinner polymeric geomembrane and two protection geotextiles. The flow directly on BGM has facilitated the recuperation of leachate as BGM has a good Manning coefficient of 0.012, (testing laboratory RK Frobel in the U.S).

- Heap Leach pad at Dolores silver mine in Mexico,

The Dolores mine is a large silver mine located in the north of Chihuahua, Mexico. Dolores represents one of the largest silver reserves in Mexico and in the world. Mexican regulations require the construction of heap leach pads with two impervious layers. The mine required to build a new heap leach pad in a steep valley with slopes greater than 26° and a rough subgrade (see Figure 6). A 4.8 mm thick BGM with a unit mass of 5.80 kg/m² was chosen.

Figure 6. Dolores silver mine heap leach pad on a slope of more than 26°

- Lithium evaporation ponds at the Atacama Salar in Chile

Lithium producers have usually employed PVC membranes for the waterproofing of the salar brine evaporation ponds to increase the lithium concentration in the solution. The use of PVC in this application poses several challenges including, among others, the need to cover it to avoid degradation by the UV radiation and the need to place a clay layer under the membrane to prevent puncture. Rockwood Lithium (now Albemarle) started looking for alternate materials to line the ponds. In 2012 they used a BGM to line three bischofite evaporation ponds with the BGM placed directly on the halite floor with no clay layer under it and no cover ton protect it from UV radiation. The BGM is 3.5 mm thick (ASTM D 5199) with a unit mass of 4.20 kg/m² following ASTM D 3776 (Figure 7). Installation was completed in 2012 and BGM continues to perform satisfactorily.

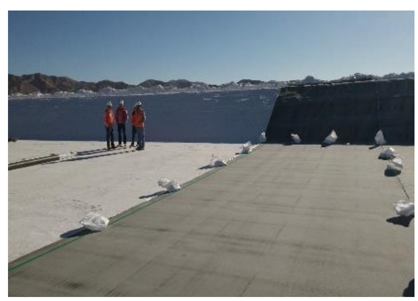

Figure 7a). Lithium evaporation pond

Figure 7b). No wrinkles of BGM despite being exposed at high temperature

- Barahona spoil dump at Codelco's Teniente mine in Chile

Construction of the access tunnel to a new level at Codelco's underground copper mine near Rancagua in Chile entailed the excavation trough several horizons of waste rock with potential for acid drainage. This required that spoils from the excavation be stored in a waterproofed area to avoid contamination of the soil with the acid drainage. Initial design considered the use of four layers of LLDPE membrane. A revision of the design by another consultant replaced the four layers of LLDPE with a single BGM geomembrane. The BGM chosen for this project is 5.6 mm thick with a unit mass of 6.4 kg/m^2. The key arguments to use BGM were r the reduced requirements for surface preparation to deploy the geomembrane and less time to build (a single BGM layer vis-à-vis four LLDPE layers) which resulted in reduced construction costs. Another argument in favour of BGM was its large unit mass that makes it less susceptible to wind uplift by the strong winds present in the project area. (Figure 8 and 9)

Figure 8. A 5.6 mm thick BGM deployed

Figure 9. Leachate collection canal

Surface preparation for BGM was limited to vegetation clearing, scarification, removal of stones larger than 60 mm and compaction. BGM was also used for the leachate collection canal because of its UV resistance and its low Manning's coefficient.

- Storage of solid wastes at a niobium mine in Brazil

A 3.5 mm thick BGM (ASTM D 5199) with a unit mass of 4.20 kg/m² (ASTM D 3776) was used for basal lining despite its intrinsic higher capital cost, in a solid waste storage facility at a niobium mine in Brazil. The customer considered the BGM because of its greater puncture resistance than other flexible geomembranes. Another reason to use BGM was the ability to continuously deploy it at ambient temperatures up to 42ºC without wrinkling. Due to its puncture resistance, BGM could be used in direct contact with the low permeability (10^{-5} m/s) laterite subgrade, combining to provide a double watertight layer. The overall cost of the work was cheaper than the initially proposed solution with a polymeric geomembrane, and the BGM also presented a safer environmental solution (double layers of low permeability BGM and soil support in laterite). See Figure 10.

a) Plan View

b) Site view of direct trafficability on BGM

Figure 10. Niobium mine in Brazil

- Sulfide deposit at La Granja mine in Peru

La Granja is a Copper-Molybdenum mine in northern Peru in the province of Chota, Cajamarca owned by Rio Tinto. The process of extracting the ore involves the use of sulfur, which, after treatment, generates sulfide waste. The mine is in a valley with a restricted site area, driving the client to make the sulfide deposits on steep slopes (the deposit is based on a 1V:1H slope) in a region with sudden changes of weather.
Rio Tinto Minera Peru had three targets in opening this mine: hold a stringent planning during construction, find a geomembrane with a high friction angle and assuming the training of local staff. These 3 targets led the designer to choose a BGM of 4 mm following ASTM D 5199 and a unit mass of 4.85 kg/m² following ASTM D 3776 for an installation by a large variation of weather and having the manufacturer to train local workers on site. Despite its high friction angle, BGM is anchored in 4 points: anchorage at the top of the slope with two intermediate anchors on the slope and anchor at the foot of the slope on gabions. (Figures 11)

Figure 11. 1H:1V Slope installation

- Furioso mine in Chilean Patagonia

The Furioso Mine is approximately 75 km southwest of Chile Chico at an elevation of about 1,400m above sea level in the Chilean Patagonia. The area is not accessible during the winter months (between mid-February through December) due to the high snowfall and poor road conditions. Daytime temperatures in winter can be as low as -25°C with wind speeds surpassing 80 km/h. Snowfall can occur just about any day of the year slowing down construction activities (Figure 12).

Figure 12. Snow on the site in mid-summer

The mine closure activities included the upper encapsulation of the mine's spoil dumps to avoid surface water runoff to enter the spoil and generate acid leachate. BGM was selected over other types of materials (GCL, HDPE and LLDPE) mainly due to its higher shear resistance at the interface with its support bed. Another factor supporting the choice of BGM was the ease of installation in harsh weather conditions. The designer chose for this project a 4 mm thick BGM with a unit mass of 4.8 kg/m2.

Despite the adverse conditions of the Furioso mine site, the job was completed in one year, earlier than initially forecasted, BGM was covered with material every day without any additional geotextile protection. (Figure 13).

Figures 13. Pushing material of high grain size all along day whatever is the t°.

The installation and seaming process does not require a specialty subcontractor and thus the mine operator used its own workforce (local Patagonian residents) to do the closure work. The large unit mass of the BGM and its low thermal expansion allowed continuous placement of the soil cover, regardless of the time of the day and the ambient temperature. (Figure 13).

4.2 - Tailings dams:

- Cerro Lindo mine in Peru

The tailings dam is a 30 m high, earth and rockfill dam built with a capacity close to 67,000 m3 for the purpose of controlling processed water at the Cerro Lindo copper mine in the Andes, 240 km south of Lima, at an elevation of approximately 2 500 m. The upstream face has a slope of 1V:2H and cement grouting was used to control seepage under the dam and trough the abutments.
BGM was installed directly on the compacted soil which was mechanically prepared to provide a smooth surface and it was mechanically fastened to a concrete plinth at the toe and abutments of the dam. Figure 14.

Figures 14. Cerro Lindo site, sealing BGM on concrete of abutments

BGM was chosen due to:

- Excellent friction angle for slope installation (34°),
- Excellent weathering resistance as the membrane will stay exposed in high altitude,
- No specialty installer or special equipment needed. Installation can be done by local workers after training by the manufacturer on site.

  After construction was completed, on August 15, 2007, the dam was subjected to an earthquake of magnitude 8.1. The site suffered another earthquake on November 3, 2010, with a 5.0 magnitude. Observations and laboratory testing of the existing BGM material after these two earthquakes proved that the dam performed satisfactorily with no damages to the BGM.

- Cerro Negro gold mine in Argentina

The Cerro Negro mine in Santa Cruz Province, southern Argentina, is one of the largest golds and silver mine in the world. As the client Goldcorp was looking for an approach to bring a “Sustainable Prosperity” for the nearby population, they were driven to use BGM due to its possible installation by local manpower after in-situ training by the manufacturer. A 4 mm thick BGM with a unit mass of 4.8 kg/m² was chosen to line the tailings pond.

Figure 15. Cerro Negro Gold Mine, Argentina

- Peñasquito Mine, Mexico

The Peñasquito mine is a polymetallic mine that belongs to Newmont-Goldcorp and it is located near the town of Mazapil in northwestern Mexico. The tailings storage facility had been lined with an LLDPE geomembrane. In late 2018, the designer decided that the next three lifts of the East Tailings dam would use BGM instead of the LLDPE. The East dam is approximately 1.9 km long and it is built with rockfill. The first lift to be lined with BGM is 13 meters high with a slope of 2, 65H:1V. To minimize material losses, the manufacturer supplied BGM in 45 m long rolls instead of the standard 65 m length. Since the initial dam was lined with LLDPE, the connection between the LLDPE and the BGM was done at a horizontal bench, using a procedure developed by the BGM manufacturer.

Figure 16. Peñasquito BGM lined - extension of the tailings dam

- Underwater repairs of HDPE liner at Antamina copper mine in Peru.

The tailings dam at the Antamina copper mine is lined with HDPE geomembrane. During construction of the 15-m high lift of phase 5 of the dam, it was required to build a new access road on the right abutment. Blasting works during the construction of the road generated rock projections, which caused several punctures on the HDPE liner, some of them below the water level in the tailing's reservoir.

Several options were considered to repair the damages to the submerged HDPE membrane, including among others – the construction of a dyke inside the tailing's reservoir and the pumping of the water to form a dry dock. After the analysis, it was decided to use a process previously used at a gold mine in Spain, which consists in placing BGM patches on top of the underwater punctures of the HDPE. Adhesion between the HDPE and the BGM is obtained by using a slow-curing asphaltic mastic placed between the two membranes. The BGM patches need to be ballasted for a minimum of 21 days (which is the curing time of the mastic) to secure a good bonding between the HDPE and the BGM.

BGM patches were cut in a dry area and the asphaltic mastic was applied to the underside of the BGM. Once prepared, the patches were handled by divers and placed on top of the HDPE punctures. Ballasting of the BGM patches was done with sandbags.

Figure 17. Antamina tailings reservoir

5. CONCLUSION

Although still not a mainstream product, BGM is becoming more commonly used for mining projects in Latin America. The projects described in the paper show that BGM is a very effective waterproofing solution for a variety of applications within the mining industry, especially in remote areas with harsh weather conditions. BGM's key features and its ease of installation normally translate into shorter construction schedules and lower overall project costs (as compared to other geomembranes in the market), particularly when the benefits of earlier production of the mining project are factored in.

REFERENCES

Beck A. (2014), The Financial Benefit of Electrical-Leak Location to the Mining Industry, Proceedings of Geosynthetics Mining Solutions, 2014 September 8−11, 2014, Vancouver, Canada Published by Info Mine Inc.

Department of Energy (1994), Prototype Hanford Surface Barrier: Design Basis Document, Office of Environmental Restoration and Waste Management, Bechtel Hanford, Report BHI-00007, November

Krishnan J.M. and Rajagopal K.R. (2003), Review of the uses and modelling of bitumen from ancient to modern times Apply American Society of Mechanical Engineers, Mech Rev vol. 56, no 2, pp. 149-214.

Rowe, R. Kerry, Chappel, M. J., Brachman, R.W.I, and Take, W.A. (2012). “Field study of wrinkles in a geomembrane at a composite liner test site,” Canadian Geotechnical Journal, Vol. 49: pp. 1196–1

Marchiol, A., Ricard, D. & Robinet, J., 2015. *Surveillance d'une géomembrane bitumineuse oxydée dans une couverture de stockage sur le long terme.* La Rochelle, Proc. 10th Rencontres 10, 251-268.

Department of Energy (1994), Prototype Hanford Surface Barrier: Design Basis Document, Office of Environmental Restoration and Waste Management, Bechtel Hanford, Report BHI-00007, November

S.F Xu, H. Zhong, AY Hu and S.Imaizumi, Evaluation of tensile force of liner system with the variation of height of incinerated ash

Bianchi Ch., Rocca-Serra C., Girollet J., Utilisation d'un revêtement mince pour l'étanchéité d'un barrage de plus de 20 mètres de hauteur. In 13ème Congrès de Grands Barrages – New Delhi – 1979