ABSTRACT

Bituminous Geomembranes (BGM) have been present on the American market for over 25 years, which are manufactured by impregnating a non-woven polyester geotextile and glass fleece within an elastomeric bitumen compound. The geotextile provides the mechanical resistance and high puncture resistance. The bitumen provides the waterproofing properties of the geomembrane, ensures its longevity and has the highest friction angle compared to any other available geomembrane on the market.

Testing results will be discussed for the friction angle of BGM with various interfaces. Tests done in private laboratories in USA (California), in Canada following ASTM standards and in public laboratories of the Ministry of French Agriculture and Engineering school following CEN standards in France. Different angle of friction values following the type of soils in contact with the geomembrane will be presented.

Examples in different applications will be discussed for the construction of solid waste storage and construction of heap leach pads on slopes, avoiding any need of a geotextile cushion in between the geomembrane and soil. These solutions permit efficiency and economic gains, therefore short delays and a quick return on investment.

A geomembrane with a high angle of friction gives an interest to build in areas with potential seismic activity. An example project describes why BGM was chosen by The Los Angeles Department of Water and Power for building two side-by-side reinforced concrete reservoirs. Another example of a project will describe the behavior of BGM under an earthquake of a magnitude of 8.1 in Peru for a tailings dam using BGM on the upstream face of the dam.

INTRODUCTION

In the 1970’s, geotechnologies initiated powerful innovative techniques. A bituminous geomembrane (BGM) was invented on-site in the USA, and was introduced in Europe by two worldwide and famous bitumen specialists: Royal Dutch Shell (a world-renowned oil company) and Colas (the first road contractor in the world).

The first applications (Figure 1) were in France, under the supervision of the
internationally recognized Geosynthetics expert, Jean-Pierre Giroud. It was for an industrial application near Grenoble and for potable water storage reservoirs in the Alps at an altitude of around 2,000 m.

Figure 1: First BGM applications

1 - STRUCTURE AND CHARACTERISTICS OF BGM

Bituminous geomembranes (BGM) are manufactured by impregnating a polyester geotextile in a bitumen compound. The geotextile provides the mechanical resistance and especially the high puncture resistance of the geomembrane. The bitumen compound provides the waterproofing properties and ensures the longevity of its mechanical properties by impregnating the geotextile totally. The components of the BGM structure are shown in Figure 2 below.

Figure 2: Typical structure of a bituminous geomembrane

- Non-woven, long fiber polyester geotextile between 200 to 400 g/m².
- 50 g/m² of glass fiber fleece.
- The geotextile and glass fleece are impregnated in a bitumen compound giving an overall thickness from 3.50 mm to 5.60 mm. This makes BGM the thickest and weightiest geomembrane on the geosynthetic world market.
- The sanded surfacing supplies a frictional non-slip surface by any type of weather that improves installation and maintenance safety of workers. At the same time, the sand protects the bitumen compound when BGM is left exposed.
On the bottom face there is an anti-root film.

Some technical characteristics of BGM are:

- A low permeability of $10^{-14}$ m/sec. Darcy’s law is permanently at this level, different to clay liners which require humidity to reach a level of maximum $10^{-10}$ m/sec using clear water and to keep a humid layer of earth above the liner (Laboratory IRSTEA, French Ministry of Agriculture, France).

- Easy to connect and seal to rock and concrete structures, thus allowing to have the same permeability at any point of the lining (Figure 3).

![Figure 3: BGM connection to a) HDPE pipe (Mongolia); b) Canals in UK (UK)](image)

- Very high mass per unit area giving an important resistance to uplift in windy regions. BGM can remain exposed (large financial and environmental economy in avoiding transport of cover materials) and can be laid in very windy regions.

- High puncture resistance. Tire-mounted vehicles and equipment can drive directly on top of the geomembrane during installation and maintenance (Figure 4).

![Figure 4: Tire mounted equipment traffic directly on top of BGM](image)

- Good dimensional stability. BGM does not form wrinkles with daily variations of temperature due to its geotextile reinforcement. Welding and placing cover material can take place at any time during the day.

- BGM can store potable water as it passes successfully TCLP (Toxicity characteristic leaching procedure) tests and has obtained the US international certificate of NSF/ANSI...
The density is 1.2 ton/m³ following Standard ASTM D 1505 and ASTM D 792 Method A so BGM can be installed under water without floating. The seams under water can be sealed with a special mastic.

BGM has the highest angle of friction for any type of geomembrane, and therefore can be used in seismic regions as demonstrated in the field (Milpo dam having supported an earthquake of a magnitude of 8.1 on the Richter scale) and by tests done by Precision Lab (now TRI Environmental) in California for the Los Angeles Department Water and Power who has tested the material’s interface friction.

2 - ANGLE OF FRICTION AND INTERFACE FRICTION

2.1 - ANGLE OF FRICTION

Two types of BGM are described:

The standard BGM material has one face that is sanded (30-35° friction angle) and the other face is smooth with an anti-root film (16° friction angle) for the lower face. Table 1 illustrates the results following tests done by the laboratory of French Ministry of Agriculture on the sanded face and at the school of Engineers INSA in Lyon following the European Standard NF EN 495-2. These same results are confirmed by tests performed by Sageos (independent Canadian laboratory) following standard ASTM D5321-02.

<table>
<thead>
<tr>
<th>ANCHORED MEMBRANE IN MATERIAL</th>
<th>FRICTION ANGLE</th>
<th>MAXIMAL HILLSIDE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rolled sand</td>
<td>39.5°</td>
<td>1V \ 1.2H</td>
</tr>
<tr>
<td>Crushed gravel</td>
<td>40°</td>
<td>1V \ 1.2H</td>
</tr>
<tr>
<td>Earth dry</td>
<td>35°</td>
<td>1V \ 1.5H</td>
</tr>
<tr>
<td>Saturated Earth</td>
<td>27°</td>
<td>1V \ 2H</td>
</tr>
<tr>
<td>Wet clay soil</td>
<td>20°</td>
<td>1V \ 3H</td>
</tr>
<tr>
<td>Aggregates of alluvial origin dry</td>
<td>35°</td>
<td>1V \ 1.5H</td>
</tr>
<tr>
<td>Aggregates of alluvial origin saturated</td>
<td>25°</td>
<td>1V \ 2H</td>
</tr>
<tr>
<td>Dry or wet materials of quarry</td>
<td>45°</td>
<td>1V \ 1H</td>
</tr>
<tr>
<td>Bound or coated materials</td>
<td>45°</td>
<td>1V \ 1H</td>
</tr>
<tr>
<td>Precast concrete - paved</td>
<td>45°</td>
<td>1V \ 1H</td>
</tr>
</tbody>
</table>

The BGM HFA (High Friction Angle) has no anti-root film on the lower face, leaving the face exposed with elastomeric bitumen. The upper face remains sanded. Values were found between 36° and 38° on both sides for a specific soil Class 2 by the PGL Lab in Anaheim, CA and by TRI testing lab in Austin, both following standard ASTM 5321.
Due to this high friction angle, BGM is the type of geomembrane retained for some specific works with steep slopes and when the friction of angle of the natural terrain is up to 34 degrees. Design alternatives are HDPE with a geotextile below waste rock material versus BGM with waste rock directly on top. Both these solutions give the same friction angle. Due to less material, the cost of the BGM solution was 10 to 20% cheaper. Some examples where BGM was the liner of choice are:

- In the United States of America: A US Navy base near Oakland, California Coletanche was chosen due its friction angle being similar to the friction angle of the wastes. With this advantage, BGM did not require to alter the existing natural topography before works to make the slope less steep, and avoids strong drawbacks in case of encroachment on waters of the lagoon.

- In France:
  - Storage of solid ash wastes in Strasbourg at the exit of an incinerator of domestic wastes. The advantage was that BGM can hold wastes directly above it versus using HDPE with a geotextile over it to obtain the same friction angle. The cost of BGM solution was 10% less costly in this case.

- Capping of domestic wastes in Île de La Réunion, France which is subject to hurricanes once or twice per year.
Figure 7: BGM HFA for installation on steep slope and layer of soil directly on upper face

- Near Lille, capping chromium wastes for Ugine Kulhmann

Figure 8: Soil and grass directly on BGM HFA installed upside down

- In Turkey, storage of solid wastes in a gold mine at Efemcukuru

Figure 9: Storage of rocks coming directly from the underground mine

- In Mexico, silver and gold mine heap leach pad on a very steep slope

Figure 10: Direct storage of rocks and gravel

- In Patagonia Chile
2.2 - SEISMIC BEHAVIOR

2.2.1 - EARTHQUAKE IN PERU OF MAGNITUDE 8.1 ON THE RICHTER SCALE.

The Cerro Lindo mine is in the Ica region of Peru and owned by Milpo, which is a Peruvian mining company headquartered in Lima. A 30 m high, earth and rockfill dam was built with a capacity close to 67,000 m³ to store and control processed water from a filter tailings deposit. The dam built is located at an altitude of approximately 2,000 m in a region characterized by strong winds. BGM was installed directly on the prepared compacted soil and was left exposed. It was anchored at the crest of the dam in a trench excavated to a width of 1 m and a depth of 0.6 m, which was then filled with compacted material. The mine is around 20 km East of Chincha, Peru where an earthquake hit in year 2007, characterized by an earthquake of a magnitude of 8.1 and resulted in ground shaking for about 3 minutes. The Peruvian government stated that 519 people were killed by this earthquake. The peak ground acceleration recorded at the Ica station was 0.27 g. A review of the dam carried out by Golder Associates (Eldridge, T.) showed that the Coletanche liner survived the earthquake without damage or change in properties.
2.2.2 - LABORATORY TESTING.

The performance of BGM during dynamic loading was confirmed by tests done at Precision Laboratory (now TRI Environmental) in Los Angeles, California. For the construction of two large potable water reservoirs in Los Angeles (client Los Angeles Department of Water and Power), it was important to evaluate if a plane of sliding occurs at either the BGM/fill interface or the BGM/Class 2 bedding material interface. Therefore, direct shear testing was planned to evaluate the frictional resistance for these two interfaces. The good behavior of BGM under seismic loading is linked to the high strength of the geomembrane but also to the high interface shear strength that develops between the geomembranes and the adjacent material. Reason for requiring these criteria being that Los Angeles is known to be located in one of the highest seismic zones in the world. The results of the testing indicate cohesion as high as 33 kN/m² and a friction angle as high as 36 degrees (Ponnaboyina, H). These high values are due to the high puncture resistance which allows the geomembrane to conform to the shape of the particles as shown on Figure 14 when the normal (N) and shear (T) loads are applied. Therefore, the slip plane is not smooth but undulated and the particles above and below the geomembrane can interlock. The geomembrane does not tear or puncture and therefore a high interface strength develops (Ponnaboyina, H). In Figure 14 we see the function of friction between particles and membrane (green arrows) that are interlocking (yellow arrows).

The tests were performed at a constant rate of displacement of about 2.5 millimeters per minute (0.10 inch per minute) to ensure that pore pressures were not developed during testing. It was noted that at higher confining pressures, the tensile resistance of the BGM becomes engaged in resisting the shear load when in contact with the Class 2 permeable material, resulting in a higher cohesion.
with a lower contribution of the interface friction angle. Therefore, for the case that the reservoir is full, a greater shear displacement is expected to occur within the BGM material itself than in the overlying Class 2 permeable material or the underlying compacted fill. For the case that the reservoir is empty, the greater shear displacement is expected to occur within the compacted fill or at the BGM/fill interface.

The SSI studies of the east reservoir that were performed using design peak ground acceleration (PGA) of 1.0g indicated that sliding (i.e., permanent displacement after earthquake) was not expected at either interfaces. Since the reservoir is covered with 30-foot high compacted fill embankments on all four sides, the additional lateral resistance derived from these embankments likely assisted in resisting the sliding forces due to earthquake load.

CONCLUSION

Due to its high friction angle, there is interest to use BGM on steep slopes for heap leach pads or capping solid wastes, and to be used in seismic regions. BGM can be placed directly over waste materials without the need for altering existing topography with friction angles up to 34 degrees.

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