Bituminous geomembranes performance for projects in high seismicity regions

Tarik Hadj-Hamou
SLR International Corporation, USA

Terry Eldridge
Golder Associates, USA

Robert McIlwraith
Axter Coletanche, Australia

Bertrand Breul
Axter Coletanche, France

ABSTRACT: In recent years the number of applications in zone of high seismicity has increased. Consequently, the need for geomembranes with high interface shear strength under dynamic loads has increased. Due to their nature, combining a geotextile for strength and puncture resistance and bitumen for the waterproofing low permeability characteristics, bituminous geomembranes (BGM) have shown to possess high interface shear resistance under seismic loads. The paper discusses the reasons for the strong resistance of BGM, namely the ability to deform and espouse the tortuous path along the interface between soil particles without punctures due to the viscous-elasticity of BGM which allows for the development of a strong interlocking between soil particles and the bituminous geomembrane yielding high values of interface shear strength.

This paper presents two cases studies. In the first case, the paper reports the use of Coletanche in a project in a highly seismic zone where the bituminous geomembrane is used as part of a leak collection system under buried concrete reservoirs. Laboratory testing was performed to establish the geomechanical properties required for use in a dynamic finite element analysis of the reservoir subjected to seismic loading.

The second case study discusses the performance of a tailings dam lined on its bituminous geomembrane in Peru in Cerro Lindo subjected to a large seismic event. Results are presented of the survey performed by a consultant on the behavior of the dam and, in particular, of the BGM following an earthquake of magnitude of 8.1 in Chincha close to the site.

Keywords: bituminous geomembrane, seismic soil structure interaction, post-earthquake performance

1 INTRODUCTION

The City of Los Angeles Department of Water and Power (LADWP) is building two large side by side concrete water reservoirs off of highway 134 in Universal City, Los Angeles, California. Each reservoir is designed to hold over 55 million gallons (210,000 m^3) of fresh water. The reservoirs will be approximately 40 ft. (12 m high and each cover approximately 50 acres (20 ha). The reservoirs include a base slab, concrete walls, and a top slab supported by concrete columns. The mat foundation varies from 50 inches (1.25 m) thick along the periphery to 36 inches (0.91 m) thick in the center. The walls are 48 inches (120 m) thick.

LADWP determined that the on-site soils beneath the east reservoir were only medium dense and could if saturated be subject to liquefaction during a strong earthquake and could settle a few inches. An order of magnitude that could lead to structural damage to the concrete reservoir and affect its integrity.

To remediate the liquefaction potential, LADWP engaged in a remediation and mitigation program that involved:

- removing and recompacting the soil to a depth of 20 ft. below the mat foundation.
- installing a leak detection and control system under the foundation.

The leak detection system installed under the reservoir consists of a gravel layer and a bituminous geomembrane. A series of perforated pipes were placed in the gravel draining towards sumps. To allow drainage, the pipes were placed in gravel filled, GCL lined trenches spaced along the footprint of the reservoir. The geomembrane was therefore not continuous under the footprint, water tightness was provided by the GCL in the trenches.

From a modeling standpoint, the profile under the reservoir consists of the concrete mat foundation of the reservoir underlain by:

- 3 ft. (0.9 m) of gravel,
- A 189 mils (4.8 mm) thick bituminous geomembrane Coletanche ES3,
- 20 ft (6 m) of recompacted fill, and
- The native material

This column is shown schematically on Figure 1.

Figure 1. Profile under the mat foundation

The geomembrane is in effect embedded between two soil layers and fully confined. The vertical loads on the geomembrane will range from a minimum when the reservoir is empty to a maximum value when the reservoir is full of water.

2 ANALYSIS

2.1 *General*

LADWP performed a full seismic time domain Soil Structure Interaction (SSI) analysis of the reservoir/soil system. To perform the analysis, they needed:

- earthquake ground motions,
- geometry of the system,
- mechanical properties (static and dynamic) of all materials involved.

Only the properties of the soils and geomembrane are discussed herein. Of particular interest was the geomechanical characterization of the bituminous geomembrane. Because geomembranes, as well as geotextiles act as separators between soil components here between the gravel and the recompacted fill, they add an element to the anticipated performance of the system: the interfaces between the material above and below the geomembrane.

Consequently, in addition to the mechanical properties of the geomembrane, the interface properties between each material in contact with the geomembrane needed to be quantified.

The bituminous geomembrane presents two sides with different texture. One side is rough and coated with sand whereas the other is smooth.

2.2 *Soils*

The fill material under the geomembrane and the drainage material above the geomembrane were specified by LADPW. In a paper published in 2013, Lew et al., described the geomechanical properties assigned to the different materials.

The two materials that will be in contact with the BGM are (1) the overlying 3-foot (0.91 m) thick drainage material consisting of permeable material and (2) the underlying subgrade consisting of compacted fill.

The drainage material consists of Class 2 permeable material as specified by California Department of Transportation (2006). The compacted fill material is the on-site soil that was excavated placed back, and recompacted to a dry density equal to 95% of the maximum dry density obtainable using ASTM D1557. According to Unified Soil Classification System, the compacted fill and Class 2 permeable materials classify as silty sand (SM) and poorly-graded gravel with sand (GP), respectively. The compacted fill is primarily a sandy material with about 10 percent fine gravel. The Class 2 permeable material contains about 65 percent fine to coarse gravel. The largest gravel size in the compacted fill is 12.7 millimeter (1/2 inch) whereas the Class 2 permeable material contains coarse gravel up to 19.1 millimeter (3/4 inch in size).

Lew et al estimate that the shear resistance of the gravel can be characterized by a factor angle of 40 to 45 degrees. They did not suggest shear strength characteristics for the compacted fill. Review of literature data indicates that for a sandy silt compacted to 95% of maximum dry density a range of value for the drained friction angle is on the order of 30 to 36 degrees.

2.3 *Interface*

The two interfaces were tested BGM/Full and BGM/Class 2 gravel to generate the geomechanical parameters for use in the SSI. The tests were conducted at different degrees of saturation: moist and fully saturated to represent potential conditions at the site. Saturation representing the case where leakage would saturate the gravel above.

The interface friction testing was performed by Precision Geosynthetic Laboratories (PGL) now TRI Environmental, Inc., of Anaheim, California using the procedures stated in ASTM D 5321 (Determining the Coefficient of Soil and Geosynthetic or Geosynthetic and Geosynthetic Friction by Direct Shear Method).

The tests were performed at a constant rate of displacement of about 2.5 millimeter per minute (0.10 inch per minute) to ensure that pore pressures were not developed during testing. Although ASTM D 5321 suggests a shearing rate of 1 millimeter per minute (0.04 inch per minute), a higher rate was used considering the materials tested were primarily granular and would not develop excess pore pressures. For a maximum displacement of 76.2 millimeters (3 inches), a single test was completed in about one-half hour.

The tests were conducted using three normal pressures of about 50, 120, and 240 kN/m2 (7.25, 17.1, and 34.8 psi). The test loads were selected based on the range of pressures anticipated in the field for empty reservoir and full reservoir cases.

The complete results are reported and discussed in Lew et al (2013) for the different saturation conclusions and normal stress conditions.

Friction angles and cohesion values as high as 37.5 degrees and 38kN/m^2 (5.5 psi) were measured. The results of the interface testing show that the angle of friction of the interface is on the same order of magnitude as the angle of friction of the soils (Class 2 gravel or compacted fill). In essence, from a shear stress continuity through the soil column shown on Figure 1 the BGM does not behave as a very weak link. As long as the deformation within the soil column at the interface does not lead to a rupture in the BGM used at the site is grade ES3 manufactured by Coletanche

Figure 2 shows the shear strength envelope retained from the interface testing used by Hudson et al (2012) in their SSI analysis. The shear strength is bi-linear following the lower bound of the values measured.

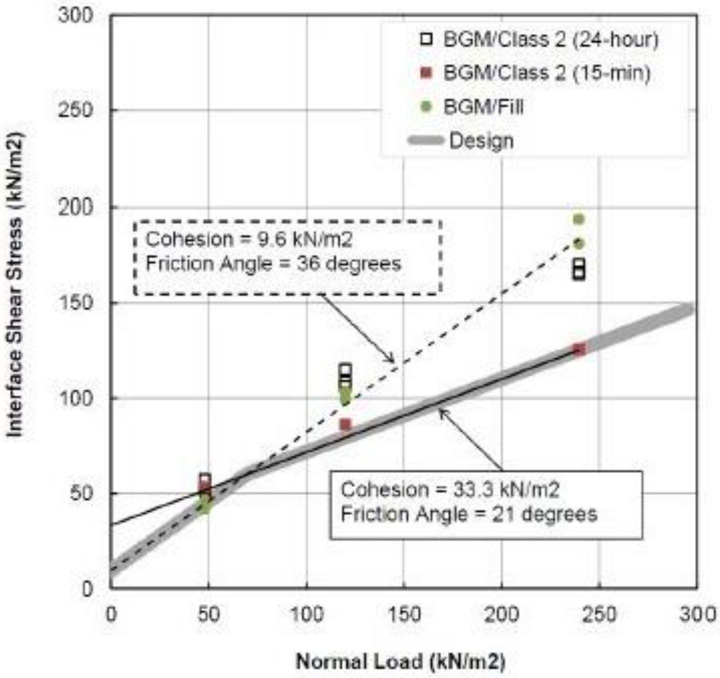


Figure 2. Stress strain curve for interface

This geomembrane is characterized by a bi-linear stress strain wave as shown on Figure 3. The bi-linear stress strain wave is characterized by a tensile modulus J_1 for the first straight line of the stress strain relationship up to the "elbow" defined by ε_{elb} and T_{elb} and a tensile modulus J_2 for the second straight line. J_2 is calculated based on the load at failure. Laboratory testing on the sample led to the following value for ES3:

ε_{elb} 4%. T_{elb} = 14 kN/m J_1=350kN/m, and J_2 is obtained from the load at failure

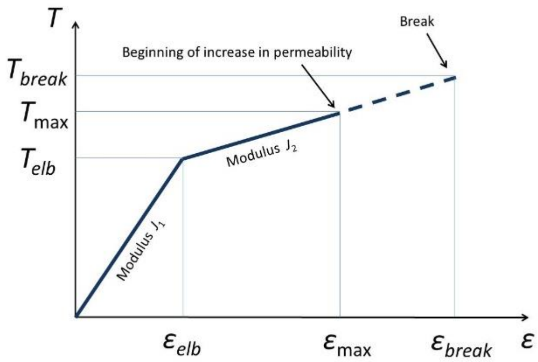


Figure 3. Typical stress strain curve for Coletanche BGM

In designing with Coletanche, it is therefore recommended to stay at strain level below 4% to benefit fully form the performance of the geomembrane.

Figure 4 shows the interlocking mechanism when a geomembrane is sheared between soil layers. Due to its flexibility the geomembrane will follow the undulations of the base soil surface and the soil above will fit within the depressions and indentations. When sheared under static or seismic loading when the earthquake induced stress waves arise through the soil column, the grains of soil enter in contact developing interlocking forces as shown on Figure 4 and result in shear stress on the geomembrane at each contact.

Because the shear strain level in the ground during an earthquake is low, less than one percent, the geomembrane, confined and locked in with the soils particles will also experience low level of shearing, much less than the 4% deemed threshold for design. Consequently, Coletanche is not affected by the seismic induced shearing and will not de overstressed during a seismic event.

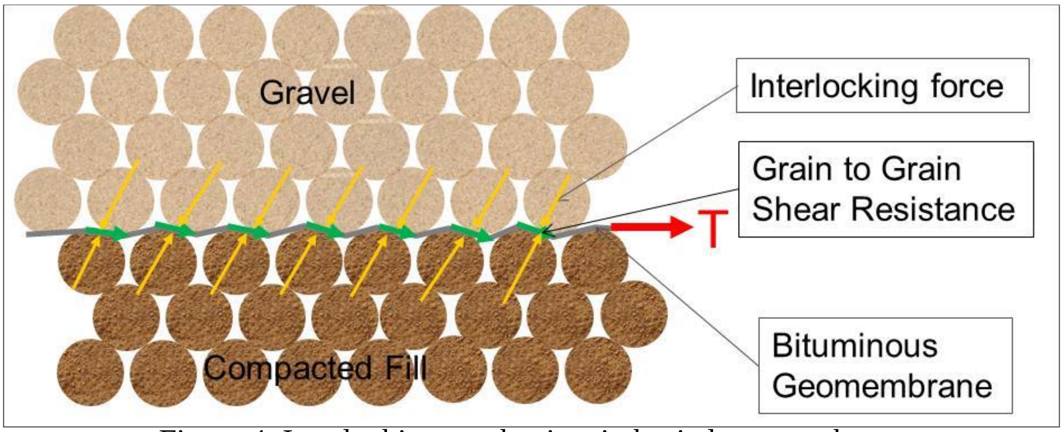


Figure 4. Interlocking mechanism in buried geomembrane

Since the interface friction angle between the soils and the interfaces are in the same value of magnitude, the risk of slippage of the confined BGM is very low.

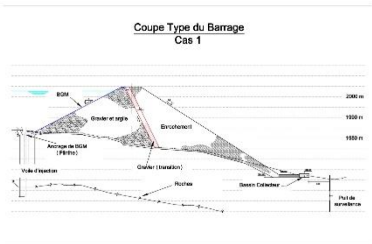
3 DETERMINATION OF CRITICAL SLIDING INTERFACE

The SSI studies performed by Hudson et al (2012) 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.

Here under two examples of dam in South America submitted to earthquake of 7,6 on Richter scale in 2007 in Chincha (Peru)and in 2015 all two near respectively the two sites . After the seism, the two dams were completely examined by the international consultant firm Golder Santiago (Chile). These 2 works were completely sounded after the seism. No damage was noticed in the membrane and the waterproofness perfectly maintained.

a 30-m high earth and rock fill dam in Peru of polluted water, Milpo is a Peruvian mining company headquartered in Lima. The company operates four mining unit. One is the Cerro Lindo mine, located near the town of Chincha.

At the Cerro Lindo mine, a 30-m high, earth and rockfill dam was built 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. This upstream face of the dam was waterproofed by means of a BGM. The upstream portion of the dam was built with compacted soil consisting of gravelly clay with a 1V/2H face slope. In the middle of the dam, a transition layer is 2 m wide and runs from the bottom to the crest of the dam. In addition, a grout curtain was installed along the entire length of the dam along the upstream toe of the dam and up to the crest of both abutments. At the downstream toe, an infiltration-water collection box and monitoring wells were installed to allow a permanent control of watertightness.



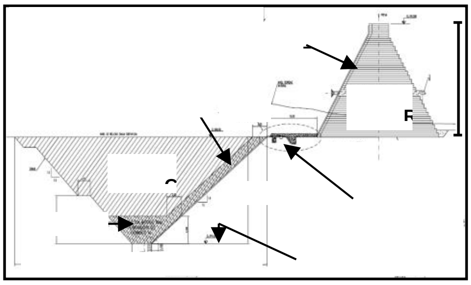
Typical cross section | Work finished | Dam in use

a 23-m high concrete dam in Chile of clear water in a copper mine,

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 used a BGM as the low permeability upstream facing element on the dam to control seepage through the dam. A deep cut-off trench was used to control seepage beneath the dam and through the abutments. An ultrasonic apparatus was used as part of the quality control on the BGM seams.

The upstream and downstream faces of the dam have the same slope: 1V/0.7H.

Downstream, a spillway and an open channel convey water to other areas for refilling a river of which along are villages, crops, cattle….



The dam foundation rests on fluvial ground, and the excavation work required for its construction reached the designed horizon, where fluvial granular soil of raised strength and density was identified.

5 CONCLUSIONS

The first case study in this paper discusses the use of a bituminous geomembrane as a leak detection and leak contact system under a reservoir. The BGM is "sandwiched" between a gravel layer above and compacted fill under. The interface shear strength test indicates that the angle of friction of the gravel, fill, and interface are in the same range. Therefore, a weak plane is not created by the BGM within the soil profile under the structure. This conclusion assumes that the resistance to puncture of the geomembrane from the particles (i.e. protrusion size) in the soils above and below the geomembrane was verified in accordance with basic geosynthetics design practice (Koerner, 1990)

Further, the strain level at which the geomechanical and hydraulic performance of the geomembrane could be affected (typically around 4% for BGM).are well below that induced in the ground during seismic shearing. The SSI analyses performed by Hudson et al (2012) confirm this behavior as the analyses did not identify a weak sliding plane.

BGM such as Coletanche can therefore be used as hydraulic barriers when confined in seismic areas without concern about their integrity.

REFERENCES

ASTM D 1557, Standard Test Methods for Laboratory Compaction Characteristics of Soil Using Modified Effort (56,000 ft-lbf/ft^3 (2,700 kN-m/m^3), *American Society for Testing and Materials*, West Conshohocken, Pennsylvania, USA.

California Department of Transportation (2006), Standard Specifications, State of California, Department of Transportation, Sacramento, California.

Coletanche (2008), Design and Application Handbook for Bituminous Geomembrane.

Hudson, Martin B., Craig A. Davis, Marshall Lew, Alek Harounian, and Liping Yan (2012), "Seismic Resilient Design of a Concrete Box Reservoir," Proceedings of the 6th China-Japan-United States Symposium on Lifeline Earthquake Engineering, ASCE Technical Council on Lifeline Earthquake Engineering, Chengdu, Sichuan, China.

Koerner, R.M. (1990), *Designing with Geosynthetics*, 2^{nd} ed., Prentice-Hall Inc., Englewood Cliffs, NJ, USA.

Lew, M; Ponnaboyina, H.; Davis, C.A.; and Perez, A. (2013). "Interface Friction Testing Between Soil and a Bituminous Geomembrane", Proceedings of Geosynthetics 2013, Long Beach, CA, April 1-4.