The Interface Strength in the Heap Leach Pad Stability Analysis: Laboratory and In-situ Tests

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ABSTRACT: In the design of heap leach pads, it is well known that the stability of the ore heap is dependent on the weakest element material, i.e. of the interface between the low permeability soil (soil liner) and the geomembrane. The interface strength is dependent on the materials involved, both of the soil as well as the geomembrane, and its shear strength is determined by direct shear testing. In order to increase the resistance of the interface, flexible single and double-textured geomembranes have been used successfully. A thin layer of sand between the soil liner and the geomembrane has also been used in order to increase the friction between materials and thus improve its resistant to sliding. This paper presents interesting examples from recent project experiences.

1 INTRODUCTION

The stability of ore heaps that are leachate in pads lined with low permeability soils and geomembranes, is dependent of weakest materials i.e., of the interface that form the soil liner and the geomembrane. For example, the strength of the interface of a low permeabil-ity soil (clay) vs. a high density smooth polyethylene geomembrane (HDPE) is equivalent to an angle of internal friction of approximately of 10 ° (Howell & Kirsten 2016, Jones & Dixon 2003), being less when the fines content of the soil is higher.

The low resistance of the interface limits the efficient use of the available spaces, be-cause the ore heap slopes should be routed to ensure the stability of the structure, resulting in a lower capacity for ore leaching.

To increase the resistance of the interface soil liner vs. geomembrane, have been devel-oped flexible geomembranes (VFPE and LLDPE), as well as textured by one or both sides, with which achieved greater interaction among the materials that make up the interface. The strength of the interface of a soil liner vs. low linear density textured geomembrane varies between 15 and 27 degrees of internal friction (Castle & Breitenbach 2015, Ale et al. 2013), which has allowed to increase the inclination of the slopes of the ore heaps and therefore achieve a higher storage capacity.

In Peru, mines are located in unfavorable topographic conditions to operate in a safe way ore heap leach facilities, by what, it was decided to implement a layer of sand, which was called "friction layer", in between the soil liner and the geomembrane, because it is known that the soil grainsize has a direct influence in the strength of the interface soil liner vs. geomembrane.

Initially, the friction layer was formed with sand in a thickness of 2", but then first experiences indicated that the sand also worked as a drain medium making it impossible that the soil liner works together in combination with the geomembrane blocking possible leaks. In order to solve the problem, a new procedure was implement which consisted in spreading sand on the compacted surface of soil liner and then compact it with a smooth roller (non vibrating), in order to force the sand particles to embed in the compacted soil; then the excess sand was removed and proceeded to install the geomembrane. Several ex-periences have allowed confirm satisfactory results of this procedure.

The resistance of the interface soil liner vs. geomembrane is dependent on the character-istics of the soil and the type of geomembrane. At the same time, the properties of the soils are very diverse (grainsize, plasticity, etc.) and may vary within the same quarry; also, the available geomembranes in the market are very different: HDPE, VFPE, LLDPE, can be smooth or textured and at the same time, the textured can be obtained from several meth-ods of manufacturing. As is sees, the combinations can be several and in the same propor-tion the strength envelope of each one of the interfaces that is possible to obtain.

During one of the campaigns of laboratory test to determine strength properties of sev-eral interfaces, it was detected that practically not had any difference between the inter-face of the soil liner without friction sand vs. geomembrane and the interface of the soil liner with friction sand vs. geomembrane. An investigation of the test procedure allowed to determine that the procedure for preparing the samples for the tests, through remolding in the laboratory, not allowed to reproduce the conditions existing in the field, since the sand almost not interacted with the geomembrane, and therefore the friction between both did not increased, in consequence, practically any difference exist with the tests that do not considered the friction sand. Then, it was decided to take in-situ samples to develop inter-face tests representative of field conditions, obtaining the expected results.

This paper presents the results of interface tests of soil liner with friction sand vs. geomembrane, in samples prepared in the laboratory, through remolding, and samples ob-tained in-situ (on site). The results show that in the laboratory, it is not possible to repro-duce the field conditions and therefore it is recommended to take in-situ samples that al-low getting real values of the interface strength, with design purposes.

2 THE INTERFACE TEST

The interface tests were developed in the TRI Environmental, Inc. (TRI) laboratory, in Texas, under the standard ASTM D 5321, that recommends the use of square or rectangu-lar boxes of dimensions not minor of 300 mm or fifteen times the d_{85} of the coarse por-tion of the soil used in the test. The soil sample is placed on a sheet of geomembrane (smooth or textured) which is fixed to the device in order to perform the test in terms of direct shear strength.

It is usual that the strength envelope of soil liners vs. geomembranes results in a non-linear response of shear strength vs. normal strength, by what even when the test considers several normal strengths, the selection of the parameters for the design is being critical.

3 INTERFACE STRENGTH SOIL LINER WITH FRICTION SAND VS. GEOMEMBRANE

3.1 *Background*

The lining system of the San Pedro Sur heap leach pad of the La Zanja mining project (Cajamarca, Peru), has been designed to meet the requirements of the Nevada Division of Environmental Protection (NDEP), which suggest a soil liner with a maximum permeability of 1×10-6 cm/s covered by a geomembrane with a maximum permeability of 1×10-11 cm/s.

The interface which is form by the soil liner and the geomembrane, becomes the weak-est material that governs the structure stability and therefore the determination of its re-sistant properties is of particular importance, having been examinated throughout the de-velopment of the La Zanja project, for the various quarries of materials that have been used and for the various types of geomembrane used in the lining of the San Pedro Sur heap leach pad.

The implementation of the friction sand in combination with the soil liner, is a practice that Knight Piésold has implemented in several of projects, in order increase them shear strength of the interface, achieving so conditions more favorable for the physical stability of the structure.

In the particular case of the La Zanja project, the friction sand has been used in sectors where the slope of the surface ground is unfavorable or it is required to enhance the interface properties, usually in the perimeter of the heap leach pad, where concentrate the resistant strengths.

In a first attempt to assess the performance of friction sand vs. LLDPE geomembrane single-side textured of 1.5 mm of thickness, was developed a test with the material that was used as protection layer, which consists of a sand silty with a maximum size particle of 1,5 inches. The test results indicated that the geomembrane presented damage, generat-ed by the size of the particles of the material used, been demonstrated that the material was not the right-one, and the gravels must be avoided. The material for the friction sand, was obtained of the El Mirador quarry within the inside of the San Pedro Sur pit, which was processed through crushing and/or screaning by the mesh 3/8 ".

Knight Piésold evaluated the behavior of the interface soil liner vs. geomembrane from the initial stage and along the development of the project, having tested soils of the differ-ent quarries used and of geomembranes of various suppliers. He first test of interface us-ing friction sand resulted in a strength envelope that indicated that for the higher normal strengths, the shear strengths was approximately 14% greater with regard to the test without friction sand (soil liner of the Gara Gara quarry vs. geomembrane LLDPE textured hand of 1,5 mm of GSE). It is important to note that the samples for the interface test were pre-pared in the TRI Environmental, Inc. (TRI) laboratory, in Texas, USA, using the materials that Knight Piésold collected on site; in an attempt to simulate the conditions under which was prepared the friction sand on the surface of the soil liner (as it is done on site), on each mold test was placed a uniform amount of friction sand, as it was possible, on which was compacted the soil liner material with the density required for the test.

To the review of the information provided by the TRI corresponding to the test de-scribed in the previous paragraph (first test), it was possible to worn that the samples remolded in the laboratory were little representative of the friction sand that is formed on site, and because of that Knight Piésold recommended to perform a second interface test using samples taken in-situ (unaltered) of the soil liner material and the friction sand, with the objective of get representative results of the interface strength, given the importance that it has in the slopes stability analysis of the San Pedro Sur heap leach pad; Minera La Zanja agreed to perform the second interface test.

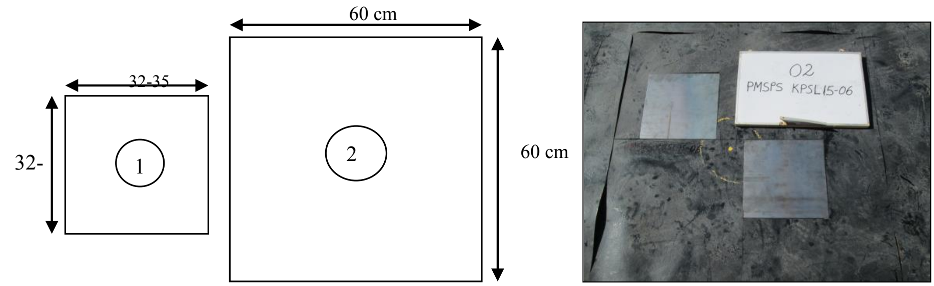
3.2 *Procedure for the taking of unaltered samples (in-situ)*

In coordination with the TRI, it was developed a specific procedure to obtain undis-turbed samples of interface soil liner with friction sand and the 1,5 mm single-side tex-tured LLDPE geomembrane. Following is summarized the procedure for taking samples:

- Locate four places for taking samples within the leach pad. It is recommended the use flat areas (avoid concave or convex areas), to get two samples of each place of sampling (identify them as A and B), i.e., eight samples will be taken.

- Carefully remove the material of the protective layer (PL), until reaching the geomembrane surface and verify that the geomembrane does not have any damage.

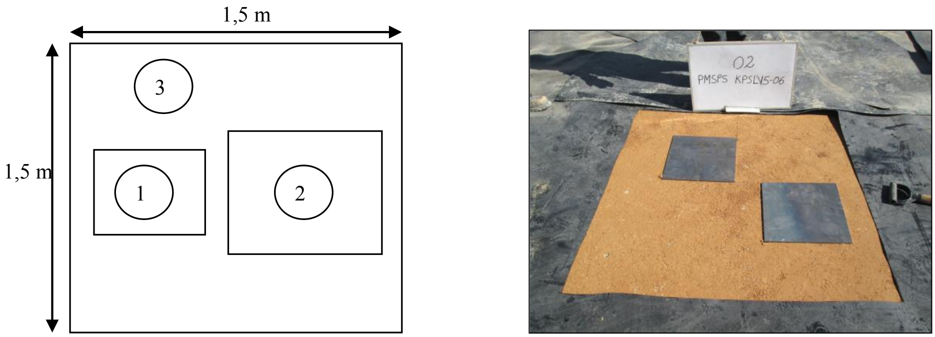
- Cut the geomembrane at a size of 32 to 35 x 32 to 35 cm, exactly where the sample will be obtained. Then, close to the area where the sample will be taken, cut the ge-omembrane at a size of 60 x 60 cm (mark the side of the geomembrane which is not in contact with the ground and write: 'without contact with the soil liner'). Take into account the issue of rain; therefore, it is necessary to have a large tent or waterproof blankets to cover the work area.



(1) Cutting of the geomembrane at the exact point where the sample will be obtained.
(2) Cutting of the geomembrane, adjacent to the location of the sample being taken.

Figure 1. Dimensions for cutting of the geomembrane.

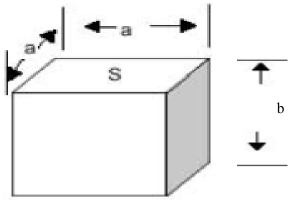
- Cut the geomembrane in an area of approximately 1,5x1,5 m around the sampling point, to facilitate the excavation for taking-off the sample.



(1) Cutting of the geomembrane at the exact point where the sample will be extracted.
(2) Second cut of the geomembrane sample.
(3) Cutting of the geomembrane, in the area around the sampling point.

Figure 2. Cutting of the geomembrane for the obtaining of the sample.

- Perform an excavation around the sample. Take into account that is need to obtain a sample of 32 to 35 cm x 32 to 35 cm x 8 cm height.



a = 32 a 35 cm

b = 8 cm

Figure 3. Excavation for the taking of the sample.

- To excavate forming a trench around the sample considering the dimensions of the sample that we need to get.

Figure 4. Excavation of trench for sample cutting.

- Once you have excavated, cut below considering the height of 8 cm. It can be ob-tained a sample of about 15 cm of height, to avoid any loss of material, and then be cut in the laboratory up to 8 cm of height, as required. Cutting is performed around the sample little by little and placing wooden wedges to give stability to the sample. If the sample is a MH, i.e. it would not have much gravel, and was compacted to a density similar to the Proctor test, it would be possible as the cutting of the sample progress, to place a plate of metal or plastic that serves as a base.

Figure 5. Sample cutting.

- When the sample had being cut, all the sides of the sample must be parafined except for the base and the top that will be protected with the same geomembrane that was cut.
- - Place waxed paper on all sides except for the base of the sample.

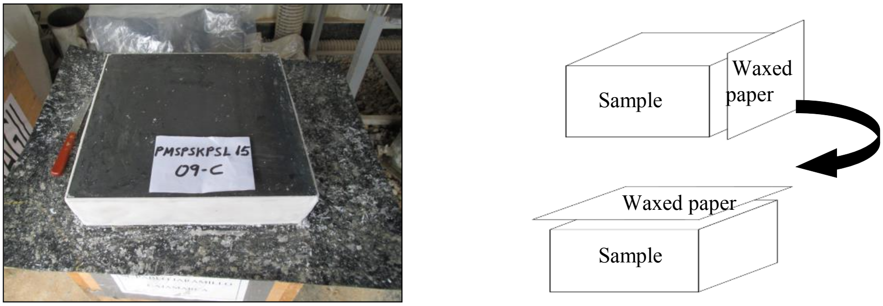


Figure 6. Parafined of the sample and placement of waxed paper.

- Place the microfilm on all sides except for the base. Start by wrapping around the sides of the sample (1); then wrap with microfilm the superior part of the sample that is covered with the geomembrane (2).

Figure 7. Placement of microfilm.

- Once the sample is properly packed, it has to flip the sample and parafining base and place waxed paper. Package the sides of the sample with microfilm as a whole. Handle as little as possible the sample.

- In case it is not possible to parafinne the sample in the point of sampling, the sample will be wrapped in microfilm and will be transferred to a proper location, where the microfilm will be discarted and the sample will be cu at 8 cm hight, if requiered. Then the steps described above will be completed.

- Once the sample is wrap in microfilm, it should be placed between two plastic or metal plates and pack them with bubble plastic and packing tape in a wooden box surrounded with sawdust to dampen.

- It is recommended to place a maximum of two samples vertically on each wooden box.

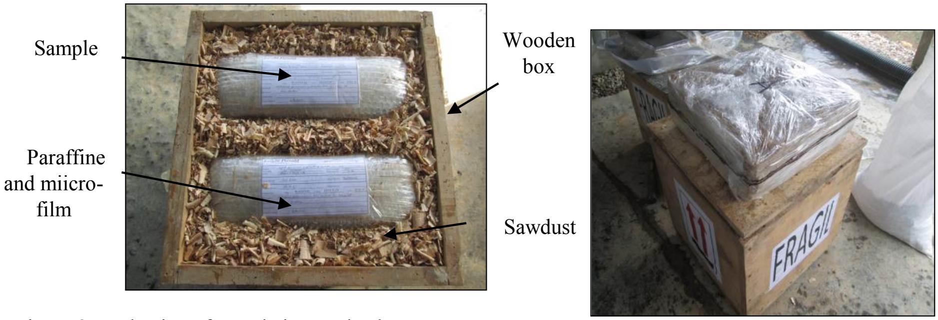


Figure 8. Packaging of sample in wooden box.

3.3 *Materials properties*

Soil mechanics tests were performed both during sampling as then in specialized laboratories. The following are the tests that were conducted:

- In-situ density by the nuclear densimeter method (ASTM D2922 - 05).
- Particle-size analysis by sieving (ASTM D 422 - 63, re-approved in 2007).
- Atterberg limits (ASTM D 4318 - 05).
- Moisture content (ASTM D 2216 - 05).
- Standard Proctor (ASTM D 698-07).
- Hydraulic conductivity using a flexible wall permeameter (ASTM D 5084-00).

Following Table 1 summarizes the main results of the soil mechanics tests.

Table 1. Summary of soil mechanics tests.

Origin of the material	SUCS Classification	Particle-size analysis			Atterberg Limits			Standard Proctor	
		Gravel (%)	Sand (%)	Silt /Clay (%)	LL	LP	IP	Optimum Moisture Content (%)	Maximum Dry Density (kN/m^3)
Soil Liner Gara Gara	MH	3,7	41,3	55	58	32	26	-	-
Friction sand from the PL (San Pedro Sur pit)	SP	21,9	63,6	14,5	-	-	-	-	-
Undisturbed samples	SC	Between 16,0 and 18,2	Between 33,5 and 35,5	Between 46,6 and 49,2	46 a 53	23 a 27	21 a 26	1,77	16,90

3.4 *The geomembrane*

The primary liner of the heap leach pad San Pedro Sur consists of a low linear density polyethylene (LLDPE) single-side textured geomembrane of 1,5 mm (60 mil, or thousandths of inch) of thickness; the geomembrane of low density has been used within the limits of the leach pad, due to its great capacity of deformation. He textured side was placed in contact with the surface of the low permeability soil/friction sand to increase the shear strenght of the interface.

Quality certificates of the geomembrane rolls installed were reviewed for those sectors where the unaltered samples were taken, finding that the geomembrane properties comply with the requirements of the Technical Specifications established during the leach pad design.

3.5 *Large scale direct shear cut tests of the interface soil liner with friction sand (in-situ samples) vs. geomembrane*

For each test were used four samples of soil liner on whose surface was conformed the friction sand, and on which was placed the single-side textured LLDPE geomembrane of 1,5 mm thickness. It is worth mentioning that because of the procedure implemented for the taking of samples, the conditions in which samples arrived to the TRI laboratory were optimal.

The samples were hydrated through immersion in water for a period of approximately 16 hours and then the water was drained by a minimum of half an hour before proceeding to the shearing stage, with a 0,25 mm/min speed test. In general, four normal loads were used considering the height of the ore heap (number of lifts) that was projected to accommodate in the San Pedro Sur. heap leach pad. Depending on the load to be used in each test, were used boxes of 305 mm x 305 mm x 102 mm (12" box), or a box of 203 x 203 x 102 mm (8" box).

3.6 *Analysis of results*

The results of the interface tests soil liner (Gara Gara quarry) with friction sand (samples taken in-situ) vs. the textured side of the LLDPE geomembrane (of GSE), indicate strength values approximately 45% higher than those obtained for the soil liner (Gara Gara quarry) iwithout friction sand vs. single-side LLDPE geomembrane (of GSE); the above is applicable for the higher normal loads. Also, the interface tests results with friction sand indicate values of approximately 27% higher than those obtained also with friction sand but in altered samples, prepared in the laboratory.

It is important to mention that the strength envelope corresponding to the interface test with friction sand samples prepared in the laboratory, presented values only 14% higher that the shear strength obtained from the test with soil liner without friction sand vs. the GSE geomembrane, which is applicable to the higher normal load.

Figure 9 shows the nonlinear envelope curves of the interface tests of soil liner with friction sand vs. single-side textured geomembrane of 1,5 mm manufactured by GSE, both in remolded laboratory samples and in undisturbed samples (taken in-situ); also is shown the strength enve lope of the interface soil liner without friction sand vs. geomembrane.

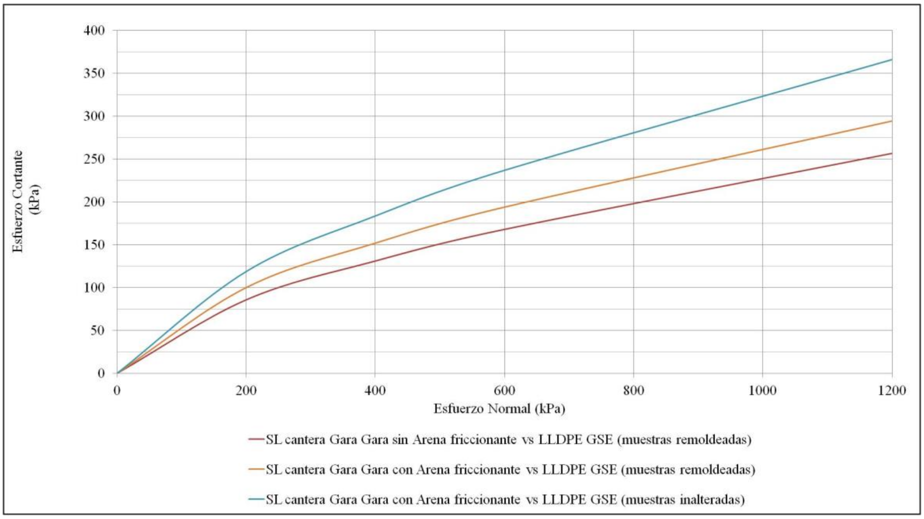


Figure 9. Envelopes of the interface tests of soil liner with friction sand vs, GSE geomembrane.

Finally, Figure 10 presents the strength envelopes of interface tests developed with posteriority for different soil liner materials and for another geomembrane provider.

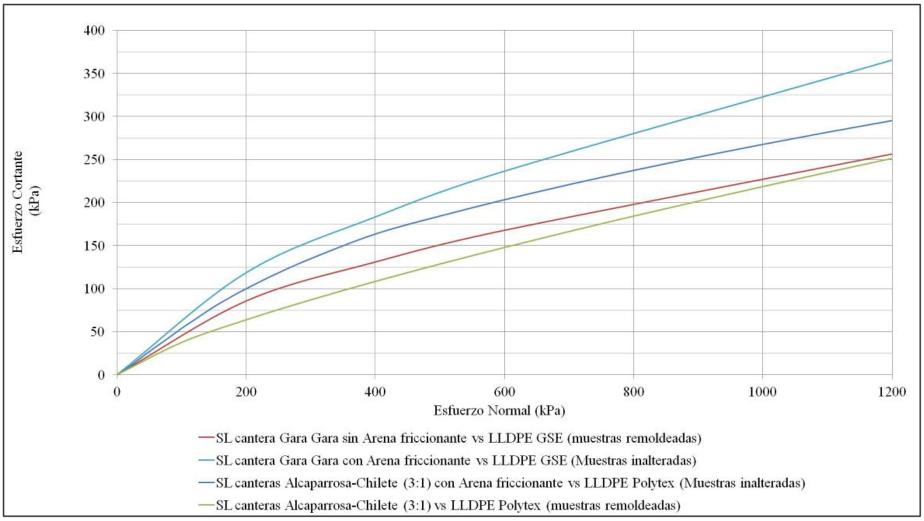


Figure 10. Envelopes of the interface tests of soil liner with friction sand vs. GSE and Polytex geomembranes.

4 CONCLUSIONS AND RECOMMENDATIONS

From the interface test of the Gara Gara quarry soil liner with friction sand, in remolded samples in the laboratory and taken in-situ vs. single-side textured LLDPE geomembrane of 1,5 mm manufactured by GSE, is possible to conclude the following:

- In general, the soils used in the tests fulfilled the Technical Specifications; only the soil liner material presented a reduced percentage of oversized material. Quality certificates of the geomembrane rolls corresponding to the sectors where the samples for interface testing were taken, indicate that the geomembrane properties met the requirements of the Technical Specifications.

- The interface test in unaltered samples, presents higher resistance than the interface test in altered samples, remolded in the laboratory. Both interfaces are made of from the Gara Gara quarry soil liner with friction sand importe from the San Pedro Sur pit, El Mirador area, sieved under the 3/8" sieve vs. the single-side textured low linear density geomembrane (LLDPE) of 1,5 mm (60 mil), manufactured by GSE.

The recommendations arising from the results of of interface tests are as follows:

- Base of the results of the different tests made, it is recommended to get the interface strength curves for each type of soil and each type of geomembrane, as well as the possible combinations, i.e., the strengths envelope is dependent of the soils properties and the geomembrane, being that a soil can vary within the same quarry and the geomembrane is dependent of the manufacturing method, raw materials, among others.

- A proper Quality Assurance (QA) management program must be implemented during the construction phase, which should be given particular interest in shaping the interface (soil liner, friction layer and geomembrane lining).

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