Soil liner-geomembrane interface shear strength using rigid substrata or overliner

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ABSTRACT: The soil liner-geomembrane interface shear strength is commonly used in leach pad stability analysis and obtained based on large scale direct shear testing. This study presents a summary of the large scale direct shear testing results by using two different procedures in order to evaluate the shear strength of a soil liner-geomembrane interface. In the first approach a rigid substrata is placed in the lower box of the direct shear device, with the smooth side of the geomembrane fixed on it, while the soil liner is placed in the upper box. In the second approach, which attempts to be more realistic, an overliner is placed with light compaction in the lower box of the direct shear device, then, similar to the first procedure, the geomembrane is fixed with the smooth side in contact to the overliner and the soil liner is placed in the upper box. In both cases the soil liner is in contact to the textured side of the geomembrane. Differences on the shear strength values between both procedures, obtained based on several large scale direct shear testing programs, are discussed and its influence on the leach pad stability analysis are compared.

1 BACKGROUND

Geomembrane materials are key components of a leach pad liner system. Usually, these materials are placed on top of a low permeability soil layer, commonly called soil liner, and covered with a drainage/protective material called overliner. Geomembrane liner typically consists of high or low linear density polyethylene (HDPE or LLPDE), smooth or single side textured. Soil liner consists of clayey soils, classified as clayey sand or clayey gravel, which provide relatively low permeability; this material is compacted according to the project specifications. Overliner consists of granular materials for drainage and/or protective purposes, and is placed in loose layers and gets some degree of compaction due to the depth of the overlying ore.

The soil-geomembrane interface shear strength is very commonly used in leach pad stability analysis and is obtained based on large scale direct shear testing (LSDS), which was standardized by ASTM D 5321 and specifies the use of a large conventional shear box apparatus with a 300 mm x 300 mm section and after proper modification.

2 SHEAR STRENGHT PARAMETERS

The soil-geomembrane shear strength parameters are influenced by several factors such as: interaction mechanism between soil liner or overliner and geomembrane; physical and mechanical properties of soil liner or overliner; mechanical properties, shape and geometry of geomembrane; normal stress; size of shear box; type of geomembrane; inherent variation in manufactured materials; consolidation history of clayey soils; compaction conditions; and moisture content.

Typically HDPE or LLDPE single side textured geomembrane is used for heap leach pad design, with the textured side in contact with the soil liner and with the smooth side in contact with the overliner, in order to increase the weakest interface strength, i.e., clayey soil with the geomembrane.

In order to evaluate the shear strength of a soil liner-geomembrane interface, two different procedures can be applied during the LSDS testing:

- In the first approach a rigid substrata is placed in the lower box of the direct shear device, with the smooth side of the geomembrane fixed on it, while the soil liner is placed in the upper box.
- In the second approach, an overliner is placed with light compaction in the lower box of the direct shear device, then, similar to the first procedure, the geomembrane is fixed with the smooth side in contact to the overliner and the soil liner is placed in the upper box.

As we can see, the only difference with both approaches is the material placed in the lower box: rigid substrata or overliner.

The use of rigid substrata is justified when the ore stacking in the leach pad is in the initial stages of the operation, when the vertical stresses are relatively low, where a good interaction between the soil liner and the geomembrane has yet to develop. This interaction starts developing when the height of the ore begins generating relatively high vertical stresses, and in this case the use of overliner would seem to be more realistic.

3 TESTING PERFORMED

With the objective of comparing both procedures, 7 LSDS tests with rigid substrata and 7 with overliner were performed. In all cases, different soil liner materials were used, but the same material for the overliner. Tests were performed using 1.5 and 2.0mm LLDPE single side textured geomembrane, as indicated in Table 2.

3.1 *Soil liner and overliner used*

The main characteristics of the soil liner materials are presented in Table 1: maximum dry density (MDD) and optimum moisture content (OMC) from Standard Proctor (ASTM D698); liquid limit (LL), plastic index (PI) and soil classification (USSC).

Table 1. Soil liner properties

Sample N°	MDD gr/cm^3	OMC (%)	LL (%)	PI (%)	USSC
1	1.759	16.5	36.3	16.2	CL
2	1.671	19.5	55.0	29.5	CH
3	1.622	21.1	48.4	22.1	SC
4	1.765	17.0	35.0	15.9	SC
5	1.753	17.0	37.9	14.5	SC
6	1.826	14.8	36.2	15.9	GC
7	1.707	17.8	33.2	13.9	CL

The overliner material corresponds to a sandy-silty gravel (GP-GM), with 5% fines, 25% sand, 70% gravel and was non-plastic.

3.2 *Testing results*

Based on our experience in the performance of a large amount of interface testing, it is known that the shear strength envelope obtained from the LSDS tests, may show non-linear behavior, which has been verified by several researchers; however, for comparison purposes only, the results obtained were adjusted to a linear envelope.

Adhesion (a) and angle of friction (δ) interface parameters were evaluated considering two conditions: 2.5cm displacement or peak value, when that was the case; and 7.5cm displacement or residual strength (post-peak) values. Table 2 shows the results obtained based on the two approaches used (RS=rigid substrata, OL=overliner), while Figures 1 through 6 show the results of the interface shear tests and the variation of the shear stress versus normal stress for Tests 1 and 5, low compressibility clay (CL) and clayey sand (SC) soils, respectively.

Table 2. Shear strength parameters from LSDS tests

N°	LLDPE Thickness (mm)	Substrata	Interface Strength Parameters			
			2.5cm or Peak		7.5cm	
			a (Kpa)	δ (°)	a (Kpa)	δ (°)
1	2.0	RS	45.0	19.4	37.0	8.3
		OL	60.0	20.0	56.0	16.7
2	1.5	RS	39.0	15.0	36.0	11.4
		OL	30.0	22.4	18.0	22.8
3	1.5	RS	26.0	22.3	28.0	16.7
		OL	21.0	21.6	23.0	23.8
4	2.0	RS	16.8	23.7	20.0	24.5
		OL	15.0	24.4	18.0	29.5
5	1.5	RS	20.8	20.4	34.4	18.8
		OL	13.0	25.4	19.0	26.8
6	1.5	RS	13.6	24.3	12.0	21.0
		OL	8.0	25.2	0.0	29.5
7	1.5	RS	32.0	16.5	16.0	15.9
		OL	8.0	24.4	9.0	28.1

3.3 *Comments*

Based on the results shown in Table 2 and Figures 1 through 6, we can observe the following:

- Practically in all cases the adhesion values are greater when a rigid substrata is used instead of the overliner.
- For 2.5cm displacement or peak value, the angle of friction is in general, higher for the cases of overliner versus rigid substrata, with variations between 1 and 8 degrees; in some cases (Tests 1, 3, 4 and 6) this difference is minor, as we can observe in Figures 2 and 5. In general, very similar behavior can be observed in the shear stress versus displacement curves (Figures 1 and 4) of the rigid substrata and overliner until about 2.0 cm displacement.
- For 7.5cm displacement, the angle of friction is in all the cases higher when overliner is used instead of rigid substrata. Differences between 5 and 12 degrees are observed (Figures 3 and 6).
- For large displacements, the differences between the shear strength using the two procedures are higher for clayey soils than for sandy soils.
- Practically for all the tests performed the more significant differences seem to be at the highest normal stress (800kPa); those differences are minor at lower normal stresses (100, 200 and 400kPa), as shown in Figures 1 and 4.
- Non-linear envelope is observed in some of the testing results, as shown in Figures 2, 3, 5 and 6.

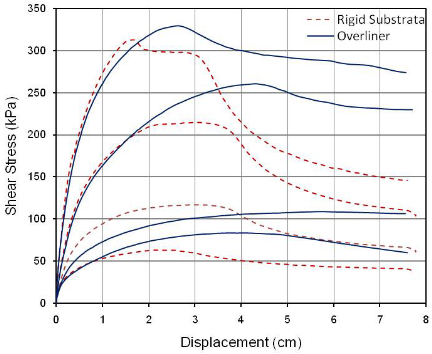

Figure 1. Interface shear test 1.

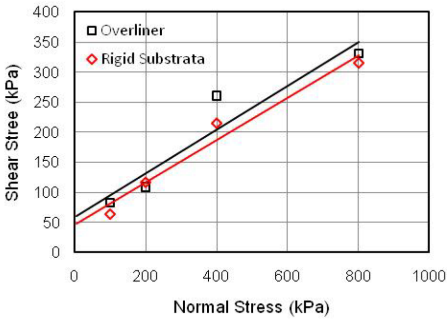

Figure 2. Shear stress - normal stress. Test 1, 2.5cm.

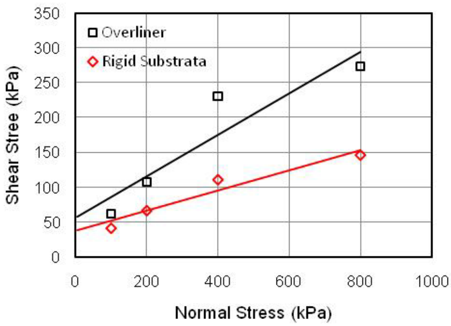

Figure 3. Shear stress - normal stress. Test 1, 7.5cm.

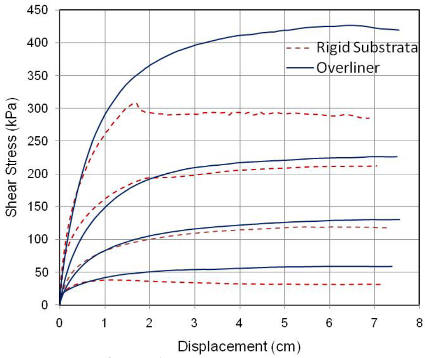

Figure 4. Interface shear test 5.

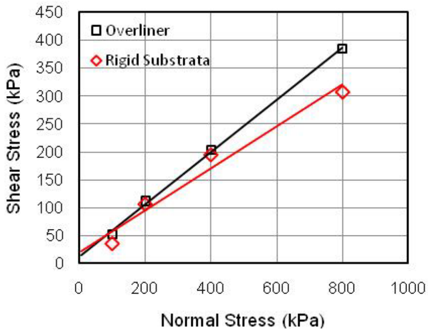

Figure 5. Shear stress - normal stress. Test 5, 2.5cm.

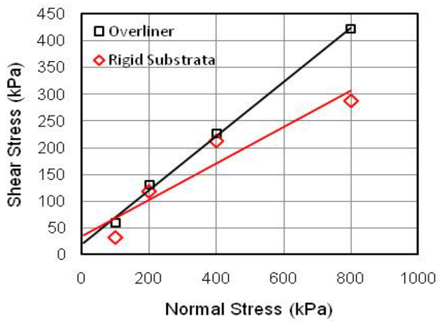

Figure 6. Shear stress - normal stress. Test 5, 7.5cm.

In addition, moisture content data were taken from two different spots of the soil liner in the shear box, the first in the center of the box and the second in the soil liner zone where the shear displacements occur. It was interesting to note that in all the cases, differences in average moisture of up to 7% were observed. Higher moisture content is observed for the testing with rigid substrata.

Based on the results obtained, the following comments are presented:

- At lower normal stresses, when the rigid substrata should provide more realistic results, the testing results indicate that the variation of the strength parameters between the two procedures is not significant.
- Although the interface shear parameters with the rigid substrata becomes more conservative, the results of the LSDS testing suggest that it may be more convenient to use the shear strength parameters obtained with the overliner.
- Furthermore, during the stability analysis a non-linear envelope should be used, which allows one to adjust the shear stress as a function of the normal stress applied.
- The current capacity of the LSDS equipment does not allow the application of higher loads (maximum 800kPa in this study, equivalent to about 45 m heap height). Consequently, the use of overliner could provide a higher overestima-

tion of the shear strength than the rigid substrata, when the height of the heap is quite large.
- Under the typical conditions of the mining operations, where no-scheduled design conditions are common, without taking into account potential deficiencies in the construction, and given the comments above, it could be more recommendable to use the strength parameters obtained based on the use of rigid substrata, i.e., more conservative parameters for leach pad stability analysis.

4 STABILITY ANALYSIS

In order to evaluate the influence in the stability of a leach pad when shear strength parameters are obtained based on the two procedures above, limit equilibrium stability analysis were performed for the hypothetical case shown in Figure 7. The Spencer method was used, considering 2 and 4% graded slope, 100m heap and linear and non-linear strength envelopes. For the linear envelope, parameters associated with the 7.5cm displacement were used. The results of the static stability analysis using Test 1 and 5 data, are presented in Table 3.

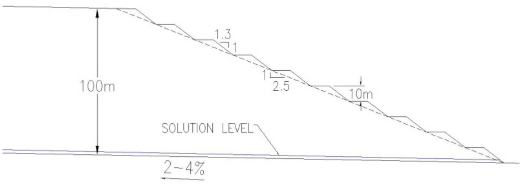

Figure 7. Hypothetic leach pad stability analysis.

Table 3. Stability analysis results.

Case	Substrata	Factor of Safety Test 1		Factor of Safety Test 5	
		Linear	Non-Linear	Linear	Non-Linear
2%	RS	1.29	1.23	1.73	1.70
	OL	1.88	1.72	1.90	1.90
4%	RS	1.20	1.18	1.72	1.68
	OL	1.71	1.65	1.88	1.88

As expected, the factors of safety are higher when using LSDS with overliner data. The differences are lower for Test 5, which is reasonable because of the sandy nature of this soil liner; a clayey soil will allow a better interaction with the geomembrane.

Also, differences between the linear and non-linear stability analysis are observed for those cases in which the strength non-linearity is evident (see Figures 3 and 6), indicating that non-linearity should be considered as part of the leach pad stability analysis. Finally the same trend in the factors of safety is observed for 2 and 4% slopes, but with the lower values for the higher slope, as expected.

5 CONCLUSION

The following conclusions are presented based on this study.

- Two LSDS procedures are presented in order to obtain shear strength parameters of soil liner-geomembrane interface. The difference between the two of them is basically the placement of rigid substrata or overliner in the lower box of the direct shear device.
- In general, the angle of friction of the soil liner interface is higher when overliner is used instead of rigid substrata. However, for low normal stresses, the shear strength difference with the rigid substrata, when this approach should be more realistic, is minimal.
- The results of the testing program executed suggests the utilization of the overliner in the LSDS for the shear strength evaluation of the soil liner-geomembrane interface is more convenient.
- Considering the unknown conditions during the leach pad operation, apart from potential construction deficiencies and possible shear strength overestimation during high stresses for deeper heaps, the utilization of shear strength parameters based on LSDS testing with rigid substrata seems to be more recommendable for the leach pad stability analysis.
- Based on stability analysis results of a hypothetic case, higher factors of safety for the case of overliner than the rigid substrata are observed, as expected. Also, differences between the linear and non-linear analysis are observed when the non-linearity of the shear strength is evident.

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