Trends on Leach Pad Liner Shear Strength: Textured Geomembrane and Soil Liner Classification

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Abstract

During the design of heap leach pads in mining industry is very common the use of liners composed by a geomembrane over a low permeability soil or soil liner as a lower interface, being the upper one the granular overliner placed on top of the geomembrane, which usually promotes the solution drainage, but it also prevents the damage from the liner that may be produced by the impact of the oversize ore, for instance ROM ore, or by the spreading equipment working on the leach pad. When the ore is less than 1,5 inches, then the overliner is not needed; in any case, the upper interface, geomembrane versus overliner or ore, will usually provide higher shear strength than the clayey soil used as a soil liner due to its granular nature. Therefore, in order to increase the shear strength of the lower interface, a single side textured geomembrane is used, where the textured side is placed in contact with the soil liner.

This research is based on data obtained from textured geomembrane and soil liner interface which have been tested on a large scale direct shear device according to ASTM-D5321. The geomembrane for testing was obtained from manufacturers or casted in place geomembrane samples, while the clayey soil liner samples come from borrow areas used on many heap leach pads projected, constructed or under construction in several mines in Peru. The analysis of the information shows a direct influence on the shear strength variation based on normal stress, asperity height and soil liner classification, the latter mainly based on gravel, sand and fines content.

The relationships obtained by the parameters that affect the liner shear strength will allow for taking better decisions during design and construction stages for selecting liner systems (geomembrane and soil liner) in heap leach pad projects, since it will allow predicting the shear strength behavior based on the data obtained and analyzed in this research. Therefore, the relationship obtained may solve common problems or accomplish better and more economical solutions to happen during design and construction stages, such as: variability of asperity height on geomembranes, changes of soil liner borrow area or soil properties to happen during design or construction, determination of a shear strength envelop
for technical specifications purposes, prevent the use of stability berms by changing just one parameter that may increase the liner shear strength, determination of the increment on interface shear strength for stability problems on block failures, among others.

**Introduction**

During the design of a heap leach pad in mining industry is very common the use of liners composed by a geomembrane over a low permeability soil or soil liner, as a way to prevent or decrease leakage of the pregnant solution into the heap foundation, which may cause an environmental damage and economical losses.

It is usual in practice for heap leach pad projects to use mainly LLDPE or HDPE textured geomembrane over a clayey soil as a liner system. In Peruvian mining projects the construction of such system has followed the GRI recommendations provided on the GM 12 (2002), GM 13 (2012) and GM 17 (2012) specifications.

During the geotechnical design and analysis of a leach pad, the main restriction is mainly related to the liner system, which usually provides an interface with low shear strength due to the relatively high fines content of the soil liner, thus this interface controls the stability conditions of such facility by a block failure. Some efforts have been made to model or predict the shear strength of this kind of liner provided by Reddy and Butul (1999), Yesiller (2005), Ivy (2003), and Blond and Elie (2006).

Based on the studies performed in the references above and the expertise of the authors in projects related to geotechnical analysis of heap leach pads, it can be observed that the interface shear strength increases with the increment of the geomembrane asperity height, normal stress increment ($\sigma_N'$) and the increment of granular material in the soil liner.

This research is focused on the interface shear strength behavior of textured geomembrane and soil liner based on the asperity height of the geomembrane, soil liner classification, normal stress and soil liner fines content. The interface shear strength was determined through the large scale direct shear (LSDS) test according to the ASTM D 5321. The geomembrane samples for testing were obtained from manufacturers or casted in place, while the clayey soil liner samples come from borrow areas used on many heap leach pad projects on design, under construction or already constructed in several mines in Perú.

**Data Preparation**

The interface shear strength has a clear non linear behavior as discussed by Stark et al. (1996), Stark and Choi (2004) and Parra et al. (2011); therefore, in this research the behavior of the interface shear strength
is evaluated by taking the shear stress related to the normal stress values directly from the LSDS test results, instead of using Mohr-Coulomb approach (angle of friction and cohesion).

A large set of LSDS testing results, 191 in total, were analyzed in this research; the following parameters were taken for the analysis: type of geomembrane (LLDPE or HDPE, most of the data corresponds to LLDPE geomembrane), nominal geomembrane thickness (1.5 mm or 2 mm), asperity height measured on laboratory, soil liner classification, Atterberg limits, peak shear stress (taken as 2.5 cm of deformation), residual shear stress (taken at 7 cm of deformation) and their corresponding normal stress, and final soil moisture content at the end of the test.

The shear stress of all samples for peak and residual strength are shown in Figures 1 and 2, which have been separated by normal stresses applied during the LSDS test. No differentiation of soil classification or fines content is presented in those figures.

![Figure 1: Peak shear strength behaviour of all the testing data for different normal stresses](image1.png)
It may be observed in Figure 1, a tendency on the increment of the peak shear strength with the increment on the asperity height. However, the peak shear strength was not taken into account in this research due to the following reasons: it is not commonly used on practice since in most leach pads is expected a deformation larger than 2.5 cm, the tendency is not as clear as in residual shear strength, and the determination of the displacement where the peak shear strength is reached is not always 2.5 cm but depends on the soil and geomembrane features.

As shown on Figure 2 and compared to Figure 1, the interface residual shear strength features a clearer tendency toward the increment with the increment on the asperity height. However, some scattering is still observed, which may be caused by the soil properties or fines content. Then, the samples were separated based on its classification according to the Unified System of Soil Classification (USSC) and fines content; the main features of the soil liner samples used in this research are summarized in Tables 1, 2, 3, 4 and 5.
Table 1: Clayey gravel with sand (GC)

<table>
<thead>
<tr>
<th></th>
<th>Gravel Content (%)</th>
<th>Sand Content (%)</th>
<th>Fines Content (%)</th>
<th>Liquid Limit (%)</th>
<th>Plastic Index (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average</td>
<td>41.9</td>
<td>27.8</td>
<td>30.3</td>
<td>31.5</td>
<td>12.6</td>
</tr>
<tr>
<td>Maximum Value</td>
<td>59.8</td>
<td>34.3</td>
<td>44.7</td>
<td>45.5</td>
<td>20.0</td>
</tr>
<tr>
<td>Minimum Value</td>
<td>32.5</td>
<td>21.6</td>
<td>15.7</td>
<td>22.0</td>
<td>9.0</td>
</tr>
</tbody>
</table>

Table 2: Clayey sand with gravel (SC)

<table>
<thead>
<tr>
<th></th>
<th>Gravel Content (%)</th>
<th>Sand Content (%)</th>
<th>Fines Content (%)</th>
<th>Liquid Limit (%)</th>
<th>Plastic Index (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average</td>
<td>24.3</td>
<td>36.7</td>
<td>38.6</td>
<td>34.4</td>
<td>15.0</td>
</tr>
<tr>
<td>Maximum Value</td>
<td>33.0</td>
<td>60.1</td>
<td>50.0</td>
<td>50.9</td>
<td>26.5</td>
</tr>
<tr>
<td>Minimum Value</td>
<td>11.3</td>
<td>28.3</td>
<td>19.2</td>
<td>27.0</td>
<td>8.0</td>
</tr>
</tbody>
</table>

Table 3: Clay with sand (CL) and high plasticity clay with sand (CH), fines content below 65%

<table>
<thead>
<tr>
<th></th>
<th>Gravel Content (%)</th>
<th>Sand Content (%)</th>
<th>Fines Content (%)</th>
<th>Liquid Limit (%)</th>
<th>Plastic Index (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average</td>
<td>10.4</td>
<td>36.3</td>
<td>53.3</td>
<td>40.3</td>
<td>20.4</td>
</tr>
<tr>
<td>Maximum Value</td>
<td>25.6</td>
<td>50.5</td>
<td>65.0</td>
<td>57.0</td>
<td>36.0</td>
</tr>
<tr>
<td>Minimum Value</td>
<td>0.0</td>
<td>25.2</td>
<td>50.0</td>
<td>17.0</td>
<td>6.0</td>
</tr>
</tbody>
</table>

Table 4: Silt with sand (ML) and high plasticity silt with sand (MH), fines content below 75%

<table>
<thead>
<tr>
<th></th>
<th>Gravel Content (%)</th>
<th>Sand Content (%)</th>
<th>Fines Content (%)</th>
<th>Liquid Limit (%)</th>
<th>Plastic Index (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average</td>
<td>9.9</td>
<td>28.4</td>
<td>61.7</td>
<td>59.8</td>
<td>23.5</td>
</tr>
<tr>
<td>Maximum Value</td>
<td>27.9</td>
<td>39.7</td>
<td>75.0</td>
<td>83.0</td>
<td>30.0</td>
</tr>
<tr>
<td>Minimum Value</td>
<td>3.5</td>
<td>13.4</td>
<td>54.0</td>
<td>50.0</td>
<td>15.0</td>
</tr>
</tbody>
</table>

Table 5: Clay with sand (CL) and high plasticity clay with sand (CH), fines content over 65%

<table>
<thead>
<tr>
<th></th>
<th>Gravel Content (%)</th>
<th>Sand Content (%)</th>
<th>Fines Content (%)</th>
<th>Liquid Limit (%)</th>
<th>Plastic Index (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average</td>
<td>3.4</td>
<td>12.7</td>
<td>83.9</td>
<td>52.3</td>
<td>27.7</td>
</tr>
<tr>
<td>Maximum Value</td>
<td>19.8</td>
<td>32.0</td>
<td>96.9</td>
<td>76.0</td>
<td>45.0</td>
</tr>
<tr>
<td>Minimum Value</td>
<td>0.0</td>
<td>3.0</td>
<td>65.0</td>
<td>29.2</td>
<td>10.1</td>
</tr>
</tbody>
</table>
There were other features that may be involved with the interface shear strength behavior such as the type of geomembrane (LLDPE or HDPE) and thickness of the geomembrane, however, not clear tendency was observed when the data was classified by those parameters as well, and there was not enough data to make a clear correlation.

A total of 21 samples were used classified as GC, 27 samples as SC, 15 samples as CL and CH with fines content (FC) below 65%, 10 samples as ML and MH with FC below 75% and 7 soil samples as CL and CH with FC above 65%.

**Shear Strength Data Processing Based on Soil Classification**

As mentioned above, the data was separated based on the USSC. The data corresponding to GC soils is shown in Figure 3 separated also by normal stresses. The regression coefficients (R) obtained for 4 different normal stresses were between 0.65 and 0.75, which mean a fairly well correlation.

![Figure 3: GC soil / textured geomembrane interface residual shear strength behaviour for different normal stresses](image)

The data of interface shear strength for SC soil is shown in Figure 4, the R coefficient is around 0.6 to 0.7, which also mean a fairly well correlation.
The data of interface shear strength for CL and CH soils with FC below 65% is shown in Figure 5, the R coefficient is around 0.5 to 0.7, which mean just a fair correlation.
The data of interface shear strength for ML and MH soils with FC below 75% is shown in Figure 6, the R coefficient is around 0.8 for normal stresses of 100 and 200 kPa, 0.6 for 400 kPa and 0.4 for 800 kPa.

Finally, the data of shear strength for CL and CH soils with FC over 65% is shown in Figure 7, the R coefficient is between 0.6 to 0.2.
Based on the Figures 3 through 7, the tendency functions for each confining stress of every soil classified were drawn in a single graph, as shown in Figure 8. Also, another way for interpreting the data was to draw the different tendency functions for every soil comparing their behaviour for each normal stress, as shown in Figure 9.
Figure 8: Summary of the tendency functions of the interface shear strength behavior for (a) GC, (b) SC, (c) CL & CH with FC $\leq$ 65%, (d) ML & MH with FC $\leq$ 75%, and (e) CL & CH with FC $>$ 65% soils.
Interface Shear Strength Discussion

- The scattering of data increases as the fines content become higher, which may be caused by the lack of information for finer soils, since it is common to avoid using very fine soils in practice due to its very low shear strength, which influence negatively the heap leach pad stability.

- There is a reliable non linear tendency of shear strength increment for GC, SC and CL and CH soils with FC content below 65%, where the behavior tends to be asymptotic at asperity heights of 0.04 cm. This conclusion agrees with the one provided by Blond and Elie (2006) and also adds an asperity of 0.04 cm as a trigger value for larger normal stresses (400 kPa and 800 kPa).

- It is also observed that for GC, SC and CL and CH soils with FC content below 65%, the rate of increment of shear strength is reduced around an asperity of 0.03 cm.

- The shear strength of GC soil is greater than SC soil at low normal stresses for asperity heights up to 0.012 cm, however, for larger normal stresses (larger than 400 kPa) the GC soil shear strength is larger than SC soil. The first behavior is explained because of the reduction of gravel content in the test, since the slot thickness to contain the soil in the LSDS test allows up to a particle diameter of 2 cm, thus the sample is sieved before is set. As for larger normal stresses, the behavior may change due to micro-dimpling effects of the gravel particles into the geomembrane. Therefore, it is expected, at field conditions, to have larger shear strength on GC soils compared to SC soils even for low confining pressures. For this study, at normal stresses above 400 kPa, the GC soil geomembrane interface shear strength is 10% to 15% larger than SC soil.

- In general, the shear strength of CL and CH soil with FC below 65% is around 5% to 15% less than SC soil, for improving the accuracy on this relationship more LSDS test results for this kind of fine soils are needed.
The tendency curves for ML and MH with FC below 75% and CL and CH with FC over 65% are set as a way to show the idea that these kind of soils provide very low shear strength and also its strength behavior is harder to predict, but its rate of increment of the interface shear strength with textured geomembrane may increase linearly, additional test results are needed to have a wider knowledge of its behavior.

Conclusions

- The shear strength of the soil liner versus geomembrane increases based on the granular nature of the soil liner, the more granular is the soil liner, the shear strength increases.
- A trigger for geomembrane asperity height that makes no meaningful increment of the interface shear strength is about 0.03 cm with an asymptotic behavior at 0.04 cm, which agrees with the research performed by Blond and Elie (2006).
- It is confirmed the reliability of the shear strength as a function of the soil classification.
- The strength behavior on dependency of the asperity height and normal stress is similar between GC, SC and CL and CH with fines content below 65%.
- There is a big scattering for shear strength data in MH and ML soils, as well as for CL and CH soils with FC over 65%, additional data is required for a better knowledge, in despite of those soils are usually not used in heap leach pad projects.
- The shear strength of GC soil is greater than a SC soil for low normal stresses, 100 to 200 kPa, until a geomembrane asperity height of 0.01 cm, after that trigger, the SC soil tends to be greater. For larger normal stresses, about 400 to 800 kPa, and until asperity height of 0.036 cm in the case of 400 kPa, the shear strength of a GC soil is greater than a SC soil.
- The shear strength behavior for soils used on practice as a soil liner in heap leach projects is quite non linear depending on the asperity height and normal stress.
- For asperity heights between 0.01 to 0.02 cm, the shear strength on GC, SC and CL and CH with fines content below 65% is about 20% lower than the strength for asperity heights between 0.03 to 0.04 cm.
- The asperity height and soil liner classification are very important parameters for interface shear strength determination for the stability analysis of a leach pad, any unexpected change during design or construction stages on such parameters will imply a change in the stability condition, therefore a reanalysis is needed in order to make sure that stability of the facility has not been affected.
• The proposed relations may be used as a preliminary input data on interface shear strength determination for leach pad stability analysis.
• By means of the relations shown on this research, the interface shear strength behavior can be predicted in case of any change of the parameters governing this shear strength may occur, based on soil classification, normal stress and asperity height.
• This research shows the importance of performing a good control by the CQC and CQA engineers in the soil liner classification and geomembrane asperity height, since the leach pad stability finally depends on these materials.

References

ASTM D5321 (2002), Standard Test ethod for Determining the Coefficient of Soil and Geosynthetic or Gosynthetic and Geosynthetic Friction by the Direct Shear Method, ASTM Standards, 04(13), Philadelphia, Pennsylvania, USA.