Shrinkage Behavior of a Liner Material with Expansive Properties for use in an Engineered Landfill

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Abstract: The liner material in an engineered landfill acts as a barrier for leachate migration and prevents contamination of nearby water resources. Compared to geosynthetic clay liners (GCL) and high density Polyethylene (HDPE) liners, compacted clay liners (CCL) are less expensive, if the materials are locally available. According to USEPA guidelines the recommended thickness of a CCL having a maximum hydraulic conductivity of $1 \times 10^{-7}$ cm/s is 1 m. However, it is possible to reduce the thickness by using a less permeable soil such as that obtained from Moragahakanda, Central Province of Sri Lanka. This Moragahakanda soil is found to be an expansive soil and its hydraulic properties could be further improved by amending with Bentonite. However, in addition to the hydraulic conductivity criteria, it is necessary to examine its shrinkage behaviour during drying to investigate the sustainability of its use as a liner. In this study, Moragahakanda expansive soil, and that amended by 5% and 10% bentonite were used as candidate materials from which experimental liners were prepared to have the same void ratio as that obtained by consolidating the same liner materials to 46.2 kPa and 92.4 kPa having a diameter of 150 mm and thicknesses of 5 mm, 10 mm and 20 mm. The disks were allowed to air dry and the variations of moisture content, area shrinkage and possible crack pattern with time were evaluated. An image processing method using ArcGIS 10.2 software was used to determine area reduction and cracked area.

Keywords: Expansive soil, Landfill liner, Shrinkage, Image processing

1. INTRODUCTION

In Sri Lanka, engineered landfills have not been established yet for disposal of municipal solid waste. However, the need for engineered landfills cannot be ignored with the increasing quantity of solid waste generation due to rapid urbanization. Generation of leachate which is a liquid produced when water or other liquids come into contact with waste or due to release of moisture present within itself creates one of the major challenges in designing and maintaining an engineered landfill. Therefore, an essential component of an engineered landfill is the liner system which acts as a barrier for leakage of leachate and prevents the transportation of contaminants to the nearby water resources. Synthetic liners consisting of geomembranes or geosynthetic clay liners (GCL) are widely in use as liner materials of engineered landfills constructed in developed and developing countries. However, as geosynthetic materials are not manufactured in Sri Lanka, Compacted Clay Liners (CCL) is an alternative to be considered as a material for a liner (Abeyrathne, 2012). However, in addition to meeting hydraulic conductivity criteria of a liner, one major challenge of using CCL as a liner material is the possibility of developing shrinkage cracks during a dry season. In this regard, use of expansive soils in CCL is advantageous as they exhibit a very high plasticity index (PI) which prolong the initiation of cracking upon drying and have the characteristic of self-healing upon wetting. Kurukulasuriya et.al. (2013) investigated expansive soil obtained from Moragahakanda in the Central Province of Sri Lanka and that amended by 5% and 10% bentonite (Bentofix®, NAUE GmbH & Co. KG, Germany) by weight as candidate materials for a liner and found that they satisfy short and long term hydraulic criteria. In this study, the shrinkage behavior of the same candidate materials obtained from Moragahakanda is investigated.
2. MATERIALS AND METHODS

The expansive soil for the study was obtained from the same location (07˚ 35’32.8” N 80˚49’59.9”E) from which soil was obtained for an earlier study as reported by Wanigaratne et.al. (2012) in which the hydraulic conductivity was determined on specimens prepared by consolidating one dimensionally to pressures of 46 kPa, 92 kPa and 184 kPa. Initially, soil classification tests such as liquid limit, plastic limit, particle size distribution and specific gravity tests were carried out to identify the basic physical soil properties. These tests were carried out conforming to methods specified by British Standards. To identify the expansiveness of the soil obtained from Moragahakanda swell pressure test was carried out.

In this study, the shrinkage characteristics were investigated on the specimens having the same voids ratio as those used in the study of Wanigaratne et.al. (2012). However, the specimens were prepared by compaction to achieve the same voids ratio. This was possible by carrying out Proctor compaction test and evaluating the voids ratio corresponding to each compacted sample represented in the compaction curve. Therefore, a relationship between the dry density and voids ration can be developed from which the specimens for this study corresponding to the same voids ratio of that obtained by consolidation could be obtained by compacting to the required dry density.

Specimens of diameter 150 mm and thicknesses of 5 mm, 10 mm and 20 mm were prepared (as has been done by Atique and Sanchez, 2011), using Moragahakanda expansive soil and that amended by 5% and 10% bentonite compacted to voids ratios corresponding to specimens consolidated to 46 kPa and 92 kPa. Trimming of compacted specimens to above thicknesses was made possible by using templates of ring shape of required heights (Fig.1) into which the compacted samples were inserted during extraction from the compaction mould. Altogether, 18 specimens were prepared and placed on glass plates and left for air drying (Fig.2).

The change in area of flat surface exposed to the atmosphere and the development of cracks were monitored daily during the drying process. For this purpose, digital photographs were taken using a 14 megapixel camera from a fixed height under almost constant light and ambient temperature conditions. This was facilitated by using a frame as shown in Fig.3. The moisture content too was computed at the time of taking the photograph using the weight of the specimen obtained immediately after taking the photograph.

![Figure 1. Circular shaped templates to prepare specimens of thickness (a) 5 mm, (b) 10 mm and (c) 20 mm](image1)

![Figure 2. Compacted specimens of candidate materials left for air drying](image2)
These images were fed into GIS (Arcmap version 10.2) software and the “Iso Cluster Unsupervised Classification” tool was used to multivariate the image. Then, the “Extract by Attributes” tool was used to select the sample from the image and the area was calculated by converting the raster dataset to polygon features using the “Raster to Polygon” tool.

However, the output result of the GIS software will be valid for an image taken at a particular height. Therefore, it is necessary to calibrate the output result given by the software with reference to the height at which the photograph was taken. This was done by calculating the areas of a square and rectangular shapes placed within a larger circle and photographing at the same height the 5 mm, 10 mm and 20 mm thick specimens had been photographed (Fig.4).

**3. RESULTS**

**3.1 Physical and Compaction Properties**

The results of Atterberg Limits, Specific Gravity and Swelling pressure tests are given in Table 1 for Moragahakanda expansive soil (Soil M) and that amended by 5% (Soil M+5%) and 10% (Soil M+10%) Bentonite. The Moragahakanda soil was classified as Sandy Clay of Intermediate Plasticity (CIS).

The preparation of compacted candidate soil samples was carried out so that the void ratio of the compacted soil sample corresponds with that consolidated under 46 kPa and 92 kPa pressure. Table 2 gives the void ratio of the consolidated soil samples (Wanigaratne et.al.2012) and the corresponding values of dry density that should be achieved on the compacted soil samples used in this study.
Table 1 Physical and Compaction Properties of Candidate Soils

<table>
<thead>
<tr>
<th>Property</th>
<th>Bentonite</th>
<th>Soil M</th>
<th>Soil M+5%</th>
<th>Soil M+10%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Liquid limit (%)</td>
<td>600 *</td>
<td>66</td>
<td>49 *</td>
<td>70 *</td>
</tr>
<tr>
<td>Plastic limit (%)</td>
<td>55*</td>
<td>29</td>
<td>21 *</td>
<td>25 *</td>
</tr>
<tr>
<td>Plasticity index (%)</td>
<td>545*</td>
<td>37</td>
<td>28 *</td>
<td>50 *</td>
</tr>
<tr>
<td>Specific Gravity</td>
<td>2.68*</td>
<td>2.59</td>
<td>2.57</td>
<td>2.55</td>
</tr>
<tr>
<td>Swell pressure (kPa)</td>
<td>-</td>
<td>126.1*</td>
<td>267.7 *</td>
<td>357.0 *</td>
</tr>
<tr>
<td>Maximum Dry Density (Mg/m³)</td>
<td>-</td>
<td>1.65</td>
<td>1.48</td>
<td>1.71</td>
</tr>
<tr>
<td>Optimum Moisture Content (%)</td>
<td>-</td>
<td>18.0</td>
<td>26.8</td>
<td>14.0</td>
</tr>
</tbody>
</table>

*- after Wanigaratne et.al., (2012)

Table 2. Target Dry Density of Compacted Candidate Soil Samples

<table>
<thead>
<tr>
<th>Property</th>
<th>Soil M</th>
<th>Soil M+5%</th>
<th>Soil M+10%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Consolidation Pressure (kPa)</td>
<td>46.2</td>
<td>92.4</td>
<td>46.2</td>
</tr>
<tr>
<td>Void Ratio</td>
<td>0.740</td>
<td>0.612</td>
<td>0.780</td>
</tr>
<tr>
<td>Dry density (Mg/m³)</td>
<td>1.53</td>
<td>1.65</td>
<td>1.44</td>
</tr>
</tbody>
</table>

3.2 Shrinkage Characteristics

An example of the transformation of digital images taken during the drying process by the GIS software to compute the surface and crack area (where applicable) is shown in Fig.5. The computed value given by the GIS software was multiplied by the calibration coefficient as given in Table 3 which was obtained by the procedure described in the earlier section. As expected, the greatest calibration coefficient was obtained when the object was furthest away from the camera lens.

![Figure 5. Steps of image processing in ArcGIS Software, (a) Sample, (b) Classification image, (c) Extracted image and (d) Rastered image](image)

Table 3. Calibration coefficients used to compute surface areas of compacted specimens

<table>
<thead>
<tr>
<th>Thickness of specimen (mm)</th>
<th>Calibration Coefficient</th>
</tr>
</thead>
<tbody>
<tr>
<td>20</td>
<td>1.12</td>
</tr>
<tr>
<td>10</td>
<td>1.16</td>
</tr>
<tr>
<td>5</td>
<td>1.20</td>
</tr>
</tbody>
</table>

Fig.6 shows the rate of drying for specimens prepared to correspond with an initial voids ratio of samples consolidated to a pressure of 46.2 kPa. Fig.7 shows the same for specimens prepared to correspond with an initial voids ratio of samples consolidated to a pressure of 92.4 kPa. Figs. 6 and 7 show that the reduction of moisture content is rapid in thin specimens as well as in specimens whose initial voids ratio is high as those correspond with samples consolidated to 46.2 kPa. This is understandable as thin specimens and those specimens that correspond with low consolidation...
pressure contained low amount of moisture and all the specimens had more or less same area of surface exposed to the atmosphere through which the exchange of water molecules and air could take place during the drying process.

Fig. 6 Rate of drying of specimens prepared to correspond with an initial voids ratio of samples consolidated to a pressure of 46.2 kPa (a) Moragahakanda expansive soil, (b) 5% Bentonite added, (c) 10% Bentonite added.

Figure 7. Rate of drying of specimens prepared to correspond with an initial voids ratio of samples consolidated to a pressure of 92.4 kPa (a) Moragahakanda expansive soil, (b) 5% Bentonite added, (c) 10% Bentonite added.
Figure 8. Variations of percentage area reduction with moisture content of the specimens with an initial voids ratio corresponding to that of specimens consolidated under a pressure of 46.2 kPa.

Figure 9. Variations of percentage area reduction with moisture content of the specimens with an initial voids ratio corresponding to that of specimens consolidated under a pressure of 92.4 kPa.
Fig. 8 shows the variations of percentage area reduction with moisture content of the specimens with an initial voids ratio corresponding to that of specimens consolidated under a pressure of 46.2 kPa and Fig. 9 shows the same variations of the specimens with an initial voids ratio corresponding to that of specimens consolidated under a pressure of 92.6 kPa. It is seen that although the moisture content is reduced gradually during the drying process of specimens, most of the reduction of area took place once the specimens reached the equilibrium moisture content.

It appears that the shrinkage taking place during the drying stage of the specimens does not reduce the area significantly and once the equilibrium moisture content is reached, the specimens continue to undergo contraction at the equilibrium water content. As the drying takes place, the large amount of water absorbed into the diffuse negatively charged layer in montmorillonite clay mineral present in Moragahakanda expansive soil and in Bentonite (Herath, 1993) would be released, thus causing the reduction in the distance between the layers.

![Figure 10. View of the sample (a) before drying, (b) after drying](image)

Fig. 10 shows that for all the 18 specimens, although the reduction of surface area occurred, no shrinkage cracks were developed. This observation is a very important as during dry season the liner will lose moisture as the leachate generated is minimal, and it is very advantageous for the liner not to develop shrinkage cracks, although expansive soils have the characteristic of self healing the cracks when wetted.

4. CONCLUSION

This study was carried out to investigate the shrinkage behaviour of candidate liner materials prepared using expansive soils from Moragahakanda and that amended by 5% and 10% of Bentonite. The above candidate materials were found to conform to hydraulic criteria of liner materials by a previous study and therefore, the specimens in this study was prepared to the same degree of compaction having the same voids ratio. Based on the outcome of this study, the following conclusions can be made.

1. Greater thickness of the specimen dries out at a lower rate.
2. Area reduction takes place, even after reaching the equilibrium water content during drying.
3. No shrinkage cracks within the surface of the specimens were visible, thus making the materials highly suitable as a liner material, provided that other criteria to determine the suitability as a liner material such as hydraulic conductivity and durability issues are satisfied.

5. ACKNOWLEDGMENTS

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6. REFERENCES


