CHARACTERIZATION OF WATER RETENTION PROPERTY OF GEOSYNTHETIC CLAY LINER

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ABSTRACT: Geosynthetic clay liner (GCL) is used as hydraulic barrier in municipal solid waste landfill (MSWL) due to the very low hydraulic conductivity of bentonite component of GCL. The GCL is used in MSWL cover liner as an alternative to compacted clay liner. One of main function of the cover liner is to limit the infiltration of rainfall into the MSWL. GCL should be sufficiently hydrated before placement for the effective performance; however, the moisture content of GCL might vary due to the fluctuations in the temperature and rainfall within the landfill area. Hence, the efficiency of the GCL in terms of hydraulic conductivity under varied moisture content need to be established. The performance of GCL under varied moisture condition can be estimated from water retention curve (WRC) of GCL. WRC is a fundamental relationship between suction and its corresponding moisture content. In the present study, total suction of GCL at different moisture content is determined using dew point PotentiaMeter. WRC fitting parameters of GCL sample are obtained by fitting experimental data of WRC to Van Genuchten (1980) and Pham and Fredlund (2008) WRC models.  

KEYWORDS: GCL, water retention curve, WP4C, suction, moisture content

1 Introduction

Geosynthetic clay liner (GCL) is used as hydraulic barrier in various barrier systems of solid and liquid waste containment facilities, e.g., municipal solid waste landfill (MSWL) due to the very low hydraulic conductivity of bentonite components of GCL. The GCL is generally about 5-10 mm in thickness and used in MSWL cover liner as an alternative to compacted clay liner (CCL), 600-900 mm of thickness (Viswanadham et al. 2012). The main function of cover liner is to prevent the migration of bio-gas (CO₂ and CH₄) to the atmosphere and to reduce the infiltration of rainfall into the MSWL (Rajesh et al. 2014). The CO₂ produces green house effect which causes rise in temperature and creates harmful effect to the atmosphere as well as human beings. The infiltration of rainfall produces excessive leachates which causes contamination of nearby water table and soil.

To check the above two problems, GCL should be sufficiently hydrated before placement in MSWL cover liner. Moisture content of GCL of cover liner might vary due to the variation of temperature and rainfall within the landfill area. Hence, the efficiency of the GCL in terms of hydraulic conductivity under varied moisture content need to be established. The performance of GCL under varied moisture condition can be estimated from water retention curve of GCL. Water retention curve (WRC) is a fundamental relationship between soil suction (matric or total suction) and moisture content (gravimetric moisture content, volumetric moisture content or degree of saturation).

A large number of literatures are available for obtaining water retention curve of soils by different methods (Fredlund and Rahardjo 1993, Lu and Likos 2004, Rajesh et al. 2016). In the last decade, some studies has been performed on water retention curve of GCLs by various methods, e.g., filter paper method (Acikel et al. 2011), high capacity tensiometer (Beddoe et al. 2010), relative humidity sensor (Beddoe et al. 2011), axis translation technique (Southen and Rowe 2007). Suction of any material can be easily, quickly and effectively measured using WP4C dew point PotentiaMeter. Even though this device is popularly being used to determine total suction in soils (Leong et al. 2003, Bulut and Leong 2008) but its usage in estimating suction in GCL is limited. Hence, in the present study, water retention curve of GCL is determined using WP4C dew point PotentiaMeter. WRC fitting parameters are obtained by fitting experimental data of WRC of GCL with popular WRC models like Van Genuchten (1980) and Pham and Fredlund (2008) WRC models.
2 Materials and Methods

2.1 Geosynthetic clay liner

A commercially available geosynthetic clay liner from CETCO (Bentomat ST) is used in the present investigation. Bentomat ST is a geotextile supported GCL which consists of granular sodium bentonite sandwiched between woven carrier and non-woven cover geotextiles held together as a composite material by needle punching. The material properties of GCL were determined in the laboratory and the same was reported in Table 1.

Table 1. Material properties of GCL

<table>
<thead>
<tr>
<th>Properties</th>
<th>Bentomat ST</th>
</tr>
</thead>
<tbody>
<tr>
<td>$M_{GCL}$ (g/m²)</td>
<td>5283.4</td>
</tr>
<tr>
<td>$M_{Bentonite}$ (g/m²)</td>
<td>4890.4</td>
</tr>
<tr>
<td>$M_{Carrier}$ (g/m²)</td>
<td>193.4</td>
</tr>
<tr>
<td>$M_{Cover}$ (g/m²)</td>
<td>199.6</td>
</tr>
<tr>
<td>Dry GCL thickness (mm)</td>
<td>7.43</td>
</tr>
</tbody>
</table>

2.2 Preparation of GCL specimens

38 mm diameter GCL specimens were cut from the GCL sheet (0.5 m x 0.5 m) using a 38 mm diameter die. Silicone gel (a semi-fluid paste) was applied along the periphery of the GCL specimens to avoid loss of bentonite during handling and testing. Prepared GCL specimens were kept in laboratory at a temperature of 25 °C for 1 hour so that the silicone gel gets harden on drying. The prepared GCL specimens are shown in Figure 1.

![Fig. 1 Prepared GCL specimens](image)

The moisture content of GCL means the moisture content of bentonite components of GCL. The initial moisture content of bentonite components of the GCL specimens were determined using oven drying method. The dry mass of bentonite components of GCL specimen is determined according to equation 1 (Risken 2014).

\[
M_s = \frac{M_{tot} - M_{gt} - M_{silicone gel}}{1 + w_{init}} 
\]

where $M_s$ is the mass of dry bentonite components of GCL specimen, $M_{tot}$ is the total mass of GCL specimen ($M_{tot} = M_t + M_w + M_{gt} + M_{silicone gel}$), $M_w$ is the mass of water, $M_{gt}$ is the mass of geotextiles in GCL specimen, $M_{silicone gel}$ is the mass of silicone gel applied, $w_{init}$ is the initial moisture content of bentonite components of GCL.

The mass of GCL specimen at target moisture content can be calculated using equation 2 (Risken 2014).

\[
M_t = M_s(1 + w_i) + M_{gt} + M_{silicone gel} 
\]

Where $M_t$ is the mass of GCL specimen at target moisture content and $w_i$ is the target moisture content of the GCL specimen.

The GCL specimens of 8-150 % moisture content were selected to represent a wide range of suction. The GCL specimens were prepared with a moisture content of 8 % (natural moisture content), 25%, 50%, 75%, 100%, 125% and 150%. The laboratory dried GCL specimens at 25 °C were immersed in tab water for different time. The GCL specimens were weighed regularly to measure the amount of hydration (or moisture content). When the required weight was achieved according to eq. 2, GCL specimens were taken out from water and stored in a sealed glass container for 7 days to achieve moisture equilibrium. After the period of moisture equilibrium, total suction of GCL specimens were measured with the help of WP4C dew point PotentiaMeter.

2.3 Test setup and test procedure

The total suction of GCL specimens was determined using WP4C dew point PotentiaMeter (0-300 MPa range) of Decagon Devices is shown in Figure 2. In WP4C, a peltier cooling device is used to cool the mirror until dew forms and then to heat the mirror to remove the dew. An optical sensor is used to detect the dew formation on the mirror. The dew point temperature is measured by thermocouple attached with the mirror. The temperature of the soil sample is measured with an infrared thermometer. A small fan is use to circulate the air and accelerate the vapour equilibrium process (Mantri and Bulut 2014). The principle behind the measurement of total suction is equilibrium of liquid phase of water in GCL specimen with vapour phase of water in the air above the GCL specimen in closed chamber (Bulut and Leong 2008). Relative humidity (RH) is determined from the dew point and GCL specimen temperature. Total suction is calculated from relative humidity value by using Kelvin’s equation.
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Fig. 2 WP4C dew point PotentiaMeter

After 7 days of moisture equilibrium period, GCL specimen was placed in PVC cup and equilibrated with air space above the GCL specimen in the chamber of the WP4C device. At equilibrium condition, water potential of air in the chamber is equal to the suction of the GCL specimen. After equilibrium, total suction of GCL specimen was measured from the display of WP4C device. The water retention curve is obtained from the moisture content and total suction data of GCL specimens.

3 Results and discussions

The results from the laboratory produce a series of discrete points in the WRC. The variation of moisture content with total suction of GCL sample is shown in Figure 3. It can be noticed that with an increase in the water content, the total suction was found to decrease. The WP4C device has a suction range of 0 - 300100 kPa. Hence, suction value of GCL less than 0.1 MPa could not be measured using the mentioned device.

![Water retention curve of GCL](image)

As the WRC is commonly used to predict engineering properties of unsaturated GCLs, it is commonly represented as a continuous curve rather than discrete points by fitting some form of mathematical function to facilitate modeling purposes. The WRC equation proposed by Van Genuchten (1980) [VG] and Pham and Fredlund (2008) [PF] are used in the present study and the same is shown in equation 3 and 4 respectively.

The VG WRC model is given in Eq. 3

\[
w = w_r + \left( \frac{w_s - w_r}{1 + (\alpha \phi_s)^n} \right)^m
\]

where \(w\) is the water content (\%), \(w_r\) is the residual water content (\%), \(w_s\) is the saturated water content (\%), \(\alpha\) is related to the inverse of air entry value, \(n\) is related to the pore size distribution, and \(m\) is related to the asymmetry of the model.

The PF WRC model is given in Eq. 4

\[
w(\psi) = w_{sat} * (M_1 + M_2) + S_1 * [-log(\psi_{ae})] * (M_1 + M_3) - M_2 \frac{[M_1 * log(10^{\psi_0}) - log(\psi_{ae})]}{\psi_{ae}} * M_3 + M_4
\]

where

\[
M_1 = \frac{log(\psi_{ae})}{ln(10)}^\left[ \frac{-1}{2} \right] \frac{\psi_{ae}^{l_2}}{\psi_{ae}^{l_2} + \psi_{ae}^{l_2}}
\]

\[
M_2 = \frac{log(\psi_{ae}^{l_2})}{ln(10)} \left[ \frac{-1}{2} \right] \frac{\psi_{ae}^{l_2}}{\psi_{ae}^{l_2} + \psi_{ae}^{l_2}}
\]

\[
M_3 = \frac{log(10^{\psi}) - log(\phi)}{log(10)} + log(\psi_{ae})
\]

where

\(w_{sat}\) is the water content at 1 kPa soil suction
\(\psi_r\) is the residual suction
\(\psi_{ae}\) is the air entry value
\(S_1\) is slope of the WRC of portion less than the air entry value
\(S_2\) is slope of WRC between the air entry value and residual suction
\(l_1, l_2\) are curve fitting parameters which controls the transition between portions of WRC.

The curve fitting parameters are obtained by fitting experimental data of WRC of GCL with VG and PF WRC model by minimizing the sum of squared error term using Excel solver function. The obtained fitting parameters are tabulated in Table 2. Figure 4 shows the fitting curves obtained using VG and PF model with experimental data. It can be inferred that PF model fitted closely with the experimental data when compared with VG model. Air entry value and residual suction is 18057.73 kPa and 23081.07 kPa respectively.
These WRC fitting parameters may be used to modeling for unsaturated behavior of particular type of GCL as same used in the present study.

4 Conclusions

Water retention curve of GCL is determined by WP4C dew point PotentiaMeter. From WRC, it is observed that total suction is increases with the decreasing of moisture content of GCL specimen. WRC fitting parameters are obtained by fitting experimental data of WRC of GCL to Van Genuchten (1980) and Pham and Fredlund (2008) model. The experimental data of WRC of GCL is well consistent with Pham and Fredlund (2008) WRC model. These WRC fitting parameters may be used to modeling for unsaturated behavior of particular type of GCL as same used in the present study.

Table 2. Fitting parameters of WRC model

<table>
<thead>
<tr>
<th>WRC Model</th>
<th>Parameters</th>
<th>Value</th>
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</thead>
<tbody>
<tr>
<td>VG</td>
<td>(W_t) (%)</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>(a) (kPa(^{-1}))</td>
<td>4.73*10(^8)</td>
</tr>
<tr>
<td></td>
<td>(n)</td>
<td>0.73</td>
</tr>
<tr>
<td></td>
<td>(m)</td>
<td>84.92</td>
</tr>
<tr>
<td>PF</td>
<td>(\psi_{ae}) (kPa)</td>
<td>18057.73</td>
</tr>
<tr>
<td></td>
<td>(\psi_s) (kPa)</td>
<td>23081.07</td>
</tr>
<tr>
<td></td>
<td>(t_1)</td>
<td>0.83</td>
</tr>
<tr>
<td></td>
<td>(t_2)</td>
<td>1.27</td>
</tr>
<tr>
<td></td>
<td>(s_1)</td>
<td>6.65</td>
</tr>
<tr>
<td></td>
<td>(s_2)</td>
<td>964.03</td>
</tr>
</tbody>
</table>

Fig. 4 Comparison of WRC with curve fitting equations

References


