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Technical note

Electrical resistance method for assessing spatial variation of water content in geosynthetics clay liners at laboratory scale

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ABSTRACT

Non-uniform moisture distribution throughout pre-hydrated geosynthetics clay liner (GCL) laboratory testing specimens could significantly affect their liquid/gas permeability test results. For a reliable comparison between different pre-hydrated GCL specimens, uniform moisture distribution condition should be ensured before testing their permeabilities. This study presents a simple non-destructive electrical probing approach to assess the moisture homogeneity of GCL specimens before their use in laboratory tests. An experimental program was conducted to check the feasibility and the validity of the proposed method on GCLs hydrated at different moisture contents. The outcomes of the experimental program prove the adequacy of the proposed method.

1. Introduction

Geosynthetic clay liners (GCLs) are most typically comprised of a thin layer of bentonite contained between two layers of geotextile with the components being held together by needle-punching or stitch bonding. They are widely used in lining systems of modern waste containment facilities to minimise migration of contaminants and gases (Bouazza, 2002; Rowe, 2012, 2014). In this respect, there is a wide body of work available on their hydraulic and/gas barrier performance (Shackelford et al., 2000; Bouazza and Vangpaisal, 2004, 2006, 2007; Benson et al., 2010; Gates and Bouazza, 2010; Scalia and Benson, 2011; Bradshaw et al., 2013; Mazzieri et al., 2013; Rowe and Abdelatty, 2013; Abuel-Naga et al., 2013, Abuel-Naga and Bouazza, 2014; Hosney and Rowe, 2014a,b; Ashe et al., 2014, 2015; Bouazza and Gates, 2014; Liu et al., 2013, 2014, 2015; Rowe and Hosney, 2015; Take et al., 2015; Rouf et al., 2015).

Several studies have shown the importance of GCL initial hydration with a non-chemically aggressive hydration fluid to improve its chemical compatibility to leachates or other more aggressive solutions (Vasko et al., 2001; Lee and Shackelford, 2005; Katsumi et al., 2008; Liu et al., 2015). In common practice, initial hydration of GCL could be achieved through a passive process in which water vapour is transferred from the subgrade to the GCL if there is no intimate contact (Rouf et al., 2014) or through an active process where moisture can be taken from the subgrade in liquid form if there is an intimate contact between the subgrade and the GCL (Rayhani et al., 2011).

To assess the effect of the initial pre-hydration on the hydraulic/gas performance of GCL at the laboratory scale, GCL specimens are usually pre-hydrated to different moisture content targets (Vasko et al., 2001; Vangpaisal and Bouazza, 2004; Katsumi et al., 2008). Furthermore, a homogenous moisture content distribution throughout the GCL specimen must be achieved otherwise the hydraulic conductivity and/or gas permeability of heterogeneously pre-hydrated GCLs to contaminant solutes and/or gas can become unreliable (Katsumi et al., 2008; Bouazza and Vangpaisal, 2003; Vangpaisal and Bouazza, 2004). This is due to the presence of preferential flow paths caused by a non-uniform distribution of moisture content in the GCL.

The usual practice of verifying the moisture content distribution in a GCL specimen is to conduct destructive tests (Bouazza and Vangpaisal, 2003; Bouazza et al., 2014) which involves cutting the

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specimen in several slices and oven dry them for 24 h. This process is most often repeated if the target moisture content distribution is not reached in laboratory experiments. This paper presents a simple non-destructive technique to assess the homogeneity of the moisture content in a GCL specimen using an electrical resistance method.

2. Proposed methodology

A non-destructive electrical resistance probing approach is proposed in this study to assess the moisture homogeneity of GCL specimens. The electrical resistivity of porous media is mainly function of moisture content and several other parameters such as temperature, soil structure, texture, mineralogy, and the salt content of the water (Archie, 1942; Gupta and Hanks, 1972; Rhoades et al., 1976; Guéguen and Palciauskas, 1992; Kalinski and Kelly, 1993; Abu-Hassanein et al., 1996; McCarter and Desmazes, 1997; Revil et al., 1998; Seladji et al., 2010; Beck et al., 2011; Kibria and Hossain, 2012). The general premise behind the use of electrical resistivity measurements for assessing the moisture homogeneity of a GCL specimen is based on the assumption that the bentonite layer of GCL specimen has homogenous properties in terms of density, structure, texture, mineralogy, and water salt content. This assumption could be supported by the fact that GCLs are man-made materials that usually go through quality control (QC) and quality assurance (QA) procedures to ensure the homogeneity condition of the materials. Therefore, the spatial variability of the electrical resistivity measurements could be directly linked to the moisture content distribution within the GCL specimen. However, it should be mentioned that the validity of this method to assess the moisture homogeneity is limited by the fact that the rate of change of electrical resistivity for clays decreases as moisture content increases to become almost zero when the degree of saturation exceeds 70% (McCarter, 1984). However, Rayhani et al. (2008) showed that for different types of GCL the maximum degree of saturation due to GCL hydration from subsoil could be in the range of 60%–80%. Therefore, the valid working range of the electrical resistance method proposed in this study fits with the purpose of verifying the moisture distribution of a pre-hydrated GCL laboratory testing specimen.

In this study a modified oedometer cell (Fig. 1) was used to quantify the spatial variation of the electrical resistivity throughout a GCL specimen. The cell is made of PVC material and can accommodate a GCL specimen having up to 100 mm diameter. The Wenner four-electrode method (Wenner, 1915; ASTM G57-06, 2012) for measuring the electrical resistivity was incorporated into the top cap as shown in Fig. 1. The electrical resistivity of the GCL specimen can be measured at different radial sections by rotating the top cap in-plan. Therefore, this method enables radial scanning of the average moisture contents throughout the GCL specimen.

The Wenner four-electrode method is usually used to measure soil resistivity in the field. The method involves using four cooper electrodes placed with equal separation, a (cm), in a straight line in the surface. A voltage is applied between the outer electrodes where the corresponding current, I, and the voltage drop between the inner electrodes, V, are measured. The resistivity, ρ (Ω cm), is then:

$$\rho = 2\pi\, a\, (V/I) \tag{1}$$

It should be mentioned that the measured ρ by the Wenner four-electrode method represents the average resistivity of a hemisphere of soil of a radius approximately proportional in homogenous media to the electrode separation where the term (2πa) is a geometrical factor defined based on a semi-infinite boundary condition (half-space). However, this geometric boundary condition is not applicable for the cell shown in Fig. 1. As the geometric boundary conditions of every radial section through the GCL specimen are similar and the main purpose of the measurements is to assess the homogeneity throughout the specimen rather than the actual resistivity (ρ) of the GCL, the electrical resistance measurements, R = V/I, can be used instead of ρ for this purpose.

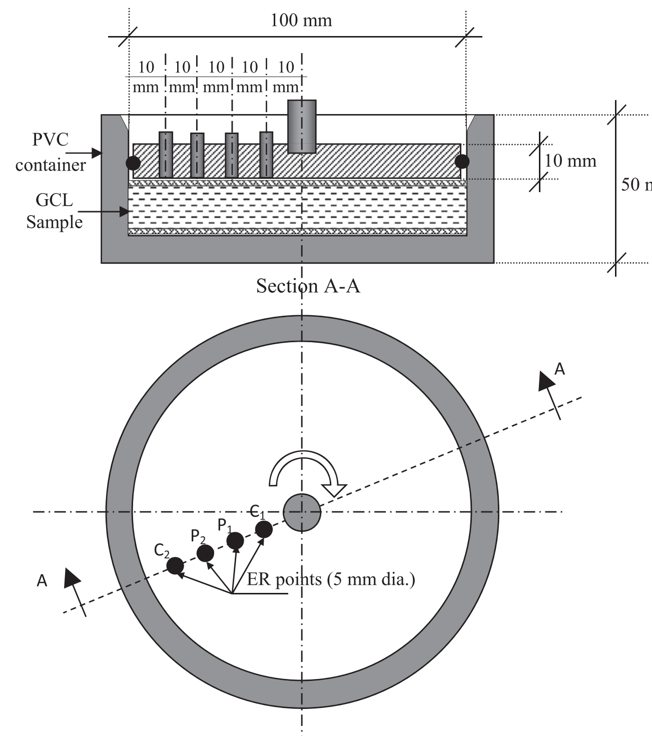

Fig. 1. Electrical resistivity cell.

In this study 10 DC voltages was impressed across the outer electrodes where the current injection time duration and delay were 10.0 s and 0.0 s, respectively. The voltage drop across the inner electrodes and the current across the outer electrodes were recorded with resolution of 250 μV, and 10 nA, respectively.

3. Material and specimen preparation

Table 1 lists the properties of the GCL material used in this study. A GCL sample was cut from a large GCL sheet, using a sharp utility knife, to an A4 size. A circular stainless steel cutting ring with an inner diameter of 100 mm was used to cut the GCL specimen. The GCL A4 size sample was placed between the cutting ring and a plywood plate, which was used as a cutting base. The whole set was then placed on the platen of a compression machine to cut the GCL specimen to the required size.

The pre-hydration process of the GCL involved immersing the cutting ring with the GCL specimen still inside in de-ionized water for different time durations (30 s, 60 s) to obtain specimens with different pre-hydrated moisture contents. Once the immersion process was completed, the GCL still in its cutting ring was stored in a double plastic bag for two-week curing under zero pressure confinement. This could represent the case when the GCL begins hydrating before the placement of a soil cover. The average moisture content (wc_{avg}) achieved was 49% and 113%, respectively, for immersion times of 30 s and 60 s, respectively. After completion of the curing period, the GCL was carefully pushed from the cutting ring into the electrical resistivity cell.