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Insufficient initial hydration of GCLs from some subgrades: Factors and causes

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ABSTRACT

Water retention and hydration tests are reported for three needle punched geosynthetic clay liners (GCLs). GCLs hydration and their maximum hydration capacity were assessed against subgrade soils prepared at different initial gravimetric water contents. The subgrade soil mineralogy and particle size distribution, as well as the carrier geotextiles used in GCLs, are shown to have a significant impact on the GCLs hydration behaviour. This work highlights the need to consider the unsaturated properties of both the GCLs and the subgrade soil when assessing the hydration of the GCLs. At gravimetric water contents above the GCL water entry value (≈30%), some forms of GCL configuration may be better than others with respect to ability to hydrate from a given soil. However, the partial hydration of GCL is mostly controlled by the bentonite microstructure for gravimetric water contents below the water entry value of the GCLs.

1. Introduction

Geosynthetic clay liners (GCLs) have been predominantly used as a hydraulic barrier in composite lining systems for waste containment facilities over the past two decades (Giroud et al., 1997; Didier et al., 2000; Lake and Rowe, 2000; Shackelford et al., 2000; Babu et al., 2001, 2002; Bouazza, 2002; Malusis and Shackelford, 2002b; Rowe, 2005; Barroso et al., 2006; Hornsey et al., 2010; Benson, 2013; Bouazza and Gates, 2014; Rowe, 2014; Mazzieri and Di Emidio, 2015; Touze-Foltz et al., 2016; Seiphoori et al., 2016; Rouf et al., 2016b; c; Bouazza et al., 2017b). GCLs (typically 5 to 10 mm-thick) are manufactured at gravimetric water contents (GWC) which can range from 5% to 40%. They may partially hydrate or dry during storage before their use under normal ambient conditions. For example, GCLs tend to achieve GWCs of 12–14% under ambient conditions at about 55% relative humidity (Gates et al., 2012; Rouf et al., 2016a). Once installed in the field (*i.e.*, at the manufactured GWC), they are expected to hydrate from the subgrade soil which in most cases has been prepared at about optimum gravimetric water content and maximum dry density.

Proper initial hydration of GCLs from the subgrade soil is essential to ensure an acceptable hydraulic performance because they need to be hydrated to a GWC higher than 80 to 100%, depending on the concentration of the solutes, to effectively function as a hydraulic barrier to fluids (Petrov and Rowe, 1997; Vangpaisal and Bouazza, 2004; Rowe, 2007, 2012; Rowe and Hoor, 2009; Hornsey et al., 2010; Rayhani et al., 2011; Rowe et al., 2011; Chevrier et al., 2012; Siemens et al., 2012, 2013; Bouazza et al., 2013; Hoor and Rowe, 2013; Bouazza and Gates, 2014; Liu et al., 2015). Very often it is implicitly assumed that GCLs will hydrate to an acceptable GWC to be functional as a fluid barrier shortly after they are installed. However, recent evidence from field observations have indicated that GCLs might be subjected to thermal cycles (such as it may occur during wet-dry cycles or if exposed to solar radiation) (Rowe et al., 2011) or the subgrade properties may cause insufficient hydration of the GCL (Benson, 2013; Bouazza et al., 2017a).

Past studies on the initial hydration of GCLs from subsoils have shown that the level of hydration attained initially by GCLs was highly dependent on the gravimetric water content of the subgrade soils at the time of contact (Rayhani et al., 2011; Benson, 2013; Siemens et al., 2013) as well as the particle size distribution (Anderson et al., 2012), and mineralogy (Bouazza et al., 2017a) of the subgrade soils. Furthermore, the hydration rate of GCLs was found to be a function of the water retention behaviour of the subgrade soils and GCLs (Sarabian and

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Rayhani, 2013; Bouazza et al., 2017a) and the hydraulic conductivity of the subsoils (Chevrier et al., 2012).

Insufficient initial GCL hydration might also be caused by a capillary break phenomenon which may occur between the GCL carrier geotextile and the subgrade. Stormont and Anderson (1999) referred to the capillary break effect in a soil-geosynthetic system as a result of resistance to water transfer from an unsaturated soil into the pores of a nonwoven geotextile. McCartney et al. (2008) observed that capillary rise could be delayed for several days when a nonwoven geotextile was placed between two soil layers. Zornberg et al. (2010) described this phenomenon as related to the air/water meniscus changing at the interface between pores of different sizes. Acikel et al. (2015) observed the capillary break effect during contact filter paper tests when applied to both geotextile sides of GCL specimens. They reported that the final gravimetric water contents of the filter papers in contact with nonwoven geotextile surfaces were lower than those in contact with the woven geotextile surface, inferring that the nonwoven geotextile was more likely to cause a capillary break than the woven geotextile.

Since the early 90s, the water retention behaviour of GCLs has been investigated by studying their bentonite and geotextile components separately (Daniel et al., 1993; Bouazza et al., 2006c; Nahlawi et al., 2007; McCartney et al., 2008) or as a whole body (Barroso, 2005; Southen and Rowe, 2007; Abuel-Naga and Bouazza, 2010; Beddoe et al., 2011; Bannour et al., 2014; Rouf et al., 2014; Acikel et al., 2015, 2018; Seiphoori et al., 2016). Various direct and indirect suction measurement and control techniques (namely: thermocouple psychrometer, filter paper, pressure plate and pressure membrane extractors, thermocouple psychrometer, relative humidity sensor, high capacity tensiometer (HCT), osmotic technique, vapour equilibrium technique, chilled mirror technique) were used to obtain GCL water retention curves.

The objective of this paper is to provide a comprehensive understanding of GCL hydration from subgrade soils under isothermal conditions from unsaturated soil mechanics and capillary break perspectives. The impact of the mineralogical and the geotechnical engineering characteristics of both GCLs and subgrades were investigated including (1) the smectite content, particle size distribution, and the initial gravimetric water content of the subgrade; (2) the microstructure and smectite content of the bentonite component of GCLs; and (3) geotextile configuration and bentonite mass per unit area.

2. Background

Bentonite is the key barrier component of GCLs. Bentonites used in GCLs have many similar properties because the industry has generally established worldwide specification limits for smectite content, exchange cation, swell index and other performance parameters (Gleason et al., 1997; Shackelford et al., 2000; Egloffstein, 2001; Gates, 2007; Gates et al., 2009). Bentonite has significantly different pore size ranges between its particular structural units; namely: layers, particles, and aggregates (Fig. 1).

A bi-modal pore structure, consisting of both inter- and intra-aggregate pores, is widely accepted for bentonites (Gens and Alonso, 1992; Alonso et al., 1999; Sanchez et al., 2006, 2016; Delage, 2007; Villar and Lloret, 2008; Romero et al., 2011; Seiphoori et al., 2014; Navarro et al., 2015; Cui, 2017). The bi-modal pore structure of bentonite can be extended to a tri-modal pore structure for GCLs with the additional consideration of pores associated with the geotextile components (Fig. 2). As defined in this paper, the tri-modal pore structure has geotextile pores as macro-pore, inter-aggregate bentonite pores as meso-pores and intra-aggregate pores and any bentonite pores smaller than intra-aggregate as micro-pores. However, some overlap within these ranges probably occurs. Furthermore, the components of GCLs have fundamentally different wetting behaviour: while bentonite surfaces are highly hydrophilic, geotextile surfaces may be (at least initially) hydrophobic (Bouazza et al., 2006a; Zornberg et al., 2010; Bouazza and Gates, 2014).

The range of very different pore sizes, which arises from the bentonite itself (bi-modal pore structure) and the geotextile (macro-pore) component (giving a tri-modal structure when there are used together in a GCL), can give rise to substantially different hydration behaviours. In addition, the macro-pores and hydrophobic behaviour geotextile components of the GCL can results in a capillary break between GCL and subgrade soil during hydration if the geotextile had insufficient hydrophilic bentonite in its structure at the GCL – subgrade contact. The geotextile components of GCLs which are the contact surfaces to the other layers (such as, subgrade) usually have some bentonite in their pores and hence have also a tri-modal pore structure with both macro-pores associated with the geotextile and needle punched fibres bundles and the range of pores (meso- and micro-pores) associated with the bentonite within a GCL. Since the pore sizes may differ by several orders of magnitude the corresponding potentials for water entry into these pores would also differ over a wide range. The capillary break effect can be seen as a result of a discontinuity in the suction values in the GCL as a whole, even if the bentonite micro-pores (intra-aggregate pores and smaller ones) are hydrated to 2 to 4 layers of water (Saiyouri et al., 2004; Gates et al., 2017).

When a GCL is covered by a geomembrane immediately after field installation to form a composite liner, its hydration can only occur through water absorption from the underlying subsoil. This process is partly governed by the water retention curve (WRC) of the GCL during hydration (Fig. 3). When the initially dry GCL is placed on the subsoil, it hydrates along its WRC wetting path: its moisture content increases while its suction decreases. As the source of available moisture, the subsoil immediately below the GCL responds to its own WRC drying path (moisture content decreases and suction increases). Thus, the balance of subsoil suction with GCL suction influences water movement between the subsoil and the GCL, and water migration temporarily ceases when the hydraulic potential driving force (suction) comes into equilibrium at the interface. Fig. 3 identifies key characteristics of the subgrade soil on the drying path such as its air entry value (AEV) and residual limit. Similarly, key characteristics of the GCL on the wetting path such as the water entry suction value (WEV) can also be identified. The water entry value (WEV) can be defined as a suction value where capillary connections of the residual water (meniscus) can form between the granules during the wetting path. Thus, the WEV is the point between the residual and the transition zones of the WRC wetting path. The corresponding value of the WEV on the drying curve, the residual limit, can be described as the minimum suction value where the granular medium can no longer hold any capillary connections between residual water on the granules during the drying path. Similar to the WEV, the AEV residual limit is the point between the transition zone and the boundary effect zone of a WRC drying path (Fredlund et al., 2012).

The hypothetical example given in Fig. 3 shows three different suction zones (Zones 1, 2 and 3) which describe capillary break during water re-distribution between two porous media. Note that Zones 1, 2 and 3 described in the current study do not exactly correspond to the boundary effect, transition and residual zones of a WRC. These characteristics zones (boundary effect, transition and residual) of the WRCs are shown by different lines patterns (solid, double line and dots, respectively) and explained in the legend of the figure to avoid confusion. Zone 1 is defined as the suction zone between saturation values and the WEV of the GCL. Both GCL and subgrade can have capillary water in this zone. Zone 2 is the suction range between the WEV of the GCL and residual limit of the subgrade soil. Within the drying path of a subgrade soil, the soil can still have capillary water; however, the GCL has not formed capillary water during wetting in Zone 2. Zone 3 can be defined as the suction range in which the wetting GCL has not formed capillary connections, and where the subgrade has lost all capillary connections during drying. In other words, Zone 3 represents the condition in which both GCL (in its wetting path) and the subgrade soil (in its drying path)