Geotextiles and Geomembranes 46 (2018) 436–447

Contents lists available at ScienceDirect

Geotextiles and Geomembranes

journal homepage: www.elsevier.com/locate/geotexmem

Liquid limit based assessment of geosynthetic clay liners subject to hydration and hydraulic conductivity testings

Tuğçe Özdamar Kul[a], A. Hakan Ören[b,*]

[a] Dokuz Eylül University, Graduate School of Natural and Applied Sciences, Dept. of Civil Engineering, Tınaztepe Campus, 35390 Buca-Izmir, Turkey
[b] Dokuz Eylül University, Dept. of Civil Engineering, Tınaztepe Campus, 35390 Buca-Izmir, Turkey

ARTICLE INFO

Keywords:
Geosynthetics
Geosynthetic clay liner
Hydration
Hydraulic conductivity
Subsoil
Water content

ABSTRACT

This study investigates and discusses the hydration and hydraulic conductivity of low performance (LP), medium performance (MP) and high performance (HP) GCLs. The performance description is made in terms of liquid limit rather than cation exchange capacity or smectite content. The liquid limits of LP, MP and HP GCLs were 108, 320, and 1163%, respectively. GCLs were initially hydrated over compacted silty sand subsoils for 7–90 days. After hydration, water contents of GCLs were determined. Regardless of GCL type, the water contents remarkably increased in the first 7 days of hydration and reached equilibrium after 30 days of hydration for LP and HP GCLs. The water content of MP-GCL continued increasing even at the end of 90 days of hydration. The final water contents were 69, 84, and 120% for LP, MP and HP GCLs, respectively. In other words, increase in the liquid limit of bentonite corresponds to increasing the final water contents of GCLs. The findings of this study are in agreement with literature findings. However, there was no such kind of a trend when smectite content or cation exchange capacity was the dependent variable. The hydraulic conductivity behaviors were totally dependent on GCL performance. Hydrated LP and MP GCLs were not able to reduce their hydraulic conductivity at the beginning of the test. The pore volumes of flow (PVF) required to reducing the hydraulic conductivity to around 3.0×10^{-11} m/s were 270 for LP-GCL and 77–109 for MP-GCL. The hydraulic conductivity of some specimens of LP and MP GCLs were more than > 1.0×10^{-7} m/s even at the end of test duration. Observations showed that particle erosion took place during permeation. In contrast, the hydraulic conductivity of HP-GCLs decreased below 3.0×10^{-11} m/s within a few PVF. This is due to polymer-treated bentonite used in HP-GCL. Post-test measurements on GCLs showed that the water contents kept increasing during hydraulic conductivity. Although water contents increased, the height of LP-GCL did not increase even after hydration and hydraulic conductivity testing, indicating lateral swelling only. MP and HP GCLs, however, had swollen laterally and vertically, resulting in greater heights for HP-GCL than that for MP-GCL.

1. Introduction

A geosynthetic clay liner (GCL) is composed of a thin bentonite layer interposed between two geotextiles. These components are generally held together by needle-punching, stitch-bonding or adhesive bonding. Due to their easy installation and low hydraulic conductivity, GCLs have been used as a protective liner for advective transport of contaminants and infiltration of surface water.

Due to the practical reasons, GCLs are generally installed at their initial water contents (around 10–15%). Then, GCLs become hydrated by water adsorption from the underlying or surrounding soil depending on the installation conditions. Hydration from the subsoil improves the hydraulic performance of GCLs. Hydration duration, subgrade soil (or subsoil) type and minerology, the water content of subsoil, GCL type, the effective stress acting on the GCLs and environmental conditions such as site temperature are some of the factors that influence the hydration of GCLs (Meer and Benson, 2007; Benson and Meer, 2009; Scalia and Benson, 2010, 2011; Rayhani et al., 2011; Anderson et al., 2012; Rowe, 2012; Rowe and Abdelatty, 2012; Sarabian and Rayhani, 2013; Bouazza et al., 2017). Many studies have been conducted to determine the hydration behavior of GCLs on different subsoils so far. However, neither of these studies evaluated the hydration behavior as a function of the liquid limit of GCL.

Lee and Shackelford (2005) made quality-based denotation for GCLs such as lower or higher quality (LQ or HQ) depending on their mineralogical (i.e. montmorillonite content), physical (i.e. plasticity index) and chemical (i.e. cation exchange capacity, CEC) properties of bentonite. However, determining especially the mineralogical

* Corresponding author.
E-mail addresses: tugce.ozdamar@deu.edu.tr (T. Özdamar Kul), ali.oren@deu.edu.tr (A.H. Ören).

https://doi.org/10.1016/j.geotexmem.2018.03.009
Received 29 June 2017; Received in revised form 16 March 2018; Accepted 23 March 2018
0266-1144/

compositions and chemical properties of bentonite is rather complex and thus, different types of equipment and chemicals are needed for these analyses. For example, X-Ray diffractometer and Inductively Coupled Plasma (ICP) are required for mineralogical and chemical analyses, respectively. These devices are expensive and therefore, not available in most geotechnical engineering laboratories. Thus, a simple identification is desirable for the expression of GCL quality.

Regardless of mineralogical and chemical properties, index properties may be sufficient alone for the quality description. For example, liquid limit and swell index can be used for this purpose. These tests are quick, simple and cheap in comparison to mineralogical and chemical analyses, and they can be usually executed in geotechnical laboratories. In addition, the hydraulic conductivities of GCLs correlate well with liquid limits and swell indices of bentonites. It is well documented that the lower the liquid limit or swell index, the greater is the hydraulic conductivity of the bentonite and vice versa (Jo et al., 2001; Kolstad et al., 2004; Lee et al., 2005; Katsumi et al., 2008b; Mishra et al., 2011; Hosney and Rowe, 2014).

Despite these advantages, the liquid limit can be preferable with respect to swell index for some reasons. The amount of soil required for the swell index test is significantly lower than that of the soil required for the liquid limit test. Swell index test is conducted only with 2.0 g of dry bentonite, while the liquid limit test is carried out with about 500 g of bentonite. The test which uses more mass may successfully represent the general properties of bentonite and hence, GCL. Moreover, solid to liquid ratio in swell index test is much lower than that in the liquid limit test. The lower solid concentration increases the intact surface between the bentonite and water molecules, resulting in a larger swell volume than it should be. Therefore, it may be better if the liquid limit is used instead of swell index for the specification of GCL quality.

The liquid limits of bentonites from GCLs used in the hydration studies are within the range of 216–630% (Katsumi et al., 2008a; Anderson et al., 2012; Rowe and Abdelatty, 2012; Barclay and Rayhani, 2013; Sarabian and Rayhani, 2013). In the case of polymer treatment, the liquid limit is as much as 743% (Emidio et al., 2015). However, there is no information about the hydration performance of GCLs which have liquid limits lower than 216% or higher than 630%. Moreover, the hydration of GCLs in these studies was not evaluated in terms of bentonite properties such as liquid limits. Mostly, compaction water contents of subsoils have been used as the variable that influence the water content of GCLs (U.S. Environmental Protection Agency (USEPA), 1996; Rayhani et al., 2011; Anderson et al., 2012; Chevrier et al., 2012; Barclay and Rayhani, 2013; Sarabian and Rayhani, 2013). There are also scarce studies in the literature that focused on the hydration and hydraulic conductivity of GCLs together. These studies were generally conducted on a single GCL (Bradshaw et al., 2012; Rowe and Abdelatty, 2012) or two GCLs containing granular or powdered bentonite (Katsumi et al., 2008a). Similarly, the hydration and hydraulic conductivity of these GCLs were not evaluated in terms of the liquid limit. In other words, liquid limit based assessment of hydration and hydraulic conductivity of GCLs have not been made in these studies.

The objective of this study is to investigate and discuss the hydration and hydraulic conductivity behaviors of GCLs as a function of their quality expressed by the liquid limit. Quality based assessment has been generally made with the montmorillonite contents of GCLs. Since polymer treatment does not change the quality of GCL, and in order not to allow any confusion, performance-based denotation will be used henceforth. For this purpose, three GCLs with wide a range of liquid limit were hydrated over silty sand and subsequently subjected to hydraulic conductivity tests. The performance descriptions of GCLs were made based on the liquid limits of bentonites which were named as low performance (LP), medium performance (MP), and high performance (HP) throughout the study.

Table 1
Properties of GCLs used in this study.

GCL properties	LP-GCL	MP-GCL	HP-GCL
Mass/unit area without geotextile (kg/m^2)	3.36–3.41	3.57–4.34	2.68–2.84
Mass/unit area with geotextile (kg/m^2)	3.55–3.60	3.74–4.51	2.85–3.02
Structure construction	Needle-punched	Needle-punched	Needle-punched
Clay Content (%)	57	72	25
Swell index (mg/2g), range	22–26	20–23	26–34
Swell index (mg/2g), mean (SD)	24 (1.5)	21 (1.3)	31 (3.4)
Liquid limit (%)	108	320	1163
Plasticity index (%)	48	290	1111
Smectite content (%)	68	64	66

SD: Standard deviation.

2. Materials and methods

2.1. Materials

Three needle-punched GCLs were used in this study which were provided by local manufacturers in Turkey. All GCLs contained granular sodium bentonite. The mass of bentonite per unit area (MPUA) of GCLs was determined in accordance with ASTM: D5993-99 (2010) and were between 2.68 and 4.34 kg/m^2 (Table 1). The initial air-dry heights of GCLs ranged from 3.3 mm to 5.3 mm.

Grain size distributions of the subsoil and GCLs were determined with wet sieving method as described in ASTM: D422-63 (2007) (Fig. 1). Since HP-GCL was polymer treated, flocculation induced fast settling occurred during hydrometer test even if a dispersion agent was used (ASTM: D422-63, 2007). Because of this, the clay content was determined as low as 25% for HP-GCL. The clay contents of LP-GCL and MP-GCL were 57% and 72%, respectively (Table 1). Consistency limits of bentonites were determined in accordance with ASTM: D4318-05 (2005). The liquid limits of LP-GCL and MP-GCL were 108% and 320%, respectively. It should be noted that the liquid limit test for LP-GCL was replicated twice owing to low liquid limit values. In contrast, HP-GCL adsorbed more water with respect to others during the liquid limit test due to polymer treatment. Table 1 presents the liquid limits of GCLs where the highest liquid limit was obtained for HP-GCL (i.e. 1163%).

The subsoil was gathered from a Municipal Solid Waste (MSW) landfill site which is located in the western part of Turkey. The subsoil had 42% fine content and was classified as silty sand (SM) according to the Unified Soil Classification System (USCS). Because of its non-plastic nature, the liquid limit of the subsoil was determined by fall cone test as described in BS 1377-2 (1990) and was 31%.

The free swell and hydraulic conductivity tests were conducted with

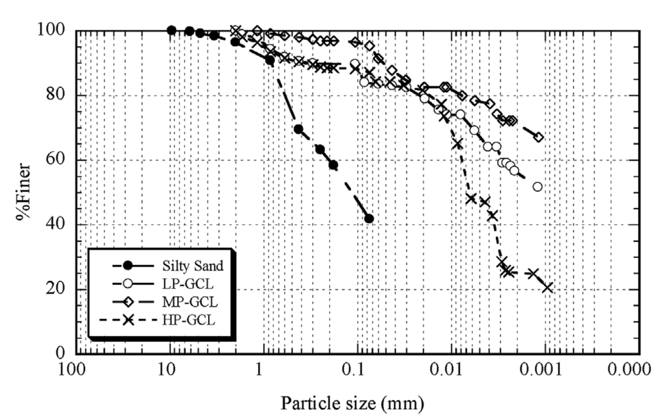

Fig. 1. Particle size distribution curves for silty sand and bentonites.