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Influence of mass per unit area on the hydration of GCLs over silty sand

Influence de la masse par unité de surface sur l'hydratation du GCL sur du sable limoneux

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ABSTRACT: This study investigates and reports the hydration performance of geosynthetic clay liners (GCLs) in terms of mass per unit area (MPUA). The hydration duration was applied for 7 and 30 days. After hydration, the GCL water contents increased significantly. However, water contents decreased as the MPUA increased. At any MPUA, the higher water contents were obtained for the GCLs hydrated for 30 days than the GCLs hydrated for 7 days. In contrast, higher MPUA was needed for the GCLs with 30 days of hydration to achieve the same water content as with the 7 days of hydration. This conclusion is further supported by the final GCL heights and void ratios. The higher MPUA means more bentonite particles inside of GCLs, resulting higher GCL heights and lower void ratios when compared to lower MPUA.

RÉSUMÉ: Cette étude examine et rapporte les performances d'hydratation d'argile géosynthétiques (GCL) en termes de masse par unité de surface (MPUA). La durée d'hydratation a été appliquée pendant 7 et 30 jours. Après hydratation, la teneur en eau de la GCL a significativement augmenté. Cependant, les teneurs en eau ont diminué quand la MPUA a augmenté. Pour toute MPUA, les teneurs en eau ont été obtenues superieur pour les GCL hydratés pendant 30 jours que GCL hydratés pendant 7 jours. Par contre, superieur MPUA était nécessaire pour GCL hydratés pendant 30 jours pour atteindre la même teneur en eau que GCL hydratés pendant 7 jours. Cette conclusion est aussi confirmée par les finals hauteurs de la GCL et les ratios des vides. La superieur MPUA signifie plus de particules de bentonite à l'intérieur des GCL, à cause de hauteurs superieur de GCL et ratios inférieur des vides quand on compare la MPUA inférieur.

Keywords: Geosynthetic clay liners (GCLs), hydration, mass per unit area (MPUA), subsoil, void ratio

1 INTRODUCTION

Geosynthetic Clay Liners (GCLs) are factory manufactured composite barriers which have been used as barrier materials since the beginning of 1990s. One of a great advantage of GCLs is having low hydraulic conductivity when compared to compacted clay liners. Bentonite is the major component of this composite material which restricts the flow across the GCL. Since GCLs are installed on soils, GCL – subsoil interaction has also a significant role on the hydraulic conductivity of GCL and thus, has been of interest by many researchers for the last decade

(Meer and Benson 2007, Bradshaw et al. 2012, Rowe and Abdelatty 2012, Bouazza et al. 2017, Özdamar Kul and Ören 2018, 2019). GCL starts to be hydrated when it is placed over the subsoil. Water migrates from subsoil to GCL because of suction difference between these two materials. Hence, the water content of GCL increases with time. The water migration lasts until water contents of either subsoil or GCL are balanced.

There are some factors that influence the hydration performance of GCLs when placed over subsoil. Basically, the hydration duration, subsoil and GCL types and environmental conditions such as temperature and pore fluid chemistry have all a deep impact on the hydration of GCLs (Meer and Benson 2007, Benson and Meer 2009, Anderson et al. 2012, Rowe and Abdelatty 2012, Barclay and Rayhani 2013, Rowe and Hosney 2013, Hosney and Rowe 2014, Bouazza et al. 2017, Özdamar Kul and Ören 2018a, 2019).

Among others, researchers have mainly focused on understanding the subsoil induced performance change on GCLs. It is reported that increase in the subsoil water contents also increase the water contents of GCLs. Moreover, subsoil type lead to change the hydration pattern of GCLs. In other words, if GCLs are hydrated over sand, silty sand or clayey subsoil, the hydration rate and the water content may possibly be different (Meer and Benson 2007, Katsumi et al. 2008, Rayhani et al. 2011, Anderson et al. 2012, Bradshaw et al. 2012, Rowe and Abdelatty 2012, Rowe and Hosney 2013, Hosney and Rowe 2014).

There are some other studies reporting the influence of GCL type on hydration as well. These studies especially handle the hydration process in terms of cation exchange that take place between subsoil and GCL (Meer and Benson 2007, Benson and Meer 2009, Rowe and Abdelatty 2012, Hosney and Rowe 2013, Özdamar Kul and Ören 2019), manufacturing differences in the GCL (Rayhani et al. 2011, Anderson et al. 2012, Sarabian and Rayhani 2013) and the bentonite type used in GCL (i.e. conventional or polymer treated bentonite) (Hosney and Rowe 2013, Bouazza et al. 2017, Özdamar Kul and Ören 2018a, 2019). However, little attention has been paid on GCL hydration so far regarding to the manufacturing differences. Although the importance of mass per unit area of bentonite on the hydration of GCLs has been reported by some researchers, it still deserves more attention (Rayhani et al. 2011).

The aim of this study is to quantify the water uptake of a GCL in terms of mass per unit area (MPUA) and hydration duration. For this purpose, a polymer GCL was hydrated over compacted silty sand for 7 days and 30 days, then the change in water contents, heights and void ratios were examined.

2 MATERIALS AND METHODS

2.1 *Materials*

2.1.1 *Geosynthetic Clay Liner (GCL)*

A polymer GCL was used in this study. It had been manufactured with woven carrier geotextile and non-woven cover geotextile by needle-punching. The average MPUA and thickness of the original GCL was 8.8 kg/m^2 and 7.7 mm, respectively.

The visual inspection of the bentonite was in granular form. The sieve analysis conducted by wet sieving method and showed that 90% of this bentonite was fine grained. The specific gravity of the bentonite was 2.70. The liquid and plastic limits of the bentonite were also determined as 400% and 60%, respectively.

2.1.2 *Subsoil*

GCL was hydrated over compacted silty sand which had been taken from a landfill. The fine content of the subsoil was 42%. The liquid limit was determined as 31%. The soil exhibited no plastic characteristic (i.e. non-plastic). Based on Unified Soil Classification System (USCS), the subsoil was named as silty sand (SM). The specific gravity of the subsoil was 2.67.

2.2 Methods

The MPUA of the GCL was measured by following the ASTM:D5993-99 (2010). The thickness measurements were made at four locations on GCL using Vernier caliper.

The sieve analyses, consistency limits tests and specific gravities of bentonite and silty sand were determined according to ASTM:D4318-05 (2005), ASTM:D422-63 (2007), ASTM:D854-14 (2014), respectively. Since its non-plastic behavior, the liquid limit of silty sand was determined by following BS 1377-2:90 (1990).

The compaction behavior of silty sand was obtained according to ASTM:D698-12 (2012). Silty sand samples were prepared at different water contents and sealed in plastic bags for one day. Prior to compaction, samples were throughly mixed once more to get homogeneous water contents throughout the samples. Then, samples were compacted in a stainless steel mold with a diameter of 150 mm and a height of 116 mm. When compaction was finished, the optimum water content and maximum dry unit weight were obtained as 12% and 18.3 kN/m^3, respectively.

3 SAMPLE PREPARATION

3.1 Arranging the MPUA of GCL

In this study, GCLs with various MPUA were prepared in the laboratory. The MPUA range of original GCLs were between 7.8 kg/m^2 and 10 kg/m^2.

Initially, GCL was cut from the roll and was weighted on a balance with 0.01 g accuracy. Then, a slight force was applied on the GCL using a stainless steel roller. This allowed bentonite to pour from the circumference of the GCL. Then, the GCL was weighted again. The rolling process was continued until the target MPUA was achieved. The target MPUA was set a value as low as 3.2 kg/m^2 herein. Rolling process is shown in Figure 1.

Figure 1 Arranging the mass per unit area (MPUA) of bentonite in GCL.

3.2 Hydration of GCLs

The field conditions of GCL hydration over the subsoil was simulated in the laboratory using flexible-wall permeameters. Silty sand was compacted at 2% wet side of optimum (i.e. 14%) and placed over the plexiglass bottom plate of the permeameter. Then, GCL with a known MPUA was placed over the compacted silty sand. Note that the non-woven face of GCL was in contact with the subsoil. Then, a geomembrane, geotextile and plexiglass top cap were mounted on the GCL in that order. This system was surrounded with a latex membrane and three O-rings were placed on top and bottom plates. The permeameter was filled with tap water. The pictural details of GCL hydration over a subsoil can be followed from Özdamar Kul and Ören 2018b, 2019.

The permeameter is then connected to the cell pressure channel which supply 10 kPa effective stress during the hydration. This low level of effective stress simulates 0.5-1.0 m of cover soil above the GCL. The influent and effluent ports of the permeameter were kept closed and thus, no flow was enabled throughout the hydration.

The GCLs were subjected to 7 and 30 days of hydration. At the end of hydration, all permeameters were dismantled and GCLs were carefully removed from the permeameters. The weights and thicknesses of the GCLs were measured and then, the fibers that connect the non-woven and woven geotextiles were cut with a sharp razor knife. The bentonite was taken with a spatula and dried in an oven at 105 °C. The water content of bentonite at the end of the hydration was accepted as the final water content of the GCL.

4 RESULTS AND DISCUSSIONS

The final water contents of GCLs at the end of 7 and 30 days of hydration are shown in Figure 2 as a function of MPUA. As indicated in Figure 2, increase in the MPUA linearly decreased the final water contents of GCLs for both hydration durations.

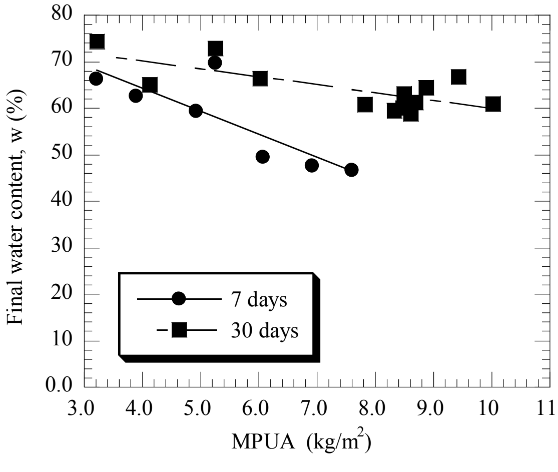

Figure 2 Change of final water content after hydration as a function of mass per unit area (MPUA).

The rate of decrement was steeper for 7 days than for 30 days. The final water content decreased from 70% to 47% for 7 days of hydration and from 74% to 59% for 30 days of hydration. Researchers showed that the water content rapidly increase in the first 7 days of hydration and this tendency reduces as the hydration period is further increased (Bradshaw et al. 2012, Rowe and Abdelatty 2012, Özdamar Kul and Ören 2019). At any MPUA herein, lower water contents were obtained for 7 days of hydration than for the 30 days of hydration. Thus, the finding of this study is in aggrement with the previous studies reported in the literature.

To reach the same water contents, more MPUA is needed for 30 days of hydration when compared to the 7 days of hydration. As shown in Figure 2, it was required to use 6.8 kg/m^2 MPUA to achieve 65% water content when GCL was hydrated for 30 days. In contrast, only 3.9 kg/m^2 MPUA is enough to reach the same water content for the same GCL when hydrated for 7 days.

The decrement in the final water content with increasing the MPUA is mainly due to the restriction of bentonite swelling on account of needle-punching of GCLs. The fibers connecting the woven and non-woven geotextiles limit the vertical expansion of GCL during hydration and therefore, the volume between the geotextiles can increase to a certain value. The swelling of bentonite particles within GCLs before and after hydration is demonstrated in Figure 3. Needle-punched fibers are not shown on the GCLs in Figure 3 do not to allow any confusion.

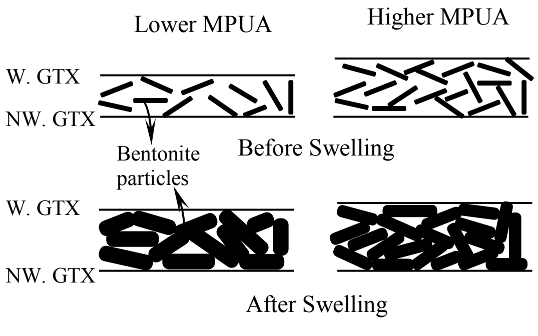

Figure 3 Schematic representation of bentonite swelling before and after hydration.

The initial height of GCL (i.e. before hydration) with lower MPUA is generally lower than the GCL with higher MPUA. That is, higher MPUA makes GCLs rather thicker (as shown in Figure 4). When GCLs are subjected to hydration, GCL with a high MPUA is expected to have a higher thickness. Indeed, such kind of tendency were observed herein during the hydration process (Figure 4). The final GCL height increased as the MPUA increased for both hydration durations.

Figure 4 also shows that the hydration duration has an influence on the final GCL height. For all considered MPUA range, lower GCL heights were obtained after 7 days of hydration, indicating the role of hydration duration on the final GCL height. It is expected because longer hydration results in greater swelling of the bentonite and consequently an increase in the final water content of the GCL (Figure 2).

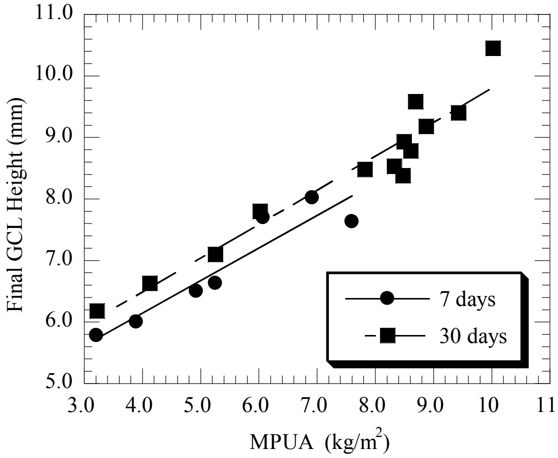

Figure 4 Change of final GCL height after hydration as a function of mass per unit area (MPUA).

Higher MPUA means stacking of more bentonite particles inside of GCL. Hence, initial and final void ratios should be expected lower for the GCL with higher MPUA than for the GCL with lower MPUA as demonstrated in Figure 3. To show this tendency as a function of MPUA, the final GCL void ratios were calculated in a manner similar to the equation proposed by Petrov et al. (1997).

Figure 5 shows that the final GCL void ratio decreased as the MPUA of the GCL increased. The measurements of final GCL heights using Vernier caliper are consistent with the calculated final void ratios. That is, similar to final GCL height, the lower final GCL void ratios were obtained for 7 days of hydration than for 30 days of hydration. Moreover, at any MPUA, the lower the final GCL height, the higher is the final void ratio. This is an important finding obtained from this study that the hydraulic conductivity may be greater at lower MPUA range.

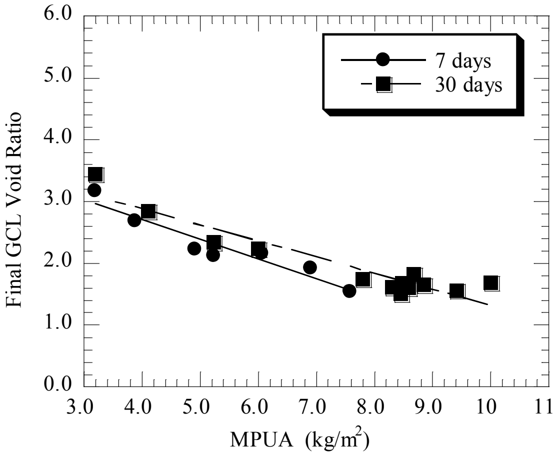

Figure 5 Change of final GCL void ratio after hydration as a function of mass per unit area (MPUA).

5 CONCLUSIONS

The hydration performance of a GCL depending on the MPUA was investigated and discussed herein for two hydration durations.

The water contents of GCLs increased as the hydration duration increased. However, this increment was rapid in the first 7 days of hydration. In addition, at any MPUA, the higher final water contents were obtained for the GCLs subjected to 30 days of hydration than the GCLs subjected to 7 days of hydration. In contrast, higher MPUA was needed for the 30 days of hydration to reach the same water content as with the 7 days of hydration.

The final water contents of the GCLs were in close relationship with their final GCL heights and final GCL void ratios. Increasing the MPUA means stacking of more bentonite particles inside of the GCL, resulting higher GCL height but lower void ratio.

The findings presented herein should be supported with the hydraulic conductivity tests. This is significant because a critical MPUA level can be defined for the hydraulic conductivity of GCL. Below this critical MPUA, the hydraulic conductivity will be high and vice versa. Since further information is needed, researchers should be encouraged to work on this concept.

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