

Laboratory Investigation of Moisture Content Redistribution on the Base of Double Composite Liner Systems

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ABSTRACT Geomembranes (GMs) and geosynthetic clay liners (GCLs) are used as part of double composite liner systems (DCLs) for hazardous waste and municipal solid waste landfills. This paper presents the results of a study of the spatial and temporal redistribution of moisture at the base of DCLs under isothermal conditions. This investigation gives a better understanding of the time taken for the moisture content to reach equilibrium. The effect of GCL's carrier on final GCL water content is also investigated. The study of water distribution will be extended with more tests incorporating temperature gradients and overburden pressure.

INTRODUCTION

Modern landfill barrier systems include a composite liner intended to reduce the outward transport of contaminants to a negligible level. The composite liner is comprised of a high density polyethylene (HDPE) geomembrane (GM) and either a geosynthetic clay liner (GCL) or a compacted clay liner (CCL) and for a well designed and constructed liner, the composite action of the HDPE GM and clay minimizes the leakage of contaminant to groundwater (Rowe 2005). Given the long contaminating lifespan of modern landfills, the long-term performance of lining systems is extremely important (Rowe et al. 200).

The use of geosynthetic materials in composite liners has increased because of their relatively low cost (Malusis & Shakelford 2002) and generally good performance for the period of time that they have been monitored (Rowe 2005, Mitchell et al. 2007). Although HDPE GMs represent the primary barrier to leachate flow, leakage through perforated wrinkles and other defects in the HDPE GM can occur and a

CCL or a GCL serve to minimize that leakage. In particular, composite liners involving a GCL have been shown to be highly effective in preventing groundwater contamination when the GCL is adequately hydrated (Rowe 2005). However for the composite action to be most effective, it is important that the clay liner below the HDPE GM be intact and not fractured for the contaminating lifespan of the landfill (Rowe 2005, Southen 2005).

Thermal gradients induced by temperature generated by the waste (Collins 13) can cause moisture movement at the base of the landfill with a consequently decrease the water content in clay liners. This complex mechanism has caused desiccation cracking in clay liners reported at various sites and in laboratory experiments (Bowders et al. 17, Sangam & Rowe 2002, Rowe 2005, Southen & Rowe 200). In particular, Southen & Rowe (2005) conducted small and large scale laboratory tests to examine the effect of thermal gradients on GCLs used in single composite liners.

The objective of this paper is to investigate, the spatial and temporal redistribution of moisture in a GCL used in a DCLSs under isothermal condition. The time taken for the moisture content to reach equilibrium and the effect of GCL's carrier are also investigated. This study is conducted as a precursor of a future examination of the effect of temperature gradient on the moisture in a GCL with time.

TESTING PROGRAM

Apparatus

Five polyvinylchloride (PVC) cells were constructed with an internal diameter of 160mm, 325mm high and a wall thickness of mm (Figure 1). The bottom of the cell was filled with 250mm of compacted silty-sand soil representative of subsoil and a double composite liner system was constructed over this subsoil.

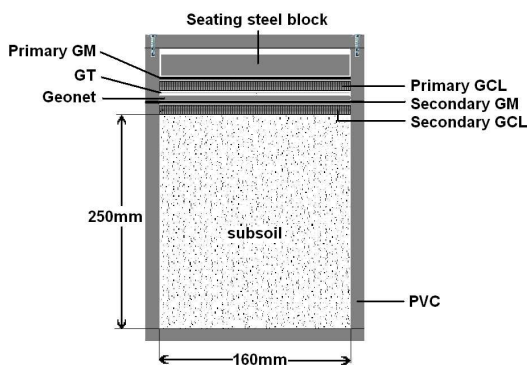


Fig.1 Schematic of test cell

Starting at top of the subsoil, the DCLSs consisted of GCL overlain by a 1.5mm thick secondary HDPE GM, a 5.3mm geonet, and geotextile (forming the leak detection/ secondary leachate collection system), a primary GCL, and a 1.5mm thick primary HDPE GM. The cell was sealed using a 10mm PVC plate and adhesive-sealant on the top and bottom boundaries.

Material properties

Tests were conducted using a silty-sand subsoil with nominal properties as indicated in table 1. The

particle size distribution of the soil is given in Figure 2 with 12% passing the 0.075 mm sieve. A standard proctor compaction test performed on the soil (ASTM D 68) and gave a maximum dry density of 1.7g/cm^3 and an optimum water content of 11.2% (Figure 3). A summary of the main properties of the other materials studied is given in table 2.

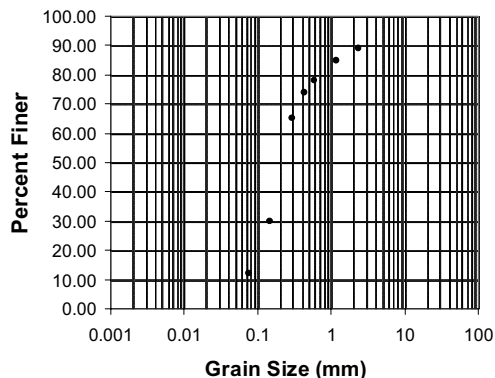


Fig.2 Grain size distribution of the subsoil

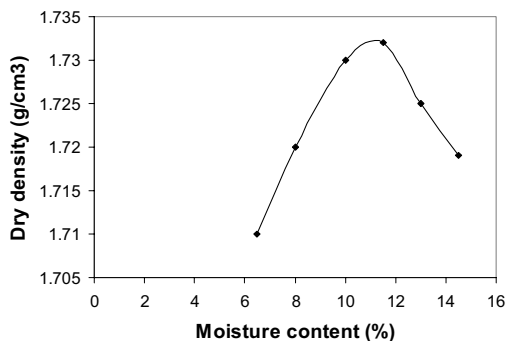


Fig.3 Compaction curve for subsoil

Test description

The soil samples were mixed with water to bring its water content to 11% and then stored in plastic bags to allow the moisture in the soil to reach equilibrium. The soil was then tamped into the test cell in four layers. Water content samples were taken from each layer. The initial moisture contents profile of the soil in five cells prior to GCL installation are given in Figure .

TABLE 1 Subsoil properties

Optimum water content	Maximum dry density	Grain size distribution		
		Silt content	Sand content	Gravel content
11.2%	1.74(g/cm ³)	12%	82%	6%

TABLE 2 Material properties based on manufacturers published data

	Reference
Geosynthetic Clay Liners (GCLs)	www.geofabrics.com.au
Nominal total mass/unit area (g/m ²)	4390
Bentonite mass/unit area (g/m ²)	4000
Nonwoven cover geotextile (g/m ²)	270
Woven carrier geotextile (g/m ²)	110
Geotextile (GT)	www.globalsynthetics.com.au
Mass (g/m ²)	280
Geomembranes (HDPE GMs)	www.gseworld.com
Thickness (mm)	1.50
Geonet	www.globalsynthetics.com.au
Thickness (mm)	5.3

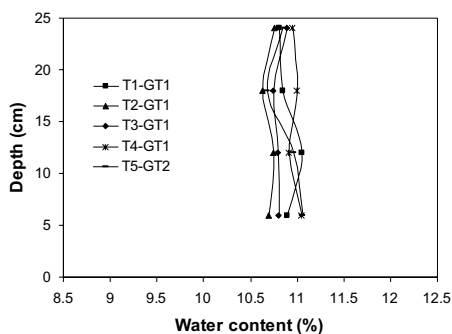


Fig.4 Initial moisture content profile for soil samples

The GCL samples were hydrated by gradually applying water until the initial water content (75%) was reached. The secondary GCL was then placed over the foundation soil, followed by 1.5mm HDPE GM. A 5.3 mm layer of Geonet was also placed over the secondary HDPE GM to simulate the secondary leachate collection system followed by GT, primary GCL and primary HDPE GM. A steel block was placed over these layers to produce an overburden stress of 1.7kPa, to ensure intimate contact between the layers.

The test cells were opened every five days and the GCL was removed for moisture content determination and then returned. Since there was no source of water for primary system this represent a severe scenario where moisture can evaporate from the GCL into the airspace and then be lost when the system is opened (the leak detection system is “breathing” with moisture loss from the layer with exchange of very humid air in the layer with less humid air from the atmosphere). The cells were excavated at the end of each test to assess the temporal variation of water content within the subsoil as soil suction equilibrated.

RESULTS

Based on theoretical considerations, isothermal conditions don't lead to desiccation (Southen & Rowe 2005) but the GCL gravimetric water content just prior to the placement of waste is significant.

The first four tests were nominally identical except for the test duration, as indicated in table 3. In these tests the woven carrier GT was in contact with the GT and subsoil for the primary and

secondary GCL respectively. In the fifth test, the GCL was reversed (so that the nonwoven geotextile was in contact with the GT and subsoil) to examine the effect of GCL's carrier on moisture uptake (T5-GT2). The choice of initial water content of GCLs was based on what would be expected from uptake of water into a GCL laid on moist subsoil (Southern & Rowe 2005).

Water contents

GCLs are highly effective in preventing groundwater contamination when they are adequately hydrated (Rowe 2005). Variation of GCLs moisture content was plotted with time in Figure 7. After a period of 170 days, approximately 32% decrease in primary GCL water content was observed due evaporation of water into the air space until there was an equilibrium between the relative humidity of the air and the suctions in the GCL. There was then loss of this moisture in the air when the samples were weighed followed by more moisture transfer from the GCL when the cell was resealed. In one sense this is an artifact of the test and the moisture loss would likely have been much less if there had been less opening of the cell to monitor moisture content. However this could occur in a real landfill situation if there was significant airflow through the leak detection system (e.g. to remove gases or to cool the liner).

Due to uptake of water from the subsoil, there was an approximately 61% increase in secondary GCL water content Figure 7. Within the first 75 days,

the secondary GCL water content increased by 50%. This confirmed that observed by Southern and Rowe (2005) and Rayhani et al. (2008). The GCLs water contents are presented in Figure 8.

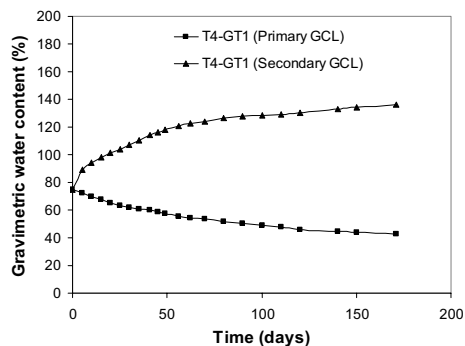


Fig.7 Gravimetric water contents for T-GT1

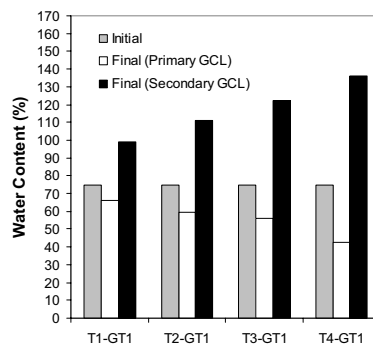


Fig.8 GCL gravimetric water contents

TABLE 3 Test conditions

Test	T1-GT1	T2-GT1	T3-GT1	T-GT1	T5-GT2
Test duration (days)	20	40	60	170	20
Initial subsoil water content (%)	10.9	10.7	10.8	10.48	10.9
Final subsoil water content (%)	9.6-11.2	8.3-11.4	8.1-11.8	7.85-10.74	9.3-11.1
Initial primary GCL water content (%)	75	75	75	75	75
Final primary GCL water content (%)	66.1	59.6	55.9	42.4	63.4
Initial secondary GCL water content (%)	75	75	75	75	75
Final secondary GCL water content (%)	99.0	110.8	122.3	136	118.8
Applied stress (kPa)	1.7	1.7	1.7	1.7	1.7

Effect of carrier on final GCL water content

The gravimetric water content distribution measured during excavation of two tests where the GCL had the woven down (T1-GT1) and the nonwoven down (T5-GT2) respectively is shown in Figure . After 20 days, the gravimetric water content for T1-GT1 was found to range from .6% below the GCL to 11.2% at the lower boundary. For T5-GT2, the water content of the subsoil was a little lower ranging between .3% below the GCL and 11.1% at the lower boundary, respectively. Thus final subsoil water content below the GCL was lower than the initial value, primarily due to uptake of water by the secondary GCL Figure 10. Over a period of 20 days, the secondary GCL water content increased from 75 to % when the woven GT was in contact with the subsoil (T1-GT1) which is smaller than the increase from 75 to 11% when the nonwoven was in contact with the soil (T5-GT2).

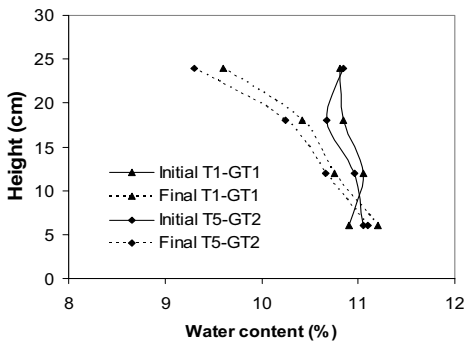


Fig.9 Subsoil gravimetric water contents assessed at the termination of T1-GT1 and T5-GT2

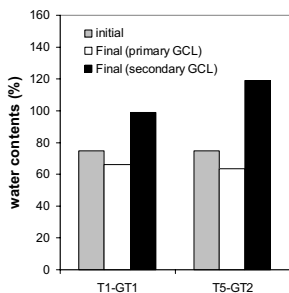


Fig.10 GCLs gravimetric water contents

The primary GCL in T5-GT2 had lower moisture content than that in T1-GT1. Gravimetric moisture content versus time is plotted in Figure 11. GCL’s carrier appears to have some effect on rate of moisture redistribution in both GCLs.

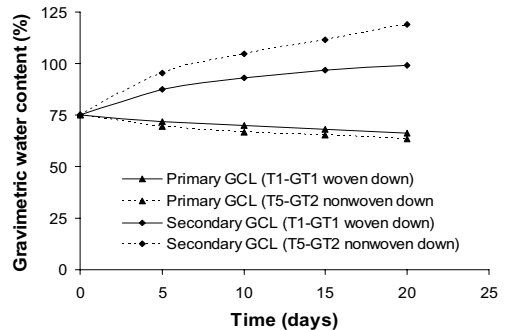


Fig.11 The effect of GCL carrier on rate of moisture redistribution

CONCLUSION

The spatial and temporal redistribution of moisture at the base of DCLs under isothermal condition was studied.

A reduction in primary GCL water content was observed due to evaporation of water into the air in the leak detection system and subsequent loss of this moisture from the leak detection layer when high humidity air was replaced by low humidity air. This reduction was marginally greater when the nonwoven GT was in contact with the subsoil.

Observations of the secondary GCL showed uptake of water from the subsoil but even though there was an increase to about 136%, the GCL and soil had not reached equilibrium after 170 days despite an initial water content of about 11% in the soil and 75% in the GCL. Thus at low stress, it may take a significant amount of time for the GCL to fully hydrate. The tests indicate that, other things being equal, moisture uptake was likely to be faster with the nonwoven geotextile component of the GCL in contact with the subsoil than with a woven carrier resting on the subsoil.

It is important to emphasize that these tests were simply to establish a sense of initial conditions before a thermal gradient is established. In order to fully investigate the behavior of GCL in a basal liner system more testing with a temperature gradient and overburden pressure are needed.

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