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An Investigation of Field Performance of Geomembrane-Geosynthetic Clay Liner Landfill Bottom Lining Systems

L. Okine[1], P. Zhang[2], T. Abichou[3], and J. Chen[4]

[1]*Graduate Research Assistant, FAMU-FSU College of Engineering, Florida State University, Tallahassee, USA, email: lokine@fsu.edu*

[2]*Graduate Research Assistant, University of Central Florida, Orlando, USA, email: poyu.zhang@knights.ucf.edu*

[3]*Professor, FAMU-FSU College of Engineering, Florida State University, Tallahassee, USA, email: abichou@eng.famu.fsu.edu*

[4]*Assistant Professor, University of Central Florida, Orlando, USA, email: jiannan.chen@ucf.edu*

1. ABSTRACT

Significant research has been performed on assessing the leakage rate through GM-GCL and US Subtitle D composite lining systems using analytical solutions and empirical equations. The main objectives of this research were to assess the field performance of a GM-GCL landfill bottom lining system, to analyse its performance against the existing leakage estimation equations, and to provide probable causes of the disparities between the calculated and observed leakage rates. The field leakage data from two landfill cells, lined with a double liner system consisting of a primary GM-GCL composite, a leak detection system (LDS), and GM-GCL secondary liner system, were found to be relatively high as compared to those obtained from leakage equations reported in literature. An analysis of the probable causes of the relatively high field leakage rate from the GM-GCL lining system included (1) the possible effects of leachate chemistry on the hydraulic conductivity of the GCL, and (2) groundwater seepage into the LDS from below. The investigation suggests that the excessive observed leakage rate was likely caused by groundwater intrusion into the LDS.

Keywords: geosynthetic clay liners, geomembranes, leakage, landfill liners, leak detection system

2. INTRODUCTION

Waste containment systems are engineered to hinder or reduce the escape of pollutants to the atmosphere and subsurface soil and/or water (Fluet et al., 1992; J. Giroud et al., 1994). Bottom lining and final cover systems of waste containment systems are designed to minimize the movement of leachate and landfill gas from the confines of the landfill. Landfill bottom lining systems are designed with a leachate collection system (LCS) for the pumping out of leachate from the landfill for recirculation or treatment. The Environmental Protection Agency in USA (USEPA) requires all landfills to keep a maximum leachate head of 0.30 m on the LCS, to ensure low leakage rates in the event that there is a defect in the lining system (USEPA, 1992).

In addition to the LCS, some lining systems are designed to have a leakage detection system (LDS) to monitor and pump out leachate that leaks from the overlying (primary) liner. An example is the Florida double lining system which consists of an LDS sandwiched between two geomembrane (GM) liners. For the Florida double lining system, a 150 mm compacted soil or GCL underlies the secondary GM. Leachate volumes are directly proportional to the moisture in the waste, the absorptive ability of the waste material to fluids, the amount of rainfall, and the water run-off at the site (Cheremisinoff, 1997).

GM defects occur as a result of deficiencies during material production, installation, the day to day operational activities, and stress cracks that occur due to the ageing of the GM (Rowe, 2012).
The design and construction of municipal solid waste (MSW) landfills in the US must meet certain minimum design standards or performance criteria as stipulated in Title 40 of the Code of Federal Regulations (Code of Federal Regulations, 2012). The United States Environmental Protection Agency (USEPA) Code of Federal Regulations, Title 40 instructs that MSW landfill units and lateral expansions should be constructed with a single composite liner comprising an upper flexible membrane liner (FML)

component of 0.762 mm minimum thickness and a minimum 0.6 m layer of compacted clay liner (CCL) with hydraulic conductivity not greater that $1x10^{-7}$ cm/s. The regulations further state that the thickness of the FML should be at least 1.524 mm when an HDPE membrane liner is used. Aside from the above, the single composite liner system must be constructed such that the FML is in direct and uniform contact with the underlying layer. The USEPA accepts alternative composite liner designs that have been assessed to be equivalent to the conventional designs in the regulatory codes (Giroud et al., 1992; Electric Power Research Institute, 2019). Some of the alternative liner designs include the use of double liner systems, double composite liner systems, and the replacement of the 0.6 m compacted clay with geosynthetic clay liner (GCL).The main idea of specifying composite lining systems is the fact that leakage that occur through defects in the GM is impeded from moving into the subsurface by the underlying CCL or GCL (Bonaparte et al., 2002).

Researchers in the past have assessed the equivalence of the above-mentioned alternative bottom lining systems to the GM-CCL system using analytical, empirical and numerical models (Giroud, 1997; Rowe, 1998; Foose et al., 2001, 2002; Touze-Foltz & Barroso, 2006). Equations proposed by the researchers show that when the GM-GCL and GM-CCL systems are compared based on the advective flow of leachate through defects in the GM, the GM-GCL system fares better. As far as the authors are concerned, published field data on the performance of GM-GCL liners are very limited (Bonaparte et al., 2002; Bonaparte & Gross, 1993). Bonaparte et al., 2002 and Bonaparte & Gross, 1993 reported that the field leakage rate observed was not only as a result of leakage through the primary GM-GCL system. Aside from leachate leaking into the LDS (from the LCS), the other sources of liquid/'leachate' that is pumped out of the LDS can be categorized as: construction water, compression water, consolidation water, and infiltration water (Gross et al., 1990; Bonaparte and Gross 1993).

The main objectives of this research were to assess the field performance of the GM-GCL landfill bottom lining systems, to analyse its performance against the existing leakage estimation equations and to provide probable causes of the excessive field-measured leakage rates.

3. METHODOLOGY

The liquid volumes removed from the LDS of one landfill (Landfill A) with a GM-GCL double composite lining system were collected and the associated leakage rates were calculated and analysed. The liquid volumes from a second landfill (Landfill B) with the Florida Double lining system were also analysed in this study. The observed LDS leakage rates from the two landfills were then compared to the leakage rate computed using theoretical equations from the literature.

3.1 Data collection

Landfill A is a multipurpose landfill located in southern Florida. The landfill facility contained Class I (MSW and Coal ash) and Class III (construction and demolition waste) containment cells. The Class I Cells contain municipal solid waste and are subject to the requirements of Chapter 62-701, Florida Administrative Code (FAC). This study focused on the Class I Cell at the landfill. A cross-section of the GM-GCL double composite lining system is shown in Figure 1.

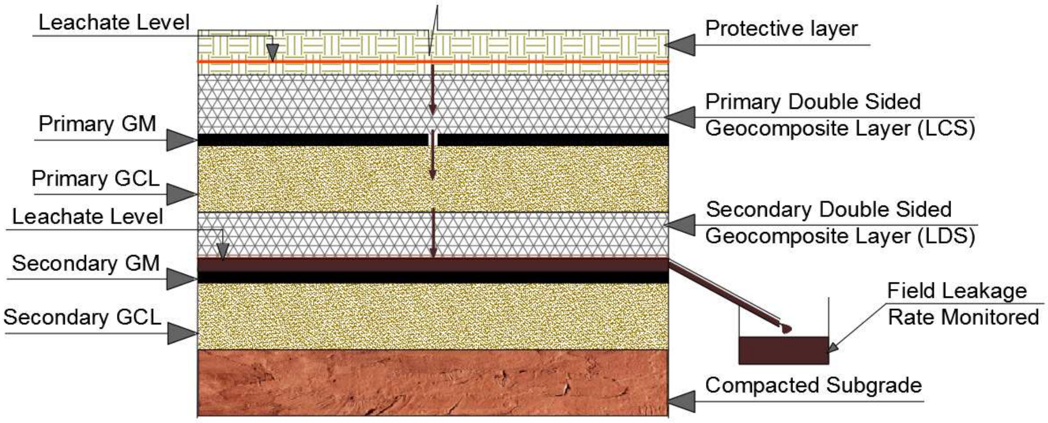

Figure 1. *Cross-section of the GM-GCL Double Composite Lining System for Cell 1 (Landfill A)*

The Class I cell was designed and is operated to have maximum leachate levels of 0.3 m and 0.1 m on the primary and secondary lining systems respectively. Leakage data for the period July 2011 to March 2016 were analysed during this study.

Landfill B is located in central Florida. Data were collected from an active cell at Landfill B with an area of approximately 105,000 m^2. The design used for the bottom lining system of the active Cell is the Florida double liner system with a GCL underlying the secondary GM. A cross-section describing the lining system of the Cell at Landfill B is shown in Figure 2. The maximum permitted leachate levels on the primary and secondary lining systems were 0.3 m and 0.1 m respectively. The leakage data for the period January 2011 to December 2020 were analysed for Landfill B.

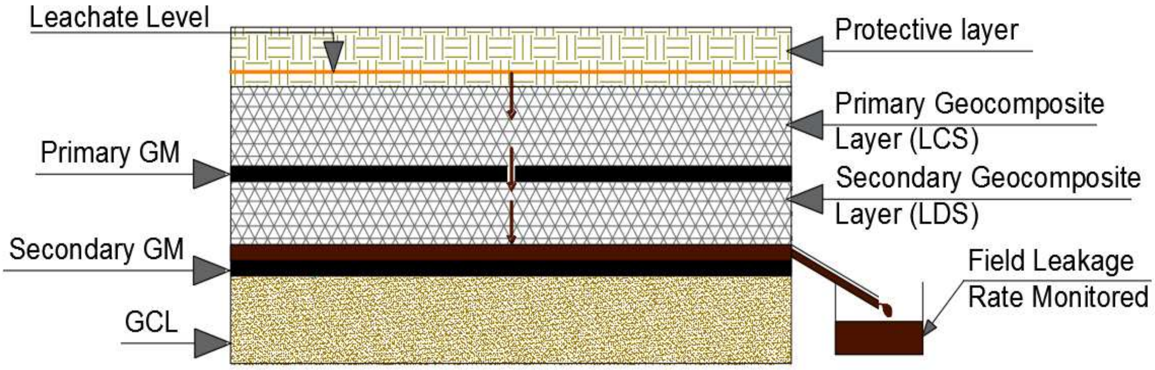

Figure 2. *Cross-section through the Florida Double Lining System for Cell 2 (Landfill B).*

3.2 Theoretical equations for predicting leakage rate

Several theoretical equations have been proposed for the estimation of leakage rate for landfill bottom liners(Giroud et al., 1992; Rowe, 1998; Touze-Foltz et al., 1999; Foose et al., 2001). The equation proposed by (Giroud 1997b) is used in this paper due to its popularity amongst practicing engineers.

Due to the undulations on the compacted soil or GCL that underlies the GM, waves or wrinkles develop in the GM. (Giroud 1997b) proposed the good and poor contact conditions to describe the interface between the GM and the underlying GCL or clay. (Giroud et al., 1994) mentioned that the interface transmissivity controls the leakage rate to a large extent. The equations proposed for good and poor contact conditions for the composite lining system are:

$$Q_{good} = 0.21\left[1 + 0.1(\frac{h}{t_s})^{0.95}\right] a^{0.1} h^{0.9} {k_s}^{0.74} \qquad \text{good contact} \qquad \text{Equation 1}$$

$$Q_{poor} = 1.15\left[1 + 0.1(\frac{h}{t_s})^{0.95}\right] a^{0.1} h^{0.9} {k_s}^{0.74} \qquad \text{poor contact} \qquad \text{Equation 2}$$

Where a= area of defect, h= leachate head, k_s= hydraulic conductivity of soil/GCL, t_s= thickness of the soil layer/GCL, Q_{good}= leakage rate for good contact condition, Q_{poor}= leakage rate for poor contact condition.

For single lining systems, (Giroud et al., 1997) proposed equation 3 to estimate the leakage rate for the scenario where the soil or geosynthetic material underlying the GM is more permeable than the material that overlies the GM. This equation is used in computing leakage into the LDS for the Florida double lining system, as follows:

$$h = \{\frac{aq_i}{2k_{om}\pi} + \frac{Q}{2k_{om}\pi}\left[\ln\left(\frac{Q}{aq_i}\right) - 1\right] + \frac{1}{4g^2}(\frac{Q}{0.6a})^4\}^{0.5} \qquad \text{Equation 3}$$

Where g= acceleration due to gravity, k_{om}= hydraulic conductivity of the layer overlying the GM, Q= leakage rate, q_i= leachate supply rate (impingement rate), a= area of defect, h= leachate head.

4. RESULTS

Figure 3 shows the observed field leakage rate for Cell 1 (Landfill A, GM-GCL). The average leakage rate obtained during the period was $2.89\text{x}10^{-11}$ $m^3/s/m^2$ with a standard deviation of $6.29\text{x}10^{-11}$. The maximum leakage rate observed was $3.44\text{x}10^{-10}$ $m^3/s/m^2$.

For the landfill with the Florida double lining system, an average leakage rate of $3.54\text{x}10^{-10}$ $m^3/s/m^2$ with a standard deviation of $5.17\text{x}10^{-10}$ was obtained (Figure 4). The maximum leakage rate observed was $3.72\text{x}10^{-9}$ $m^3/s/m^2$. The average leakage rate for Cell 2 (Landfill B, Florida double liner) was an order of magnitude higher than that observed from Cell 1 of Landfill A.

Using the equations described in Section 3 to compute the theoretical leakage rate, a circular defect with area 1 cm^2 per 4046.86 m^2 of landfill bottom liner. Also, the hydraulic conductivity and thickness of the GCL used were 5×10^{-11} m/s and 9×10^{-3} m respectively.

Figure 5 shows a comparison between the average field leakage rate for Cell 1 of Landfill A (GM-GCL) and the theoretical leakage rates computed using Equations 1 and 2. The average field leakage rate is an order of magnitude higher than the leakage rate computed using the poor contact interface condition scenario and two orders of magnitude higher than the good contact condition scenario. This implies that the leachate volumes pumped from the LDS of Cell 1 (landfill A, GM-GCL) are much higher than those computed theoretically to predict leakage rates.

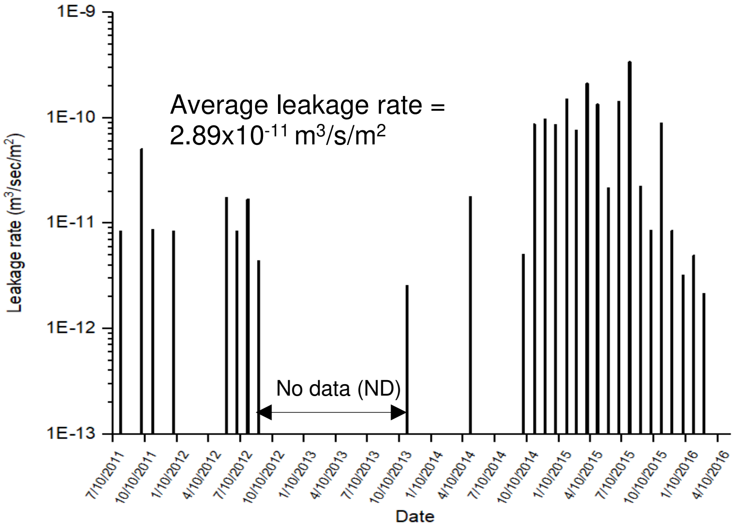

Figure 3. *LDS leakage rate for Cell 1- Landfill A (GM-GCL lining system)*

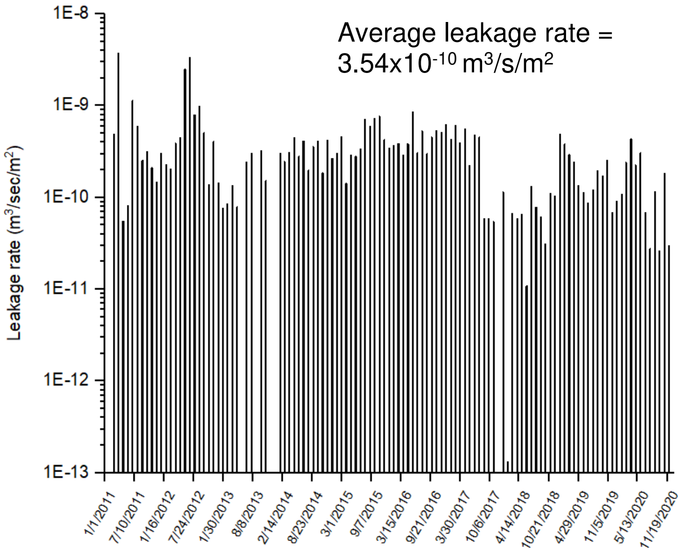

Figure 4. *LDS leakage rate for Cell 2- Landfill B (Florida double lining system))*

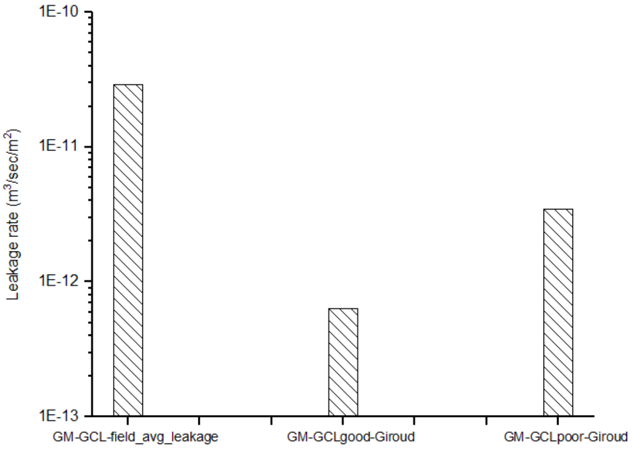

Figure 5. *Comparison of the average field leakage rate for Cell 1 (Landfill A, GM-GCL) and the theoretical leakage rates (good and poor contact) using equations 1 and 2*

5. DISCUSSION

The probable causes of the high field leakage rates obtained for the GM-GCL double composite lining system include:

- number of defects and leachate head,
- an ineffective GCL,
- the upward seepage of groundwater through the secondary GM-GCL system.

5.1 Number of defects and leachate head

Leakage through the GM-GCL lining system is a function of the number and size of defects and the leachate head on the GM. In order to have the average leakage rate for cell 1 of landfill A, the primary GM should have 9–number 1 cm^2 defects per 4046.86 m^2 (for the poor contact condition scenario). A 1 m leachate head (3 times the regulatory level) on the primary GM can also cause higher leachate volumes pumped from the LDS in Cell 1 (landfill A). Due to the quality control and quality assurance instituted by the FDEP for the installation of bottom lining systems, 9–number 1 cm^2 defects on the primary GM is less likely to occur. Apart from the FDEP requiring landfill operators to maintain a maximum of 0.3 m of leachate head, periodic jet cleaning of the LCS ensures all blockade in the system are removed to prevent the build-up of leachate in the landfill.

5.2 Hydraulic conductivity of GCL

To attribute the high leakage rate obtained in the GM-GCL liner to the hydraulic conductivity of the GCL, a hydraulic conductivity of 1.09x10^{-6} m/s needs to be assumed to obtain the field leakage rate of 2.89 x 10^{-11} m^3/s/m^2 for good contact condition. For the poor contact condition, a hydraulic conductivity of 2.06x10^{-7} m/s is required. Based on the research conducted by (Abichou, 2019; Li et al., 2019) on the effect of co-disposal leachate (leachate from landfills that accept MSW and coal ash) on the hydraulic conductivity of conventional GCLs, the hydraulic conductivity obtained was in the order of x10^{-10} m/s. It is therefore unlikely that the high field leakage rate obtained is due to the increase in hydraulic conductivity of the GCL as a result of contact with the leachate.

5.3 Groundwater seepage into LDS

In analysing the movement of groundwater into the LDS, the configuration of the secondary lining system (of the double GM-GCL) becomes GCL-GM due to the direct impact of water pressure on the secondary GCL. For the GCL-GM configuration, there is higher leakage into the LDS (as compared to the GM-GCL system) because the groundwater seeps through the entire surface area of the secondary GCL. For the

GM-GCL system, leakage through the GCL is only limited to areas where there are defects in the GM. The Darcy's law and Equation 3 can be used to approximate the rate of seepage of groundwater into the LDS. To compute the groundwater intrusion into the LDS, the groundwater level was taken to be 0.3 m above the GCL elevation, which translates into an upward pressure of 2.943 kPa. Applying an upward groundwater pressure of 2.943 kPa to the GCL, an approximate leakage rate of 1.01 x 10^{-11} $m^3/s/m^2$ is obtained in the LDS. A comparison of the leakage rate computed as a result of the upward groundwater pressure and the average field leakage rate for Cell 1(GM-GCL double composite liner) is shown in Figure 6.

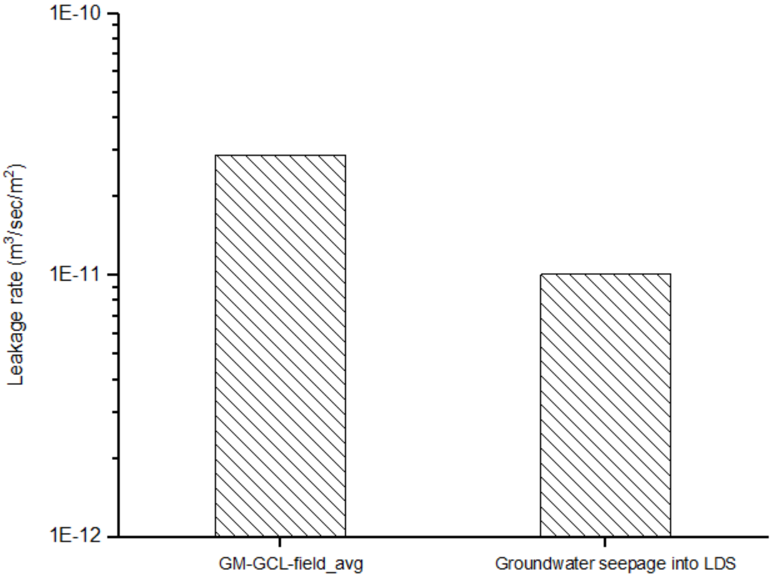

Figure 6. *Comparison of the average field leakage rate for Cell 1 (Landfill A, GM-GCL double composite liner) and groundwater seepage into the LDS.*

6. CONCLUSION

GM-GCL composite systems have been used in lining the base of waste containment systems particularly because of the ease of installation, the low permeability of the material and the relatively thin GCL material which translates into more waste storage capacity for the landfill. The field performance of the GM-GCL composite lining system was assessed in this study. The field leakage rate for a landfill cell obtained were relatively high when compared to the equations used in predicting the leakage through GM-GCL composite systems and the field leakage rate for a landfill cell lined with the Florida double liner system.

Although the relatively high field leakage rate for the GM-GCL composite lining system can be caused by a high leachate head, defects having areas larger than proposed by earlier researchers, a greater number of defects, or the effect of aggressive leachate on the hydraulic conductivity of the GCL, the authors attribute the high field leakage rate for the GM-GCL to the upward movement of groundwater into the leachate detection system based on the investigation conducted.

7. ACKNOWLEDGEMENTS

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