Geomembrane liner failure: modelling of its influence on contaminant transfer

V. Nosko
Sensor s.r.o., Nobelova 34, 831 02 Bratislava, Slovakia

N. Touze-Foltz
Cemagref, Unité DEAN, BP 44, 92163 Antony Cedex, France

Keywords: Geomembranes, Leak detection, Monitoring, Quality control, Wrinkles

ABSTRACT: The statistical results of the electrical damage detection system installed at more than 300 sites covering more than 3.250.000 m^2 are presented with respect to the cause of the damage vs. size of damage and location of damage respectively. Another important result is that in cases of more than a few membrane failures per one site, the distribution of damage is not regular. The failures generally amalgamate in specific areas located irregularly in the geomembrane liner: flat floor areas, edges, corners, penetration of geomembrane, end of road access, joint of slopes and bottom, seams, temporary storage of granular materials, areas of loading and unloading of such materials, areas of regular motion of heavy plants, etc. The mathematical modelling based on such statistical results show very important information. The main critical parameters are the location of failures and then a density of their occurrence. The size of a hole (even though it may look very critical in time when it is revealed) is less important than previous ones. These results point out the fact that in order to adequately quantify the rate of liquid flow through a composite liner, more information than the density of holes in the geomembrane is needed. Indeed, it is necessary to know the exact position of the holes, and their relative positions with regard to the position of wrinkles in the geomembrane. These results are only partial ones and the research continues.

1 INTRODUCTION

Every single day of our lives has significant value. Everyday we surround ourselves with critical actions, which decreases life's value. We strongly depend on the environment and its contamination decreases our chance to live longer. It was not long ago when a scientist discovered that a clay layer between dangerous material and subgrade is not enough protection and that some other synthetic impermeable material should be used. Geomembranes appear to be the best material for the separation of dangerous, toxic solids and liquid materials. While knowledge of quality installations of geosynthetic layers increases, the problem of their integrity after the installation appears to be a crucial factor in their overall usefulness.

During our active work in the field of geosynthetics, and our active contributions during conferences, meetings, etc., we discovered that the subject of the quality of geomembrane installation is discussed everywhere. It has been only a few years since electrical leak detection and location methods have become commercially used as a tool for deciphering some information regarding the integrity of the geomembrane after installation and placing protection on the top of their surface. Several authors have presented their results and some of them (Laine, Darilek 1993; Crozier, Walker 1995; Nosko et al. 1996; etc.) bring very useful contributions to highlight the problem. Since then, more and more people have been involved in such a business to answer the question "How dangerous it is to leave the damage unrevealed and not repaired?".

2 ANALYSES OF GEOMEMBRANE LINER FAILURES

Therefore, based on such indications, we started to create and study some statistical data mainly obtained by SENSOR DDS® technology. This technology has been widely used in the last ten years for in-situ monitoring of the integrity of geomembrane liners. During that period we have been collecting and analyzing data from several thousand failures from 16 countries, which represents more than 300 sites and approximately 3.250.000 m^2. This study was performed based on three criteria: position of damage, size of damage, and cause of damage. The obtained data are shown in tables as a function of location of damage and cause of damage versus size of damage, respectively (see Table 1 and 2).

One of the main purpose of this study is to present the distribution details of damage throughout the controlled area. We have discovered that in cases of multiple holes, the cause of the damage can be grouped in several common categories which are defined below in Table 1. In addition, we would like to highlight the relationship between the location and cause of the damage inside the same inspected area. The controlled area is divided into 5 regions representing the typical locations of the landfill cells and for our identification purpose. (see Figure 1).

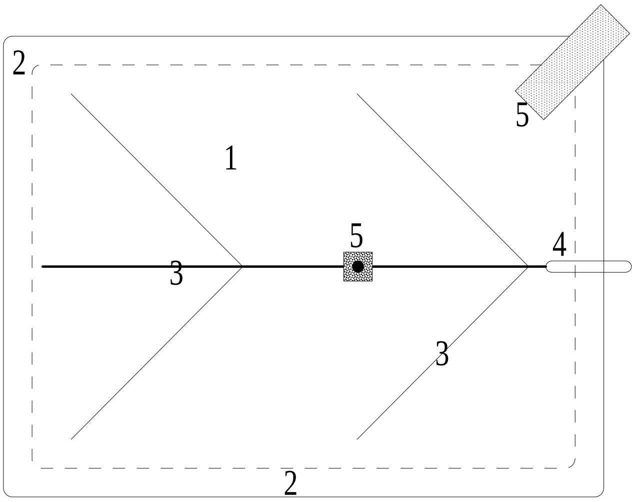

Figure 1. Schematic view of a landfill with the numbering of the parts.

One can easily notice that the majority of damage were caused by stones within the protection layer and heavy equipment (bulldozer, caterpillar, front loader, etc.). Engineers as well the site workers and operators should be able to make proper provisions to minimise these types of damage occurring.

Another very important fact that we discovered was that the most failures were located within flat areas (#1) where again stones and heavy equipment caused the majority of failures. We can see slightly different pattern in other areas like corners and drainage areas (#2) such that more damage caused by extrusion welds and by heavy equipment are noticed. However, the damage due to the stones are the key contributor of the failures. It is understandable that the other results we obtained in the case of pipe penetrations through a geomembrane (#4) were comprised mostly of failures of extrusion welds.

Regarding damage done by various sizes of stones, we found the problem of counting the exact amount of single holes. Mostly the damage by stones occur as one typical area with several (sometimes tens) small and single holes grouped together. Hence, we adopted an idea that a single hole caused by the stones is defined as an area with holes are clustered together within 5 cm diameter region. If another group of holes clustered is separated by more than 5 cm, we would consider that as a separate hole.

Table 1. Cause of damage vs. size of damage

Size of damage (cm^2)	Stone	%	Heavy equip.	%	Welds	%	Cuts	%	Worker directly	%	Total
< 0.5	332	11.1	-	-	115	43.4	5	8.5	-	-	452
0.5 – 2.0	1720	57.6	41	6.3	105	39.6	36	61.0	195	84.4	2097
2.0 – 10	843	28.2	117	17.9	30	11.3	18	30.5	36	15.6	1044
>10	90	3.0	496	75.8	15	5.7	-	-	-	-	601
Amount	2985		654		265		59		231		4194
Total	71.17 %		15.59 %		6.32 %		1.41 %		5.51 %		

Table 2. Location of damage

Amount of damage	Flat floor 1*	Corner, edge, etc. 2	Under a drainage pipes 3	Pipe penetration 4	Other 5**
4194	3261	395	165	84	289
100 %	77.8 %	9.4 %	3.9 %	2.0 %	6.9 %

* (see plan view of model landfill pond)

** (road access, temp. storage, concrete structure, etc.)

The tables 3 to 7 show the analysis of the cause of the damage vs. location. Such information is very useful to help understand what goes on at the landfill construction sites in terms of the geomembranes.

Table 3. Flat floor

Type of failure	Amount of holes	%
Stones	2641	81.00
Heavy equipment	430	13.20
Worker	130	4.00
Cuts	33	1.00
Welds	26	0.80
Total	3261	100.00

Table 4. Corner, edge, etc.

Type of failure	Amount of holes	%
Stones	234	59.20
Heavy equipment	75	18.90
Worker	14	3.50
Cuts	4	0.90
Welds	69	17.50
Total	395	100.00

Table 5. Under a drainage pipes

Type of failure	Amount of holes	%
Stones	50	30.30
Heavy equipment	24	14.30
Worker	24	14.50
Cuts	23	13.70
Welds	45	27.20
Total	165	100.00

Table 6. Pipe penetration

Type of failure	Amount of holes	%
Stones	-	-
Heavy equipment	-	-
Worker	7	8.50
Cuts	1	0.60
Welds	77	90.90
Total	84	100

Table 7. Other (road access, temp. storage, concrete structure, etc.)

Type of failure	Amount of holes	%
Stones	60	20.60
Heavy equipment	125	43.40
Worker	56	19.30
Cuts	-	0.00
Welds	48	16.70
Total	289	100.00

3 ESTIMATION OF THE RATES OF LIQUID FLOW DUE TO HOLES IN GEOMEMBRANE OF COMPOSITE LINERS

3.1 *Assumptions*

The general liner system considered (Figure 2) follows from Rowe (1998) and Touze-Foltz et al. (1999) and includes a geomembrane resting on a low-permeability clay liner of thickness H_L and hydraulic conductivity k_L. The z-axis origin corresponds to the top of the soil liner with upward being positive. It is assumed that the geomembrane is not in perfect contact with the soil liner and that there is a uniform transmissive zone between the geomembrane and the soil liner surface that is referred to as the "transmissive layer". In the following, it is assumed that: (i) liquid flow is under steady state conditions; (ii) the soil liner and the foundation layer are saturated; and (iii) liquid flow through the liner is vertical.

Analytical solutions have been developed by Touze-Foltz et al. (1999) for the axi-symmetric (circular hole in flat surface of geomembrane) and two-dimensional (hole in a wrinkle) cases as presented on Figure 2. These solutions will be used in the following to quantify the influence of the hydraulic head and of the size of the hole on the rate of liquid flow either for the axi-symmetric and two-dimensional cases. No particular assumptions are made regarding the dimension, position, or the number of holes in the wrinkles, but rather it is assumed that the rate of liquid flow in the composite liner is not limited by the holes (the hole limiting case is discussed by Rowe (1998) and Touze-Foltz et al. (1999)).

In the following calculations, the values of hydraulic conductivities of CCLs and of hydraulic transmissivities of the transmissive layer between CCLs and geomembranes given by Rowe (1998) are adopted. Two values of hydraulic transmissivities are used for the transmissive layer between geomembranes and CCLs: The first one is $\theta = 1.6\times10^{-8}$ m^2s^{-1} when the hydraulic conductivity k_L of the CCL is equal to 10^{-9} ms^{-1}. This hydraulic transmissivity corresponds to "good contact" conditions as defined by Giroud (1997) in developing his semi-empirical equations (Rowe 1998). The second one is $\theta = 10^{-7}$ m^2s^{-1} when the hydraulic conductivity k_L of the CCL is also equal to 10^{-9} ms^{-1}. This hydraulic transmissivity corresponds to "poor contact" conditions as defined by Giroud

(1997). It can correspond to the transmissivity obtained in case a geotextile is put in the transmissive layer.

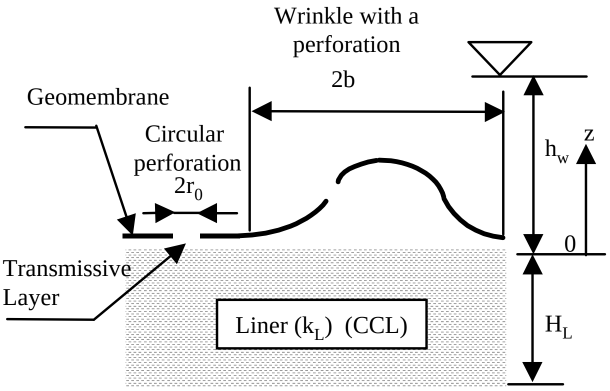

Figure 2 : Schematic showing a hole of radius r_0 and a wrinkle with a perforation in a geomembrane and the underlying stratum (modified from Rowe, 1998 and Touze-Foltz et al.,1999)

The liner thickness which is not an important parameter in determining the rate of liquid flow is set equal to 1 m.

The hydraulic head h_w on top of the composite liner is varied from 0.03 m to 3 m, to test the influence of the position of the hole (distance to the leachate sump). The hole area is varied from 0.1 cm^2 to 10 cm^2 according to data presented previously.

The boundary condition at the downstream end of the transmissive layer will be referred to as field boundary conditions. It corresponds to a zero-flow and zero-hydraulic head and is the limit of validity of solutions developed by Touze-Foltz et al. (1999).

3.2 *Results obtained*

3.2.1 *Axi-symmetric case*

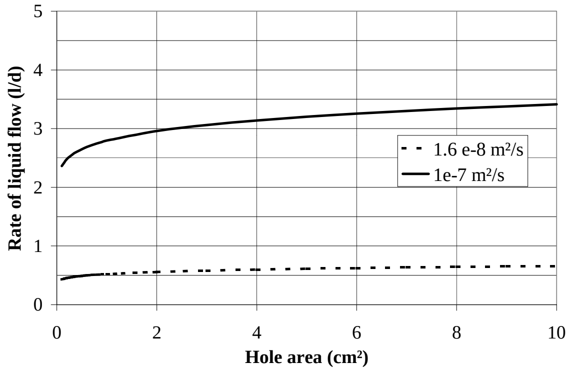

Figure 3: Evolution of the rate of liquid flow with the hole area, for the two values of hydraulic transmissivities adopted for the axi-symmetric case

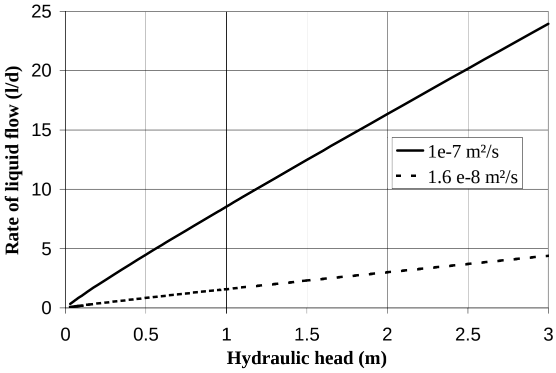

Figure 4: Evolution of the rate of liquid flow with the hydraulic head, for the two values of hydraulic transmissivities adopted for the axi- symmetric case

Figure 3 Shows the evolution of the rate of liquid flow obtained for a single hole for both values of hydraulic transmissivities adopted. The hydraulic head on top of the composite liner was equal to 0.3m for the calculations performed. One can notice that the hole size is not the influent parameter on the rate of liquid flow, whatever the value of hydraulic transmissivity. As shown on Figure 3 the hydraulic head is a much more important parameter. Indeed, the rate of liquid flow is nearly proportional to the hydraulic head applied on top of the composite liner. As a result, it seems that as far as circular holes are concerned, it is much more important to perfectly know their location than their size in order to adequately estimate the rate of liquid flow through the composite liner.

One can notice as well on Figures 3 and 4 that an increase in the hydraulic transmissivity by a factor close to 5 results in an increase in the rate of liquid flow by nearly the same factor. As a consequence, the use of a geotextile in the transmissive layer resulting in an increase of the hydraulic transmissivity may not be a convenient practice as it will significantly contribute to increase the rate of liquid flow. More research is needed to clarify this point and especially to quantify the hydraulic transmissivity of the transmissive layer at field scale.

3.2.2 *Two-dimensional case*

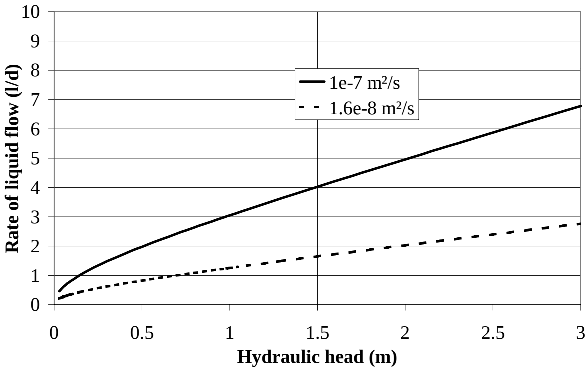

Figure 5: Evolution of the rate of liquid flow with the hydraulic head, for the two values of hydraulic transmissivities adopted for the two-dimensional case

For calculations performed assuming a damaged wrinkle in the geomembrane, the width of wrinkle adopted was 0.2 m. Figure 5 shows the rates of liquid flow obtained as a function of the hydraulic head applied on top of the composite liner. The evolution of the rate of liquid flow (given here for a meter of wrinkle) with the hydraulic head is nearly linear, especially for hydraulic heads greater than 0.5 m. The rate of liquid flow is less sensitive to an increase in the hydraulic transmissivity than in the axi-symmetric case. Indeed, the increase from a value of θ equal to 1.6×10^{-8} m^2s^{-1} to a value of θ equal to 1.6×10^{-8} m^2s^{-1} results in a increase by a factor 2.5 of the rate of liquid flow.

These results point out the fact that in order to adequately quantify the rate of liquid flow through a composite liner a density of holes in the geomembrane is not a sufficient information. Indeed, it is necessary to know the exact positions of holes, and their relative positions with regard to the position of wrinkles in the geomembrane.

REFERENCES

Crozier, F., Walker, T. (1995). CQA+GLLS=TEC: How Much Does Your Liner Leak? *Monthly Journal of the Waste Management,* London, February 1995.

Giroud, J.P. (1997). Equations for Calculating the Rate of Liquid Migration Through Composite Liners Due to Geomembrane Defects. *Geosynthetics International*, Vol.4, No. 3-4, pp.335-348.

Giroud, J.P. (1999). Lessons Learned from Failures Associated with Geosynthetics. *Geosynthetics 99, Conference Proceedings*, Boston, Massachusetts, April 28-30, 1999.

Laine, D.L., Darilek, G.T. (1993). Locating Leaks in Geomembrane Liners of Landfills Covered with a Protective Soil. *Geosynthetics ’93, Conference Proceedings*, Vancouver, British Columbia, March 30 – April 1, 1993.

Nosko, V., Andrezal, T., Gregor, T. and Ganier, P.G. (1996). SENSOR Damage Detection System (DDS) – The unique geomembrane testing method. *Geosynthetics: Applications, Design and Construction.* Proceedings of the First European Geosynthetics Conference Eurogeo 1, Maastricht, Netherlands, 30 September – 2 October 1996.

Nosko, V., Ganier, P.G. (1999). Damage Detection System – The New Tool for In-Situ Testing of Integrity of Geomembranes: Comparison & Results. *Landfill Interest Group.* Cape Town, South Africa, 16-17 September 1999.

Rowe, R.K. (1998) "Geosynthetics and the minimization of contaminant migration through barrier systems beneath solid waste", Keynote paper, *Proceedings of the Sixth International Conference on Geosynthetics,* Atlanta, March, Vol. 1, pp. 27-103.

Touze-Foltz, N., Rowe, R.K. and Duquennoi, C. (1999) "Liquid Flow Through Composite Liners due to geomembrane Defects: Analytical Solutions for Axi-symmetric and Two-dimensional Problems, *Geosynthetics International*, Vol. 6., No. 6, pp. 455-479.


8
27.1.1999


6.9.96
EL.-169
č.7


4.1.96
No.-4
EL-80