Table of contents Search Author index

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Lessons learned from geo-electrical leaks surveys

A. L. ROLLIN, M. MARCOTTE and L. CHAPUT , Solmers Int., Quebec, Canada
F. CAQUEL, LRPC Nancy, France

ABSTRACT: Early detection of geomembrane damages during liner installation is essential to any rigorous quality assurance monitoring process. Since a synthetic liner is deemed to play the role of flow controller, quality control can be achieved by on-site inspection and testing during construction phase. Experience demonstrates that gross damages occur during covering layer installation and during geomembrane installation. More than 1.5 million square meters, corresponding to more than 150 geo-electrical surveys, have been reported with an average of 17.4 leaks/ha. Approximately 80% of all detected leaks were smaller than 500 mm^2 with larger leaks being holes and tears. Damages have been identified at extrusion welds, at T and Y joints, around protruding couplings and pipes, in corners and at slope bottoms. The large number of leaks found during these electrical leak detection surveys performed after rigorous CQA Programs is larger than the one expected during design phase stressing the need to improve existing programs.

1 INTRODUCTION

1.1 *General*

Several failures in geomembranes can occur during their installation. They are more related to the quality of the sub-grade and drainage layer materials and the installer expertise. Short-term failures are due to the placement of the drain granular material, traffic of mobile equipment, thermal shrinkage, weight and properties of the material place under and above the liner. Experience demonstrates that in ponds built according to a strict Construction Quality Program (CQA) damages prior to the placement of a protective cover are frequently found during specialized surveys. In landfills, most of the damages occurs during placement of the over-cushion layer according to Colucci et al. 1995, Laine et al. 1993, Phaneuf et al. 2001. The electrical leak detection system has demonstrated its validity and usefulness whenever an important leak can be forecasted (Cadwallader 1998, Peggs 1993b).

1.2 *Electrical leak location systems*

Electrical leak location method has been used to locate leaks in PE, CSPE, PP, PVC and bituminous geomembranes installed in basins, ponds and landfill cells. The principle behind the technique is to place a voltage across a synthetic geomembrane liner and then detect areas where electrical current flows through a discontinuity in the liner (as shown in Figure 1). Essentially, the liner must be an insulator and an electrical potential is applied across the geomembrane between a liquid retained by the liner and the sub-grade.

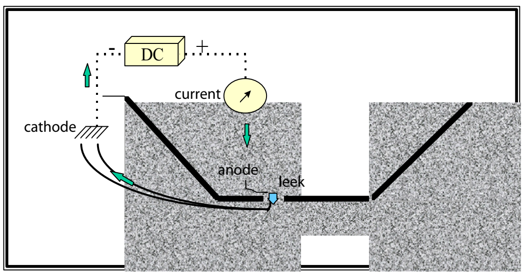

Figure 1. Schematic of electrical leak detection method

The geo-electric techniques of locating potential leaks in a liner can be performed on uncovered dry liners, on liners covered with water and on liners covered by a protective soil layer. They are used to rapidly evaluate leak defects in 100% of a geomembrane liner at a rate of about 9000 to 13000 m^2/day (375 to 540 m^2/h) per equipment (Peggs 1993b, Rollin et al. 1999).

1.3 *Leaks location on exposed geomembrane*

Single geomembrane placed directly on soil, such as in impoundment facilities and for the secondary and primary geomembranes of a double composite lining system in landfills, in geomembrane-lined concrete and in steel tanks, can be tested using the water puddle and water lance techniques. Water is usually supplied by gravity from a tank truck parked at the top edge of the pond or landfill. For this technique to be effective, the leaking water must come into immediate contact with the electrical conducting medium to which the ground electrode of the 12 or 24 VDC supply can be connected. These techniques locate leaks independently (large damages not masking small leaks) with the possibility to detect leaks in geomembrane joints and sheets as work progressed during the construction phase.

Figure 2. An electrical leak detection survey on exposed GM

The principle behind another technique, water covering the liner, has been described abundantly by Peggs (1989, 1990 1993a), Darilek et al (1988, 1989) and Laine et al (1989, 1991, 1993). Similarly to the previous techniques, this electrical leak survey requires an electrically conductive layer below (soil) and above the liner (water or humid soil). A cathode ground is established and an anode is placed in the contained water. The voltage impressed across the liner produces a low current flow and a relative uniform voltage distribution in the material above the liner. If the liner has a leak, electrical current flows through the leak causing a localized abnormally in the potential gradient. A hand held probe is then traversed through the water and the current traced to the defect.

Finally, the PE co-extrusion technology made it possible to produce a liner with a thin (approximately 5 mil) electrically conductive layer using electrically conductive carbon black. This manufacturing process allows the PE geomembrane to become spark-testable over 100% of its surface using standard spark testing equipment (Gundle 1992). The conductive layer can be charged with 15 000 to 35 000 volts and a brass or neoprene sponge wand is then passed over the non-conductive layer on top. Any breach in the liner will transmit a spark with an audible alarm signal.

1.4 *Leaks location on covered geomembrane*

The main advantage of this technique is the detection of leaks with a granular layer covering the liner (provided the cover soil is homogeneously electrically conductive). The principle behind this technique has been described abundantly by Peggs (1989, 1990 1993), Darilek et al. (1988, 1989) and Laine et al. (1989, 1991, 1993). This electrical leak survey requires an electrically conductive layer below (soil) and above the liner (humid granular layer). The voltage impressed across the liner produces a low current flow and a hand held probe is then traversed through the soil to trace to the defect.

2 SURVEYS

2.1 *Sites surveys*

Leak location system was developed in the early 1980 at the South West Research Institute in San Antonio under an US EPA sponsored research program (Laine et al. 1988) and commercial surveys have been available since 1985 in USA (LLSI 1998) and since 1992 in Europe (Colucci et al. 1995). Recently 300 electrical resistivity leak location surveys which were conducted throughout the world were reported by Nosko et al. (1996, 2000). These leak location survey summaries assessed geomembrane damage found in more than 3,000,000 m^2 of liner installations in 11 countries (Phaneuf et al 2001).

Survey results obtained by Laine et al. (1989), Darilek et al. (1989), Colucci et al. (1995, 1996), Peggs et al. (1990, 1996, 2001), Phaneuf et al. (2001), Nosko et al. (1996, 2000) and Rollin et al. (1999) have been assessed. Many of these surveys were conducted after a conventional construction quality assurance program has been implemented. These data exclude results obtained from electrical conductive geomembrane, permanent monitoring systems, systems which are restricted to seam testing only and systems which may detect leaks non-electrically.

The analysis of 1827 leaks reported by Colucci et al (1995), Darilek et al (1989), Laine et al (1993) and Rollin et al (1999) indicated that 65% related to seaming and 35% located in the sheet material with an average leaks density equal to 17.4 leaks/hectare, a number far greater than expected and usually considered during the design phase. The structures surveyed (defined as an individual liner which was inspected in a single survey) consisted of steel tanks, concrete tanks, basins and ponds, uncovered primary and secondary landfill liners and soil covered landfill liners. The liner materials used at the sites were high-density polyethylene (HDPE), low density polyethylene (LLDPE), flexible polypropylene (FPP), pre-fabricated bituminous (PBGM), polyvinyl chloride (PVC) and chlorosulfonated polyethylene (CSPE).

In a 1996 survey data reported by Nosko et al, results obtained in landfills indicated that 73 % of damage occurs when the soil layers are placed on top of the geomembrane, 24 % occurs during geomembrane installation and 2 % occurs during the post construction phase. So, contrary to the general perception, in landfills most damage detected occurs during covering layer installation and not caused by improper seaming.

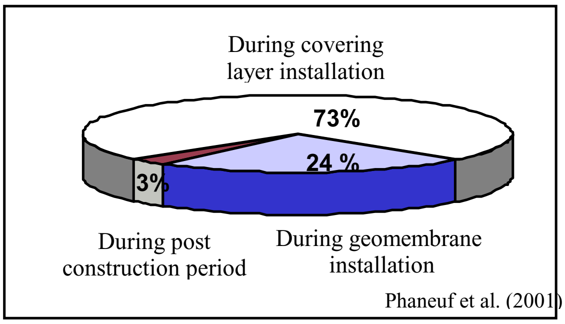

Figure 3. Causes break down of geomembrane leaks.

2.2 *Leaks density*

Leaks densities reported by many authors are shown in Table 1. Leaks density is ranging from 26.0 to 2.0 leaks/hectare. The density reported by Laine et al. (1989) is relatively larger than others simply because this set of surveys was performed on small containment facilities such as ponds and basins. The number of leaks per hectare in landfill primary and secondary liners reported are for uncovered liners equal to 14.0 leaks/ha (Laine et al. 1993) and for covered liners equal to 22.5 leaks/ha (Laine et al. 1993) and to 15.31 leaks/ha (Colucci et al. 1995).

Table 1. Reported leaks density

reference	sites	status of GM	total area surveyed	leaks/hectare
Laine et al 1989	28	uncovered	207,000	26.0
Laine et al 1993	58	covered	364,000	22.5
Laine et Mosley 1993	169	uncovered		14.0
Laine et Mosley 1993	17	covered		22.0
Colucci et al 1995	25	covered	300,000	15.3
Rollin et al 1999	8	uncovered	230,000	2.0

The leaks densities reported by Rollin et al. (1999) are relatively lower than others because the surveys were performed during the liners installation, a geotextile has been installed between the sub-grade material and the liner and very strict CQA programs were implemented. Also 63% of surveyed area was basins lined with bituminous and polypropylene geomembranes. Analysis of the data presented in Table 1 indicates that larger leaks densities are found in smaller installations as pointed out by Colucci et al. (1995), Rollin et a.l (1999) and Phaneuf et al. (2001) and presented in Figure 4.

The reasons for the greater number of leaks per hectare to liners installed in smaller installations have been summarized by Colucci et al. (1995): smaller installations have proportionally more complex features (corners, sumps, penetrations) where extrusion welding is used; larger installations tend to have stricter construction quality program; and larger installations generally receive less traffic.

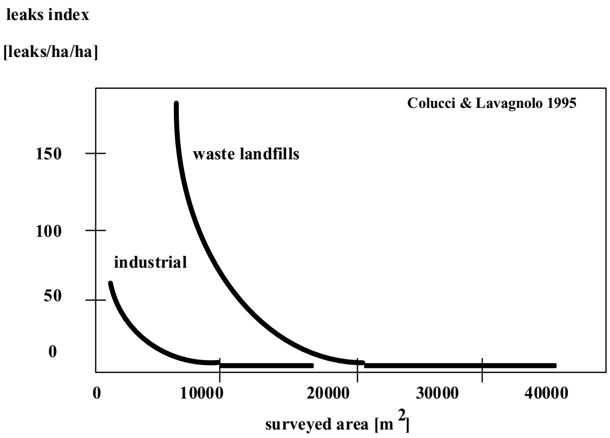

Figure 4. Leaks index as a function of sites surveyed area

Two curves have been plotted to differentiate between the numbered of leaks detected in waste containment cells and in hazardous waste containment sites. The leak densities in industrial sites are probably lower as a result of greater construction quality assurance program implemented.

2.3 *Types of potential leak paths*

Types of potential leak paths can be related to the quality of the sub-grade material, quality of the cover material, accuracy in their installation and quality of GM installation that is responsible factors for short-term liner leaks. Leaks detected during surveys can be divided into many categories: holes (gouges and punctures) – being object shaped leaks with downward or upward protruding rims; tears – being linear or areal leaks with tooth-edge borders; cuts – being linear leaks with neat close edges; lack of seam bond – being partial or total lack of seaming between sheets; burns (melted zones) – area where the polymer has been melted during the welding process.sheets; burns (melted zones) – area where the polymer has been melted during the welding process.

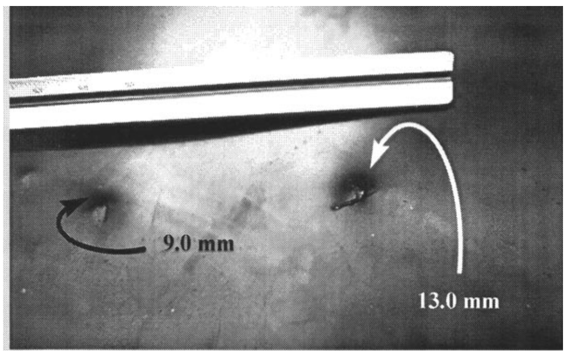

Figure 5. Photograph of leaks in a HDPE geomembrane

In an attempt to correlate leak types to the data gathered by Colucci et al. (1995), mean leaks densities were calculated at sites where known low and high quality sand and gravel layers have been installed. A high quality gravel layer can be defined as "alluvial well graded gravel, well rounded surfaces and well washed" and a high quality protective sand layer as "layer thickness >30cm, well graded, absence of gravel and absence of stones". An average of 39.4 leaks/ha was obtained for low quality sub-grade layers as compared to 8.0 leaks/ha for high quality sub-grade soil. On the other hand, an average of 19.5 leaks/ha has been obtained for low quality cover soil. These results are suggesting that a low sub-grade quality was probably responsible for the majority of leaks found during liner installation and that low quality cover soils were responsible for approximately 35% of the detected leaks. Cuts and faulty seams represents 15% of detected leaks (63/422 leaks).

2.4 *Leaks location*

For basins and ponds, approximately 35% of all detected leaks are located in the sheet material while 65% are related to extrusion welding particularly at repair patches, edges and in the vicinity of pipe penetrations. Cuts have been located close to corners along the bottom perimeter (from falling knives during slope installation), in the vicinity of particular points and in the vicinity of fillet weld repair patches. Similarly, small leaks have been located in fillet weld repair. For landfills, Nosko et al. (2000) reported that 78 % of the leaks where found on the flat floor, 9 % in corners and edges, 4 % under pipes, 2 % at pipe penetrations and 7 % at road and structures.

2.5 *Leaks size*

Data reported by Colucci et al. (1995) are presented in Table 2. Approximately 80% of all detected leaks are smaller than 500 mm^2 with larger leaks being holes and tears. Pinhole seam leaks located in geomembrane liners using electrical leak location method has been analyzed and presented by Laine (1991). 30 hectares and 5 hectares wastewater containment facilities were surveyed after seams have been checked using air pressure in dual seam canal and vacuum box tests. A total of 31 leaks had been found (5 leaks/ha). The leaks detected using the electrical system were mainly located at fillet weld repair patches from incomplete bonding and incomplete fillet weld to sheet. Their size ranging from 0.5 to 1 mm with leak path extending under the weld.

Table 2. Leak size as a function of leak type (Collucci et al. 1995)

leak size (mm^2)	**holes**	**tears**	**cuts**	**seams**	**total**	**% total**
0-20	44	31	12	11	98	**23**
20-100	37	49	21	4	111	**26**
100-500	60	49	2	8	119	**28**
500-1 000	22	11	0	4	37	**9**
1 000- 10 000	10	22	0	1	33	**8**
> 10 000	15	9	0	0	24	**6**
	188	171	35	28	422	

For covered and un-covered geomembranes, Nosko et al. (2001) found that the predominant size of stone-related damage is typically 50 to 200 mm^2, damage related to heavy equipment is typically larger than 1000 mm^2, damage related to faulty welds is typically under 50 mm^2 and damage related to cuts typically 5o to 200 mm^2. This information can be compared with leaks found by Collucci et al. (1995), Phaneuf et al. (2001) and Rollin et al. (1999).

3 LESSONS AND CONCLUSIONS

The number of leaks detected during geo-electrical leak location of numerous sites is greater than expected and considered during design phase. Giroud et al (1989) estimated leak flow rates for geomembrane sandwiched by permeable high quality soil layers on the assumption of a single small hole of area equal to 3.1 mm^2 per acre.

Table 3. Leak size as function of leak type (Phaneuf et al 2001)

	size of damage (Nosko et al (2000))									
size	punctures	gouges	cuts	tears	burns	scrapes	bonds	seams		% total
mm										
<1	10	1	2			1	1	1		12
2 to 10	28	11		1	8	7	4	1		46
11 to 50	7	1	7	2		3	2	1		18
51 to 100			3	1		1		3		6
101 to 500	1		1			1		1		3
501 to 1000							1	2		2
> 1000						2	1	1		3
unknown	4	3		1		2	1	2		10
% otal t	38	12	10	4	6	13	8	9		

For a well-designed granular leachate collection layer, a 3 cm liquid head can be assumed resulting in a 300 l/ha-d leaking flow rate. Laine et al. (1989) estimated a leaking flow rate of 42 gal/acre-d (393 l/ha) on the estimation of 12 leaks/acre. As suggested by Bonaparte et al. (1990) and Beech et al. (1998), an acceptable flow rate of liquid collected in the leachate collection system of a composite liner would be 150 l/ha-d representing approximately 2.5% of the produced liquid reaching the liner. Considering a mean leak density of 17 leaks/ha for composite liners in landfills and considering leaks of the same size with a liquid head equal to 1 cm, the leak dimension should be equal to 1.5 mm ($A = 1.8\ mm^2$). Since it is impossible to guarantee that there will be no larger leaks in the geomembrane and greater liquid head, this analysis indicates that probable relatively larger leakage rates are encountered at sites where minimum CQA programs were implemented.

The higher leaks density found in smaller installations suggest that greater CQA should be implemented for small impoundment facilities such as for the leachate collection pond too often neglected (single liner with complex features). Since the liquid head is approximately 3 m, large leakage rates should be expected.

The data indicate that as much as 97 % of all geomembrane defects were introduced during the construction process. The large number of leaks found during these electrical leak detection surveys performed after rigorous Construction Quality Assurance Programs stresses the need to improve existing programs. Greater cares must be exercised during construction phase for high quality of sub-grade and cover soil materials, accuracy of installation of liner on sub-grade soil, inspection of fillet extrusion welds in vicinity of pipe penetration, sumps and at repair patches.

The electrical leak detection system has demonstrated its validity and usefulness and should be mandatory in a construction quality assurance program. The electrical leak detection system performed during liner installation could be a viable substitute to non-destructive testing of seams.

4 REFERENCES

Beech J.F., Cargill K.W. & Huff W.J. 1998. Evaluation of Liner System Performance Using Liquids Management Data, Proceedings of 6th International Conf. on Geosynthetics, IFAI, Atlanta, pp 269-272, March

Bonaparte R. & Gross B.A. 1990. Field Behavior of Double-Liner Systems, Waste Containment Systems, ASCE Geotechnical Pub. no 26, pp 52-83

Cadwallader M. 1998. Time to Shift the Paradigm: The "Cutting Edge" of Geomembrane QA/QC, *GFR, April*

Colucci P. & Lavagnolo M.C. 1995. Three Years Field Experience in Electrical Control of Synthetic Landfill Liners, *Proceedings of Sardinia'95, CISA, Cagliari, pp 437-451, Oct*

Darilek G.T. & Parra J.O. 1988. The Electrical Leak Location Method for Geomembrane Liners, *EPA/600/S2-88/035, Sept.*

Darilek G.T., Laine D. & Parra J.O. 1989. The Electrical Leak Location Method for Geomembrane Liners, *Proceedings of Geosynthetics'89, IFAI, pp 456-462, San Diego*

Giroud J.P. & Bonaparte R. 1989. Leakage through Liners Constructed with Geomembranes, II: Composite Liners, *Geotextiles and Geomembranes, vol 8, no 2, pp 71-112*

Gundle 1992. Gundleline HDC: Electrically Conductive Geomembrane, *Technical Specifications Guide*

Laine D.L., Miklas M.P. & Parr C.H. 1988. Loading Point Puncturability Analysis of Geosynthetic Liner Materials, *EPA Project EPA/600/S2-880/40, August*

Laine D.L. & Miklas M.P. 1989. Detection and Location of Leaks in Geomembrane Liners Using an Electrical Method, *Proceed. 10th Nat. Conf., Superfund'89, Washington, Nov.*

Laine D.L. 1991, Analysis of Pinhole Seam Leaks Located in Geomembrane Liners Using the Electrical Leak Location Method, *Proceed. Geosynthetics'91, Atlanta, pp 239-253*

Laine D.L. & Darilek G.T. 1993. Locating Leaks in Geomembrane Liners of Landfills Covered with a Protective Soil, *Proceed. Geosynthetics'93, vol 3, pp 1403-1412, April*

Leak Location Services Inc [1998], Electrical Leak Location Method.

Nosko V., Andrezal T., Gregor T. & Garnier P. 1996, Sensor Damage Detection System – The Unique Geomembrane Testing Method, *Proceed. EuroGeo, Netherlands, pp 743-748*

Nosko V. & Touze-Foltz N. 2000. Geomembrane Liner Failure: Modeling of its Influence on Containment Transfer, *Proceedings Second EuroGeo, Bologna, pp 557-560*

Phaneuf R. & Peggs I.D. 2001. Landfill Construction Quality: Lessons Learned from Electrical Resistivity Testing of Geomembrane Liners, *Geotechnical Fabrics Report, vol 19, no 3, April pp 28-35*

Peggs I.D. & Pearson D.L. 1989. Leak Detection and Location in Geomembrane Lining Systems, *ASCE Annual Meting, Fort Lauderdale, September*

Peggs I. 1990. Detection and Investigation of Leaks in Geomembrane Liners, *Geosynthetics World, vol 1, issue 2, winter, pp 7-14*

Peggs I.D. 1993a. Practical Geoelectric Leak Surveys with Hand-Held, Remote and Water Lance Probes, *Proceedings of Geosynthetics'93, IFAI, pp 1523-1532, Vancouver*

Peggs I.D. 1993b. Advances and New Thinking in Landfill Liner Construction Quality Assurance Practices, *Proceedings of Sardinia'93, CISA' Cagliari, pp 121-128*

Peggs I.D. & McEuen R. 2001. Three Challenging Electrical Integrity/Leak Surveys on Uncovered and Deep Waste-Covered Liners, *Proceedings of the Geosynthetics Conference 2001, Roseville, USA, pp 245-262*

Rollin A.L., Marcotte M., Jacquelin T. & Chaput L. 1999. Leak Location in Exposed Geomembrane Liners Using an Electrical Leak Detection Technique, *Proceedings of Geosynthetics'99, Boston,pp615-626*