A GUIDE TO DETECT LEAKS ON INSTALLED GEOMEMBRANES

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ABSTRACT: A synthetic liner is deemed to play the role of flow controller such that early detection of geomembrane damages during liner installation is essential to any quality assurance monitoring process. Experience demonstrates that even in sites built according to a strict Construction Quality Program (CQA), most of the damages found did occur during installation of the sub-grade and drainage layer materials on the geomembrane. A total in excess of 7.0 millions square meters corresponding to more than 465 geo-electrical surveys have been reported: Rollin (2002) 19.5 leaks/ha for 1.5 Mm^2 in 150 surveys and 12.9 leaks/ha found surveying installed HDPE, PVC and fPP liners installed in 39 sites in Europe, North and South America totalizing 2.5 Mm^2, Hruby et al (2003) 11 leaks/ha for 3 Mm^2 in 276 sites.The large number of leaks found during electrical leak detection surveys performed after rigorous CQA programs stresses the need to improve existing programs. ASTM Committee D35 on Geosynthetics issued in 2002, a new guidance for locating leak paths in installed geomembranes by electrical methods (D 6747, Standard Guide for Selection of Techniques for Electrical Detection of Potential Leak Paths in Geomembranes) describing options for detecting leaks. In this paper, the techniques used to check the integrity of an installed geomembrane are presented and data obtained during detection surveys will establish their usefulness.

1 DEVELOPED SYSTEMS

Electrical leak detection systems were developed in the early 1980's and commercial surveys have been available since 1985. Systems have been used successfully to locate leak paths in electrically-insulating geomembranes such as polyethylene, polypropylene, polyvinyl chloride, chlorosulfonated polyethylene and bituminous geomembranes installed in basins, ponds, tanks, ore and waste pads, and landfill cells. The principle behind theses techniques is to place a voltage across a synthetic geomembrane liner and then locate areas where electrical current flows through discontinuities in the liner (as shown schematically in Figure 1). Insulation must be secured prior to a survey to prevent pipe penetration, flange bolts, steel drains and batten strips on concrete to conduct electricity through the liner and mask potential leak paths. The liner must act as an insulator across which an electrical potential is applied. These electric detection methods of locating potential leak paths in a geomembrane can be performed on exposed liners, on liners covered with water and/or on liners covered by a drainage soil layer.

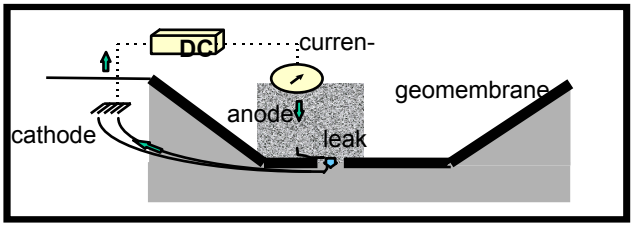

Figure 1: Schematic of electrical leak detection method

1.1 *On exposed geomembrane*

The water puddle and water lance systems are appropriate to survey a dry uncovered geomembrane during its installation when placed directly on a subgrade (Peggs (1993b), Rollin et al (1999)). The lower conductive layer is usually the soil and the upper conductive layer being water. A cathode ground is established and an anode is placed in a water puddle maintained by a squeegee (as shown in Figure 2) or to the water stream of a lance. For this technique to be effective, the leaking water must come into contact with the electrical conducting medium to which the ground electrode of the 12 or 24 volts DC supply can be connected. As the water flows through a leak path, as small as 1mm in size, it is then located by an audio signal or by measuring a current of magnitude proportional to the size of the leak. It can also be used to search for leak paths in geomembrane-lined concrete and steel tanks.

Figure 2: Photo of a survey with the water puddle system

Features - The main advantage of these systems is the possibility to detect leak paths in geomembrane joints and sheets as work progresses during the construction phase. Larger leak paths do not mask smaller ones because this technique locates discontinuities independently on uncovered liner. The electrical survey rate of approximately 500 square meters per hour per operator does not affect the installation work schedule and permits a rapid construction quality control (CQC) of the installer work. The approximate set up time could varied from 1 to 3 hours.

Limitations - This technique cannot be used with the protective layer covering the liner. The presence of wrin-

kles and waves, steep slopes and lack of contact between the liner and the conductive soil at bottom of slopes inhibits the survey speed. This technique cannot be used, during stormy weather, when the membrane is installed on a desiccated sub-grade, or whenever conductive structures cannot be insulated or isolated. The procedure to detect potential leak paths in seams of repair patches is difficult and lengthy since it is requiring a certain infiltration time.

1.2 *The water-covered geomembrane system*

The principle behind this system is to test a geomembrane while it is covered with water, a technique similar to the previous system requiring an electrically conductive layer below (sub-grade) and above the liner (water or saturated drainage layer) (Peggs (1989, 1990 1993a), Darilek et al (1988, 1989) and Laine et al (1989, 1991, 1993)). A cathode ground is established and an anode is placed in contained water. The voltage impressed across the liner (by a high voltage dc or ac power supply) produces a low current flow and a relative uniform voltage distribution in the material above the geomembrane. To maximize this current, a high voltage power supply with safety circuits is used that can provide up to 300 volts DC. A hand held probe is then traversed through the water and an electrical current flows through the discontinuity causing a localized abnormality in the electrical paths. The typical procedure is to flood the test area, then locate the potential leak paths, drain the area and perform repairs.

Features - This system has the advantage of being used to locate potential leak paths in in-service impoundments. The water head on the liner facilitates the survey speed from minimizing the presence of wrinkles and waves, steep slopes and lack of contact between the liner and the conductive soil at bottom of slopes. A hand held probe or a probe on a long cable is scanned through the water to locate these places where current is flowing through a leak. A typical procedure is to flood the test area to a depth of approximately 0.15 to 0.75 m. This technique can locate very small leaks, smaller than 1 mm. The signal amplitude is proportional to the amount of electrical current flowing through the leak, so practical measures should be taken to maximize the current through the leaks. The signal amplitude is inversely related to the distance from the leak, so the scanning spatial frequency should be designed to provide the desired leak detection sensitivity. The survey rate depends primarily on the spacing between sweeps and the depth of the water. A close spacing between sweeps is needed to detect the smallest leaks. For a survey with a towed probe with the probe scanned within 0.4 meters of every point, the survey rate is 800 to 1,000 square meters per hour per two persons, including establishing the survey lines. The approximate set up time is 30 to 90 minutes. These times do not include the time to flood the liner.

Limitations - The main disadvantage of this system is that it cannot be applied to detect potential leak paths in geomembrane joints and sheets as work progresses during the construction phase since, as a pre-service inspection method, is the need to flood the geomembrane with water. Three other limitations are recognized : the presence of large leak paths may influence the detection of small leak paths in their vicinity; depending on the bottom configuration of the surveyed application, the water depth can be substantial in some areas; the procedure is more lengthy consisting of flooding the area, probing to locate the leak paths and draining of the area to perform repairs .

1.3 *The electrically conductive geomembrane*

Co-extrusion technology makes possible the manufacture of a polyethylene geomembrane that can be spark tested. The material has a thin layer of electrically conductive material as an inherent part of the geomembrane. This provides a way to spark test the installed geomembrane (Gundle (1992)). The conductive geomembrane is installed such that the conductive side is against the sub-base and the non-conductive side is on top. The testing utilizes a voltage source to charge an element such as an electrically conductive neoprene pad. The charge is then transferred to the (underlying) conductive layer of the geomembrane through the capacitance effect. Another conductive element is then swept over the (upper) non-conductive surface to inspect for the presence of potential leak paths. Where a discontinuity occurs, a closed circuit is created and a spark is produced.

Features - The main advantages of this technique are: this is the only system that utilizes a conductive grounding layer that is an integral part of the membrane being tested thus eliminating the issue of inconsistent grounding; it can be performed during construction; no water pumping is required; current flow is miniscule; primary and secondary liners can be tested; all slopes can be tested; it can detect leak paths smaller than 1 mm. The rate of testing depends on the type of equipment used. Using a 2-m wide brush, travelling at 3 to 5 km/hr, the rate can be up to 500 – 1500 square meters per hour . The set-up time required is approximately 30 minutes.

Limitations - The presence of wrinkles and waves and steep slopes inhibits the survey speed. This technique cannot be used during stormy weather. The location of leak paths with the protective granular layer covering the liner is not possible. It is not the intention of this method to replace traditionnal non-destructive testing of seams since a conductive path through the conductive layer on the bottom of the upper flap of a fusion weld seam must be conducted with a lower voltage and lower leak detection sensitivity.

1.4 *The soil-covered geomembrane system*

This method tests the geomembrane after the drainage soil layer is emplaced (Peggs (1989, 1990 1993), Darilek et al (1988, 1989, 2003) and Laine et al (1989, 1991, 1993)). It is similar to the water-covered geomembrane method except the geomembrane is covered with a soil layer, and point-by-point measurements are made on the surface of the soil. The soil must have some moisture, but it does not have to be saturated with water. It requires an electrically conductive layer below the geomembrane.

The most common implementation of this method is to make dipole measurements using two moving electrodes spaced a constant distance apart as shown in Figure 3. Pole measurements can also be made by making potential measurements on the soil cover using one moving electrode referenced to a second distant electrode. The data can be taken on a grid or at regular points along parallel survey lines. The data can be plotted in the field and analyzed to locate areas with a characteristic leak signal. The data can be analyzed in raster data form or using contour plots.

Features - This method has the distinct advantage of locating potential leak paths that are made during the emplacement of the protective soil layer. These construction damage leaks have been found to be prevalent type of damage to geomembranes that are difficult to detect during construction activities. This technique can be used in wet conditions. With proper signal sampling, this technique can locate small leaks, typically as small as 3 mm. The

survey rate depends on the sampling density of the measurements. The rate of testing also depends on data acquisition methodology and whether the data interpretation is accomplished in the field. The approximate survey rates for a survey taking one measurement every square meter is 400 to 1,000 square meters per hour per person, including establishing the survey lines and including data interpretation. Setting up the equipment and electrodes typically requires 1 to 2 hours.

Figure 3: Photo -survey of a covered geomembrane

Limitations - A limitation of this method is that the soil surface must have some moisture to make adequate electrical contact with the soil. In cases where the surface of the soil is desiccated, the soil must be wet with water, or the dry soil has to be scraped away at the measurement points. The presence of large leaks may influence the detection of small leaks in their vicinity.

1.5 *The grid system*

This permanent system has been developed to monitor leaks under the lined bottom and final cover of landfills (Nosko (2000)). It requires an electrically conductive grid of electrodes below the geomembrane and liquid above the liner. The leaks are located by taking potential measurement via a widely spaced grid of electrodes under the lined area. The data collected are then processed to determine the distribution of the current density that best reproduces the observed voltage data.

Features - The system is used principally as a permanent monitoring system. It can alert an operator on a continuous or sequential period basis. The technique permits isolating the general location of a leak. It can be used under cover soil and with liquid stored in the application. Telemetry can be used for remote and/or ongoing monitoring. The maximum area of testing per station (comprising of 130 to 200 electrodes) is approximately of 10000 m^2 with a 5 to 12 minutes per scan done by one person.

Limitations - The main limitation is related to the placing of the electrodes under the floor area. Because of the large amount of wire needed for large grids, the system is usually installed in smaller sections. It cannot be used during construction phase.

2 THE ASTM D6747 STANDARD GUIDE

The standard guide for the “Selection of Techniques for Electrical Detection of Potential Leak Paths in Geomembrane” is intended to assist individuals or groups in assessing different options available for locating potential leak paths in installed geomembranes through the use of electrical methods. Electrical Leak Location is defined as any method which uses electrical current or electrical potential to detect and locate potential leak paths and a potential leak path is any unintended opening, perforation, breach, slit, tear, puncture, crack, or seam breach. Scratches, gouges, dents, or other aberrations that do not completely penetrate the geomembrane are not considered. The guide does not cover systems that are restricted to seam testing only, nor does it cover systems that may detect leaks non-electrically. It does not cover systems that only detect the presence, but not the location of leaks.

Leak paths detected during surveys have been grouped into five categories: Holes – round shaped voids with downward or upward protruding rims; Tears – linear or areal voids with irregular edge borders; Linear cuts – linear voids with neat close edges; Seam defects – area of partial or total separation between sheets; Burned through zones – areas where the polymer has been melted during the welding process.

System functionality or calibration - A realistic test of the leak detection sensitivity should be performed and documented as part of the leak location survey. An actual or artificial leak simulator can be used.

For the ***water puddle and water lance systems*** *:* an artificial leak consists of a leak path of a specified size in an electrical conductor (1mm recommended) that is connected to the material under the geomembrane with an insulated wire. The leak location equipment and procedures should be demonstrated to be able to detect the artificial leak when water is covering the potential leak path on the geomembrane.

For an ***water-covered geomembrane***, an artificial leak consists of a leak path of a specified size in an electrical conductor (1mm recommended) that is connected to the material under the geomembrane with an insulated wire. The artificial leak is then submerged in the water on the geomembrane. The leak location equipment and procedures should be demonstrated to be able to detect the artificial leak when the leak is midway between sweeps of the leak location probe. The leak location survey procedures must be such that the leak location sensor sweeps are no further apart than the sweep spacing as that used to demonstrate the leak detection capability.

For ***soil-covered geomembrane***, the artificial leak (size of 3 mm recommended) is buried in the protective soil cover at the depth of the geomembrane. The leak location equipment and procedures should be demonstrated to be able to detect the artificial leak when the leak is midway between the measurement points on the surface of the protective soil. The leak location survey procedures must be such that the measurements are made no further apart than those used in the leak detection test.

For ***electrical conductive geomembrane***, the leak location equipment (the mobile brush) and procedures should be demonstrated to be able to detect the artificial leak on the geomembrane.

Considerations - In selecting one of the many systems described, the following considerations must be taken into account : Subgrade restrictions (conductivity, moisture content, etc…) ; Geosynthetics underneath or above the geomembrane; Uncovered material restrictions (waves, wrinkles, steep slopes, etc…); Cover material restrictions (conductivity, water saturation, etc…); Water requirement

(depth necessary, quantity of water needed, bottom slope); Protruding accessories (pipes, steel bars, access platforms, etc…); Economic factors; Intent of test

Reporting - The CQA report should contain the following parameters : Description of the survey site; Climatic conditions; Type of geomembrane; Cover material description; System and specific conditions of survey; Type, location and size of detected potential leak paths; Map of the surveyed areas; Survey on repaired areas if desired

3 ASTM STANDARD PRACTICES

Two standard practices are being developed at ASTM. Each is a performance-based practice for electrical methods for detecting leaks in exposed geomembranes and for detecting leaks in covered geomembranes: Standard Practice for Leak Location on Exposed Geomembranes Using the Water Puddle System and Standard Practice for Leak Location in Geomembranes Covered with Water or Earth Materials. These documents are complement the standard guide by identifying specifications and characteristics of electrical leak detection systems.

4 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. For a well-designed granular leachate collection layer in landfill cell, 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.

Data reported by Colucci et al (1995) are presented in Figure 4 and Table 1. Approximately 80% of all detected leaks are smaller than 500 mm^2 with larger leaks being holes and tears. For covered and un-covered geomembranes, Nosko et al (2000) 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 50 to 200 mm^2 (see Table 2). This information can be compared with leaks found by Collucci et al (1995), Phaneuf et al (2001) and Rollin et al (1999).

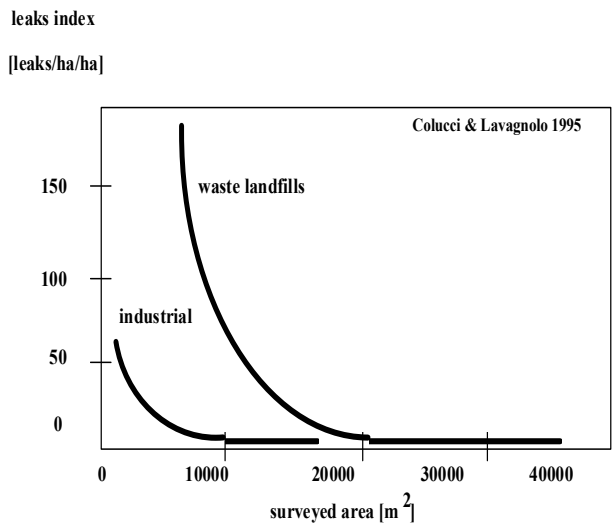

Figure 4: Leaks index as a function of sites surveyed area

Table 1: 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	

Table 2: Size of detected leaks

size of damage (Nosko et al (2000))										
size mm	punctures	gouges	cuts	tears	burns	scrapes	bonds	seams		% total
<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
% total	38	12	10	4	6	13	8	9		

The higher leaks density found in smaller installations (see Figure 4) 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 subgrade 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.

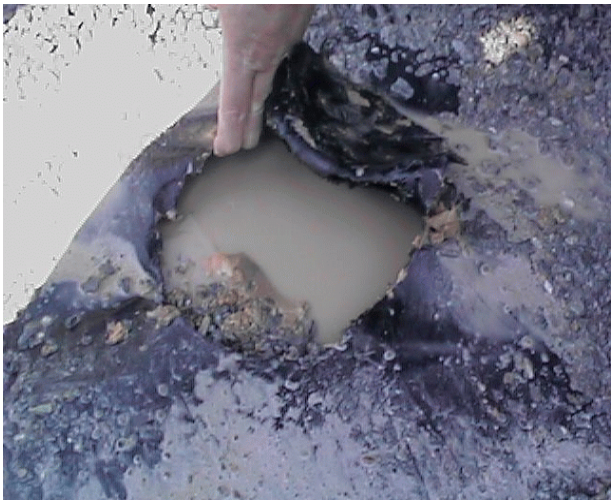

Figure 5: Photo of a large hole detected at covered geomembrane

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