GeoAmericas2020
4th PAN AMERICAN CONFERENCE ON GEOSYNTHETICS
26-29 APRIL 2020 • RIO DE JANEIRO • BRAZIL

New findings on Exposed Geomembrane Leak Location methods, with a focus on the Water Puddle and Arc Test Methods

Carl Charpentier, Leak Location Manager, Groupe Alphard, Montreal, Canada
Thierry Jacquelin, President, Groupe Alphard, Montreal, Canada

ABSTRACT
The electrical leak location methods used on exposed geomembranes are typically the Water Puddle method (ASTM D7002) and the Arc Test method (ASTM D7953). Other methods do exist, including the Water Lance method and the Spark Test method, similar to the Arc Test method but only suitable for surveys performed on conductive backed HDPE geomembrane. Both the Water Puddle method and the Arc Test method are commonly used on PVC, HDPE and bituminous geomembranes, but the question remains as to whether the two methods can be seen as equivalent. An obvious difference is found in their voltage use and leak location methodologies: the Water Puddle method applies low voltage (around 40 V) to water passed through defects in the geomembrane, whilst the Arc Test method applies high voltage (up to 35,000 V) to pass electrical arcs directly through any defects. But the differing effects on the two methods used in specific conditions are still not widely understood and may not be equivalent. The first part of the paper will present how each of the two leak location methods work, highlighting their differences and their respective limitations. Results from tests of both methods on different types of geomembranes of varying thicknesses will then be presented. The goal of this paper is to educate engineers and leak location practitioners on the differences between the available exposed membrane leak location methods and on which methods are more suitable given the types of geomembrane tested, weather and site conditions, and project particularities.

1. INTRODUCTION

Geomembranes are used in various types of projects. From ponds to damn to mining projects, they all share the same purpose: prevent flow of liquid to the environment. Whether it is to prevent chemical pollution or to store valuable assets like mining ores or potable water, leaks in geomembranes are a real issue that need to be dealt with carefully. Geoelectrical methods that are used to help lower the risk of leakage through liners and are separated into two categories: methods for exposed liners and methods for covered liners. This paper will focus on two of the Electrical Leak Location (ELL) methods on exposed liners:

- Water Puddle Method (WPM), as described in ASTM D7002;
- Arc Test Method (ATM), as described in ASTM D7953.

There are two other exposed geoelectrical methods, the Water Lance method and the Spark Test method, that will not be discussed in this paper because the first is outdated and the second only works on conductive geomembranes. They both have their respective standards (D7003 and D7240) and all methods are described in the global ASTM standard D6747. The Water Lance method is considered outdated due to the large volume of water it uses compared to the WPM and the relative difficulty of precisely locating leaks. The Spark Test method is similar to ATM, using high voltage of around 30,000V and generating arcs through defects, but the grounding method uses electrical capacitance through the geomembrane, and enables the detection of leaks on the panel itself. The Spark Test method can be a lot more complicated to setup and use, depending on the brand of equipment used, and site conditions.

The two methods discussed here are based on the same basic principle: the geomembrane is preventing the electrical current to flow through it, but when there is a leak, current will gain access to subgrade via water or air. Both methods are ON and OFF types, meaning there is either no current loop, or there is an electrical path from the structure to the subgrade (e.g. a leak, a wire, a concrete structure or even water reaching the outside of the structure). The next section will describe these two methods in more detail.

2. WPM AND ATM METHODS DESCRIPTION

2.1 Water Puddle Method (ASTM D7002)

The WPM (ASTM D7002) relies on the intrinsic insulation properties of geomembranes for the detection of small perforations (<1 mm²) in the geomembrane, generally produced at the time of the installation (see following figure). A continuous DC voltage is applied into the metallic water puddle structure, and a grounding electrode is placed outside the limits of the geomembrane. In the presence of a leak, the current will pass from the metallic structure, through the defect, into the subgrade and to the grounding electrode, thus producing a visual and auditory signal. This technique requires only a thin film of water on the surface of the geomembrane and provides a validation of the entire exposed surface traversed during the survey.

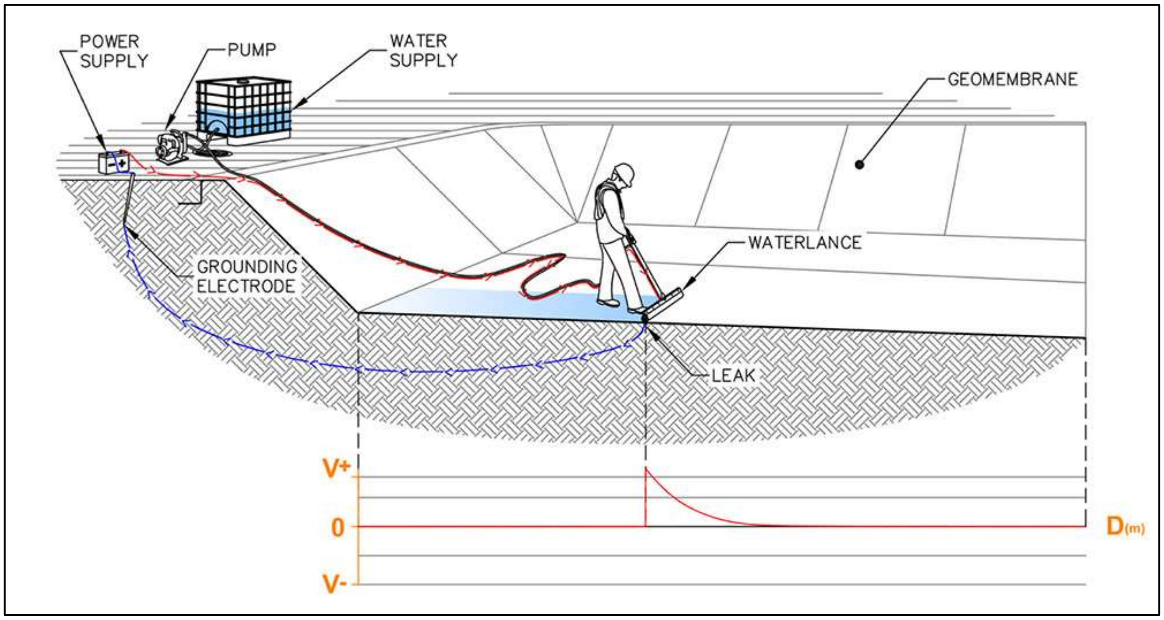

Figure 1. Water puddle method schematic.

2.2 Arc Test Method (ASTM D7953)

As with the WPM, the ATM (ASTM D7953) relies on the intrinsic insulation properties of geomembranes for the detection of small perforations (<1 mm²) in the geomembrane, generally produced at the time of the installation (see following figure). A high voltage is applied to the arc test wand and a grounding electrode is placed outside of the limits of the geomembrane. No conductive medium, such as water, is required when performing the survey. In the presence of a leak, the current will create a spark that originates from the wand, passes through the defect into the subgrade, and terminates at the grounding electrode. An auditory signal will then be produced. This method provides a validation of the entire exposed surface traversed during the survey. Since a spark acts as the contact between the wand and the subgrade, this technique is not limited by the degree of slope of the subgrade, as can be the case with a water-based leak location method.

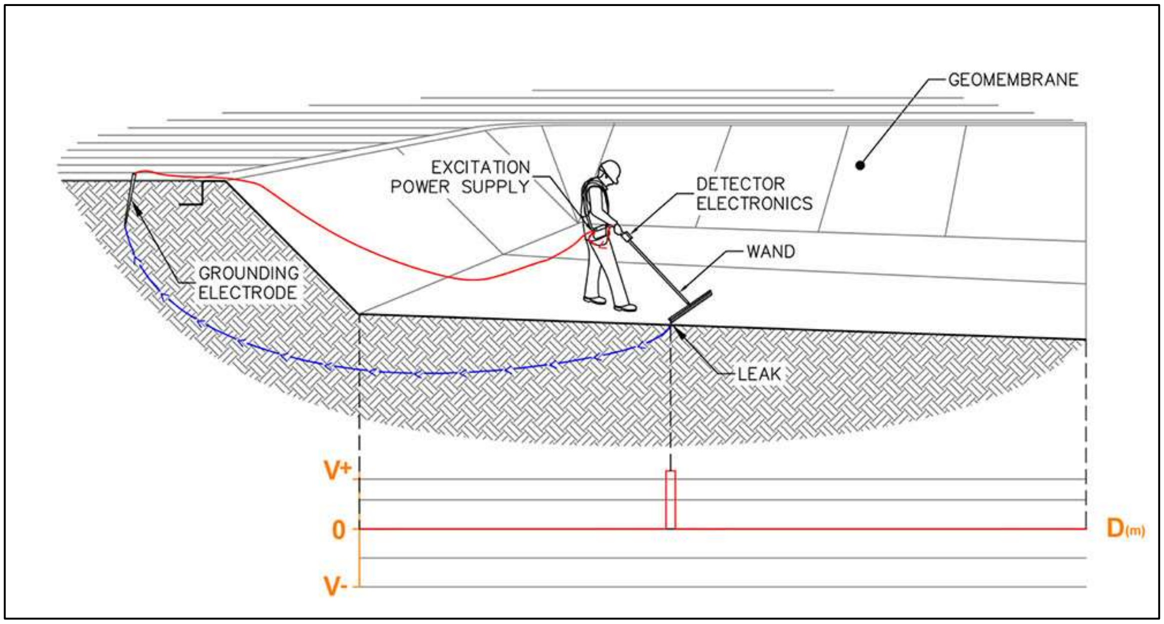

Figure 2. Arc Test method schematic.

3. METHOD ACCURACY IN REGARD TO DIFFERENT ASPECTS

3.1 Type of Geomembrane, Compatibility

The WPM can be used on any geomembrane that is not entirely conductive. This includes PVC, all types of polyethylene geomembrane, and bituminous liners. Ethylene Propylene Diene (EPDM), which is conductive throughout, is therefore not compatible.

While the ATM should work on all types of geomembranes beside EPDM, there have been instances where very large defect rates (~300 leaks/ha) have been reported on bituminous or PVC geomembranes. Because the voltage used is high (up to 35,000 V), if the geomembrane is at all porous (cracks or air bubbles) or is simply too thin, an arc can make its way through the liner and create a pinhole fault (reported by manufacturers).

3.2 Minimum Thickness for the Use of the Methods

There is no minimum thickness for the WPM, as it uses a very low voltage (typically below 50V DC). There is limited risk of the weight of the equipment causing tears in the liner, but any geomembrane layer sufficiently fragile to be damaged by the weight of the equipment is already insufficiently robust.

The real concern is with the ATM. Testing on 0.75mm thick PVC geomembrane produced unanticipated results. Sparks were crated by the broom apparatus whilst the lance was powered on, but after 10 minutes of contact with the same area of geomembrane these sparks had not caused any damage. To distinguish between these superficial sparks and the arc phenomena used to locate leaks, these sparks will be referred to as “surface arcs” whilst arcs passing through faults in the geomembrane material will be referred to as “direct arcs”.

It appears that surface arcs are only present on 0.75 mm thick PVC geomembrane, and they may be dependant on a highly conductive subgrade layer (e.g. a mixture of sand and salt with a high moisture content). When testing on thicker geomembranes, such as a 1.5 mm HDPE membrane, no surface arcs were visible even when the subgrade material was highly conductive. Strangely, it appears that faults in the geomembrane do not allow a direct arc to pass when surface arcs are visible. When surface arcs appear, the technician can lift the broom a few millimetres away from the geomembrane, causing the surface arcs to disappear and, if a leak is present, for direct arcs to be generated as expected. The fact that the direct art is only generated when the broom is held a few millimetres above the liner, or if the tip of the broom is in direct contact with the fault, show that some element of the process is not working as expected with these parameters. This may be because a portion of the voltage is passing through the geomembrane through a magnetic field or some similar phenomena, lowering the arc tester’s working voltage enough that the production of direct arcs is impossible. More testing is currently being performed to better understand the minimal thickness of geomembranes for ATM testing.

3.3 Wrinkles

With the exception of bituminous geomembranes, wrinkles form in geomembrane materials when exposed to heat or direct sun. Generally speaking, direct contact with the subgrade—the conductive medium—is required for most leak location methods. The equipment used for the WPM is usually heavier and studier than the equipment used for either of the high voltage methods; its weight alone can flatten small wrinkles to ensure the necessary contact with the conductive subgrade. This is not possible with ATM equipment, as it is less robust and charged with up to 35,000 V.

Not much can be done to mitigate the effect of wrinkles with the ATM aside from performing the survey early in the morning or at night when temperatures are cooler, as stated by Beck (2015): *"(…) an electrical arc will not form if the arc tester probe is too far away from the subgrade, as would be the case over a wrinkle. For both methods, effort is made to push down the wrinkles, or the survey is performed at night."* If a survey must be performed on a wrinkled geomembrane, the only option is to ensure that the broom is held as low as possible over the geomembrane to maintain proximity to the subgrade. A technique that "surfs" over wrinkles is however acceptable for the Spark Test method, since the conductive medium in question is the geomembrane layer itself, which can therefore generate the spark required for leak location.

3.4 Presence of Dirt or Water on the Geomembrane

Whilst a clean and dry geomembrane is preferable when performing a WPM survey, it is a necessity for the ATM survey. As a spark can only be generated on a dry surface, leaks remaining beneath a puddle during the survey will not produce an electrical arc and will not be detected, giving the operator the false impression that the geomembrane layer is leak-free. With the WPM a leak hidden in a puddle can be detected, but the exact location of the leak must be confirmed visually, or during a second survey once the surface has dried. In either case, the area must be dry for repair works to be completed.

Dirt (sand, dust, etc.) present on the liner might trigger alarms or false positives with the ATM, as the electrical current discharges on the surface in the dirt. With the WPM however, the alarm will only sound if a hole is present. In all cases, it may be necessary to clear the membrane in order determine the exact position of the leak and to allow the installer crew to complete repairs.

Laboratory tests were conducted HDPE geomembrane samples punched with 1 mm holes. Firstly, the bare geomembrane was tested using both methods in ideal conditions and both worked as intended. The ATM was then used to test liners with dry sand (this test is impossible for the WPM as it inherently dampens the test surface). Finally, both methods were used to test liners covered with wet sand and then with a full puddle of water. Results were straightforward for the WPM, with the leak signal being detected in each test as soon as the electrical path from the equipment to the fault was completed.

The voltages used for the ATM testing ranged from 800 – 34,000 V, increasing in increments between 500 – 5,000 V. All tests conducted at 5,000 V or less produced negative results, implying that the minimum voltage required for a direct arc is likely greater than 5,000 V. The rest of the data collected for the ATM was inconclusive. Sometimes a leak signal was heard when approaching a puddle, but the alarm did not sound when entering the puddle. At other times the alarm did sound when entering the puddle, and sometimes no leak signal was produced at all. Whilst the WPM produced a clear signal in every test situation, the ATM provided various false positives and random signals on dry sand, wet sand and water.

3.5 Slopes

On slopes with a gradient greater than 3:1, water tends to flow down the geomembrane rather than through any faults. As such, the ATM is the preferred method for steep slopes. The laboratory tests conducted on an inclined bench apparatus showed that the efficiency of the WPM greatly depended on the speed of the survey and the size of the hole. Decreasing the survey speed on slopes with WPM is therefore recommended to improve the chances of successfully finding small leaks. On a vertical wall, as would be the case in tanks or damns, the ATM would be ideal, given the reduced effectiveness of the WMP, the lightweight ATM equipment, and the fact that there would be no sand or water deposits on the vertical geomembrane.

3.6 Minimal Electrical Conductivity of the Subgrade, Freezing Conditions

Both WPM and ATM rely on the conductivity of the subgrade in order to create an electrical circuit through faults in the geomembrane. This means that a double-lined pond equipped with a geogrid or geocomposite (geogrid heat-bonded to one or two geotextile(s)) is not compatible with exposed ELL methods. There are products on the market that add an electrically conductive layer for leak location purposes, including conductive geotextiles and conductive geomembranes. If a double-lined pond is already built and ELL is required, the only way to get a conductive path underneath the top geomembrane is to flood the layer between the two geomembranes, but this can pose risks to the pond. The geomembrane can float on the water at the lowest point, causing deformations and stress on extrusion seams. It may also be difficult to perform WPM surveys on a geomembrane layer resting on water layer, as the weight of the operator on the geomembrane creates a low point in the geomembrane causing survey water to accumulate in the surrounding area.

At temperatures drop below zero, the water in the subgrade freezes and becomes non-conductive, rendering traditional ATM and WPM surveys ineffective. However, if an alternative conductive medium is in place, such as a conductive geomembrane or conductive geotextile underneath the liner, then any leak location method can used in sub-zero environments. Of course, performing a WPM survey in freezing conditions engenders many challenges since water is used. The hoses must have a constant flow of water through them in order to prevent them from freezing, extra care must be taken when walking on geomembrane materials covered with a thin layer of ice, and the hoses and the equipment must be drained completely at the end of the day or prior to taking a break.

4. ADDITIONNAL CONSIDERATIONS

4.1 The Use of Water During Construction

When performing leak location surveys in dry regions, the limited water supply can pose problems for the WPM, potentially increasing survey costs or delaying the completion of the survey. Another factor to consider that most ponds and impermeable systems have built-in surface water management systems. This means that water collected by the system is considered clean rainwater and can be safely released directly into the environment, including water used during the Water Puddle survey. However it is sometimes impossible to isolate the pond, cell or confinement system, particularly in landfill extension projects, and all water used during the WPM must be passed through the sites leachate collection system. In this case, the water used during the WPM (around 2 cubic meters per day) must be treated, and treatment costs should be considered in the costing of the leak location survey.

A positive feature of the additional water on the geomembrane surface is that it makes it easy to visually check that 100% of the surface was tested and that no areas were forgotten or skipping. The ATM does not leave any identifying marks on the liner during the survey and the operator is responsible for ensuring that all areas of the site are included in the survey.

4.2 WPM Analogue Sensitivity

It was mentioned above that the WPM is a binary method with an ON/OFF detection system – there is either a fault or not. This is true in ideal conditions, when the geomembrane surface and the area of the fault are dry and there is no background noise to disturb the signal. In such conditions the detector can be set at its maximum sensitivity, reaching maximum signal of the audio alarm as soon as the leak areas is dampened. However, conditions are rarely optimal, with water and residue often being found on the geomembrane surface. In such cases, the sensitivity can be reduced to pick up variable tones or buzzer frequencies as the operator approaches a leak. This kind of flexibility is not possible with the ATM, because there is no real variability in the size of the sparks. In the case of the WPM, the signal is the amount of current drawn by the site, through leaks or other connexions to subgrade. It is still a lot easier and faster not having to concentrate on the tiny variations on the audio signal and just run the device in maximal sensitivity.

4.3 Health and Safety Hazards

Of the two methods the ATM poses the most significant electrical hazard, using up to 35,000 V compared to the relatively low voltage used by the WPM. There have been no recorded incidents of accidents with the ATM, but as the equipment is available to be bought on the retail market and used without training caution should be taken.

The biggest risk factor for the WPM is muscular injuries, as the method can be physically demanding for the operator. The lance is generally heavier than the equipment used in the ATM, and some models are fitted with a sponge roller that is also heavy when saturated. A hose must also be pulled during the survey. To relieve the operator of the physical load of WPM survey, an additional technician can be hired, or a smaller hose diameter can be used (as long as water flow remains adequate for the completion of the survey). Slips and falls on slopes also pose a larger risk with the WPM than the ATM due to the additional water on the geomembrane surface.

Where ELL surveys are required in the oil & gas industry, the use of electrical tools is strictly controlled to prevent the creation of sparks in flammable environments. Clearly the ATM is inappropriate for use in such environments, and only the WPM can be safely operated without any spark risk.

5. CONCLUSION

As stated in ASTM standard D6747, "Each method has specific site and labor requirements, survey speeds, advantages, limitations, and cost factors. A professional specializing in the electrical leak location methods can provide advice on the advantages and disadvantages of each method for a specific project". Given the variety of factors to take into consideration when planning an ELL, the company providing the services should possess the expertise required to select the method that is best suited to the job in question. The goal is always to provide a service that ensures a worksite is as free from leaks as possible when the survey is completed. The following list provides an overview of various job types and their respective ELL methods:

- Mostly slopes, or slopes steeper than 3:1 → ATM for effectiveness;
- Wet or dirty geomembrane → WPM;
- Double-lined systems with flooded secondary drainage systems → ATM because of water managing;
- Large surfaces → WPM for survey speed;
- Chemical sites with potential release of explosive gas → WPM;
- Temperatures below freezing → ATM;
- All remaining conditions → WPM, or whichever the ELL company is most comfortable with.

The planning of these various factors can be challenging, especially when the client is not familiar with ELL methods. For engineers, it is important to consult ELL specialists before producing final sites designs because adjustments can be required to facilitate the ELL survey that will create costs and delays that can be avoided in most cases. It is also imperative to seek an experienced company because it is very easy to miss leaks, and sometimes very complicated to optimize site conditions and tweak instruments to be able to find smaller defects. Even if a dipole survey is planned after the installation of a protective layer, repairs will inevitably be much cheaper when the geomembrane is still exposed.

REFERENCES

ASTM D 7007. Electrical Methods for Locating Leaks in Geomembranes Covered with Water or Earth Materials, *American Society for Testing and Materials*, West Conshohocken, Pennsylvania, USA.

ASTM D 6747. Standard Guide for Selection of Techniques for Electrical Leak Location of Leaks in Geomembranes, *American Society for Testing and Materials*, West Conshohocken, Pennsylvania, USA.

Beck. A. (2016). Best Practices for Groundwater Protection, *GeoAmericas 2016*.

Beck, A. (2015). Available Technologies to Approach Zero Leaks, *Geosynthetics 2015 Conference Proceedings*, Portland, Oregon, February 15-18, 2015.

Beck. A. (2014). Designing to minimize geomembrane leakage, *Geosynthetics Magazine*, August/September Issue.

Darilek, G.T. and Laine, D.L. (1999), *Performance-based specification of electrical leak location surveys for geomembrane liners*, Geosynthetics '99, Boston, Massachussetts, USA, April 1999, pp. 645-650.

Darilek, G.T. and Laine, D.L., (2010). Leak Location Surveys, The Past, The Present, The potential, *GSI Annual Meeting 2010.*

Forget, B. et al., (2005). *Lessons Learned from 10 Years of Leak Detection Surveys on Geomembranes*, Sardinia Symposium, Sardinia, Italy.

Thiel, R., Beck, A. & Smith, M.E. (2005). *The Value of Geoelectric Leak Detection Services for the Mining Industry*, Geofrontiers, ASCE, Waste Containment and Remediation. pp. 1-6.

Touze Foltz. N. (2002). *Méthodes de détection et de localisation de défauts dans les géomembranes*. Ingénieries, E A T, 2002, pp. 17-25.