# New Standard Practice for Electrical Leak Location of Covered Geomembranes

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ABSTRACT
It has been over fifteen years since the publication of the first version of ASTM D7007 for the standard practice for locating leaks in installed geomembranes covered with liquid and/or earthen material. Since then, the standard remains largely unchanged and is now outdated with the advancement of the practices and the development of new technologies. Some of the issues with ASTM D7007 include: (i) it provides little information on how to properly prepare a site for a dipole survey, despite being the key aspect for a successful survey. (ii) The procedures to determine measurement density do not fully incorporate the procedures needed to effectively locate a real hole in the liner. (iii) The procedures are ineffective in controlling the survey extent and precision of measurement locations. (iv) Finally, only general survey parameters are required to be presented in the dipole survey report and providing survey data is optional and it may be with raw data files. Accordingly, a new standard practice, ASTM D8265, incorporating new technologies, such as GPS-based data acquisition and voltage mapping, and improved methodologies was approved by the ASTM committee D35 in June 2019. The ASTM D8265 updates the practices in ASTM D7007 to the state-of-the-art methodologies that have significantly improved the effectiveness of dipole surveys, making them more precise, accurate and transparent. This paper details the new standard practice ASTM D8265 and how it differs from ASTM D7007. Case studies are presented, showing how the new practice improves the effectiveness and the documentation of the method.

RESUMO
A primeira publicacao da ASTM D7007 ocorreu ha 15 anos para a normatizacao de praticas de localizacao de furos em geomembranas instaladas cobertas com liquido e/ou solos. Desde entao, esta norma permaneceu praticamente inalterada e atualmente esta desatualizada com os avancos das praticas e o desenvolvimento de novas tecnologias. Alguns dos problemas com a ASTM D7007 incluem: (i) fornece pouca informacao sobre como preparar de forma correta um local para inspecao dipolo, apesar disto ser uma aspecto fundamental para o sucesso da inspecao. (ii) Os procedimentos para determinar a densidade de leituras nao incorporam completamente os procedimentos necessarios para efetivamente localizar um furo real na geomembrana. (iii) Os procedimentos sao inefetivos em controlar a extensao da inspecao e a precisao de localizacao de medicoes. (iv) Finalmente, apenas parametros genericos de inspecao necessarios a serem apresentados no relatorio de inspecao dipolo e o fornecimento de dados eh opcional e pode ser com arquivos de dados nao tratados. Desta forma, uma nova norma, ASTM D8265, incorporando novas tecnologias como aquisicao de dados baseada em GPS e mapa de voltagem, e melhorias metodologicas foi aprovada no comite da ASTM D35 em Junho de 2019. A ASTM D8265 atualiza as praticas na ASTM D7007 para metodologias do estado-da-arte que melhoram significativamente a efetividade de inspecoes dipolo, tornando-as mais precisas e transparentes. Este artigo detalha a nova norma ASTM D8265 e como ela difere da ASTM D7007. Estudos de caso sao apresentados, mostrando como a nova pratica aumenta a efetividade e a documentacao do metodo.

## 1. INTRODUCTION

### 1.1 Importance of Covered Geomembrane Surveys

Installed geomembranes are critical for the protection of water resources. Studies show that the most significant damage to the geomembrane occurs during cover material placement (Nosko et al. 2015). It is therefore critical that an electrical leak location (ELL) survey be performed after placement of the cover materials. Moreover, it is equally critical that the survey is performed properly and that oversight of survey results is possible. The lack of adequate transparency in the covered geomembrane ELL methods set forth by ASTM D7007 has spurred the creation of a completely new standard practice. Rather than revamp the old method, the insight gained to date on the methods has led to a new approach to the testing methodology.

Research and case studies show that even very small holes can cause large problems with excessive leakage through the geomembrane (Beck 2014, Rowe 1998). Small holes are sometimes difficult to detect with the bare geomembrane methods and holes located on wrinkles may not be detectable (Gilson-Beck 2019). It is therefore advantageous to induce hydraulic head across a geomembrane during the leak detection testing, necessitating a test that can be performed while the geomembrane is covered.

## 1.2 ASTM D7007 Background

The ASTM D7007 requires demonstration of the method's effectiveness using a real or an artificial leak to calculate the signal to noise ratio. This ratio is found by comparing the oscillation in the voltage field when a real or artificial leak is present to when it is not present. The leak signal must be at least three times greater than the voltage oscillations when it is not present. The measurements are taken at some offset to the leak. The offset used determines the allowable measurement density and a measurement density of up to 3.05 meters by 3.05 meters is allowed. If a signal to ratio of 3:1 cannot be achieved, then ASTM D7007 mandates that the testing proceed at a measurement density of one meter by one meter. This means that if a survey is not working at all due to poor site conditions, then the method is applied regardless. If the sensitivity is compromised by isolation issues, no leaks will be found even if leaks are present and the method application will be deemed "successful". Even worse, the survey will take longer than anticipated, so if a smaller measurement density was anticipated during the bidding process, the survey could cost many times more to perform even though it is completely ineffective.

One site known to the Authors had good survey area isolation, but a 3:1 signal to noise ratio could only be achieved if a 1.5 meter by 1.5 meter grid was used. The survey proceeded and the survey rate was four times longer than anticipated (project was budgeted as a 3 meter by 3 meter measurement density). A large hole was found nearly exactly half way through the survey. This hole was excavated and isolated, and then a 3:1 signal to noise ratio could be achieved at a 3 meter by 3 meter spacing. The remaining half of the survey was completed at a 3 meter by 3 meter measurement density with a much better sensitivity. If a 3 meter by 3 meter spacing had been used initially, the entire first half of the survey area could have been resurveyed with the improved sensitivity once the hole was isolated for less time that it had taken to survey it with the 1.5 m by 1.5 m spacing.

Besides the limitation of the signal to noise ratio in ASTM D7007 as the procedure to demonstrate method effectiveness and surveying grid, this standard does not addresses the importance of clear, reliable location data attached to each voltage reading during surveys. It only requires a general description of the location of detected leaks but not of all voltage data points taken. Accordingly, it is common practice in the industry to have data collection performed along string lines.

String lines can be moved along with the survey, or installed at the beginning of the survey as permanent markers. String lines are time-consuming to install and difficult to place on some sites due to wind and equally difficult to keep in place. Unless measuring tapes are used as string lines, the distance traveled along the string line is referenced by data point numbers. If an extra data point is taken by mistake, or a data point is mistakenly not taken due to technological or operator error, this will cause error in the data point locations. Data taken with string lines are therefore fraught with logistical and human error, which causes the spatial references to be unreliable. Because spatial references are unreliable, emphasis must be placed on the experience of the data collector. If leaks are not noticed during the survey, but only afterwards during senior review, it is difficult to return to the precise location where the data was taken, especially if the leak signal is subtle.

Reporting requirements for ASTM D7007 include the results of the signal to noise ratio calculation(s), descriptions along with locations of any leaks detected, and the recorded data in ASCII format if requested by the client. However, data in ASCII format only makes sense to the operator, leaving the client, the actual owner of the data with no means to independently review and understand the results. This lack of transparency on the spatial distribution of all collected data may undermine client's confidence on the dipole method and weaken the whole market.

## 1.3 Development of ASTM D8265

The idea for the new ASTM 8265 emerged from a request to the Author for a standard practice that could document a zero leak condition for installed geomembranes. Due to the uncertainties, limitations, and lack of adequate documentation in all of the existing ELL standard practices, a completely new approach had to be taken. This section details the critical lessons learned and technologies developed that instructed the standard.

### 1.3.1 Electrical Mapping

The GPS-based mapping technology was the solution to two dire needs that ASTM D7007 lacked; spatial accuracy and survey speed. In addressing these two problems, the GPS-based mapping inadvertently addressed problems with ASTM D7007 that practitioners of the methods were not even aware of yet. An example of a GPS-based electrical map created using the dipole method is shown in Figure 1.

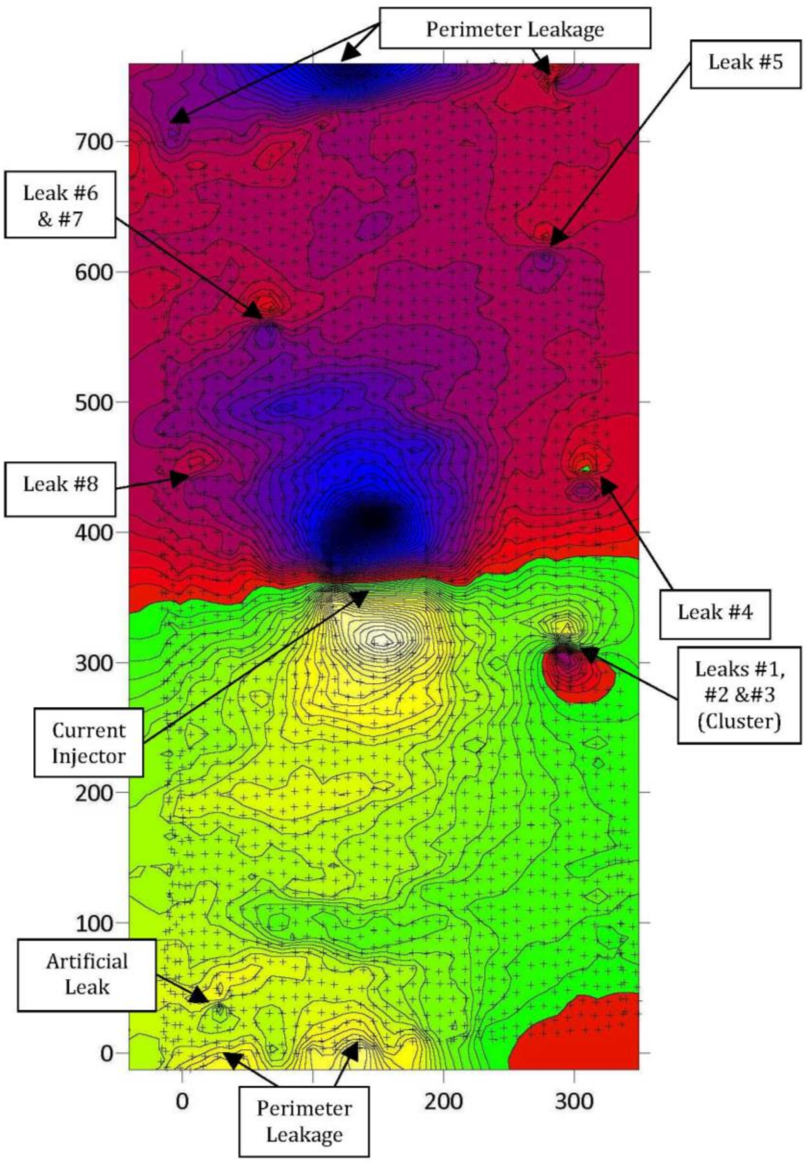



Figure 1. Electrical map created using the dipole method.

Regarding the necessity for speed, many sites are so battled by weather phenomena or pressed by construction schedule that if the ELL survey cannot be performed quickly, it cannot be practically performed at all. The GPS-based data recording system was designed to facilitate survey speed by first removing the need for string lines. A local coordinate system is created by the user by defining two points in the survey area, along the direction of travel line for the survey. The operator need only follow along the same value of the X-Axis to walk in a straight line. This removes the need to physically place a string line, which is time consuming. Additionally, the operator can make sure that every data point maintains accuracy along the X-axis. Without spatial accuracy, data collected along adjacent lines can be transposed, creating nonsensical patterns in the data. Data is taken quickly without review, except to make sure that the dipole probes make good contact with the surface of the survey area. In this manner, depending on how good the contact is between the dipole probe and the cover material, and how good the site support is for watering the surface when necessary; data acquisition can be performed on 4,000 $m^2$ of surface area in 1-2 hours using a three meter by three meter double dipole.

Because the mapping technology provided a rapid way to collect data, with senior review occurring after all of the data were taken, the reviewer was able to see all of the locations of current draw at once. If the location of highest current draw is pinpointed and excavated first, all subsequent locations of current draw will become stronger. The tiniest anomaly caused by a pinhole could be nearly as visible as dozer damage if all other leaks in the circuit are removed by the time the anomaly caused by a pinhole is investigated.

It is impossible to hide faulty and/or poor quality data with an electrical map. In one glance, everything occurring electrically in the survey area is visible (Figure 1). Most importantly, the electrical mapping provides an additional level of detection sensitivity by viewing the electrical anomalies in plan view rather than as a graphical plot. Patterns created in the voltage field by a leak may not have a large enough magnitude to be noticeable in a graphical plot, but the pattern remains discernible on an electrical map (Figure 1).

The colors on the map represent voltage values recorded during the application of the dipole method and make it easy to recognize a shift from positive to negative values. Negative values are represented by red changing to blue with increasing magnitude. Positive values are represented by green changing to yellow with increasing magnitude. The negative/positive polarity of the entire survey area is created by the current injector electrode. The characteristic leak signal voltage pattern is opposite to that of the current injector electrode, since current is exiting the survey area at current leakage locations and entering the survey area at the current injector location. Data acquisition locations are shown by tick marks so areas of missed data are visible.

Anomalies indicative of leak locations on this map feature a positive circular peak on top of a negative circular peak, separated by closely spaced contour lines, similar to the shape of a butterfly on its side. This particular site had some isolation issues in addition to multiple holes. The smallest leak signal, Leak #8, was a knife slice that was so small that it was not visibly discernible when the cover material was removed. For this project, Leaks 1,2 and 3 were excavated first. Then, Leak 4 was excavated, and so forth. The smallest anomaly, which resulted in Leak 8, may have been difficult to pinpoint if the other leaks had been left in the survey circuit.

### 1.3.2 Current Draw Quantification

The equipment designed and fabricated expressly for dipole method surveying provides a current output screen so that it can be observed as voltage is applied to the survey area. This is one means of ensuring that the wires connected to the survey area are not broken. As long as the current is able to travel from the current injector to the return, some current will be measured. One site located in Northern CA, USA during the dry season had no measurable current draw. When the dipole approached the current injector, no voltage field was observed by dipole measurements. All connections were checked and rechecked, but nothing changed. The artificial leak was then connected. Suddenly, a current draw was reported and the dipole was able to measure the electrical field when approaching the current injector. Leak detection sensitivity of the artificial leak was unprecedented. This was the first truly electrically isolated site with no leaks present in the installed geomembrane that the Author had experienced. This is a rare phenomenon because perfect survey area isolation is difficult to achieve on containment facility construction sites and nearly impossible to achieve in areas with rainfall. When the current has nowhere to travel except the artificial leak, the signal from that leak can be nearly as large as the current injector itself. This site instructed the importance of the current draw measurement as an indicator of installed geomembrane integrity.

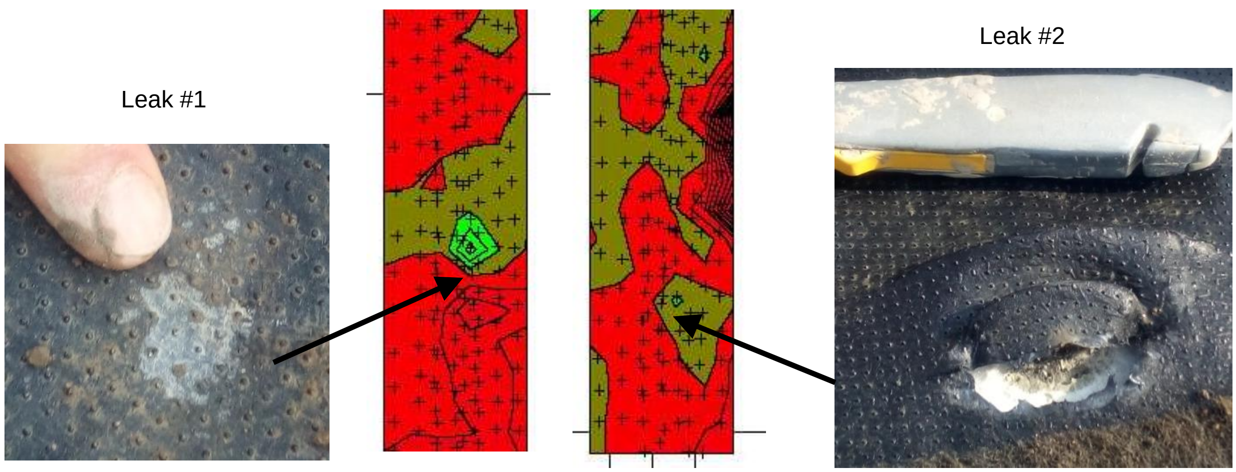
Another important point about current draw pertains to safety. Regardless of applied voltage, it is a specific range of current that is considered dangerous for the human body. For direct current (DC), the range is 300-500 mA that can stop the human heart. Higher currents can cause burns. It is therefore important from a safety perspective to limit the applied current to less than 300 mA.

Nearly every site with poor leak detection sensitivity exhibits a relatively high current draw with a relatively low applied voltage. Typically, an applied voltage of 350 VDC of a soil-covered survey area results in a current draw of less than 100 mA, even with a few significant holes or isolation issues. One site known to the Authors reached a current level of 250 mA with an applied voltage of only 40 VDC and was stopped from getting any higher from a current limiter installed for safety. The artificial leak could not be detected even when the dipole was right on top of it. A survey of the entire area did not reveal any discrete hole locations. When site personnel started removing cover material in random locations, holes were found. The geomembrane was riddled with holes caused by a soil disker throughout the survey area and the geomembrane was not salvageable.

The relationship of applied voltage and site response current is therefore an extremely important indicator of geomembrane integrity and/or site isolation (Gilson, 2019). The Author's experience shows that if the connection of the artificial leak causes a significant increase in current draw, it will correspond with high leak detection sensitivity.

1.3.3 Leak Size

It is one misconception created by ASTM D7007 that the real or artificial leak size is of great importance. This leads to the erroneous conclusion that if you can demonstrate the detection of an artificial leak of a given size somewhere, that holes anywhere of that diameter or greater are guaranteed to be found. In fact, leak size is irrelevant; what matters is the leak contact. Figure 2 shows two different portions of electrical mapping performed at the same site. Leak signal #1 was generated by a pinhole that was barely visible with the naked eye (Figure 2a) but easily identifiable in the voltage map (Figure 2b). Leak #1 was in a wet area of the containment facility. On the other hand, Leak signal #2 was generated by an approximately 15 cm rip that even damaged the underlying geosynthetic clay liner (Figure 2d) but hardly identifiable in the voltage map (Figure 2c). Leak #2 was in a drier area of the site as opposed to Leak #1. This case demonstrates the misconception of ASTM D7007 that Leak #2 should have significantly larger signal than Leak #1. This occurred because the lower water content of the materials above and below the geomembrane at the location of Leak #2 had significantly lower electric conductivity and worse contact with the liner than the wetter materials at the location of Leak #1.




| (a) | (b) | (c) | (d) |
|---|---|---|---|
| Leak #1, barely visible to the naked eye, located in a wetter area | Leak #1 signal in voltage map | Leak #2 signal in voltage map | Leak #2, 15 cm rip exposing underlying GCL, also damaged, located in a drier area |

Figure 2. Mapping portions of same survey area with two different leak sizes.

To further document this phenomenon, two different artificial leak sizes, with diameters of 6.4 mm and 3.2mm respectively, were installed at the same site, with the same contact condition. The current draw for each size leak was documented. The current draw for the 6.4 mm artificial leak was 20 mA. The current draw for a 3.2 mm diameter leak was 17 mA. There was hardly any difference in detectability between the two leaks sizes, in spite of the fact that one was twice the diameter of the other.

The practice of using an artificial leak should therefore remove focus from the leak size and recognize it as a simple functionality test to ensure that the survey circuit is functioning properly. With a properly functioning electrical circuit, each existing leak will have a unique pattern depending on the contact it provides between the cover material and the underlying layer and the electrical conductivity of each layer. The wetter the cover and underlying layers, the higher is the electric conductivity.

1.3.4 Multiple Surveys

A small test pad (~20m x ~20m) was constructed in order to assess the effectiveness of a dipole method survey on various thicknesses of cover material. Test holes were placed in the liner in locations unknown to the dipole method practitioner. The method detected five leak locations, which were each pinpointed, excavated and isolated from the cover material. Since the survey area was small, the entire test pad was completely resurveyed rather than only checking 5 m around each hole (as prescribed by ASTM D7007). In one location not adjacent to any other hole but in the thicker area of the test pad, a large leak signal was detected, isolated, and excavated. A much smaller hole than the five previously located was uncovered. A review of the data from the initial survey showed absolutely no leak signal where the sixth hole was located. This rare opportunity to perform multiple surveys when the first survey contained significant leaks revealed that holes can masque other, smaller (or drier) holes not only in their immediate vicinity, but anywhere in the survey area.

#### 1.3.5 Site Preparation

The largest lesson learned over the years is that site conditions are the important factor in leak detection sensitivity. This is why the focus of applying the methods to be maximally effective must start with how to prepare the site to optimize testing conditions. The two largest factors in site conditions are isolation of the cover material in the survey area and adequate moisture in both the cover material and the leaks themselves.

It is sometime practically impossible to achieve perfect site conditions. To address this, any site feature that compromises ideal preparation should be documented. This way, if there are issues with the testing results, the potential cause can be determined from the testing documentation. Additionally, compromised site preparation can explain site response current measurements.

## 2. CASE STUDY – ASTM D8265 APPLIED

For the years leading up to the publication of ASTM D8275, the Authors informally practiced the proposed new standard practice. This case study provides a glimpse into the results of this new approach.

### 2.1 Initial Survey Results

A dipole method survey was performed in accordance with the requirements detailed by ASTM D8265. Figure 3 shows the electrical mapping of the survey area (Figure 3b) and the mapping of the artificial leak (Figure 3a), which was left disconnected during the survey since the survey area was small. A large leak (~0.5m wide) was located during the survey (Figure 3c). The entire survey area was resurveyed, since the leak was very significant. It should be noted that the applied voltage and response current of the first survey were 125V and 116 mA, respectively. The applied voltage and response current of the second survey were 500V and 15 mA, respectively. Additionally, the artificial leak signal was much stronger during the second survey (Figure 4a), showing how the hole uncovered during the original survey was compromising leak detection sensitivity. From the results of the second survey (Figure 4b), which was able to detect a pinhole not visible to the naked eye, extreme confidence comes from the final electrical map and the associated site response current that no other leaks are present in the installed geomembrane. Figure 4c shows a leak detected during the second survey.

## 3. ASTM D8265

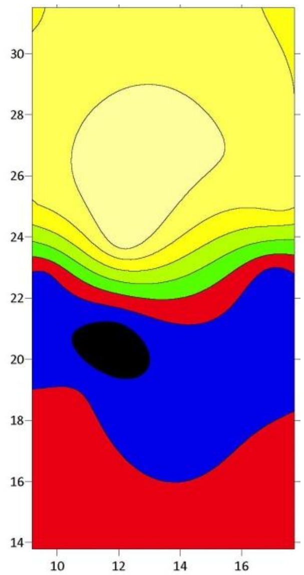
### 3.1 General Requirements

When using the dipole method with ASTM D8265, general method application will be similar to ASTM D7007.

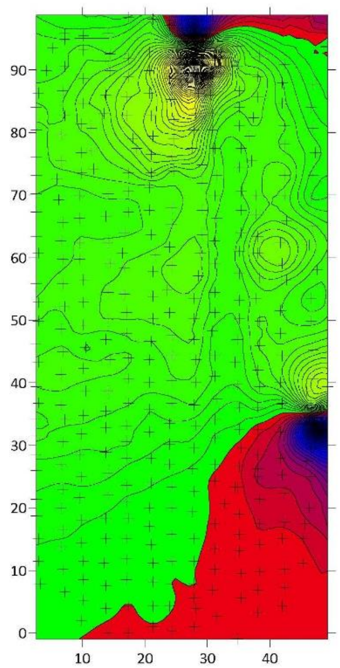
The survey area must be properly prepared for electrical methods with adequate isolation and sufficiently conductive materials. The material directly above the geomembrane should be saturated in order to ensure active leakage at the time of the survey. The conformance to the site preparation requirements shall be documented. An artificial leak conforming to the requirements of the artificial leak used for ASTM D7007 may be used. The condition directly above the geomembrane (degree of saturation by visual observation) must be documented along with the placement of the artificial leak. The measurement probes used for data collection shall not be electrically reactive with the material covering the geomembrane.

In order to assess the functionality of the method before beginning the survey, the artificial leak is installed. Three data acquisition locations are required, as shown in Figure 5.

If using the dipole method, voltage measurements shall be taken and recorded at the following positions: front foot directly over artificial leak, back foot directly over artificial leak, front foot directly over Measurement Point 1, and back foot directly over Measurement Point 2. This provides guidance for leak signal strength when reviewing the electrical map of the survey area. It also shows how detectable the artificial leak is, which will be the main indicator of method functionality.



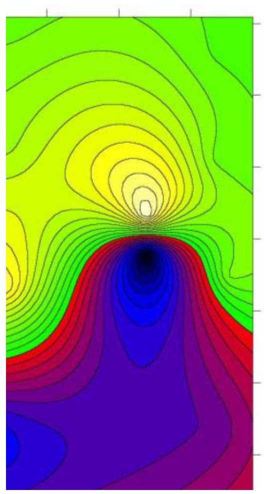

(a)
Mapping of artificial leak



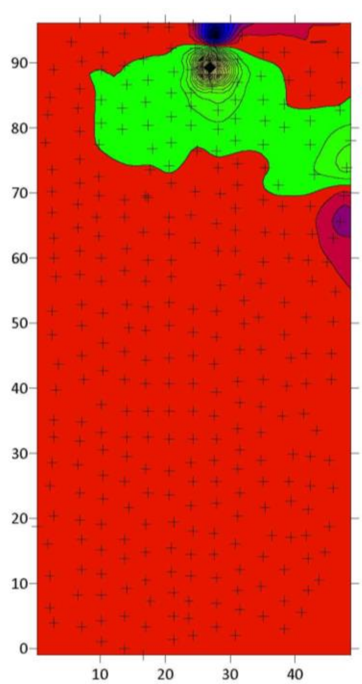

(b)
Survey area voltage map

(c)
0.5 m wide leak initially found

Figure 3. Initial site dipole survey voltage maps.



(a)
Mapping of artificial leak during second survey




(b)
Survey area voltage map of second survey

(c)
Leak found during second survey

Figure 4. Site dipole survey voltage maps of the second survey.

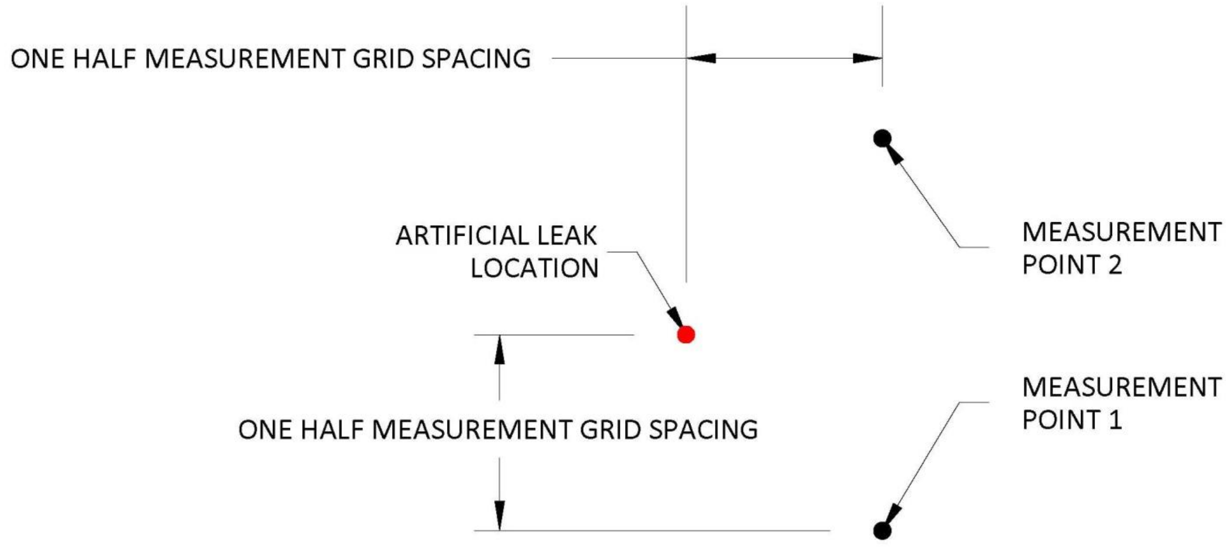



Figure 5. Artificial leak measurement locations.

A log of applied voltage and corresponding site response current shall be documented for the various survey area conditions.

An electrical map or maps shall be generated for the complete survey area(s) in a grid pattern fully encompassing the survey area(s). Measurement acquisition locations shall be displayed on the map(s). If the survey is conducted using dipole measurements, all edges of the survey area must be surveyed parallel to the edge in addition to the typical grid pattern, as necessary. Measurement acquisition locations shall be displayed on the map(s). Additional maps shall be generated depending on the influence of the artificial leak on site response current as detailed below.

3.2 Condition 1 – ASTM D8265 Section 7.3.6

If the artificial leak increases the site response current by less than or equal to 10%, then the artificial leak may remain connected during the survey. The artificial leak should be visible on the survey area electrical map and can be used to inform the contour interval used for mapping. In this case, two additional maps must be created: (i) a map comprising at least 9 m in all directions around the artificial leak location with the artificial leak unplugged; and (ii) a map comprising at least 9 m in all directions of the current injector location after it has been moved at least 15 m from the original position.

3.3 Condition 2 – ASTM D8265 Section 7.3.7

If the artificial leak increases the site response current by more than 10%, then the artificial leak may not remain connected during the survey. In this case, three additional maps must be created: (i) a map around the artificial leak location with the artificial leak connected; (ii) a map around the current injector while the artificial leak is connected; and (iii) a map comprising at least 9 m in all directions of the current injector location after it has been moved at least 15 m from the original position with the artificial leak disconnected.

3.4 Leak Location in Soil-Covered Survey Areas

Locations on the electrical map indicating current draw shall be catalogued in order of largest to smallest. Starting with the largest signal, the current draw locations shall be investigated, pinpointed when possible and excavated once pinpointed. All pinpointed signals indicative of current draw locations shall be documented. Any locations that were investigated but not confirmed to be leaks shall be documented. At each location where a leak has been isolated, the surrounding area shall be checked in the immediate vicinity.

3.5 Zero Leak Verification and Multiple Surveys

This standard acknowledges that multiple surveys may be necessary to locate all leaks in installed geomembranes, especially if significant leaks are located during the initial survey. This is determined by the initial survey results.

In the rare case that a survey area can be completely isolated from ground, the new standard can be used to provide evidence that no leaks exist in the installed geomembrane. As detailed in Section 1.3.2, when there are no isolation issues and no actual or artificial leaks present in the survey area, there is a barely measurable current draw with correspondingly extremely low (or no measurable) voltage changes when approaching the current injector. This is why Condition 2 in Section 3.3 above requires a map of the current injector both with and without the artificial leak. The current injector will be invisible or nearly invisible if there are truly no leaks in the survey area (provided that a sufficiently electrically insulative geomembrane is being tested).

If documentation of a zero-leak condition is desired but leaks are found during the survey, then the leaks shall be repaired and a second survey shall be performed.

3.6 Special Cases

This section details what is not specified by ASTM D8265, especially issues that might be surprising to practitioners of ASTM D7007. Some of these might be appropriate to specify in a project specification and some may not be. Each is discussed below.

3.6.1 Measurement Density

Some project specifications known to the Authors mandate a particular measurement density, however this mandate leaves out the factor of dipole spacing. A measurement grid of three meters by three meters is not the same when used in tandem with a one meter dipole as opposed to a three meter dipole. By increasing only the dipole spacing from one meter to three meters, leak signal strength is increased by approximately 75% (Lugli and Mahler 2016). Thus, with a larger dipole, a smaller measurement density may be used. Measurement density is also meaningless when a site has such poor site conditions that a leak cannot be detected even when the dipole is right on top of a leak. The required measurement density will be a function of dipole spacing as well as applied method, as appropriate. ASTM D8265 does not specify a measurement density, but the required documentation is so transparent that if a leak cannot be detected by the method used, including the specified measurement density, it will be apparent in the testing results, so it is left to the expertise of the practitioner. A layperson or engineer without extensive experience in the methods should never specify measurement density in a project specification.

3.6.2 Geophysical Method

ASTM D7007 is commonly called the “Dipole Method”. However, there are some more advanced geophysical methods being used, especially on ponds and permanent monitoring installations, that can be more effective than the dipole method, especially for filled ponds and deeply filled impoundments. These alternative methods are based on measurements of electrical response, but there are no standardized practices for them. ASTM D8265 is written loosely enough that any electrical method may be used. The demonstration of the effectiveness of whatever method is used is provided by the mapping of the artificial leak. The dipole method does not have to be used. However, it should be noted that for thin cover materials (up to three meters) or where the dipole can get close to the liner (water-covered), the dipole method has the best track record for effectiveness and precision. A partner specification to this standard practice could be the mandate of the dipole method, which will maximize its effectiveness as long as the impoundment is not deeply filled.

3.6.3 GPS-Based Data Recording

A local coordinate system based on string lines placed throughout the survey area can also be used to create the electrical map of the survey area. However, this system is extremely prone to human and spatial errors as discussed. A partner specification to this standard practice could be the GPS-based data acquisition requirement.

3.6.4 Artificial leak size

ASTM D8265 recognizes that leak signals are dependent on site and leak contact conditions and that the artificial leak is only used to verify functionality of the equipment and method used. A partner specification to this standard could be an artificial leak size of 6.4 mm, since that is what has commonly been used for soil-covered surveys per ASTM D7007. The specifying Engineer must keep in mind that artificial leaks are expensive and time consuming to fabricate and cannot be purchased off the shelf, so the specifying Engineer should not just make up an artificial leak size. Companies who typically perform this type of testing might only have a 6.4 mm artificial leak.

### 3.6.5 The Use of an Actual Leak

The use of an actual leak is not recommended by ASTM D8265. The ultimate goal of this standard practice is to eliminate all leaks from the installed geomembrane, so creating a hole would be counterproductive. Also, once created, an actual hole is sometimes impossible to remove it from the survey circuit (i.e. if conditions are wet). Experience has shown that even a relatively small hole can create enough current draw to masque the smallest of holes in a survey area.

## 4. DISCUSSION AND CONCLUSIONS

This paper addressed current issues with the ASTM D7007 - Standard Practices for Electrical Methods for Locating Leaks in Geomembranes Covered with Water or Earthen Materials. This standard was conceived over fifteen years ago and remains largely unchanged. Since the publication of ASTM D7007, a considerable amount of knowledge has been gained through experience by this industry. Procedures and equipment have significantly evolved during this time. The present paper explained how and why the current ASTM D7007 (i) provides little information on how to correctly prepare a site for dipole survey; (ii) does not establish procedures to locate a real hole in the geomembrane effectively in the procedure for establishing measurement density; (iii) does not provide control of the survey extent and precision of the location of the measurements; and (iv) does not enforce survey operator to provide data to client in a transparent, easy-to-understand format.

Additionally, this paper explained the procedures of the newly published ASTM D8265 and how it removes some of unimportant and unscientific requirements of ASTM D7007, while at the same time, establishing effective new procedures that significantly improve the methodology, adding transparency to the method and establishing the current state of the art in electrical leak location. The ASTM D8265 establishes a procedure focused on checking whether the method is functioning and site conditions are adequate using an artificial leak, rather than creating the misconception of minimum leak size detectability as per ASTM D7007 in its measurement density procedure. The ASTM D8265 also provides a procedure that uses current data readings to pre-diagnose whether the site liner has potentially a significant of insignificant number of leaks.

Additionally, the ASTM D8265 establishes a logical procedure in investigating potential leak signals by requiring the operator to indicate in the electrical map the current draw readings from largest to smallest. This new standard addresses a formal procedure for documenting a zero-leak condition based on site current draw response and formalizes when multiple surveys are necessary. Finally, this paper addresses issues no specified in the ASTM D8265 neither in ASTM D7007 but may occur during dipole surveys regarding measurement density, geophysical methods, GPS-based data recording, the use of artificial leaks and their sizes and the use of an actual leak instead of an artificial leak.

Any reviewer who understands the principles of ELL can perceive from the required reporting documents how well a survey worked and whether the results should be questioned.

### 4.1 REFERENCES

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