Study pertaining to leak simulations in electrical leak location dipole testing. A better understanding of dipole testing calibration using various plate sizes and shapes

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Abstract. According to standard ASTM D7007 for geoelectrical leak location (ELL) surveys on earth materials, a hole simulation or calibration must be performed before starting the actual survey. The standard also states that a 1/4 in diameter metal plate must be detectable based on specific signal strengths, if not, the survey cannot be considered completed by the ASTM standard and must be conducted on a 1 m x 1 m grid. Most ELL companies only perform the 1/4 inch test to see if the surveying speed will be fast or slow. The better the signal, the larger the grid, the faster the survey. Usually, leak location practitioners will then proceed to the leak location either way. The number of projects that fail the 1/4 inch test is quite important, so how do we push things further to ensure the best efficiency on site? What information is necessary to understand how the site responds to the test and what can we do to improve the quality of the survey? Here we will compare data gathered within 11 years with various calibration plate sizes and will explain the effects of field specific parameters, such as the simulation's position, moisture, thickness, cover material homogeneity, and the most important factor of all: peripherical electrical isolation.

1 Introduction

Most containment projects today use geosynthetics to offer efficient and sustainable solutions to a variety of complex challenges. They can be used for stability, puncture protection, drainage, erosion control, and water proofing, amongst many other areas. The reality is that leaks are part of the equation and can hardly be ignored, or else their flow through geomembranes can result in contamination of surrounding areas or loss of valuable liquid.

Electrical Leak Location has been used and upgraded for decades. Its main goal is to reduce the number of leaks on a liner during operations but has other important benefits such as pushing the different contractors to get their best personnel on site to make as few mistakes as possible, measuring the performance of said contractors whether leaks were found or not, and sometimes even helping contractors to enhance their work methods to prevent future defects, making them better.

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There are a few normalized methods used on an exposed geomembrane (water puddle, spark test, arc test), but this article focuses on leak location of covered geomembranes using the dipole method.

2 Dipole method

The principle behind the dipole method is to trap electricity into a natural material layer and take measurements on a specific grid to pinpoint where the electricity finds a way to cross the non-conductive geomembrane. To accomplish this, an electrical isolation needs to be prepared all around the site with a strip of exposed geomembrane or geotextile. The power source's negative output is simply grounded outside.

This way, electricity will spread in the natural material layer and try to find a defect through the geomembrane to cross it and reach the negative electrode outside. When this occurs, a typical signal is detectable in the leak's vicinity which indicates that a defect is probably in the area. It is then possible to shut the power source down, excavate the area to expose the defect, and have it repaired by the specialized installer. It is wise to re-survey the area after patching to make sure the leak signal was not hiding a weaker signal next to it.

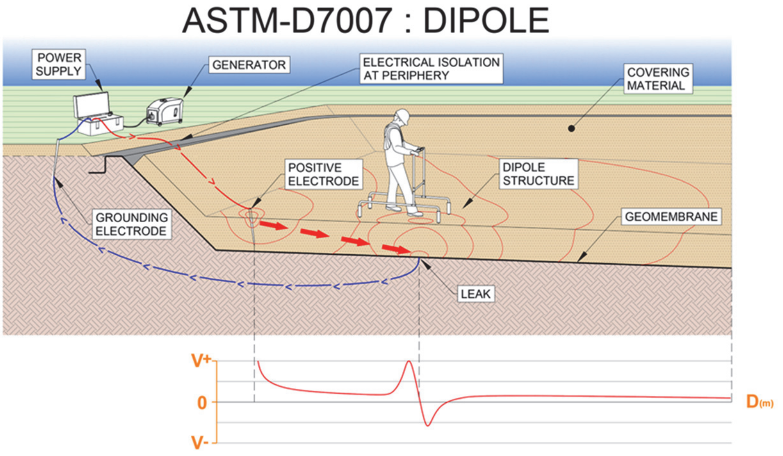

Fig. 1. Dipole Schematic.

3 Protocoles and standards

The dipole method was first commercially used in Texas in 1985 by the company LLSI (Charpentier *et al*., 2023). Shortly after, an ASTM standard was written to provide guidelines on how to perform the method efficiently, and make sure no inexperienced company would advertise leak location without the proper knowledge, equipment, and methodology. It is easy to pretend to survey and find no leaks!

Therefore, the ASTM D7007 standard reveals valuable information on how to set up the site, determine the grid size (or survey density), and measure a site's electrical response, also known as the dipole's precision.

The 3 crucial parameters that influence the quality of signals are:
- natural material layer thickness (typically 1 m-thick maximum);
- electrical isolation all around, including pipe penetrations and other metallic structures;
- homogeneity of natural materials, presence of rocks, waste, other scrap, or multiple layers of different materials, like 300 mm of gravel on top of 300 mm of sand.

Knowing all those factors is not enough to perform a dipole survey. It is very helpful to communicate them to engineers and contractors to increase chances of favorable conditions, but one does not simply go on site and proceed with the survey in hopes of finding a leak signal somewhere (AKA blind survey). A calibration is required at the beginning of every project to know what to expect on site, and if necessary, to request that the client adjusts on-site conditions if results are too bad.

4 How leak simulations work

As explained, a typical leak signal is generated when electrical current crosses the geomembrane to reach the ground. Ideally, a hole would be cut straight in the geomembrane and refilled with earth material to measure the strength of the signal generated by the leak. Of course, it is not recommended to damage the geomembrane, Studies show that grinding and re-welding weakens the installed HDPE geomembrane (Toepfer, 2015). It is also foolish to pay an installer to be mobilized to a site to repair a test-leak when no other defects were found.

In this regard, the ASTM standard proposes the use of an artificial leak, sometimes called “calibration plate”. This little device is a simple metallic plate fixed to a non-conductive frame connected to a copper wire. It can be plastic, PVC, or anything similar, with a small metal circle on top, no thicker than 25 mm. The leak simulation is placed in the excavation down to the geomembrane or geotextile, face up, and is then backfilled to the average thickness for the designed project. The copper wire is connected to another electrode placed outside of the site, therefore connected to the ground through natural materials in place. This copper wire is a shortcut for the electrical current, but the resistance it would normally face going from the leak to the ground electrode would be equivalent along the edges of the site.

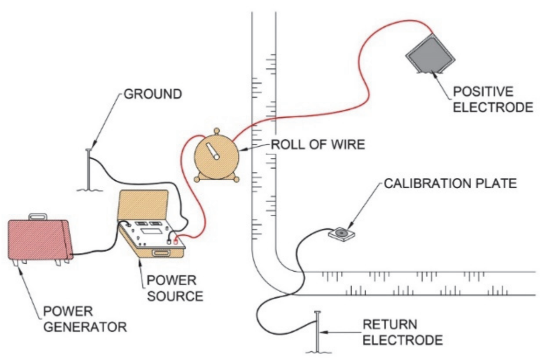

Fig. 2. Dipole setup.

It could be said that the distance between the artificial leak and the ground electrode does not necessarily need to be the same between the return electrode and the ground electrode. Electricity travelling through earth material does not work the same way as in circuits, therefore putting the return electrode closer to the ground would not enhance the signal and is sometimes simpler to install. Even though it can be said that any distance greater than 3 m will show the same electrical resistance as there would be between the calibration plate and the ground (ASTM D7007), it is preferred to respect that distance whenever possible to make sure the values measured are realistic.

5 Leak simulation results, measurement grids, best and worst-case scenarios

The sensitivity target with the dipole method, as explained in the standard, is a 6.4 mm diameter circle (1/4 in). If the leak locator can detect a leak that small, the method is considered functional on that specific site. It is easy to plug and unplug the calibration plate and see its effect on the "normal signal" in the area. The real question is **"Would this variation in the signal be strong enough that the leak locator would stop the survey and start excavating the area for visual confirmation of a defect?"**

When focusing on a value, the difference between a normal voltage and a leak signal would seem obvious, but in fact, values do vary a lot during a survey. Variations can happen when the soil has different moisture contents, when thickness varies, or when your dipole is sitting on a rock or somewhere less conductive. When surveying, almost any voltage variation could look like a small leak signal, and the result of the leak simulation really sets a variation tolerance and what can be considered background noise, etc.

The complete calibration starts with a series of aligned measurements over the unplugged leak simulation. It is important to record the lowest and highest voltage values measured on this series, called ΔV. Then, the same procedure needs to be carried out over the plugged leak simulation, and again to measure the leak signal's strength (between maximum positive value and maximum negative value if the signal crosses the ΔV). Based on ASTM, if the leak signal is at least 3x the ΔV, the leak is considered visible, and the dipole method is compatible with site-specific conditions.

There is a very important notion to realize before jumping to conclusions: the dipole is in fact 2 conductive tips connected to an electronic detector, at a fixed distance. The mobile equipment has a fixed size, and values measured will be maximal when a tip is right over the leak simulation, meaning taking a voltage measurement right before and immediately after the leak. In fact, it is not known where the leaks will be, and having one right under a tip would be considered the best-case scenario. What if the leak locator is misfortunate and a defect is halfway between both tips, and even worst, right between 2 measurement lines?

The worst-case scenario is then the most important of the two. It will tell you if the 6.4 mm diameter plate is generating enough of a signal to be visible from any relative position of the dipole. Here is a schematic of best-case and worst-case positions.

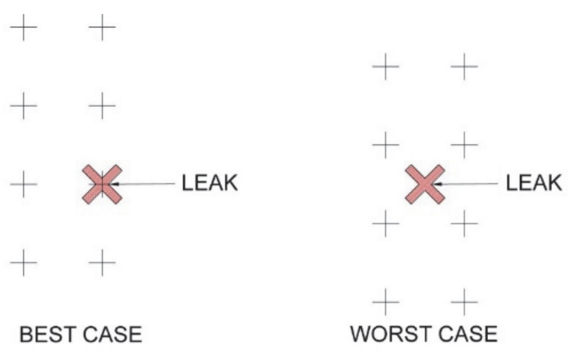

Fig. 3. Dipole position relative to a leak.

6 What happens when the leak simulation is not visible

What is the use of the best-case scenario? First, it is easier to set up the dipole when the signals are loud and clear which confirms everything is connected and working. Then, difficulties can arise when a simulation is not positioned properly or a positive electrode is placed further from the leak simulation, etc.

Sometimes, the leak simulation will generate more than 3x the background noise when tested for the best-case scenario but will not be strong enough for the worst-case scenario, or in other cases, both tests fail. Based on the ASTM standard, the only thing to do when the calibration fails is to do the best you can and use a 1 m grid and spacing. This solution may seem weak: what if a leak locator planned on carrying out a dipole survey on a 1 m grid? He would not even need to calibrate, just blindly survey the best he can…

7 Going the extra mile

After more than 20 years of experience, an improved methodology was put in place using multiple sizes of calibration plates, ranging from 6.4 mm to 30 cm x 30 cm. This way, the standard ¼ inch hole can be used following the standard guideline, but in case of a failed calibration, it is possible to switch simulation size and redo a series of measurements and check if the new leak size is detectable or not. The client can be informed of the exact sensitivity of the site in worst-case and best-case scenarios. For example, a dipole survey could find a 6.4 mm hole if fortunate, but only a 25 mm hole if unfortunate. This provides a sensitivity range for the project manager, who then can decide if he wants to enhance those values by putting more effort into electrical isolation, surface watering, and access ramp isolation, etc.

If effort is put into making a dipole survey more sensitive, it is quick and easy to redo a calibration on the already buried calibration plates to see if the signal strength changed, and to know what to expect from the site signal until the client is satisfied. If we follow the ASTM standard thoroughly, even if the designed project's sensitivity shows a minimal visible leak of 900 cm^2, if the grid is 1 m x 1 m, the project still follows the standard, and the methodology is accepted. On the other hand, if calibration fails and the survey grid is 2 m or 3 m long, the leak locator cannot report that ASTM guidelines were respected.

Calibration sizes are not absolute. Certain sites have very poor leak signals and smaller defects than the leak simulations can be found. Nevertheless, it is a good indication of signal quality in specific field conditions.

8 Conclusion

The dipole method is a geoelectrical tool used to detect anomalies in an electric field. Those anomalies can be caused by changes in the electrical resistivity of natural materials (moisture content, different materials, bad contact conductivity under tips) or a defect in the geomembrane that draws current from the site.

There are ways to set up a project to maximize dipole sensitivity, and all those adjustments can still be carried out early in the project if the dipole calibration shows poor results. There is nothing magical here, it is simply a matter of understanding and controlling how electricity travels through earth materials and geomembrane leaks. Calibration plates are used as leak simulations to validate the method's accuracy at the beginning of each project since there is no way to know exactly a site's configuration and electrical response before being on site.

Those calibrations are described in the ASTM D7007 standard, and it is easy to understand exactly which signal is considered visible or too weak to be excavated and visually inspected.

Different leak simulation sizes can be used to better understand which leak dimensions can be expected to be found. The next technological step, to push the boundaries even further, is to add a microcontroller to the simulations which will plug and unplug them, generating a bigger and better signal. Then, based on previous data and machine learning, it will generate leak signals to pinpoint the minimal leak size that can be found with best-case and worst-case scenarios on site. This way, the client would know exactly which leak size can be detected with extrapolated dimensions, based on a multipole plate calibration board.

The goal of this article is to gain added value devoid of human error, show the geosynthetic community that electrical leak location is based on science, and that improvements can always be made to enhance technologies and methodologies.

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