

PERFORMANCE-BASED SPECIFICATION OF ELECTRICAL LEAK LOCATION SURVEYS FOR GEOMEMBRANE LINERS

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ABSTRACT

Electrical leak location surveys can be a crucial part of the final quality control of geomembrane liner installations. The method has been offered as a commercial service since 1985 and is the only practical test method that can find holes in the liner after protective soil cover is put on the liner. During the past fourteen years the test method has been used on a wide variety of installations worldwide and is becoming a standard test method offered by several testing companies. However, merely specifying an electrical leak location survey as a requirement does not address the key elements needed to obtain a successful and meaningful leak location survey. A performance-based specification based on sound engineering practices is needed to achieve the specified degree of leak detection sensitivity and accuracy. This paper addresses the fundamental concepts of the electrical leak location detection sensitivity and provides information to allow design engineers, owners, and regulators to accurately specify electrical leak location surveys to achieve the desired results. A practical calibration test is described to determine and verify the measurement parameters needed to obtain a given leak detection sensitivity and to validate the various electrical leak location method implementations and field procedures.

INTRODUCTION

The electrical leak location method is a very powerful tool that can be used to locate leaks in geomembrane liners of landfills, ponds, and tanks. The method has several advantages over conventional test methods because the testing is accomplished after final construction, and after the liner is subjected to construction activity. In addition, this is the only effective method to locate leaks under the protective soil cover of a landfill liner. The initial development of the electrical leak location method began in 1981 and the first commercial surveys were performed in 1985. Today more than twenty companies worldwide offer various types of electrical leak location surveys. Therefore, personnel specifying electrical leak location surveys must understand the parameters that

affect the leak detection sensitivity and specify measures to verify the proper operation of the field equipment and procedures.

ELECTRICAL LEAK LOCATION METHOD

General. Figure 1 is a diagram showing the electrical leak location method. The electrical leak location method is to detect electrical paths through holes in the geomembrane liner. A voltage is connected to an electrode placed in soil or water covering the liner and to an electrode in contact with conducting material under the liner. Because the geomembrane liner is an electrical insulator, current will flow only through the leaks. This current produces localized anomalous areas of high current density near the leaks. These anomalous areas are located by making electrical potential measurements in the survey area. The data is typically recorded and plotted for analysis.

ANALYSIS

Leak Detection Sensitivity. Leak detection sensitivity is the ability to find leaks of a specified size. The detection of leaks using electrical methods is highly dependent on the proper implementation of the selected survey method, type of equipment, survey procedures, site characteristics, data interpretation, and experience of the survey personnel. The two primary controllable factors affecting leak detection sensitivity are the level of current flowing through the leak, and the distance from the leak that the leak location measurements are made. The amplitude of the leak signal is proportional to the amount of electrical current flowing through the leak. To increase the current, the voltage impressed across the liner must be increased. Also, the leak signal rapidly attenuates with distance from the leak. Therefore, increasing the impressed voltage and

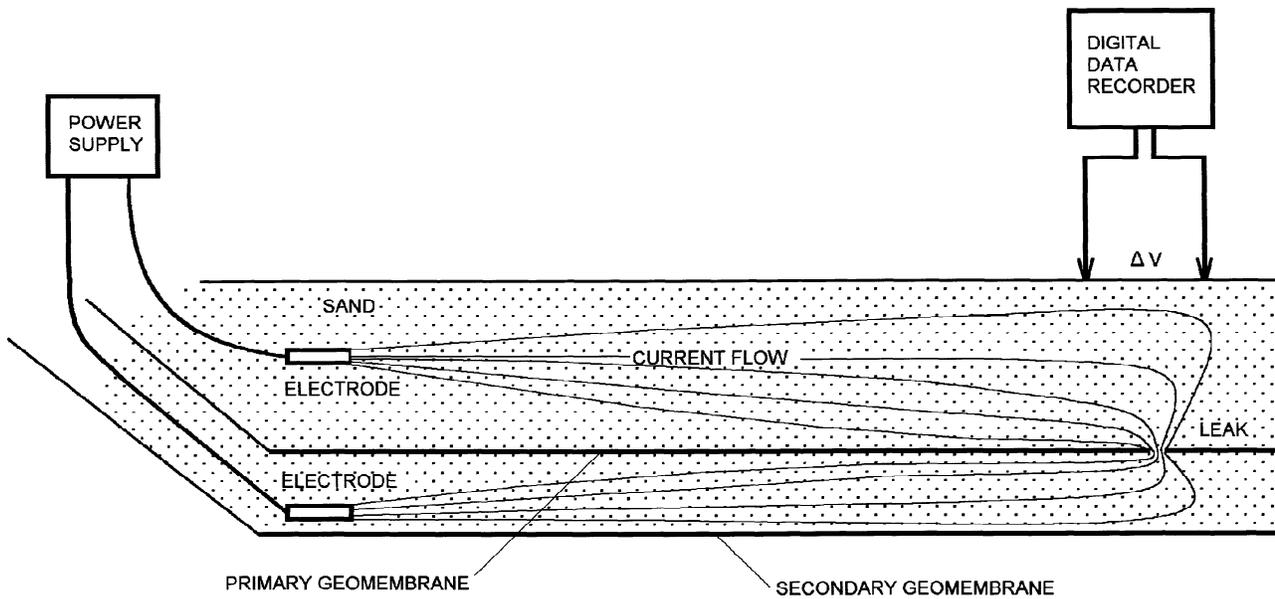


Figure 1. Diagram of the Electrical Leak Location Method

increasing the measurement density will increase the size of the leak signals to improve leak detection sensitivity. The leak detection sensitivity also depends on the electrical resistivity of the materials above and below the liner, the thickness of the soil overlying the liner, and other practical matters such as the homogeneity of the material.

Analysis of Leak Detection Sensitivity. The electrical response of a leak in a geomembrane liner was derived by Parra (1988). He derived the electrical potential for a current source in a three-layer half-space. Figure 2 shows that the very complicated result can be closely approximated by the very simple model of the potential in an infinite conducting half-space (Darilek et al., 1996). For that model the potential difference caused by current flowing from the current source is derived as:

$$\Delta V = \frac{I \rho}{2 \pi r (r + \Delta r)} \quad (1)$$

where ΔV = voltage difference (leak signal); I = current (current flowing through the leak); ρ = resistivity of the half space (resistivity of the soil covering the liner); r = distance from the current source (distance from the leak); and Δr = radial distance between the measurement electrodes. From this equation it can be seen that the leak signal decreases essentially inversely with the square of the distance from the leak. The leak signal is also directly proportional to the current flowing through the leak. By Ohm's law, the current flowing through a leak is proportional to the voltage impressed across the leak and inversely proportional to the resistance of the leak. The resistance of a leak can be modeled as the sum of: 1) the contact resistance with the material above the leak; 2) the resistance of the material in the leak; and 3) the contact resistance with the material below the leak. For circular leaks the values for terms 1 and 3 can each be closely approximated using the equation of resistance of a plate ground (Sunde, 1969) at the surface of the earth, which is:

$$R = \frac{\rho}{4 a} \quad (2)$$

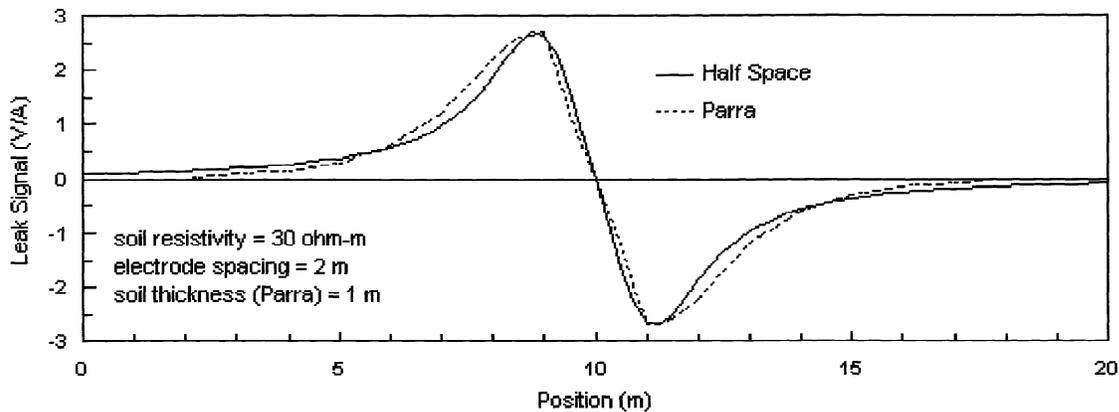


Figure 2. Comparison of Two Mathematical Models for Leak Signal

where R = resistance; and a = radius of the leak. For circular leaks, term 2 is calculated from the definition of resistance as:

$$R = \frac{\rho t}{\pi a^2} \quad (3)$$

where t = thickness of the liner. Combining these terms yields:

$$R = \rho \left(\frac{1}{2a} + \frac{t}{\pi a^2} \right) \quad (4)$$

For most leaks of practical interest, the leak radius is much greater than the thickness of the liner, so the second term in the parentheses can be ignored. From this exercise, the resistance of a leak is inversely proportional to the radius of the leak, so the leak signal will be approximately proportional to the radius of the leak. Figure 3 is a plot of the leak signal amplitude versus distance for several values of excitation current using these relationships. The curves are for a 1 mm liner, 10 mm radius leak, 30 ohm-meter soil, and a 1 m distance between the measurement electrodes. The curves show the importance of using a high voltage and making the measurements at close spacings. This analysis assumes ideal conditions of homogeneous soil, no voltage drop because of multiple leaks or other extraneous electrical paths, and no measurement noise. For rapid field data acquisition under average field conditions, measurement noise can be in the 5 to 20 millivolt range. Therefore, a valid leak signal cannot be measured for many combinations of voltage and measurement spacing previously shown in Figure 3. For these and other practical reasons, a safety factor must be used, for example by making the measurements on closer spacings. Also, because field data frequently has invalid data points, the spatial leak signal must be adequately sampled so the shape of the leak signal can be recognized as being distinct from invalid data points. However, these relationships provide important engineering guidelines for establishing or comparing leak location survey parameters.

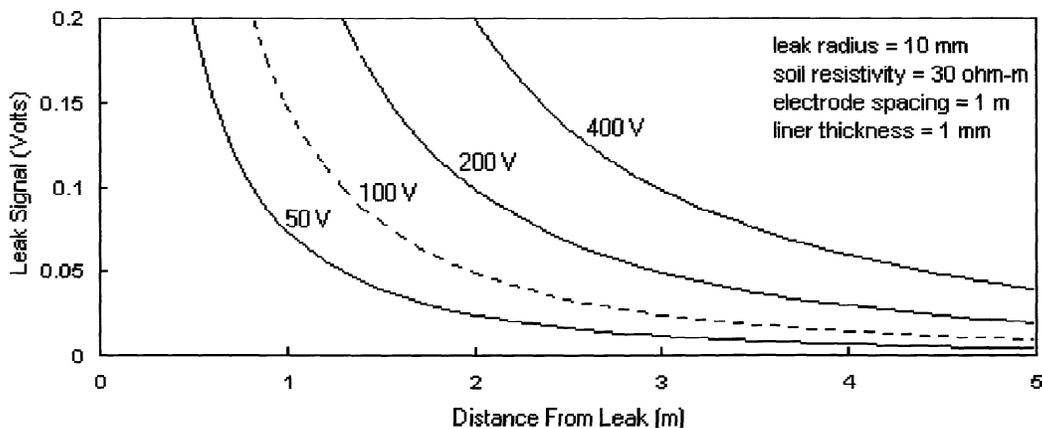


Figure 3. Leak Signal Amplitude versus Distance from Leak for Various Excitation Voltages

This analysis shows the need for establishing criteria for leak detection sensitivity. A leak survey taken with low excitation voltage, with wide measurement spacings, or without a systematic method for recording the data can produce invalid results. One approach to specify leak detection procedures is to specify all of the minimum parameters and procedures to conduct a survey. However, this approach would tend to unnecessarily stifle innovation. This specification rationale would not allow variations in the application of the method, or would be a weak specification to allow for variations. Because electrical leak location surveys are in their growth stage, such a specification method is not recommended. Instead, a performance-based specification can be used under which a minimum performance is specified, and the method used to obtain this performance can be decided by each practitioner.

PERFORMANCE-BASED SPECIFICATIONS

The most important parameter for a performance-based specification for electrical leak locations surveys is leak detection sensitivity. Sensitivity is defined as the minimum size leak that will produce a specified output signal with a specified signal-to-noise ratio. A typical leak detection sensitivity for surveys with 600 mm of soil on the liner is a 10-mm leak diameter leak, although much smaller leaks are often easily detected. Leak detection sensitivity is different from leak detection accuracy, which is the maximum error in the distance between the measured leak signal and the actual position of the leak. The leak location sensitivity can be verified by making measurements near an actual leak put into the liner. Although this method is the most valid, it requires the leak to be repaired.

As an alternate, an artificial leak can be used. An artificial leak is an electrical equivalent of a leak in a liner - an area at the liner depth where electrical current can flow to the material below the liner. An artificial leak is an electrode buried in the soil at the liner depth, connected to a length of insulated wire, the other end of which is connected to a suitable electrode in contact with the conducting material below the liner. The artificial leak should be defined in the construction quality control plan and should be specified to correspond to the leak detection sensitivity that is desired for the specific site. The most critical part of the artificial leak is the electrode buried above the liner. It can be specified to be a metal coupon of a specified size, an actual hole in a calibration cell, or even an insulated wire with a specified short length of insulation stripped off. A calibration cell can be a flat, electrically-insulating container with a top that is the approximate thickness of the geomembrane liner. A hole that corresponds to the desired leak detection sensitivity is placed in the top of the container. A suitable metal electrode connected to the insulated wire is located inside the bottom of the container. The container is filled with a sample of the actual soil that is placed on the liner.

To more closely correspond to an actual leak, a series resistor can be placed in the artificial leak circuit to simulate the resistance of the path between the leak and the power supply electrode placed below the liner. The equivalent path resistance of the medium below the liner depends on several factors, but a first order approximation can be a specified portion of the measured resistance of the circuit between the power supply electrodes placed above and below the liner.

The artificial leak then be used while collecting data along survey lines or on a grid at various distances from the artificial leak. The ends of the survey line or the edges of the grid should extend beyond the influence of the artificial leak. The data is inspected to determine the maximum distance that the leak can reliably be detected with a specified signal-to-noise ratio. The noise is the extraneous signal that is not related to a leak. One method to measure the level of the noise is to make measurements with the excitation signal disconnected. The maximum peak-to-peak value of the noise signal can be defined as being the noise level. The noise signal must be defined over a measurement interval. The measurement interval can be equal to the spatial width of the measured leak signal, or over a specified number of measurements. A leak signal with a signal-to-noise ratio of 3:1 as defined above can be reliably recognized as a valid leak signal.

The actual leak location survey must then be taken with the survey line or grid spacing no more than twice the distance from which the artificial leak can be reliably detected. A level of sampling redundancy can be specified so that if bad data points are taken, the leak detection sensitivity would not be compromised. The position of the excitation electrode can be arbitrary for the test, but production survey measurements must not be taken any farther than the distance to the excitation electrode during the tests with the artificial leak.

SUMMARY AND CONCLUSIONS

Because several implementations of electrical leak location methodologies are evolving, specifications must be written to ensure that the desired leak detection sensitivity is obtained. Rather than rigidly specifying the exact field procedures and equipment capabilities, a performance-based specification is recommended. By using a synthetic leak, measurements can be made to determine the leak detection sensitivity for measurements made at various spacings from the synthetic leak. The measurements that successfully detect the leak with a specified signal-to-noise level define the sampling interval and measurement spacings for the production survey. A similar rationale can be used for electrical leak location surveys made with only water covering the liner.

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