Journal of Hazardous Materials, 21 (1989) 177-187
Elsevier Science Publishers B.V., Amsterdam — Printed in the Netherlands

EPA **Project Summary**

The Electrical Leak Location Method for Geomembrane Liners

Glenn T. Darilek and Jorge O. Parra

An electrical method for locating leaks in geomembrane liners was developed and demonstrated for a wide variety of applications. Geomembrane liners are sheets of elastomeric material used to prevent the leakage of waste and to prevent rainwater from infiltrating solid waste landfills and surface impoundments. When no leaks are present, a voltage applied between the material in the liner and the earth under the liner produces a relatively uniform electrical potential distribution in the material in the liner. Leaks are located by mapping the anomaly in the potential distribution caused by current flowing through a leak. A computer simulation model of layered earth sequences above and below an insulating liner with a leak was developed to efficiently predict the effect of a wide range of parameters on the leak signature.

Tests on a double-lined physical model demonstrated the applicability of the method for a variety of drainage layers under various test conditions such as leak size, electrode depth, and presence of protective cover soil. Leaks smaller than 0.8 mm in the primary liner can be reliably located to within 10 mm. Leaks in the bottom liner can be detected, but not located. The electrical leak location method was successful in finding a leak in a full-scale impoundment that had been fully tested using the vacuum box method.

The method was adapted for locating leaks in the geomembrane liner of landfill cover systems. Scale model tests demonstrated the applicability of the method under a wide range of cover soil thicknesses and leak sizes. Special non-polarizing electrodes were used to locate leaks as small as 3 mm under 600 mm of cover soil.

This Project Summary was developed by EPA's Hazardous Waste Engineering Research Laboratory, Cincinnati, OH, to announce key findings of the research project that is fully documented in a separate report of the same title (see Project Report ordering information at back).

This material was originally published by the U.S. Environmental Protection Agency, 1988.

Introduction

The most common method of disposal of solid and hazardous wastes is in landfills and surface impoundments. To prevent contamination, geomembrane liner systems are often installed beneath the landfill or impoundment to form an essentially impermeable barrier that prevents the migration of contaminant liquids. Installation practices and operational factors can result in leaks in the form of punctures or separated seams. An electrical leak location method was developed to effectively locate leaks in geomembrane liners to ensure that liners have been installed and seamed properly and that no damage has occurred.

Technical Discussion

Figure 1 shows the basic electrical leak location method for detecting and locating leaks in a geomembrane liner. The leak location method makes use of the high electrical resistivity of the geomembrane liner material. When no leaks are present, a voltage impressed across the liner produces a relatively uniform voltage potential distribution in the material above the liner. If the liner is physically punctured or separated, conductive fluid flows through the leak establishing a conductive path for current flow, which produces an anomaly in the measuzed potential in the vicinity of the leak. Therefore, leaks can be located by measuring the potential distribution patterns in the material covering the liner. The electrical leak location method can be used in liquid impoundments, as a pre-service inspection of solid waste landfills, and to locate leaks in the final cover for landfills or impoundments. The method will not damage the liner.

Computer Simulation Model

Research Approach

A computer model was developed to investigate the performance capabilities of the electrical leak location method. The model can accommodate various electrical and dimensional parameters in the three layers comprising the lined impoundment or landfill. The electrical anomaly of a circular hole in a thin, highly resistive layer was used to model the response of a geomembrane lined impoundment or landfill containing a damaged geomembrane liner. The waste material, the liner, and the soil under the liner are simulated by infinite horizontal layers. The secondary potential for a leak in a geomembrane liner is in the form of an integral equation, which includes a

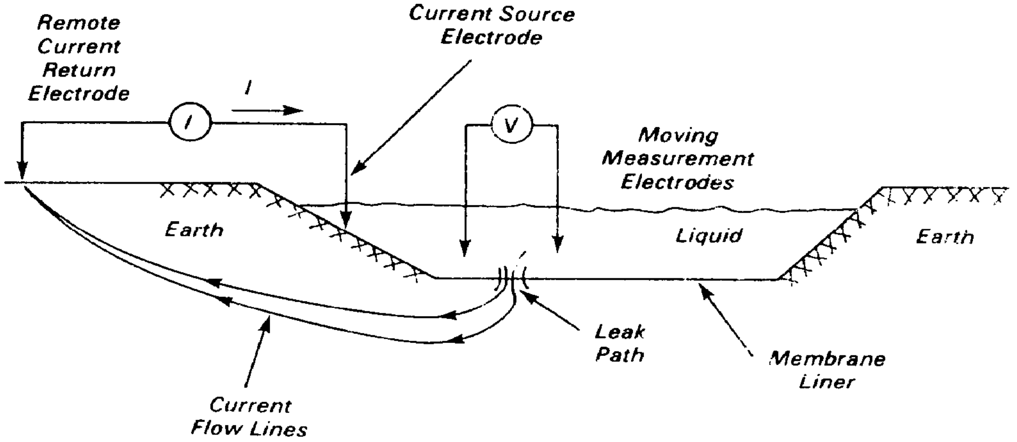

Figure 1.

three-layer medium Green's function. Multiple circular leaks in the thin resistive liner can also be modeled.

To verify the validity of the modeling technique, synthetic leak signatures were computed and compared with field data measured under the same conditions. The excellent agreement between experimental and synthetic model data verified the accuracy of the general solution for predicting leak signatures.

Parametric Study

Model studies of the electrical leak detection survey technique were made to characterize the performance of the method under various conditions of the electrical parameters of the waste materials, the measurement electrode array, the measurement dipole depth and proximity to the leak, the size and number of leaks, and the impoundment depth. Figure 2 shows a typical family of leak anomaly responses illustrating the effects of various measurement depths for a single leak located in a liquid waste impoundment. A substantial improvement in detection sensitivity is obtained when the potential array is closer to the leak. The peak-to-peak anomaly amplitudes for different waste layer resistivity values were calculated. When a constant current is injected, the leak detectability is increased linearly with the resistivity of the waste material.

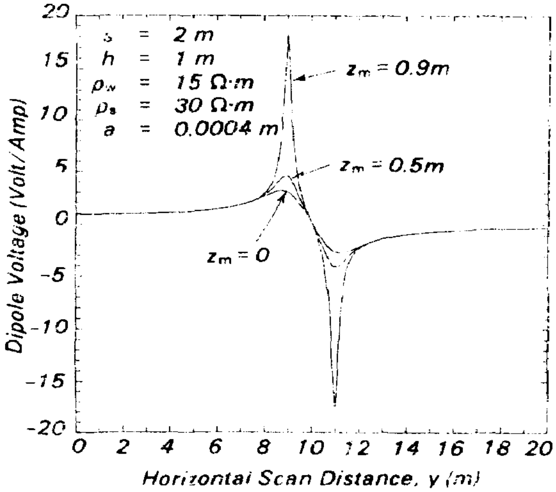

Figure 2.

Figure 3 shows the peak-to-peak anomaly responses calculated for various dipole offset distances from the leak center as a function of the survey height above the liner. An improvement in leak detectability is observed for survey lines located within a radius of 10 cm from the leak center when the depth of the detector is increased.

Field data can be acquired in geomembrane-liquid impoundments using either horizontal or vertical dipole detectors. Figure 4 shows that the horizontal dipole response is stronger than the vertical dipole response because of the closer proximity of the two electrodes to the plane of the liner. However, it may be more practical to make subsurface survey scans using a vertical dipole detector rather than a horizontal dipole detector. With a vertical dipole, the leak can be more easily and accurately located because the leak is located at the peak of the unipolar response. The horizontal dipole detector exhibits a bipolar anomaly in which the

Key:

- s = electrode spacing
- h = depth of the water
- ρ_w = resistivity of the liquid
- ρ_s = resistivity of the soil under the liner
- a = radius of the leak
- z_m = depth of electrodes
- x = offset distance from the leak

leak location corresponds with the crossover between the bipolar leaks. Multiple leaks can be resolved with less ambiguity when a vertical dipole is used. Figure 5 shows a typical vertical dipole anomaly response of a leak. In this case, the leak is directly associated with the maximum anomaly response.

The detection capabilities for multiple leaks in a geomembrane-lined impoundment were analyzed by computing leak signatures for two leaks oriented

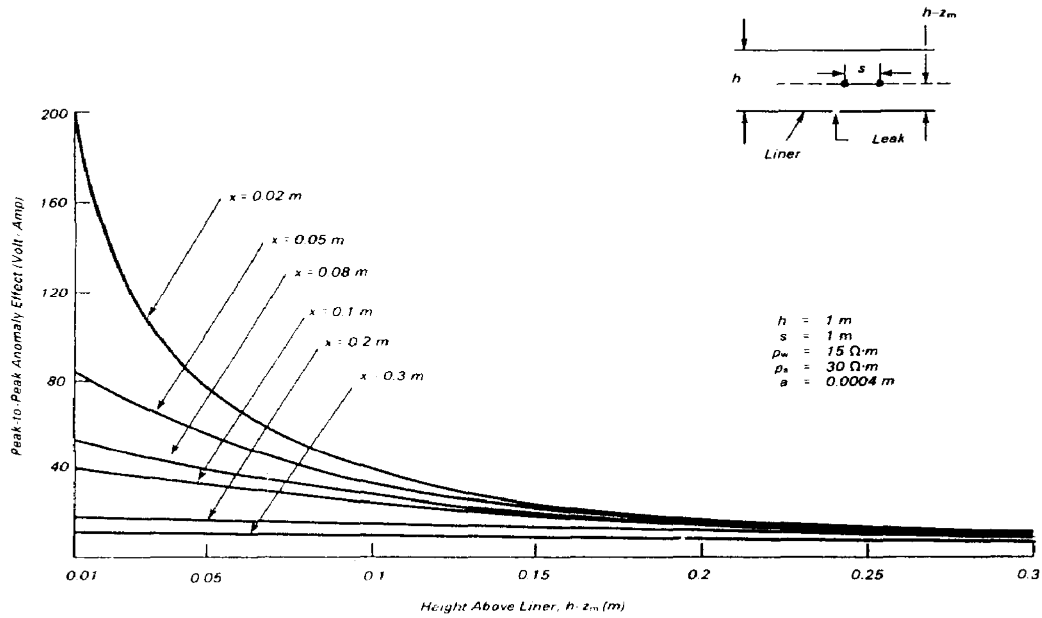

Figure 3.

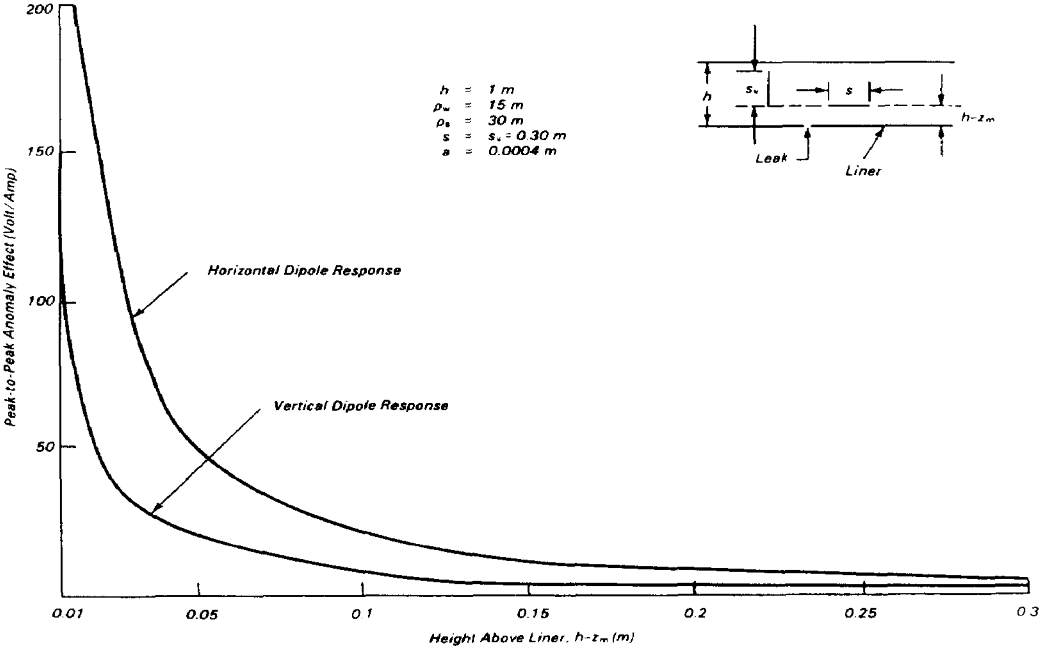

Figure 4.

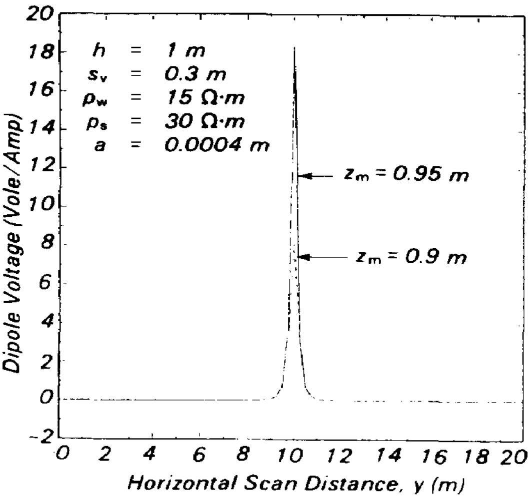

Figure 5.

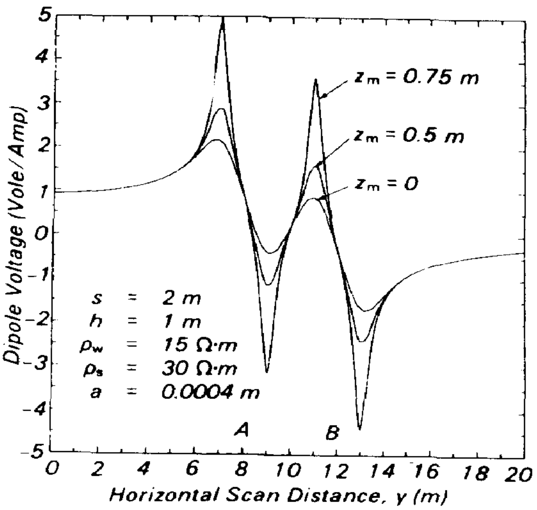

Figure 6.

radially away from the current source. Figure 6 shows horizontal dipole leak signatures computed for two survey depths when the leaks are spaced two meters apart. As expected, when the horizontal separation between leaks becomes less than the horizontal dipole spacing, separate resolution of the two leaks is lost. When leaks are located at separations approximating the horizontal dipole detector spacing, the resolution is poor. However, when measurements are acquired using a small dipole detector spacing, the resolution is improved.

Results of the Computer Simulation Model Study

The derived geomembrane leak detection model is an important and significant analysis technique for leak location and assessment of damaged geomembrane liners. This technique can be implemented as an aid in planning surveys and processing leak survey data acquired in lined impoundments or landfills. The computed leak responses point out the practical importance of performing the survey measurements near the bottom of the impoundment. The results also indicate that the horizontal dipole detector spacing must be less than the leak separation or a vertical dipole must be used to improve leak resolution. The injected current must be increased to offset the effect of lower measured leak anomaly attributed to lower resistivity of the liquid.

Instrumentation for Scale Model Tests and Full-Scale Field Evaluations

Instrumentation was assembled to test the electrical leak location method on outdoor physical models and at full-scale field installations. A simplified block diagram of the electronic components is shown in Figure 7. A transmitter provides the current needed to generate potentials in the impoundment. The receiver measures the resultant potentials, which are then logged by the computer. For full-scale field surveys, a dual-drum electric logging winch is equipped with the logging cable and a nylon rope drawn through a remote sheave. The electrodes are suspended from two floats to make potential gradient measurements.

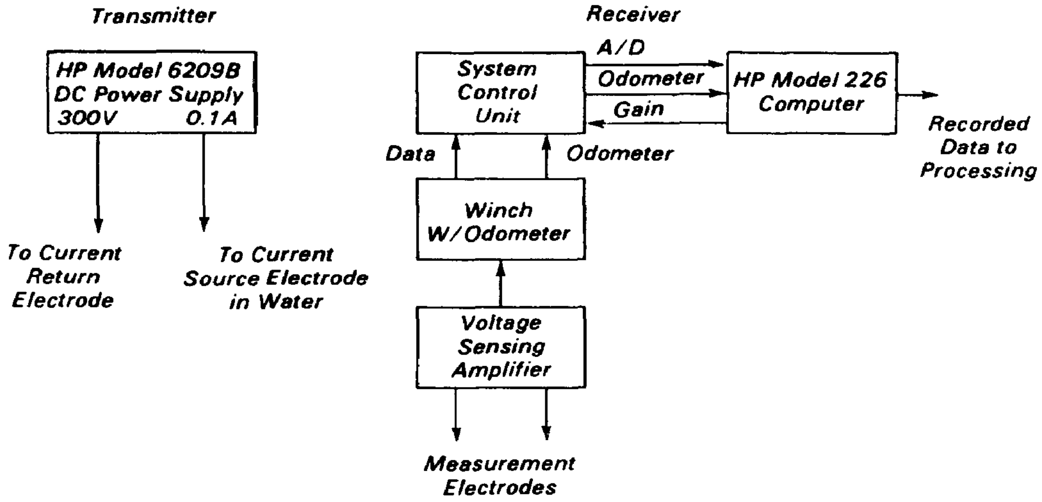

Figure 7.

Double Liner Model Tests

Background

Double-lined facilities are required to meet EPA minimum technology standards for hazardous waste impoundments. By placing the current return electrode in electrical contact with the liquid-saturated drainage layer located between the two liners, the electrical leak location method is applicable for detecting and locating leaks in the upper liner. Simple electrical continuity tests between the drainage layer and the earth can also determine the existence of a significant leak in the bottom liner, but not the location of that leak.

Research Approach

A scale model with dimensions of 3 m x 3 m was used to test the electrical leak location method for locating leaks with various impoundment configurations, including different types of drainage layers, various types of leaks, and a protective soil cover over the primary liner. An electrode support bar was used to position the potential electrodes at a constant depth as close as possible to the liner. Tests were conducted using various electrode materials and geometries to determine the best and most practical electrode configurations for electrical leak location surveys in liquid-filled impoundments.

Results of Double Liner Model Tests

Figure 8 is a contour plot of the data for a leak with a diameter of 5.1 mm with a drainage layer consisting of a sandy loam soil layer placed over the geotextile mat, which is then placed over the geonet material. The location of the leak is clearly indicated by the dipolar contour pattern. The potential gradient pattern caused by the current injection electrode is also evident in the data. Other tests indicated that a leak with a diameter of 25 mm and a 15-cm slit leak produce anomaly characteristics very similar to the leak with a diameter of 5.1 mm. However, the larger leaks required less voltage to produce the same anomaly amplitude.

The characteristic dipolar negative-to-positive transition of the leak anomaly was clearly indicated for a leak with a

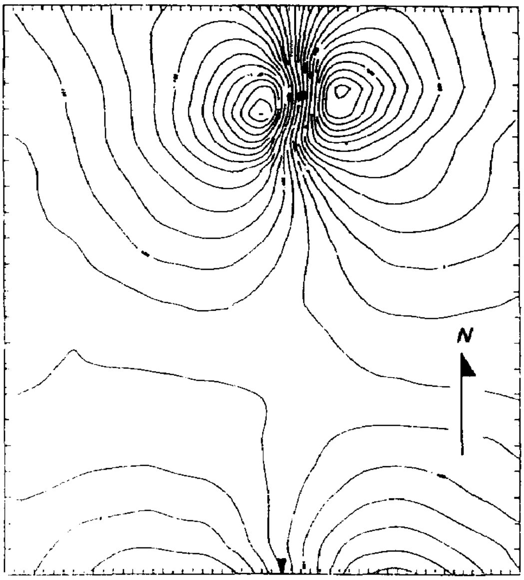

Figure 8.

diameter of 5.1 mm on tests conducted with a protective soil cover with a thickness of 15 cm placed over the geomembrane liner. The approximate location of the leak can be determined from the contour data, but the dipolar pattern is weaker.

Figure 9 shows the relative leak anomaly amplitudes for various electrodes when the centerlines of the electrodes were scanned directly over the leak and 15 cm offset from the leak. The sensitivity of the stainless steel and carbon electrodes was comparable. When the electrodes were scanned directly over the leak, the anomaly amplitudes were inversely related to the length of the electrodes. However, when the electrodes were scanned along a line 15 cm from the leak, the 30-cm line electrode produced the largest anomaly. Most importantly, the leak anomaly was barely detected when the localized point electrodes passed within 15 cm of the leak, where the longer electrodes produced easily detectable anomalies.

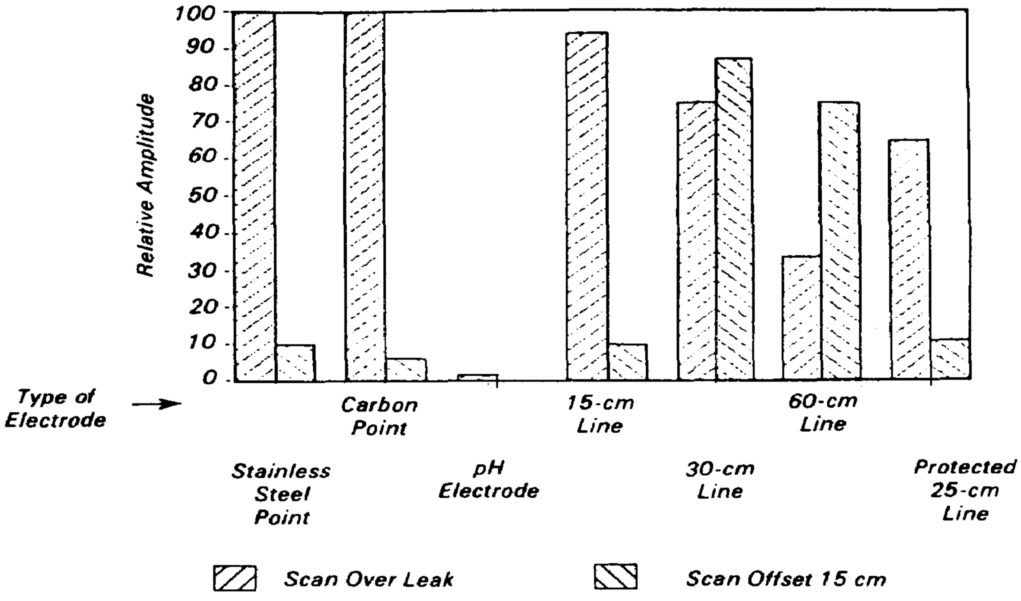

Figure 9.

Locating Leaks in Cover Systems

Background

Geomembrane liner material is widely used for landfill final cover systems. An impermeable cap is placed over the hazardous waste to prevent rainwater from percolating through the waste and leaching chemicals that could migrate into groundwater or surface water. The electrical leak location method was adapted to make surface soil potential measurements to locate leaks in final cover system geomembrane liners. Polarization noise is caused by electrochemical reactions at the interface between the soil and metal electrodes. This noise can be reduced to a significant degree by using half-cell electrodes. These electrodes typically consist of a plastic tube with a porous ceramic tip. Electrical contact is made through a metal electrode in a saturated salt solution in the half-cell.

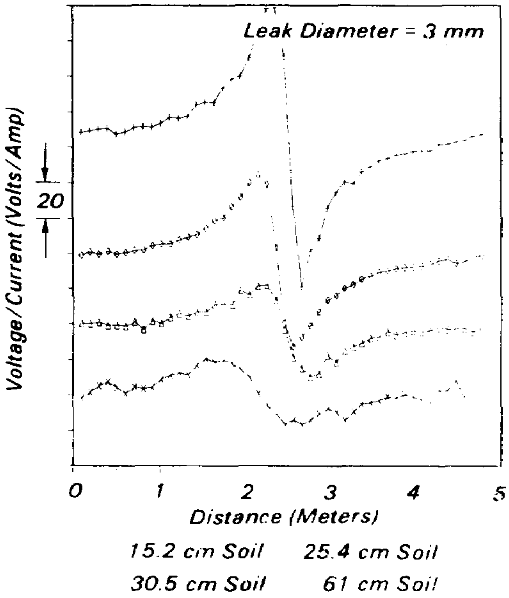

Figure 10.

Research Approach and Results

Experiments were conducted using a physical model with dimensions of 5 m x 5 m. Figure 10 is a plot of the measured leak anomaly for several soil cover thicknesses. Although the peak-to-peak amplitude of the anomaly decreases rapidly with increasing soil cover, the leak was easily detected for all of the soil cover depths tested. Tests were performed with 60 cm of soil cover to show that electrode contact noise is reduced significantly when the electrodes are inserted in the ground to a depth of approximately 25 mm or when the dry ground surface is scraped off prior to the measurements.

Other Leak Location Methods for Cover Systems

The infrared imaging technique was evaluated for detecting subtle temperature differences in the soil cover related to localized areas of low thermal conductivity caused by the drainage of soil moisture through a leak in the underlying geomembrane. The hypothesis was that during early morning or immediately after sunset, when solar heating was introduced or removed, heat would not be conducted as well in the slightly drier soil above a large leak in the geomembrane, which would result in a detectable temperature difference associated with the leak. The tests indicated that the infrared imaging technique was not applicable because no temperature anomalies were detected, even with only 67 mm of soil cover.

Other methods for detecting leaks in the geomembrane liner of cover systems, including ground-penetrating radar, tracer gas, the electromagnetic induction method, encapsulated chem-icals, and electronic transponders, were analyzed. Ground-penetrating radar was judged to offer the highest likelihood of success. Under suitable conditions, the method can detect areas of concentrated moisture beneath the geomembrane liner caused by leaks in the liner. However, the success of the method depends upon the soil having only moderate conductivity and, hence, reasonably low dissipation of electro-magnetic energy. Ground-penetrating radar may offer the additional capability of mapping the depth of the soil cover and the lateral extent of the seepage through a leak.

Liner Resistivity Tests

Research Approach

Tests were conducted to measure electrical resistance changes in liners over a period of time to determine whether the electrical resistance of the liner materials changes after exposure to waste liquids, thereby reducing the usefulness of the survey technique. The tests were performed in triplicate using five different types of liner material exposed to four different liquids. The liner materials tested included polyvinyl chloride, high-density polyethylene, two thicknesses of chlorosulfonated polyethylene, and chlorinated polyethylene. The liquids used in the tests included sodium hydroxide solution, pH of 10; sulfuric acid solution, pH of 1; sodium chloride solution, 10 percent by weight; and deionized water.

Results of Liner Resistivity Tests

The test results indicated that the measured resistance values were at least two orders of magnitude higher than the resistance needed to allow the practical application of the electrical leak location method. The electrical leak detection technique will not be affected for liner systems constructed from the materials tested under exposure to these liquids.

Field Demonstration Surveys

Full-scale surveys at the Southwest Research Institute test impoundment were performed to detect and locate four small circular leaks, each 0.79 mm in diameter. The impoundment was filled with water to a depth of approximately 46 cm. The contour plot of the data shown in Figure 11 graphically indicates the

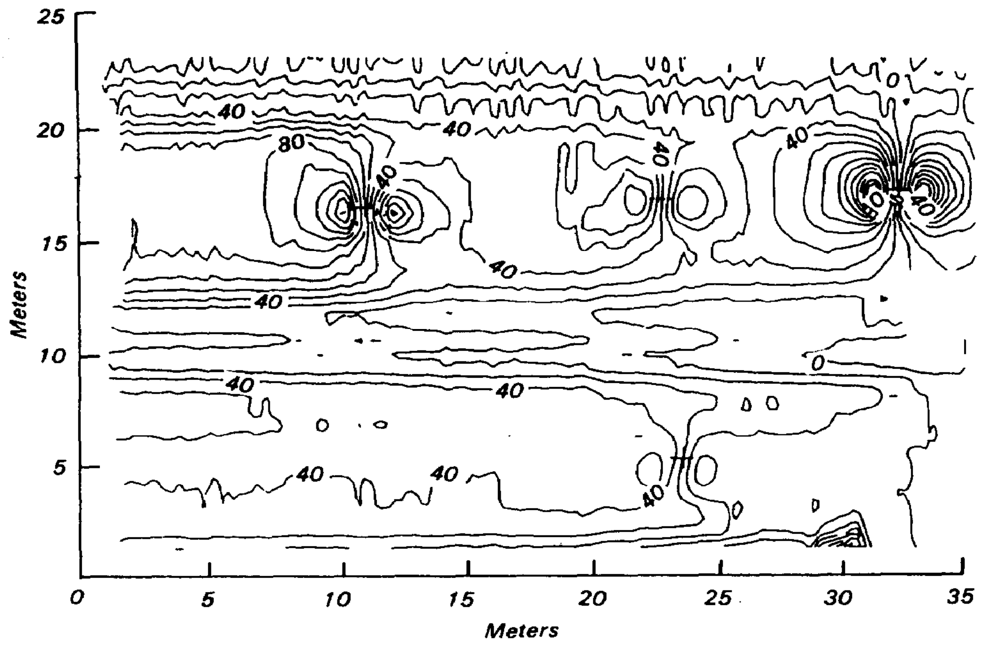

Figure 11.

locations of the four leaks. The contour plot, together with the potential plots for each survey line, provide a straightforward means to analyze and interpret the data for leak detection and location purposes.

The electrical leak location method was demonstrated at another full-scale impoundment in the San Antonio, Texas area. Although the complete liner had been tested previously using the vacuum box method, a 2.0-cm long leak was found. The characteristic leak anomaly was clearly evident on scan lines as far away from the leak as 1.5 m, and no false indications were obtained.

Conclusions and Recommendations

An electrical method for detecting and locating leaks in geomembrane liners for hazardous waste impoundments and landfills has been developed and demonstrated successfully in a wide variety of applications. The project demonstrates the validity and usefulness of the electrical leak location method for testing the integrity of the geomembrane for single and double liners and final cover systems. The technique is cost effective for construction quality assurance and in-service performance monitoring.

The computer simulation model efficiently and accurately predicts the effect of a wide range of measurement parameters on the leak signature. The computer simulation model indicates that leak location sensitivity is increased very significantly when the electrodes are scanned as close to the liner as possible. For a given level of injected current, leak location sensitivity increases proportionally with the resistivity of the material on the liner.

Tests on a double-lined model demonstrated that the method can be applied to a wide variety of double liner configurations of drainage layers with various test parameters such as leak size, electrode depth, and protective soil cover. Leaks smaller than 0.8 mm in diameter can be reliably located. Leaks can be detected from distances greater than 1.5 m from the leak. Linear electrodes oriented perpendicular to the scan direction, with scans offset by approximately the length of the electrodes, produce the highest likelihood of detecting all leaks compared with surveys using localized electrodes. The electrical leak location method is less sensitive for locating leaks in geomembrane liners with liquid and protective soil cover over the liner. The shape and size of the leak have little effect upon the shape of the leak signature. However, the leak size affects the leak current, thereby increasing the amplitude of the leak signature. A simple continuity test can indicate the presence, but not location, of leaks in the bottom liner.

The electrical leak location method is also an effective method for locating leaks in geomembrane liners of waste impoundment or landfill final cover systems. Non-polarizing half-cell electrodes were used to greatly reduce the polarization voltage noise. The method was very successful in locating leaks as small as 3 mm under 60 cm of soil cover.

The most promising method studied for locating leaks in final cover systems, other than the electrical leak location method, is ground-penetrating radar. Limited testing using infrared imaging was unsuccessful in detecting localized areas of low thermal conductivity caused by drainage of soil moisture through a leak.

Laboratory tests indicated that there was no significant decrease in the resistivity of typical liner materials during a 13-week exposure to water, salt water, acidic solution, and basic solution. Exposure of these typical liner materials to these chemicals had no effect on the applicability of the electrical leak location method.

The equipment and procedures for conducting full-scale leak location surveys also can detect leaks with a diameter of 0.8 mm up to 1.5 m away from the leak. A leak was found in an impoundment that had been fully tested using the vacuum box method.

The electrical leak location method has been developed to the stage of industry use for nonhazardous applications, including pre-service leak location surveys for impoundments and landfills and surveys of nonhazardous in-service impoundments. Additional development will bring the method into application for hazardous material impoundments and for final cover systems. The electrical leak location method should be demonstrated at one or more field installations for final cover systems and for a liner with a protective soil cover in place. The ground-penetrating radar technique should be evaluated for detecting leaks in final cover systems. Methods should be developed to repair in-service geomembranes.

Glenn T. Darilek and Jorge O. Parra are with the Southwest Research Institute, San Antonio, TX 78284.

***Charles J. Moench, Jr.**, is the EPA Project Officer (see below).*

The complete report, entitled "The Electrical Leak Location Method for Geomembrane Liners," (Order No. PB 88-220 496/AS; Cost: $19.95, subject to change) will be available only from:

National Technical Information Service
5285 Port Royal Road
Springfield, VA 22161
Telephone: 703-487-4650

The EPA Project Officer can be contacted at:

Hazardous Waste Engineering Research Laboratory
U.S. Environmental Protection Agency
Cincinnati, OH 45268