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Standard Practices for Electrical Methods for Locating Leaks in Geomembranes Covered with Water or Earthen Materials[1]

This standard is issued under the fixed designation D7007; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

1. Scope

1.1 These practices cover standard procedures for using electrical methods to locate leaks in geomembranes covered with water or earthen materials. For clarity, this practice uses the term "leak" to mean holes, punctures, tears, knife cuts, seam defects, cracks, and similar breaches in an installed geomembrane (as defined in 3.2.5).

1.2 These practices are intended to ensure that leak location surveys are performed with demonstrated leak detection capability. To allow further innovations, and because various leak location practitioners use a wide variety of procedures and equipment to perform these surveys, performance-based operations are used that specify the minimum leak detection performance for the equipment and procedures.

1.3 These practices require that the leak location equipment, procedures, and survey parameters used are demonstrated to result in an established minimum leak detection distance. The survey shall then be conducted using the demonstrated equipment, procedures, and survey parameters.

1.4 Separate procedures are given for leak location surveys for geomembranes covered with water and for geomembranes covered with earthen materials. Separate procedures are given for leak detection distance tests using actual and artificial leaks.

1.5 Examples of methods of data analysis for soil-covered surveys are provided as guidance in Appendix X1.

1.6 Leak location surveys can be used on geomembranes installed in basins, ponds, tanks, ore and waste pads, landfill cells, landfill caps, and other containment facilities. The procedures are applicable for geomembranes made of materials such as polyethylene, polypropylene, polyvinyl chloride, chlorosulfonated polyethylene, bituminous material, and other electrically-insulating materials.

1.7 The values stated in SI units are to be regarded as standard. No other units of measurement are included in this standard.

1.8 (**Warning—**The electrical methods used for geomembrane leak location could use high voltages, resulting in the potential for electrical shock or electrocution. This hazard might be increased because operations might be conducted in or near water. In particular, a high voltage could exist between the water or earthen material and earth ground, or any grounded conductor. These procedures are potentially VERY DANGEROUS, and can result in personal injury or death. The electrical methods used for geomembrane leak location should be attempted only by qualified and experienced personnel. Appropriate safety measures must be taken to protect the leak location operators as well as other people at the site.)

1.9 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. Referenced Documents

2.1 *ASTM Standards:*[2]

D4439 Terminology for Geosynthetics

D6747 Guide for Selection of Techniques for Electrical Leak Location of Leaks in Geomembranes

3. Terminology

3.1 For general definitions related to geosynthetics, see Terminology D4439.

3.2 *Definitions of Terms Specific to This Standard:*

3.2.1 *artificial leak, n*—an electrical simulation of a leak in a geomembrane.

3.2.2 *current source electrode, n*—the electrode that is placed in the water or earthen material above the geomembrane.

3.2.3 *dipole measurement, n*—an electrical measurement made on or in a partially conductive material using two closely-spaced electrodes.

[1] These practices are under the jurisdiction of ASTM Committee D35 on Geosynthetics and is the direct responsibility of Subcommittee D35.10 on Geomembranes.

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[2] For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

3.2.4 *earthen material, n*—sand, gravel, clay, silt, combinations of these materials, and similar materials with at least minimal moisture for electrical current conduction.

3.2.5 *leak, n*—for the purposes of these practices, a leak is any unintended opening, perforation, breach, slit, tear, puncture, crack, or seam breach. Significant amounts of liquids or solids may or may not flow through a leak. Scratches, gouges, dents, or other aberrations that do not completely penetrate the geomembrane are not considered to be leaks. Types of leaks detected during surveys include, but are not limited to: burns, circular holes, linear cuts, seam defects, tears, punctures, and material defects.

3.2.6 *leak detection distance, n*—The distance that a leak location equipment and survey methodology are capable of detecting a specified leak. The leak is usually specified as a circular leak with a specified diameter. For surveys with earthen materials on the geomembrane, the leak detection distance is usually measured from the surface projection of the leak.

3.2.7 *noise, n*—the unwanted part of a measured signal contributed by phenomena other than the desired signal.

3.2.8 *pole measurement, n*—an electrical measurement made on or in a partially conductive material using one measurement electrode and a remote reference electrode.

3.2.9 *potential, n*—electrical voltage measured relative to a reference point.

4. Significance and Use

4.1 Geomembranes are used as impermeable barriers to prevent liquids from leaking from landfills, ponds, and other containments. The liquids may contain contaminants that, if released, can cause damage to the environment. Leaking liquids can erode the subgrade, causing further damage. Leakage can result in product loss or otherwise prevent the installation from performing its intended containment purpose. For these reasons, it is desirable that the geomembrane have as little leakage as practical.

4.2 Geomembrane leaks can be caused by poor quality of the subgrade, poor quality of the material placed on the geomembrane, accidents, poor workmanship, manufacturing defects, and carelessness.

4.3 The most significant causes of leaks in geomembranes that are covered with only water are related to construction activities including pumps and equipment placed on the geomembrane, accidental punctures, and punctures caused by traffic over rocks or debris on the geomembrane or in the subgrade.

4.4 The most significant cause of leaks in geomembranes covered with earthen materials is construction damage caused by machinery that occurs while placing the earthen material on the geomembrane. Such damage also can breach additional layers of the lining system such as geosynthetic clay liners.

4.5 Electrical leak location methods are an effective final quality assurance measure to detect and locate leaks.

5. Summary of the Electrical Leak Location Methods for Covered Geomembranes

5.1 The principle of the electrical leak location method is to place a voltage across a geomembrane and then locate the points of anomalous potential distribution where electrical current flows through leaks in the geomembrane. Additional information can be found in Guide D6747.

5.2 *General Principles:*

5.2.1 Figs. 1 and 2 show diagrams of the electrical leak location method for a geomembrane covered with water and for a geomembrane covered with earthen materials respectively. One output of an electrical excitation power supply is connected to a current source electrode placed in the material covering the geomembrane. The other output of the power supply is connected to an electrode in contact with electrically conductive material under the geomembrane.

5.2.2 When there are leaks, electrical current flows through the leaks, which produces high current density and a localized anomaly in the voltage potential distribution in the material above the geomembrane. Electrical measurements are made to locate those areas of anomalous signal at the leaks.

5.2.3 Measurements are made using a dipole or pole measurement configuration. Various types of data acquisition are used, including audio indications of the signal level, manual measurements with manual recording of data, and automated digital data acquisition.

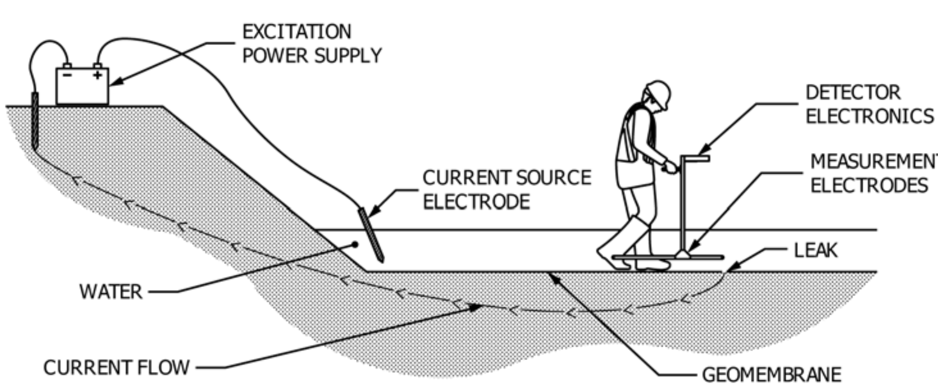

FIG. 1 Diagram of the Electrical Leak Location Method for Surveys with Water Covering the Geomembrane

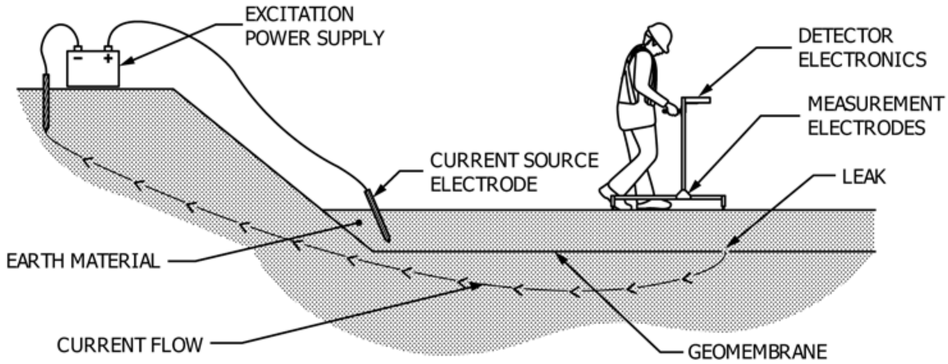

FIG. 2 Diagram of the Electrical Leak Location Method for Surveys with Earthen Material Covering the Geomembrane

5.2.4 Direct current and alternating current excitation power supplies and potential measurement systems have been used for leak location surveys.

5.3 *Leak Location Surveys of Geomembranes Covered with Water:*

5.3.1 Leak location surveys for geomembranes covered with water can be conducted with water on the geomembrane or with water covering a layer of earthen materials on the geomembrane.

5.3.2 For leak location surveys with water on the geomembrane, usually a dipole probe is systematically scanned through the water covering the geomembrane to locate the points of anomalous potential distribution. The dipole spacing is typically 0.2 to 1 m.

5.3.3 Various types of probes can be used to perform the surveys. Some are for when the operator wades in the water; some are for towing the probe back and forth across the geomembrane; and some are for raising and lowering along vertical or sloping walls.

5.3.4 The probe is typically connected to an electronic detector assembly that converts the electrical signal from the probe to an audible signal that increases in pitch and amplitude as the leak signal increases.

5.3.5 When a leak signal is detected, the point with the maximum signal is then determined. This point of maximum signal corresponds to the location of the leak. The location of the leak is then marked or measured relative to fixed points.

5.3.6 The leak detection distance depends on the leak size, the conductivity of the materials within, above, and below the leak, the electrical homogeneity of the material above the leak, the output level of the excitation power supply, the design of the measurement probe, the sensitivity of the detector electronics, the survey area configuration and isolation, and the survey procedures. Leaks as small as 1 mm in diameter have been routinely found, including tortuous leaks through welds in the geomembrane. Leaks larger than 25 mm in diameter can usually be detected from several metres away.

5.3.7 The survey rate depends primarily on the spacing between scans and the depth of the water. A close spacing between scans is needed to detect the smallest leaks.

5.4 *Leak Location Surveys of Geomembranes Covered with Earthen Materials:*

5.4.1 For leak location surveys with earthen materials covering the geomembrane, point-by-point measurements are made on the earthen material using either dipole measurements or pole measurements. Dipole measurements are typically made with a spacing of 0.5 to 3 m. Measurements are typically made along parallel survey lines or on a grid pattern.

5.4.2 The survey procedures are conducted by systematically taking measurements of voltage potential in a grid pattern. Leaks can be located during the performance of the voltage measurements, but the voltage data must be collected for post-survey evaluation. The measurements and positions can be recorded manually or using a digital data acquisition system. Appendix X1 details the two main methods of data analysis and the advantages and disadvantages of each.

5.4.3 The data is typically downloaded or manually entered into a computer and plotted. Sometimes data is taken along survey lines and plotted in graphical format. Sometimes data is taken in a grid pattern and plotted in two-dimensional contour, shade of gray, or color contour plots, or in three-dimensional representations of the contours. The data plots are examined for characteristic leak signals.

5.4.4 The approximate location of the leak signal is determined from the data plots and additional measurements are made on the earthen material in the vicinity of the detected leak signal to more accurately determine the position of the leak.

5.4.5 The leak detection distance depends on the leak size, the conductivity of the materials within, above, and below the leak, the electrical homogeneity of the material above the leak, the design of the measurement electrodes, the output level of the excitation power supply, the sensitivity of the detector electronics, the survey procedures, the survey area configuration and isolation, and the data interpretation methods and expertise. Usually leaks as small as 5 mm in diameter can be located under 600 mm of earthen material. Leaks larger than 25 mm in diameter can usually be detected from several metres away.

5.4.6 The survey rate depends primarily on the spacing between the measurement points, the type of data acquisition, and whether data interpretation is accomplished in the field. A close spacing between measurement points is needed to adequately replicate the leak signals and to detect smaller leaks.

6. General Leak Location Survey Procedures

6.1 The following measures shall be taken to optimize the leak location survey:

6.1.1 Conductive paths such as metal pipe penetrations, pump grounds, and batten strips on concrete should be isolated or insulated from the water or earthen material on the geomembrane whenever practical. These conductive paths conduct electricity and mask nearby leaks from detection, as well as compromising the overall survey quality.

6.1.2 In applications where a single geomembrane is covered with earthen materials that overlap the edges of the geomembrane, measures should be taken to isolate the edges. If earthen materials overlap the edges of the survey area to earth ground, electrical current will flow from the earthen material to earth ground, compromising survey sensitivity. Isolation can be accomplished by either: performing the leak location survey before the edges of the geomembrane are covered; removing the earthen materials from a narrow path around the perimeter of the geomembrane; or allowing the edge of the geomembrane to protrude above the earthen materials.

6.1.3 There must be a conductive material directly below the electrically-insulative geomembrane being tested. Typically leak location surveys on a properly-prepared subgrade will have sufficient conductivity. Under proper conditions and preparations, geosynthetic clay liners (GCLs) can be adequate as conductive material. There are some conductive geotextiles or other conductive materials with successful field experience which can be installed beneath the geomembrane to facilitate electrical leak location survey (that is, on dry subgrades, or as part of a planar drainage geocomposite).

6.1.4 For lining systems where an electrically-insulative geomembrane is overlain by a drainage geonet geocomposite, if the geocomposite is not saturated or is not manufactured to be conductive, only leaks that penetrate both geosynthetics can be detected; as a dry drainage geonet geocomposite is electrically-insulative.

6.1.5 For lining systems comprised of two geomembranes with only a geonet or only a geocomposite between them, the volume between the geomembranes shall be filled with water to provide the conductive material. The water level in the area between the geomembranes should be limited so that it exerts a pressure less than the pressure exerted by the water and any earthen materials on the primary geomembrane. When the head pressure of the water under the geomembrane exceeds the downward pressure exerted by the weight of the water and any earthen materials on the geomembrane, the primary geomembrane will begin to float. For surveys with only water on the geomembrane, the survey area will be limited to the area of the geomembrane that is covered with water. For surveys with earthen materials on the geomembrane, the survey area can be calculated from the relative density of the earthen materials, the thickness of the earthen materials and the slope of the geomembrane. Additional area can be surveyed by placing water on the earthen material on the primary geomembrane.

6.1.6 For surveys with earthen materials on the geomembrane, the earthen materials shall have adequate moisture to provide a continuous path for electrical current to flow through the leak. Earthen materials usually have sufficient moisture at depth, but sometimes the surface of the earthen materials becomes too dry. This dry material shall be scraped away at the measurement points, or the surface shall be wet with water. The earthen materials do not have to be saturated with water. The amount of moisture required depends on the earthen material, the equipment and procedures.

7. Leak Location Survey Procedures for Surveys with Water Covering the Geomembrane

7.1 The leak location survey shall be performed by scanning the leak location probe along the submerged geomembrane. The maximum distance between adjacent scans shall be determined by a leak detection distance test using an artificial or actual leak. The advantages and disadvantages of using the artificial or actual leak are listed in Table 1. A leak detection distance test shall be conducted on each geomembrane being tested for each set of equipment used before the set is used on that geomembrane. Periodic leak detection distance tests are specified in 7.8.

7.2 *Artificial Leak Procedures*—Annex A1 contains the procedures for using an artificial leak to conduct a leak detection distance test and determine the detection distance for surveys with water on the geomembrane.

7.3 *Actual Leak Procedures*—Annex A2 contains the procedures for using an actual leak to conduct a leak detection distance test and determine the detection distance for surveys with water on the geomembrane.

7.4 *Leak Location Survey*—The leak location survey shall be conducted using procedures whereby the leak location probe passes within the detection distance of all locations on the geomembrane being surveyed for leaks. Because the probe detects leaks within the detection distance on both sides of the

TABLE 1 Comparison of Artificial Leaks versus Actual Leaks for Leak Detection Distance Test with Water on the Geomembrane

Factor	Actual Leak	Artificial Leak
Repairs	Geomembrane must be repaired after test	No geomembrane repair
Mobility	Moving location requires another actual leak to be made and repaired.	Can be easily moved without needing geomembrane repair
Test adequacy of the conductivity of the material under the geomembrane	Yes, could be important for double geomembranes	Yes for single geomembranes, yes for double geomembranes if the artificial leak current return path corresponds to actual site survey conditions
Convenience	Must drill hole, sometimes under water, position is difficult to determine	Artificial leak is just placed in the water, can usually see the position

probe, the distance between leak detection sweeps can be no more than twice the detection distance. In addition to these procedures, any seams that can be visually located, or located by feel as the probe is scanned on the geomembrane, shall be surveyed for leaks by passing the probe directly along the seam or seam flap.

7.5 The leak detection distance test shall be conducted at the farthest distance where the leak location survey will be performed from where the current source electrode is located.

7.6 The criteria used to define the system leak detection distance as required in 7.3 and 7.4 and described in Annex A1 and Annex A2 shall not to be used as the leak detection criteria. Any definite, repeatable leak signal indication shall be considered to be a leak.

7.7 The locations of all leaks found shall be marked or measured relative to fixed points.

7.8 *Periodic Leak Detection Distance Test*—The leak detection distance test using the artificial or actual leak shall be conducted for each set of equipment, as a minimum, at the beginning and end of each day of survey. For this test, the current source electrode shall be no closer to the artificial or actual leak than the maximum distance used during the survey. The periodic leak detection distance tests shall produce a leak detection distance larger than the leak detection distance used for the leak location survey. If any leak detection distance is smaller, then the area surveyed with that set of equipment in the period since the previous leak detection distance test shall be repeated.

8. Leak Location Survey Procedures for Surveys with Earthen Material Covering the Geomembrane

8.1 The distance between adjacent survey lines or grid points shall be determined by a leak detection distance test using an artificial or actual leak. The advantages and disadvantages of using the artificial leak and actual leak are listed in Table 2. A leak detection distance test shall be conducted on each geomembrane being tested for each set of equipment used before the set is used on that geomembrane. Periodic leak detection distance tests are also specified in 8.12

8.2 *Artificial Leak Procedures*—Annex A3 contains the procedures for using an artificial leak to conduct a leak detection distance test and determine the detection distance for surveys with earthen materials on the geomembrane.

8.3 *Actual Leak Procedures*—Annex A4 contains the procedures for using an actual leak to conduct a leak detection distance test and determine the detection distance for surveys with earthen materials on the geomembrane.

8.4 *Leak Location Survey*—The results of the leak detection distance test shall determine the measurement spacings for the leak location survey. The leak location data shall be taken on survey lines or on a grid spaced no farther apart than 1.5 times the leak detection distance determined in the leak detection distance test, or 3.05 m, whichever distance is less.

8.5 For dipole measurements, the measurement electrode spacing shall be the same as that used for the leak detection distance test.

8.6 The spacing between measurements along the survey line or longitudinally along the grid shall be no more than that used during the leak detection distance test.

8.7 The leak detection distance test shall be conducted at the farthest distance where the leak location survey will be performed from where the current source electrode is located.

8.8 (**Warning—**Because of the high voltage that could be involved, and the shock or electrocution hazard, do not come in electrical contact with any leak unless the excitation power supply is turned off.)

8.9 Leaks can be located as the survey progresses, but the voltage measurements shall be recorded, plotted, and analyzed for leak signals. Appendix X1 details the two main methods of data analysis and the advantages and disadvantages of each. The positions of these leak signals shall be located and the leaks excavated. The leaks shall be repaired or electrically isolated from the earthen material on the geomembrane. The leak signals have a certain spatial distribution that can mask other nearby leaks, therefore, these additional measurements must be taken after the initial pinpointed leaks have been isolated or insulated. In some instances, such as when the leak

TABLE 2 Comparison of Artificial Leaks versus Actual Leaks for Leak Detection Distance Test with Earthen Material on the Geomembrane

Factor	Actual Leak	Artificial Leak
Repairs	Geomembrane must be repaired after test. If a geotextile cushion is on the geomembrane, it also must be removed and repaired.	No geomembrane or geotextile cushion repair.
Mobility	Moving location requires another actual leak to be made and repaired.	Can be easily moved without needing geomembrane repair
Test adequacy of the conductivity of the material under the geomembrane	Yes	Yes for single geomembranes, yes for double geomembranes if the artificial leak current return path corresponds to actual site survey conditions
Effect on survey sensitivity	Affects sensitivity of immediate vicinity of leak; leak must be isolated in order to survey surrounding area.	None when artificial leak is disconnected.
Convenience	Must drill hole and take measures to prevent damage to secondary geomembrane, where applicable.	No drilling of hole or possible damage to secondary geomembrane.

is under water, it may not be practical to isolate the leak while the leak location crew is on site. In those cases, when the leak is repaired, the earthen materials should be removed from an area corresponding to the spatial distribution of the leak signal and the geomembrane should be visually inspected for leaks.

8.10 The leak location data shall then be re-collected for in an area extending 5 m before and beyond and on both sides of the position of the original leak. If another leak signal is detected, this process shall be repeated until no additional leaks are detected.

8.11 The signal plus noise to noise ratio (*R* value) used to define the system leak detection distance as required in 8.2 and 8.3 and described in Annex A3 and Annex A4 shall not be used as the leak detection criteria. Any definite, repeatable characteristic leak signal indication shall be investigated to be a leak.

8.12 *Periodic Leak Detection Distance Tests*—A full or partial leak detection distance test shall be conducted according to Annex A3 or Annex A4 for each set of equipment at the beginning and end of each day of survey as a minimum. The periodic leak detection distance tests should show that the artificial or actual leak can be detected with the specified 3:1 (S+N)/N from a distance of half the survey line spacing. If they do not, the site conditions shall be modified until the leak detection distance is regained and the area surveyed that lacked adequate sensitivity shall be resurveyed.

9. Reporting Requirements

9.1 The leak location survey report shall contain the following information:

9.1.1 Description of the survey site,

9.1.2 Weather conditions,

9.1.3 Cover material description,

9.1.4 Type of geomembrane,

9.1.5 Liner system layering,

9.1.6 Description of the leak location method,

9.1.7 Survey methodology,

9.1.8 Description of the artificial or actual leak used,

9.1.9 Results of leak detection distance tests,

9.1.10 Results of periodic leak detection distance tests,

9.1.11 Specific parameters of survey including dipole spacing, spacing between measurements or scans, spacing between survey lines, and dipole orientation along survey lines as applicable,

9.1.12 Location of detected leaks,

9.1.13 Where visible, type and size of leaks, and

9.1.14 Map of the surveyed areas showing the approximate locations of the leaks.

9.2 For surveys with earthen materials covering the geomembrane, raw data files or records shall be maintained. They should be provided to the client if specified by contract or other specification.

10. Keywords

10.1 construction quality assurance; electrical leak location method; geoelectric leak location; geomembrane; leak detection; leak location

ANNEXES

(Mandatory Information)

A1. PROCEDURES FOR LEAK DETECTION DISTANCE TEST FOR SURVEYS WITH WATER COVERING THE GEOMEMBRANE USING AN ARTIFICIAL LEAK

A1.1 *Artificial Leak*—If an artificial leak is used, the artificial leak shall be constructed using an electrically insulating container. Fig. A1.1 shows the construction of the artificial leak that shall be used for the leak detection distance test with water on the geomembrane. The container has a lid with a thickness greater than the geomembrane under test or a means for sealing a disk of geomembrane to the opening of the container. The disk is constructed of geomembrane with the same or greater thickness as the geomembrane to be tested. An insulated wire enters a sealed penetration into the container. The wire is terminated with a metal electrode. A weight should be used in the container so the filled container is not buoyant. Under justified cases of unfavorable site conditions or excessive leaks present in the geomembrane, the specified diameter of the leak in the artificial leak may not be practically detected. Under those circumstances, an artificial leak with double or triple the specified diameter should be used to verify proper equipment operation and the probe shall be scanned within 200 mm of every point on the geomembrane. If it is suspected that existing numerous or large leaks in the geomembrane may be causing the poor sensitivity, it is recommended that two surveys be performed; the first to locate and uncover the large leak(s) and the second to perform the entire survey at the desired sensitivity.

A1.2 (**Warning—**Because of the high voltage that could be involved, and the shock or electrocution hazard, do not touch the artificial leak or the end of the artificial leak wire or electrode unless the excitation power supply is turned off. Do not drill a hole in the artificial leak unless the excitation power supply is turned off or the artificial leak is disconnected.)

A1.3 The other end of the insulated wire shall be connected to a ground electrode or an electrode between the geomembranes in a double geomembrane installation. The distance between the artificial leak ground and the return electrode of the excitation power supply shall be greater than 3 m.

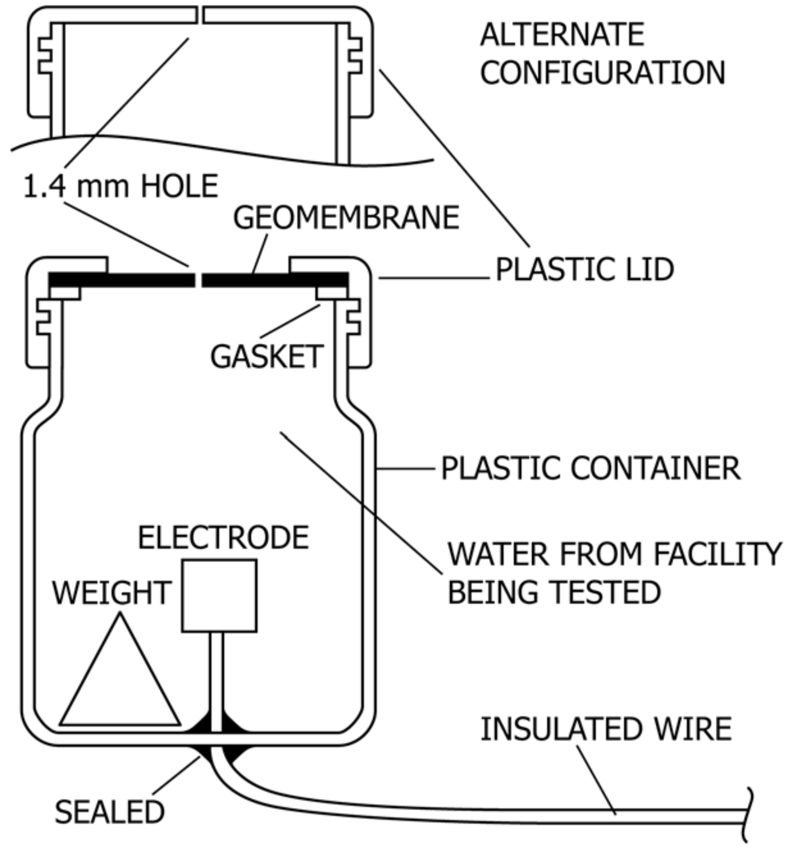

FIG. A1.1 Artificial Leak for Surveys with Water Covering the Geomembrane

A1.4 If a wading survey is to be performed, the artificial leak shall be more than 3 m from the edge of the water.

A1.5 *Leak Detection Distance Test*—The excitation power supply shall be turned on and the leak location probe for each set of equipment shall be scanned in the vicinity of the artificial leak. The scans shall be made in the manner that the actual leak location survey will be conducted. The probe shall be scanned at various distances from the artificial leak to determine the distance where the leak signal is distinguishable from the background noise level. When the signal from the artificial leak while connected to ground is easily detectable, the distance from the measurement line to the artificial leak shall be measured and recorded. This is the leak detection distance.

A2. PROCEDURES FOR LEAK DETECTION DISTANCE TEST FOR SURVEYS WITH WATER COVERING THE GEOMEMBRANE USING AN ACTUAL LEAK

A2.1 (**Warning—**Because of the high voltage that could be involved, and the shock or electrocution hazard, do not attempt to drill the actual leak hole or touch the leak when the excitation power supply is turned on.)

A2.2 The actual leak shall be constructed by drilling a hole with a diameter no greater than 1.4 mm in the installed geomembrane that is to be tested. For a double geomembrane system, measures shall be taken to ensure that the drill bit does not damage the secondary geomembrane. The hole shall be drilled, and the drill bit moved forward and backward in the hole so the geomembrane material is removed rather than displaced. The leak location shall be adequately marked or its position referenced so its position will be known when the actual leak is covered with water.

A2.3 *Leak Detection Distance Test*—The excitation power supply shall be turned on and the leak location probe for each set of equipment shall be scanned in the vicinity of the leak. The scans shall be made in the manner that the actual leak location survey will be conducted. The probe shall be scanned at various distances from the leak to determine the distance where the leak signal is distinguishable from the background noise level. This distance to the actual leak shall be measured and recorded. This is the leak detection distance.

A3. PROCEDURES FOR LEAK DETECTION DISTANCE TEST FOR SURVEYS WITH EARTHEN MATERIAL COVERING THE GEOMEMBRANE USING AN ARTIFICIAL LEAK

A3.1 *Artificial Leak*—If an artificial leak is used, the artificial leak shall be a circular metal surface on a flat, electrically insulating substrate. An insulated wire is connected to the metal surface. The artificial leak shall have no sharp edges that could damage the geomembrane. Fig. A3.1 shows the maximum dimensions and typical construction for the artificial leak for surveys with earthen materials covering the geomembrane. The diameter of the metal surface shall be no greater than 6.4 mm. This artificial leak size is intended for leak location surveys with up to 600 mm of earthen materials on the geomembrane. If the thickness of the earthen material is greater, or unfavorable site conditions exist, a larger artificial leak size should be specified. Caution must be exercised to avoid specifying a too small artificial leak size that cannot be practically detected.

A3.2 (**Warning—**Because of the high voltage that could be involved, and the shock or electrocution hazard, do not touch the artificial leak or the end of the artificial leak wire or electrode, or pour water on it when the excitation power supply is turned on.)

A3.3 The other end of the insulated wire shall be connected to a ground electrode or an electrode between the geomembranes in a double geomembrane installation. The distance between the artificial leak ground electrode and the return electrode of the excitation power supply shall be greater than 3 m.

A3.4 The artificial leak shall be buried to within 25 mm of the geomembrane. The artificial leak shall be at least 10 m from any edge of the survey area. The artificial leak shall be backfilled with at least 50 mm of earthen material and then no more than 250 mL of water should be poured over the partially buried artificial leak. The excavation shall then be backfilled. The location of the artificial leak shall be clearly marked on the surface. The addition of water above the artificial leak is to simulate the natural conditions of real leaks, which typically have been exposed to moisture draining from the earthen material and concentrating at the surface of the impermeable geomembrane.

A3.5 *Leak Detection Distance Test*—Closely-spaced measurements shall be taken to determine the leak signal and background noise signal as follows:

A3.5.1 With the artificial leak wire disconnected, and the excitation power supply turned on, a line of data shall be taken and recorded over the artificial leak to measure and quantify the background noise level (*N*). Measurements shall be taken on a line that extends at least 5 m in front of and in back of the artificial leak. The spacing of the measurements shall be the same as that planned for the leak location survey.

A3.5.2 The background noise level (*N*) shall be defined as the difference between the maximum and minimum measured potential with the artificial leak disconnected and the excitation power supply turned on.

A3.5.3 With the artificial leak connected, and the excitation power supply turned on, leak location measurements shall be made and recorded along closely-spaced parallel lines or on a grid centered on the artificial leak. The distance from each of the parallel lines to the surface projection of the artificial leak shall be measured. Fig. A3.2 shows the geometry of the

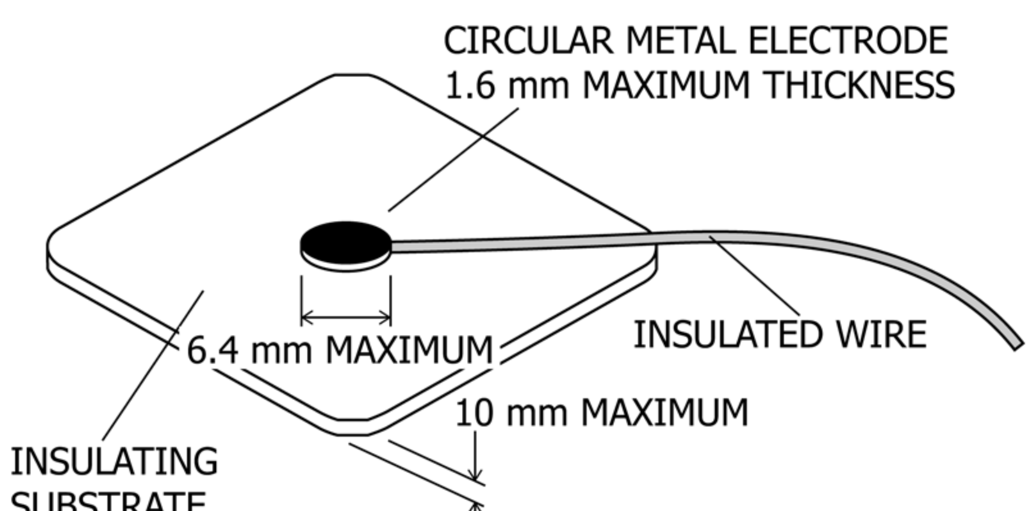

FIG. A3.1 Artificial Leak for Surveys with Earthen Materials Covering the Geomembrane

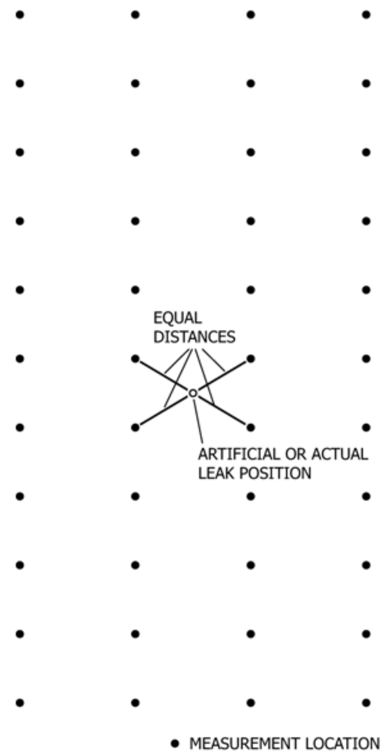

FIG. A3.2 Geometry for Measurements With Artificial or Actual Leak for Surveys with Earthen Materials Covering the Geomembrane

measurements. The measurement layout is such that the artificial leak is at the farthest distance from the adjacent measurements. The lines shall be centered on the artificial leak and at least 5 data points taken (at least 5 dipole spacings), along each data line.

A3.5.4 These signals are the artificial leak signal plus noise ($S + N$). The recorded leak location data shall be examined to determine the peak-to-peak leak signal plus noise to noise ratio $R = (S + N)/N$ for each of the recorded data lines. Fig. A3.3 shows an example of the measurements of N and $S + N$. The measured leak signals shall have the characteristics of a leak. Spurious, false, and unrepeatable data points that deviate from the theoretical leak signal shall not be used to determine R. The leak signal shall be represented by 5 or more data points in the data.

A3.5.5 The two farthest lateral lines or grid lines of data with an R value greater than 3.0 shall be noted and their distance to the surface projection of the artificial leak shall be recorded. The average of these distances is defined to be the leak detection distance.

A3.5.6 If site conditions prevent an R value greater than 3.0 from being obtained, the leak location survey shall be conducted with a uniform density of 1 measurement per square metre. These procedures can be followed provided the leak location equipment can be demonstrated to detect a shallower artificial leak from a lesser distance, and that the periodic leak detection distance tests described in 8.12 are made at the lesser distance.

A3.5.7 The distance from the artificial leak to the current source electrode shall be measured and recorded.

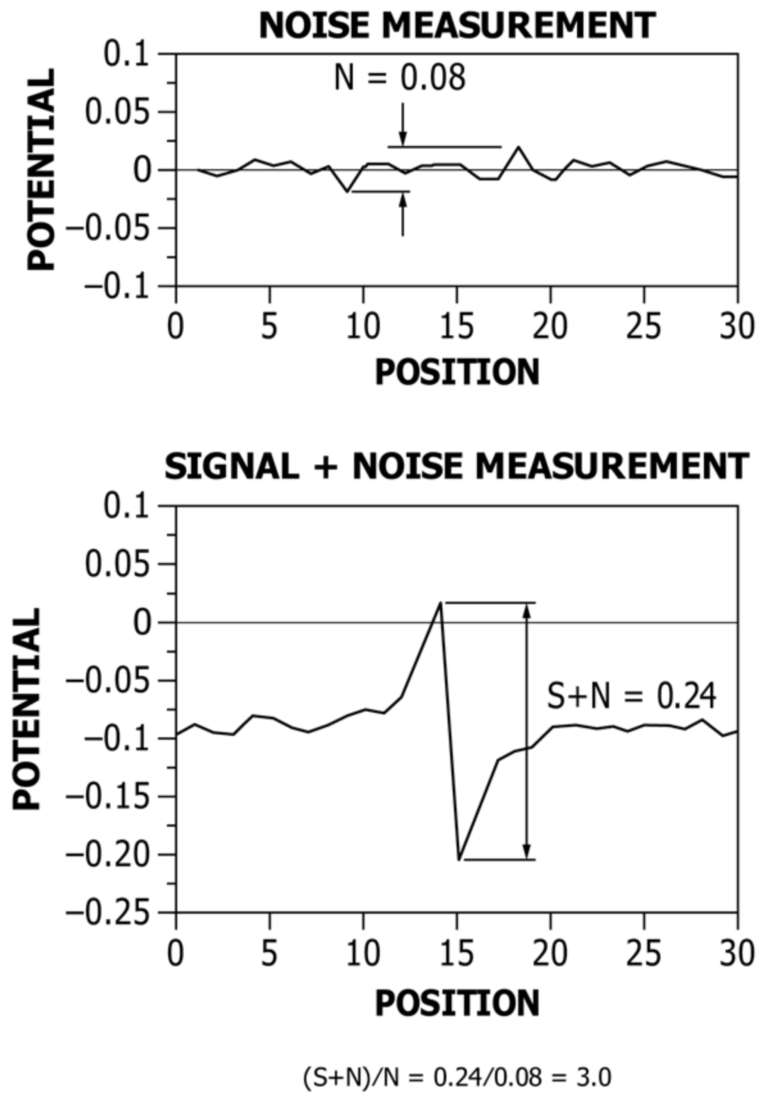

FIG. A3.3 Example of Determining (*S* + *N*) / *N*

A4. PROCEDURES FOR LEAK DETECTION DISTANCE TEST FOR SURVEYS WITH EARTHEN MATERIAL COVERING THE GEOMEMBRANE USING AN ACTUAL LEAK

A4.1 (**Warning—**Because of the high voltage that could be involved, and the shock or electrocution hazard, do not attempt to drill the actual leak hole, or touch the leak, or pour water on it when the excitation power supply is turned on.)

A4.2 *Actual Leak*—If an actual leak is used, it shall be constructed by drilling a hole with a diameter no greater than 6.4 mm in the installed geomembrane that is to be tested. For a double geomembrane system, measures shall be taken to ensure that the drill bit does not damage the secondary geomembrane. The hole shall be drilled, and the drill bit moved forward and backward in the hole so the geomembrane material is removed rather than displaced. The leak shall be placed at least 10 m from any edge of the survey area.

A4.3 The leak shall be backfilled with more than 50 mm of earthen material and then no more than 250 mL of water should be poured over the partially buried actual leak. The excavation shall then be backfilled. The location of the actual leak shall be clearly marked on the surface. The addition of water above the artificial leak is to simulate the natural conditions of real leaks, which typically have been exposed to moisture draining from the earthen material and concentrating at the surface of the impermeable geomembrane.

A4.4 *Leak Detection Distance Test*—Closely-spaced measurements shall be taken to determine the leak signal and background noise signal as follows:

A4.4.1 With the excitation power supply turned on, a line of data shall be taken and recorded either over the actual leak position before it is drilled, or at a location offset by 5 to 10 m from the actual leak position in order to measure and quantify the background noise level (*N*). The line shall extend at least 5 m in front and in back of the leak. The spacing of the measurements shall be the same as that planned for the leak location survey.

A4.4.2 The background noise level (*N*) shall be defined as the difference between the maximum and minimum measured potential with the excitation power supply turned on.

A4.4.3 With the excitation power supply turned on, leak location measurements shall be made and recorded along closely-spaced parallel lines or on a grid centered on the actual leak. The distance from each of the parallel lines or grid points to the surface projection of the actual leak shall be measured. Fig. A3.2 shows the geometry of the measurements. The measurement layout is such that the actual leak is at the farthest distance from the adjacent measurements. The lines shall be centered on the actual leak and extend at least 5 m in front and in back of the actual leak.

A4.4.4 These signals are the actual leak signal plus noise ($S + N$). The recorded leak location data shall be examined to determine the peak-to-peak leak signal plus noise to noise ratio $R = (S + N)/N$ for each of the recorded data lines. Fig. A3.3 shows an example of the measurements of N and $S + N$. The measured leak signals shall have the characteristics of a leak. Spurious, false, and unrepeatable data points that deviate from the theoretical leak signal shall not be used to determine *R*. The leak signal shall be represented by 5 or more data points in the data.

A4.4.5 The two farthest lateral lines or grid lines of data with an *R* value greater than 3.0 shall be noted and their distance to the surface projection of the actual leak shall be recorded. The average of these distances is defined to be the leak detection distance.

A4.4.6 If site conditions prevent an *R* value greater than 3.0 from being obtained, the leak location survey shall be conducted with a uniform density of 1 measurement per square metre. These procedures can be followed provided the leak location equipment can be demonstrated to detect a shallower artificial leak from a lesser distance, and that periodic leak detection distance tests described in 8.12 are made at the lesser distance.

A4.4.7 The distance from the actual leak to the current source electrode shall be measured and recorded.

APPENDIX

(Nonmandatory Information)

X1. METHODS OF DATA ANALYSIS FOR SURVEYS WITH EARTHEN MATERIAL COVERING THE GEOMEMBRANE

X1.1 The two main data analysis methodologies are graphical data analysis and voltage contour mapping data analysis. In both, the data are recorded for post-survey analysis.

X1.1.1 Graphical data analysis is where the grid pattern is established using string lines or suitable markings on the surface of the earthen materials must be sufficiently accurate and documented. The data are organized so that they correlate to a physical location in the survey area along the survey lines.

X1.1.1.1 Fig. X1.1 shows an example of graphical data analysis along several survey lines. Many such survey traverses would be created throughout the survey area. The distance along the survey line is shown on the X-axis and the voltage measurement values collected by the dipole along the survey line are plotted as corresponding values on the Y-axis. The characteristic leak signal and position is easily determined from the plots.

X1.1.2 Voltage contour mapping data analysis is where the grid pattern established for performing the survey can be controlled with sufficiently accurate GPS. The data is automatically organized spatially using GPS with a minimum precision of +20 % of the survey grid spacing. If the GPS measurement points do not have this precision, then the leak signature in the contour plot may not be discernable.

X1.1.2.1 Fig. X1.2 shows an example of voltage contour mapping data analysis in a portion of a survey area. The figure is a plan view of the survey area, with the voltage measurements plotted as contour lines. Leak locations appear as opposite peaks of positive and negative values, oriented along the direction of the survey (direction the dipole is facing when the measurement is taken). The pattern peaks will be separated by closely-spaced voltage contours. A local X and Y axis is created for the survey area in plan view, with the voltage measurements collected by the dipole contoured as isopotential lines. The voltage values are color-coded to represent positive and negative values for ease of interpretation.

X1.1.2.2 The map will likely require mapping at several contour intervals to observe all magnitudes of leak signatures throughout the range of the voltage values. Several maps will likely be required at mapping intervals of the entire dynamic range for detecting leak signals just above the noise. A separate voltage contour map should be created for each position of the current injector electrode. Sources of larger electrical leakage will appear as a larger series of peaks than sources of smaller electrical leaks, as shown in the Fig. X1.2, where Leak #1 is a more significant electrical leak than Leak #2. Creating the color range intervals is an iterative process and several maps may be required for survey areas with a large range of data.

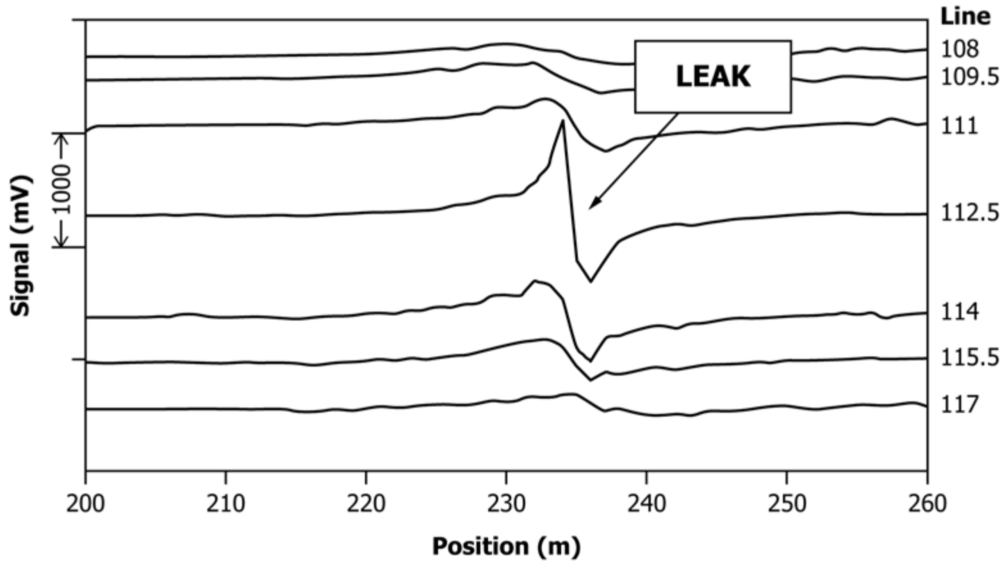

FIG. X1.1 Example of Graphical Data Analysis

X1.1.2.3 The contour intervals and the color range intervals shall be based on the artificial or actual leak (Annex A3 or Annex A4) so that the farthest signals used to determine the survey line spacing are easily discernible on the voltage contour map.

X1.2 The advantages and disadvantages for each data analysis methodology are compared in Table X1.1.

TABLE X1.1 Comparison of Data Analysis Methodologies

Method	Advantages	Disadvantages
Graphical Data Analysis	Economical	Survey lines must be established using string lines or other markings on the surface of the survey area until the leaks are marked for excavation and repair
	Data quality can be periodically assessed as survey progresses	Does not provide land survey coordinates for leak locations
	Provides quality control documentation	
Voltage Contour Mapping Data Analysis	No string lines required if survey grid directed by GPS	Requires very expensive data acquisition system and high-precison GPS
	Data quality can be periodically assessed as survey progresses	
	Provides approximate land survey coordinates for leak locations	
	Provides easily interpreted quality control documentation	

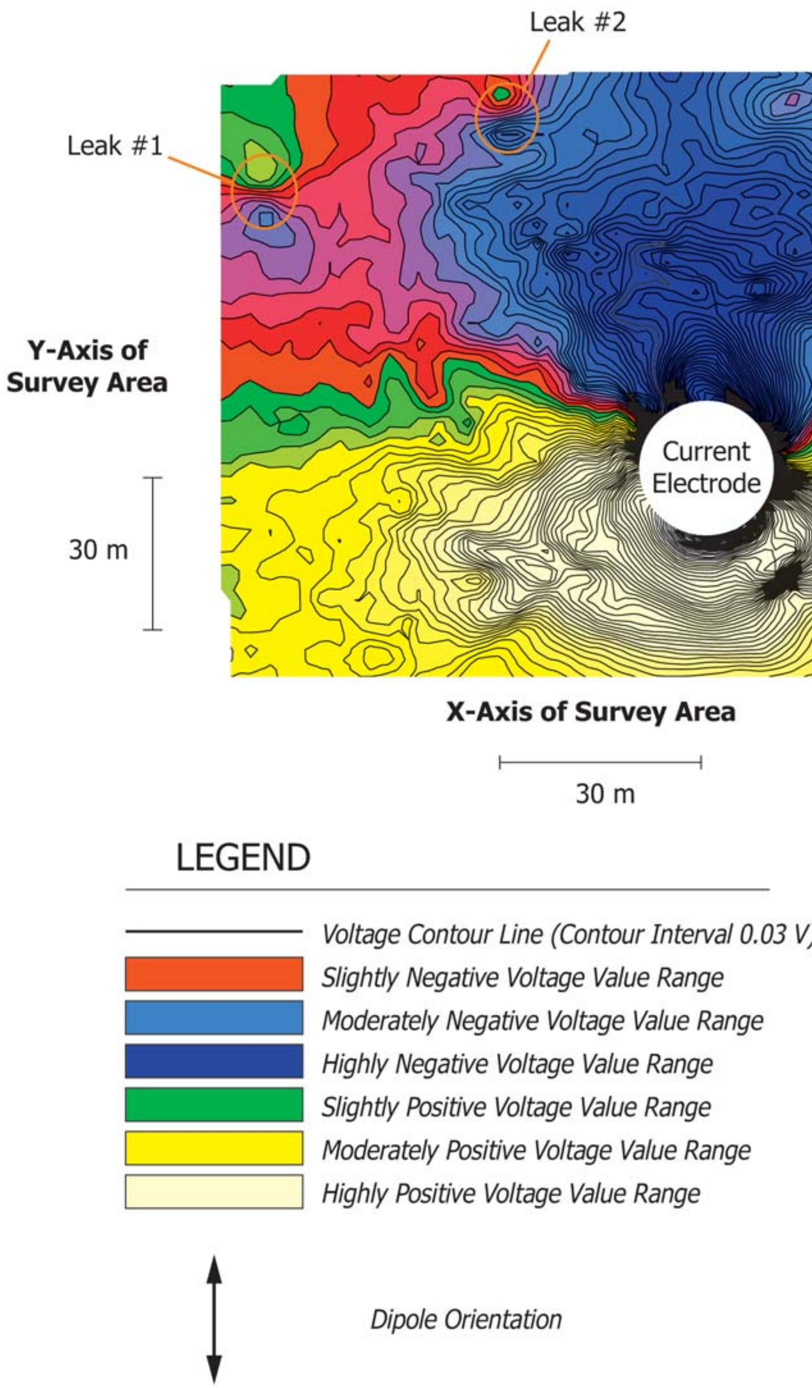

FIG. X1.2 Example of Voltage Contour Mapping Data Analysis Within Portion of Survey Area