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Standard Guide for Selection of Techniques for Electrical Leak Location of Leaks in Geomembranes[1]

This standard is issued under the fixed designation D6747; 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 This guide is intended to assist individuals or groups in assessing different options available for locating leaks in installed geomembranes using electrical methods. For clarity, this guide uses the term "leak" to mean holes, punctures, tears, knife cuts, seam defects, cracks, and similar breaches in an installed geomembrane (as defined in 3.2.3).

1.2 This guide does not cover systems that are restricted to seam testing only, nor does it cover systems that may detect leaks non-electrically. It does not cover systems that only detect the presence, but not the location of leaks.

1.3 (**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 earth 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.)

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

1.5 *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 requirements prior to use.*

2. Referenced Documents

2.1 *ASTM Standards:*[2]

D4439 Terminology for Geosynthetics

D7002 Practice for Electrical Leak Location on Exposed Geomembranes Using the Water Puddle Method

D7007 Practices for Electrical Methods for Locating Leaks in Geomembranes Covered with Water or Earthen Materials

D7240 Practice for Leak Location using Geomembranes with an Insulating Layer in Intimate Contact with a Conductive Layer via Electrical Capacitance Technique (Conductive Geomembrane Spark Test)

D7703 Practice for Electrical Leak Location on Exposed Geomembranes Using the Water Lance Method

D7953 Practice for Electrical Leak Location on Exposed Geomembranes Using the Arc Testing Method

3. Terminology

3.1 For general definitions used in this guide, refer to Terminology D4439.

3.2 *Definitions of Terms Specific to This Standard:*

3.2.1 *conductive-backed geomembrane, n*—a specialty geomembrane manufactured using the coextrusion process with an insulating layer in intimate contact with a conductive layer.

3.2.2 *electrical leak location, n*—a method which uses electrical current or electrical potential to locate leaks in a geomembrane.

3.2.3 *leak, n*—for the purposes of this guide, 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

[1] This guide is 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.

detected during surveys include, but are not limited to: burns, circular holes, linear cuts, seam defects, tears, punctures, and material defects.

3.2.4 *leak detection sensitivity, n*—the smallest leak that the leak location equipment and survey methodology are capable of detecting under a given set of conditions. The leak detection sensitivity specification is usually stated as a diameter of the smallest leak that can be likely detected.

3.2.5 *poor contact condition, n*—for the purposes of this guide, a poor contact condition means that a leak is not in intimate contact with the sufficiently conductive layer above or underneath the geomembrane to be tested. This occurs on a wrinkle or wave, under the overlap flap of a fusion weld, in an area of liner bridging and in an area where there is a subgrade depression or rut.

4. Significance and Use

4.1 Geomembranes are used as barriers to prevent liquids from leaking from landfills, ponds, and other containments. For this purpose, it is desirable that the geomembrane have as little leakage as practical.

4.2 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.

4.3 Geomembranes are often assembled in the field, either by unrolling and welding panels of the geomembrane material together in the field, unfolding flexible geomembranes in the field, or a combination of both.

4.4 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.

4.5 Experience demonstrates that geomembranes can have leaks caused during their installation and placement of material(s) on the geomembrane.

4.6 Electrical leak location methods are an effective and proven quality assurance measure to locate leaks. Such methods have been used successfully to locate leaks in electrically-insulating geomembranes such as polyethylene, polypropylene, polyvinyl chloride, chlorosulfonated polyethylene and bituminous geomembranes installed in basins, ponds, tanks, ore and waste pads, and landfill cells.

4.7 The principle behind these techniques is to place a voltage across an electrically insulating geomembrane and then locate areas where electrical current flows through leaks in the geomembrane (as shown schematically in Fig. 1). Other electrical leak paths such as pipe penetrations, flange bolts, steel drains, and batten strips on concrete and other extraneous electrical paths should be electrically isolated or insulated to prevent masking of leak signals caused by electrical short-circuiting through those preferential electrical paths. The only electrical paths should be through leaks in the geomembrane. These electrical detection methods for locating leaks in geomembranes can be performed on exposed geomembranes, on geomembranes covered with water, or on geomembranes covered with an earthen material layer.

5. Developed Methods

5.1 Electrical leak detection methods were developed in the early 1980's and commercial surveys have been available since 1985.

5.2 The principal conditions for the successful application of the methods are as follows:

5.2.1 There must be sufficiently conductive material above the geomembrane or the geomembrane should be clean and dry (extent depends on method),

5.2.2 There must be sufficiently conductive material underneath the geomembrane,

5.2.3 There must be good contact of the material above and below the geomembrane through the leak, and

5.2.4 The sufficiently conductive material above and below the geomembrane are to be in contact only through the leak locations.

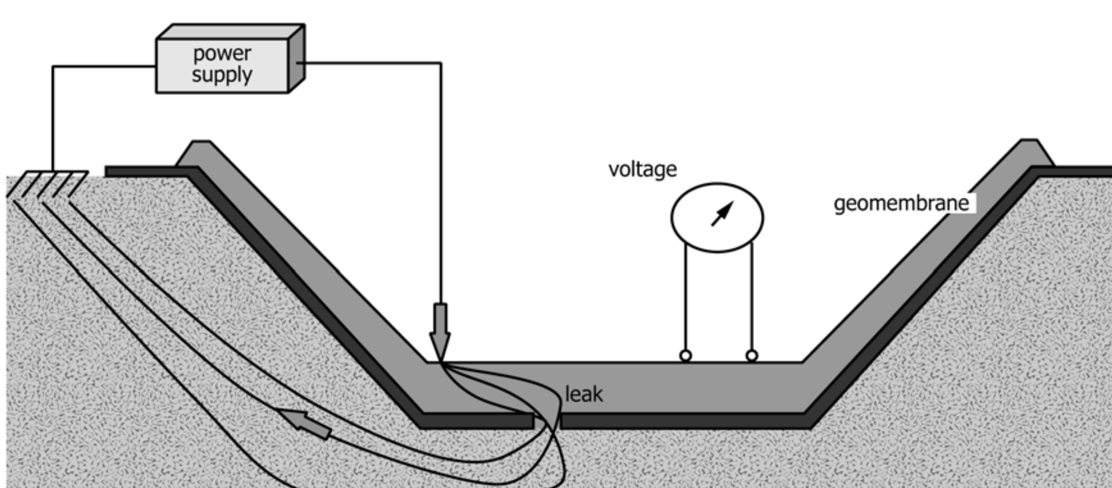

FIG. 1 Schematic of the Electrical Leak Location Method (Earthen Material-Covered Geomembrane System is Shown)

5.3 The methods can be organized into two categories depending on whether the geomembrane is bare or covered with a sufficiently conductive material. A short description of each of the methods that can be applied to these geomembrane conditions is presented in Sections 6 and 7.

5.4 Choosing which method is appropriate for a particular application will depend foremost on whether the geomembrane is bare or covered with water or earth. If the geomembrane is bare, multiple methods are effective. Each method has different features and limitations and typical leak detection sensitivities, as described in Section 6. If the geomembrane is covered, the method selection will depend on whether the material is covered with water or earth, and whether the method is to be performed as part of construction or as part of a permanent leak monitoring system, as described in Section 7.

5.5 For geomembranes that are to be covered with earthen materials, for enhanced leak detection, a bare geomembrane leak survey method should be performed before cover material is placed. The survey on the bare geomembrane will detect the smaller leaks caused during the geomembrane installation. Then after the earth material is placed, the dipole method (Practices D7007) can be used to locate any damage incurred during material placement. If only the dipole method is used, the smallest leaks caused during liner installation will likely not be detected due to the variable and generally lower sensitivity of the dipole method.

5.6 Conductive-backed geomembrane is manufactured using a coextrusion process with an insulating layer in intimate contact with a sufficiently conductive layer and can be used to overcome the subgrade conductivity and hole contact limitations of the water puddle, water lance, arc testing, and soil-covered dipole leak location methods. If it is used, the geomembrane should be installed with the manufacturer's recommended specific installation procedures and equipment to enable electrical leak location methods. If the manufacturer's specific recommendations are not followed, in most cases false positive signals will be measured along the seams. In some cases, some of the methods may not work at all. For example, the false positive signals along the seams can draw too much current away from the survey area for the dipole method to be effective, and if the water puddle method is used, false signals from the seams can mask the signal of a hole near the seam.

6. Exposed Geomembrane Methods

6.1 *Comparison of Methodologies:*

6.1.1 Currently available methods include the water puddle method (Practice D7002), the water lance method (Practice D7703), the spark testing method (Practice D7240), and the arc testing method (Practice D7953).

6.1.2 All of the methods listed in 6.1.1 are effective at locating leaks in exposed geomembranes. Each method has specific site and labor requirements, survey speeds, advantages, limitations, and cost factors. A professional specializing in the electrical leak location methods can provide advice on the advantages and disadvantages of each method for a specific project. Alternatives to a project's specified method should be accepted when warranted by site conditions, logistics, schedule, or economic reasons.

6.2 A summary of the comparisons of the exposed geomembrane electrical leak location methods is presented in Table 1.

6.3 *The Water Puddle Method—*This technique is appropriate to survey a dry uncovered geomembrane placed directly on a sufficiently conductive layer below the electrically insulating geomembrane. Practice D7002 is a standard practice describing the water puddle method. The lower sufficiently conductive material is usually the subgrade soil and the upper sufficiently conductive layer is the water in an applied puddle. One electrode of a low voltage power supply is placed in contact with the lower sufficiently conductive material and another electrode is placed in a water puddle maintained by a squeegee or roller bar (as shown schematically in Fig. 2). Water is usually supplied from a tank or other pressurized water source. For this technique to be effective in locating leaks, the water in the puddle or stream must come into contact through the leak with the electrical conducting material below the geomembrane. This completes an electrical circuit and electrical current will flow. Detector electronics are used to monitor the electrical current. The detector electronics convert a change in the current into a change in an audio tone. This method can typically locate leaks as small as 1 mm in diameter and smaller.

6.3.1 *Features—*The main advantage of this method is the detection of leaks in geomembrane seams and sheets while the geomembrane installation work progresses during construction. The method does not require covering the geomembrane with water other than the small puddle of water. Procedures can be used to differentiate smaller leaks from larger leaks in their vicinity. The electrical survey rate of approximately 1000 m^2/h per operator does not affect the installation work schedule and permits a rapid construction quality control of the geomembrane installers' finished work. The approximate setup time varies from 1 to 3 h. The method requires a minimal amount of training to be proficient.

6.3.2 *Limitations—*Unless a geomembrane manufactured with a conductive layer in intimate contact with the insulating geomembrane is being tested, leaks may not be detected in poor contact situations such as at the peak of a wrinkle and in any area where the subgrade is not in intimate contact with the geomembrane, unless measures are taken to make the contact. This technique cannot be used during rainy weather or when the membrane is installed on an electrically non-conductive material, typically a desiccated subgrade, and in the near vicinity of conductive structures that cannot be fully insulated or isolated. The detection of leaks in seams of repair patches is difficult and time consuming since it requires a potential lengthy water infiltration time. A constant water source is required for the application of the water puddle. The water applied to the geomembrane must not be allowed to flow off to the surrounding soil. The geomembrane must be reasonably clean and mostly dry at the commencement of the survey. Conductive objects such as concrete sumps, batten strips, or metal pipes connected to the conductive layer under the geomembrane must be electrically isolated from the water applied to the survey area and cannot be leak tested.

TABLE 1 Summary of Comparisons of Exposed Geomembrane Leak Location Methods (typical)

Geomembrane Type	Water Puddle	Any non-conducting or conductive-backed geomembrane[A]
	Water Lance	Any non-conducting or conductive-backed geomembrane[A]
	Spark Tester	Conductive-backed geomembrane
	Arc Tester	Any non-conducting or conductive-backed geomembrane[A]
Subgrade Conductivity	Water Puddle	Must be sufficiently conductive
	Water Lance	Must be sufficiently conductive
	Spark Tester	Not relevant; Spark testing used exclusively on conductive-backed geomembrane
	Arc Tester	Must be sufficiently conductive
Water Source Requirement	Water Puddle	Required – low volume
	Water Lance	Required – high volume
	Spark Tester	Not required
	Arc Tester	Not required
Additional Labor Requirement for Movement of Water Supply Hoses	Water Puddle	May be required
	Water Lance	May be required
	Spark Tester	Not required
	Arc Tester	Not required
Power Supply	Water Puddle	12 to 36 volts DC or AC
	Water Lance	12 to 36 volts DC or AC
	Spark Tester	6000 to 35 000 volts DC, AC, or pulsed
	Arc Tester	6000 to 35 000 volts DC, AC, or pulsed
Effectiveness on Side Slopes and Vertical Walls	Water Puddle	Effective: slightly less effective on vertical walls
	Water Lance	Can be effective: less effective on vertical walls
	Spark Tester	Effective: not dependent on contact between geomembrane and subgrade
	Arc Tester	Can be effective: project specific
Setup and Calibration Time	Water Puddle	1 hour
	Water Lance	1 hour
	Spark Tester	30 min
	Arc Tester	30 min
Measurement Time	Water Puddle	A second or two
	Water Lance	A second or two
	Spark Tester	Instantaneous
	Arc Tester	Instantaneous
Operator Training Time Requirement	Water Puddle	1 day
	Water Lance	1 day
	Spark Tester	1 hour
	Arc Tester	1 hour
Typical Survey Speed (varies depending on equipment used)	Water Puddle	1000 m^2 per hour per operator
	Water Lance	900 m^2 per hour per operator
	Spark Tester	500 m^2 per hour per operator
	Arc Tester	900 m^2 per hour per operator
Tolerance to Wet and Dirty Geomembrane	Water Puddle	Tolerant to slightly wet and dirty sites
	Water Lance	Tolerant to slightly wet and dirty sites
	Spark Tester	Tolerant to slightly dirty but dry sites
	Arc Tester	Tolerant to slightly dirty but dry sites
Effectiveness in Locating Leaks in Poor Contact Conditions[B]	Water Puddle	Somewhat effective: depends on if water can get through leak and make contact with subgrade[B]
	Water Lance	Somewhat effective: depends on if water can get through leak and make contact with subgrade[B]
	Spark Tester	Effective
	Arc Tester	Somewhat effective: depends on arc length[B]
Leak Detection Sensitivity	Water Puddle	Smaller than 1 mm diameter
	Water Lance	Smaller than 1 mm diameter
	Spark Tester	Smaller than 1 mm diameter
	Arc Tester	Smaller than 1 mm diameter

[A] If used, conductive-backed geomembrane must be installed per the manufacturer's recommendations in order to allow it to be tested using all of the available electrical leak location methods. In particular, there must be some means to break the conductive path through the fusion welds along the entire lengths of the welds, the undersides of adjacent panels (and patches) should be electrically connected together, and a means of preventing unwanted grounding at the anchor trenches or other unwanted earth grounds should be provided.

[B] If conductive-backed geomembrane is being tested and it has been installed using specific installation guidelines with the intent of enabling electrical leak location surveys, then all methods become effective at locating leaks in poor contact conditions.

6.4 *The Water Lance Method*—This technique is appropriate to survey a dry uncovered geomembrane placed directly on a sufficiently conductive layer below the electrically insulating geomembrane. Practice D7703 is a standard practice describing the water lance method. The lower sufficiently conductive material is usually the subgrade soil and the upper sufficiently conductive layer is the water in a stream of water. There are two ways to implement the water lance method set up, as detailed in Practice D7703. Fig. 3 shows one way to connect the power supply and sensor. The meter measures the voltage drop in a continuous stream of water. Another implementation is the same electrical set up as that used for the water puddle method previously shown in Fig. 2 except a continuous stream of water is used instead of a squeegee. Water is usually

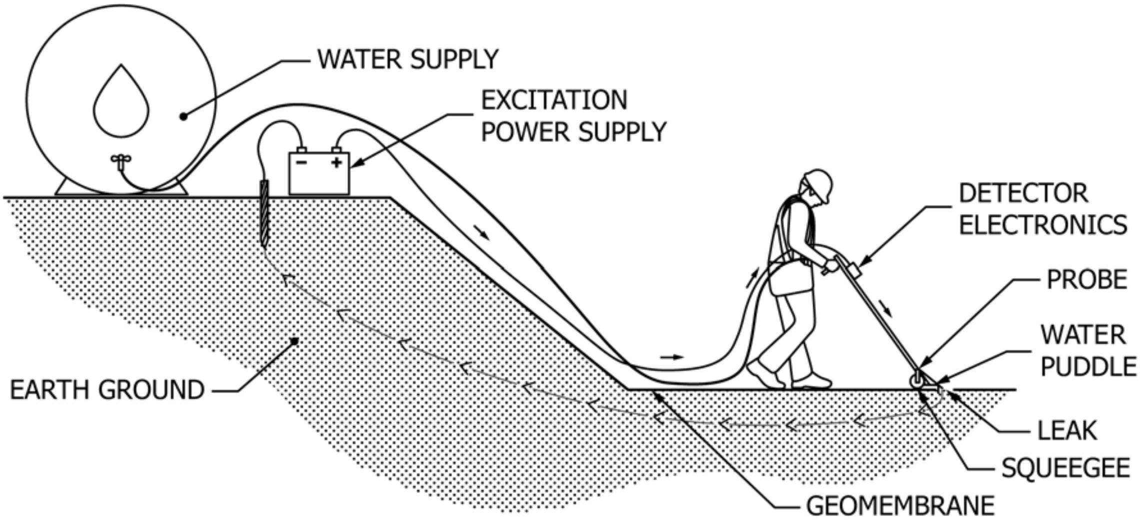

FIG. 2 Schematic of Water Puddle Method

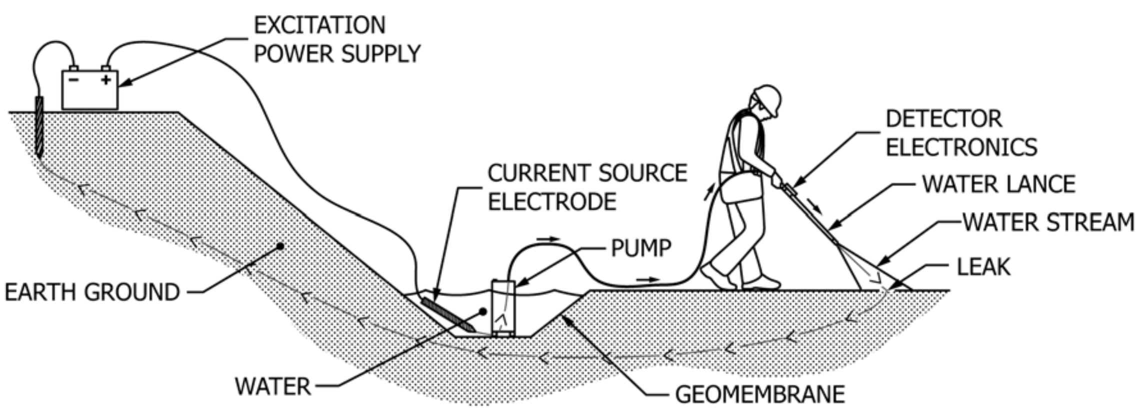

FIG. 3 Schematic of Water Lance Method

supplied from a tank, the sump or low spot of a survey area, or other pressurized water source. For this technique to be effective in locating leaks, the water in the stream must come into contact through the leak with the electrical conducting material below the geomembrane. This completes an electrical circuit and electrical current will flow. Detector electronics are used to monitor either the electrical current or the voltage between two points along the column of the water lance. The detector electronics converts a change in the current or voltage into a change in an audio tone. This method can typically locate leaks as small as 1 mm in diameter and smaller.

6.4.1 *Features*—The main advantage of this method is the detection of leaks in geomembrane seams and sheets while the geomembrane installation work progresses during construction. The method does not require covering the geomembrane with water other than the water stream. Procedures can be used to differentiate smaller leaks from larger leaks in their vicinity. The electrical survey rate of approximately 900 m^2/h per operator does not affect the installation work schedule and permits a rapid construction quality control of the geomembrane installers' finished work. The approximate setup time varies from 1 to 3 h. When the water lance is set up to measure voltage potential along the water column in the water lance, it can be less susceptible to current short-circuiting, but the overall survey sensitivity would be less than when the lance is set up to measure current. The method requires a minimal amount of training to be proficient.

6.4.2 *Limitations*—Unless a geomembrane manufactured with a conductive layer in intimate contact with the insulating geomembrane is being tested, leaks may not be detected in poor contact situations such as at the peak of a wrinkle and in any area where the subgrade is not in intimate contact with the geomembrane, unless measures are taken to make the contact. This technique cannot be used during rainy weather or when the membrane is installed on an electrically non-conductive material, typically a desiccated subgrade, and in the near vicinity of conductive structures that cannot be fully insulated or isolated. The detection of leaks in seams of repair patches is difficult and time consuming since it requires a potential lengthy water infiltration time. A constant water source is required for the application of the water stream. The water stream must be continuous to detect a leak. The water applied to the geomembrane must not be allowed to flow off to the surrounding soil. The geomembrane must be reasonably clean and mostly dry at the commencement of the survey. Conductive objects such as concrete sumps, batten strips or metal pipes connected to the conductive layer under the geomembrane must be electrically isolated from the water applied to the survey area and cannot be leak tested.

6.5 *The Arc Testing Method*—This technique is appropriate to survey a clean (or slightly dirty), dry uncovered geomembrane placed directly on a sufficiently conductive layer below the electrically insulating geomembrane. Practice D7953 is a standard practice describing the arc testing method. The lower sufficiently conductive material is usually the subgrade soil. One electrode is placed in contact with the lower sufficiently conductive material or subgrade. Another electrode is introduced above the geomembrane as an electrically conductive probe with a very high voltage power supply (as shown schematically in Fig. 4). The test probe is swept over the upper surface to inspect for the presence of leaks. Where a leak occurs, a closed circuit is created and an electrical arc is produced. In addition to a visual arc, the equipment has an audible and visual alarm. Different types of test probes can be utilized with the equipment depending on the area to be tested. For example, small probes are used in confined areas and large probes can be used on large, open areas. This method can typically locate leaks as small as 1 mm in diameter and smaller.

6.5.1 *Features*—The main advantage of this technique is that the technique is not dependant on the use of water. All slopes and vertical walls can be tested. The method can detect pinhole leaks. The electrical survey rate of approximately 900 m^2/h per operator does not affect the installation work schedule and permits a rapid construction quality control of the geomembrane installers' finished work. Repairs can be performed immediately upon location of a leak. The setup time required is approximately 30 min. The method requires very little training to be proficient.

6.5.2 *Limitations*—The maximum arc length for leak detection depends on the site conditions and equipment voltage. Unless a geomembrane manufactured with a conductive layer in intimate contact with the insulating geomembrane is being tested, leaks will not be detected in poor contact situations such as at the peak of a wrinkle, under a seam overlap flap, and in any area where the subgrade is not within the maximum arc length of the geomembrane, unless effort is made to improve the contact. This technique cannot be used during rain events. The geomembrane must be dry and clean (or slightly dirty). Conductive objects such as concrete sumps, batten strips, or metal pipes connected to the conductive layer under the geomembrane cannot be leak tested.

6.6 *The Spark Testing Method*—Coextrusion technology made it possible to manufacture a polyethylene geomembrane that can be spark tested. Practice D7240 is a standard practice for this method. The material has a thin layer of electrically conductive material on one surface as an integral part of the geomembrane. This provides a way to spark test the installed geomembrane. The conductive-backed geomembrane is installed such that the non-conductive surface is on top. The testing utilizes a very high voltage power supply to charge an element such as an electrically conductive neoprene pad. The geomembrane acts as a dielectric of a capacitor that provides a low impedance through the geomembrane. Another conductive element is then swept over the upper surface to inspect for the presence of leaks. When the probe is scanned over a leak, the high voltage causes a spark through the leak to the co-extruded lower layer as shown in Fig. 5. To facilitate leak location, equipment must include an audible alarm. Different types of equipment are utilized depending on the area to be tested. For example, small, hand-held detectors are used in confined areas and large detectors can be used on large, open areas. This method can typically locate leaks as small as 1 mm in diameter and smaller.

6.6.1 *Features*—One advantage of this technique is that the technique is not dependant on the use of water. All slopes and vertical walls can be tested. The method can detect pinhole leaks. Since the geomembrane tested is manufactured with a conductive layer in intimate contact with the insulating geomembrane, the problems of insufficiently conductive subgrade and poor hole contact are eliminated. This means that the technique can locate holes on wrinkles and waves and when the subgrade is not sufficiently conductive. It can be performed while construction is ongoing. All slopes and vertical walls can be tested. The rate of testing depends on the type of equipment used. Using a 2-m wide brush, travelling at 3 to 5 km/h, the rate can be up to 500 to 1500 m^2/h. Repairs can be performed immediately upon location of a leak. The setup time required is approximately 30 min. The method requires very little training to be proficient.

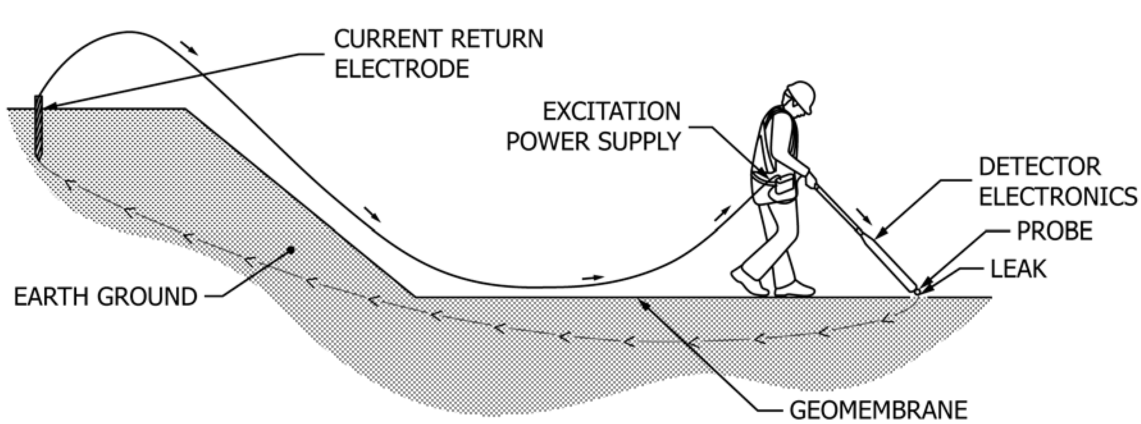

FIG. 4 Schematic of Arc Testing Method

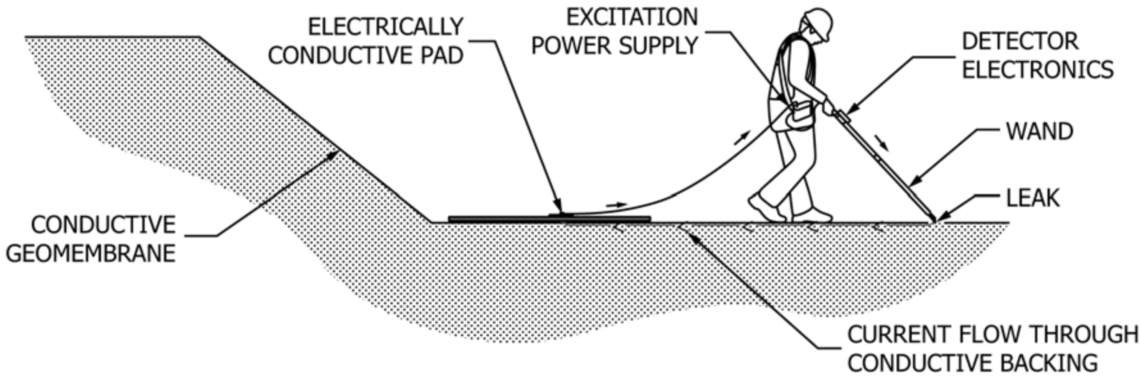

FIG. 5 Schematic of Spark Testing Method

6.6.2 *Limitations*—A geomembrane manufactured with a conductive layer in intimate contact with the insulating geomembrane (conductive-backed geomembrane) is required. The presence of wrinkles, waves and steep slopes may reduce survey speed. This technique cannot be used during rain events, and it is only applicable for exposed geomembranes with an insulating layer in intimate contact with a conductive layer that are clean (or slightly dirty) and dry. If the geomembrane coextruded with an insulating layer above a conductive layer is not installed per recommended installation procedures to enable electrical leak location methods, the seams cannot be reliably tested for leaks. Conductive objects such as concrete sumps, batten strips, or metal pipes connected to the conductive layer under the geomembrane cannot be leak tested. Leaks cannot be found under a seam overlap.

7. Covered Geomembrane Methods

7.1 *Comparison of Methodologies:*

7.1.1 Currently available methods include the dipole method (Practice D7007) and a permanent monitoring system.

7.1.2 The difference between the dipole method and the permanent monitoring system is that the dipole method is a mobile survey method and does not require any permanent electrode installation, while the permanent monitoring system requires electrode installation as part of geomembrane lining system construction. The dipole method detects and locates leaks at the time of the survey, while the permanent monitoring system provides continuous leak monitoring for as long as the monitoring system components are designed to last.

7.1.3 The dipole method is organized into two very different survey methodologies, depending on whether the geomembrane is covered with water (liquid) or earth materials. However, the survey method for geomembranes covered with water can also be used with some thickness of earthen materials, sludge or sediment on the geomembrane under the water. But because the leak detection probes cannot be scanned as close to the geomembrane, leak detection sensitivity will be decreased with greater thicknesses of the material.

7.1.4 The success of the covered geomembrane electrical leak location methods is highly dependent on site conditions (principals outlined in 5.2). Poor site conditions can adversely affect the leak detection sensitivity and in some cases prevent meeting the sensitivity requirements of the relevant ASTM standard practice.

7.2 A summary of the comparison of the covered geomembrane electrical leak location methods is presented in Table 2.

7.3 *The Water-Covered Geomembrane Method*—This method is to test the geomembrane while it is covered with water, with a sufficiently conductive material below the geomembrane. Practice D7007 contains a standard practice for this method. An electrical power supply is connected to one electrode which is placed in the water and another electrode is placed in contact with the sufficiently conductive material under the geomembrane. The voltage impressed across the geomembrane produces a low current flow and a relatively uniform voltage distribution in the material above the geomembrane. An electrical current flowing through the leaks causes localized anomalies in the electrical potential at the location of the leak as shown schematically in Fig. 6. To maximize the current flowing through the eaks, a high voltage power supply with safety circuits can be used. A hand-held probe or a probe on a long cable (drag probe) is scanned through the water to localize the current flowing through a leak. This method can typically locate leaks as small as 1.4 mm in diameter and smaller including tortuous leak paths through extrusion welds. The signal amplitude is inversely related to the distance from the leak, so the scanning spatial frequency should be designed to provide the desired leak detection sensitivity.

7.3.1 *Features*—This method has the advantage of being used to locate leaks in in-service impoundments. Primary geomembranes can be tested when a sufficiently conductive material is available underneath the geomembrane. The water covering the geomembrane ensures that any holes in the geomembrane will actively leak, providing good electrical contact with the sufficiently conductive material under the geomembrane through any leaks, resulting in optimum leak detection sensitivity even in poor contact situations. While this technique can be performed in rainy conditions, it is never recommended to do a survey during stormy conditions. The method can also be used for the detection of leaks with an earthen material layer covering the geomembrane (for example after the installation of the drainage layer on the geomembrane). Various probes are used depending primarily on the depth of the water including probes to use while wading, towed probes for deep or hazardous water, and a plumb probe for vertical walls. The survey rate depends primarily on the spacing between sweeps and the depth of the water. A close

TABLE 2 Summary of Comparisons of Covered Geomembrane Leak Location Methods (typical)

Power Supply	Dipole Method – Water Covered	36 to 75 volts DC
	Dipole Method – Soil Covered	50 to 1000 volts DC/3A (1 to 5 kW)
	Permanent Monitoring System	50 to 1000 volts DC/3A (1 to 5 kW)
Setup and Calibration Time	Dipole Method – Water Covered	Few Hours
	Dipole Method – Soil Covered	Half Day
	Permanent Monitoring System	One Hour (once system is installed)
Effectiveness on Deep Cover Materials	Dipole Method – Water Covered	Effective in deep liquid (with remote drag probe)
	Dipole Method – Soil Covered	Lower sensitivity at greater than 1 m. Not appropriate at greater than 3 m.
	Permanent Monitoring System	Effective
Effectiveness in Locating Leaks in Poor Contact Conditions[A]	Dipole Method – Water Covered	Effective
	Dipole Method – Soil Covered	Not effective for small leaks[A]
	Permanent Monitoring System	Effective if standing water is present (above the height of any in-place wrinkles)[A]
Survey/Measurement Speed	Dipole Method – Water Covered	800 to 1200 m^2 per h per operator
	Dipole Method – Soil Covered	400 to 4000 m^2 per h per operator
	Permanent Monitoring System	System dependent
Applicable for Existing Installations	Dipole Method – Water Covered	Applicable: Site specific
	Dipole Method – Soil Covered	Applicable: Site specific
	Permanent Monitoring System	Applicable: if sensors installed above the geomembrane
Leak Detection Frequency	Dipole Method – Water Covered	Once at time of survey
	Dipole Method – Soil Covered	Once at time of survey
	Permanent Monitoring System	Continuous or at desired frequency
Leak Detection Sensitivity	Dipole Method – Water Covered	Smaller than 1.4 mm diameter (when only thin or no cover soils present)
	Dipole Method – Soil Covered	Smaller than 6.4 mm diameter (for up to 0.6 m cover material)
	Permanent Monitoring System	Depends on cover material but can be as sensitivity as water-covered dipole method

[A] If comductive-backed geomembrane is being tested and it has been installed using specific installation guidelines with the intent of enabling electrical leak location surveys, then all methods become effective at locating leaks in poor contact conditions.

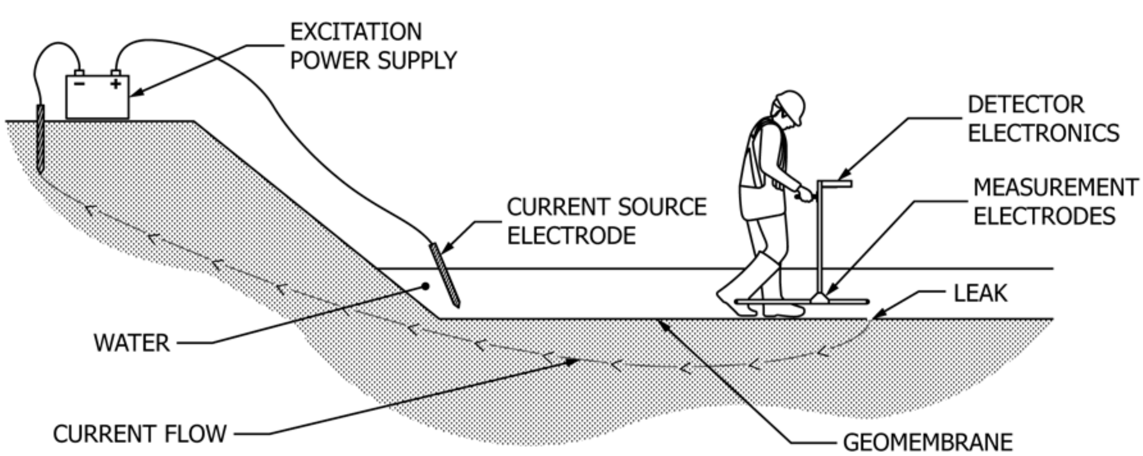

FIG. 6 Schematic of the Water-Covered Geomembrane Method

spacing between sweeps is needed to detect the smallest leaks. The survey rate for a survey while wading, sweeping the probe so that it comes within 0.25 m of every point on the submerged geomembrane is 800 to 1200 m^2/h per person. For a survey with a towed probe with the probe scanned within 0.4 m of every point, the survey rate is 800 to 1000 m^2/h per two persons, including establishing the survey lines. The approximate setup time is 30 to 90 min. These times do not include the time to cover the geomembrane with water.

7.3.2 *Limitations*—The main disadvantage of this method is that it cannot be applied to detect leaks in geomembrane joints and sheets as work progresses during construction, because of the need to cover the geomembrane with water. The presence of large leaks may interfere with the detection of small leaks in their vicinity. Large sources of current leakage such as concrete sumps, batten strips, metal pipes, or inlet or outlet pipes filled with solution can prevent the effectiveness of the method. The procedure requires the time and effort to cover the area with water, probing to locate leaks and draining the area to repair any found leaks. If the solution covering the geomembrane is highly conductive, more advanced methods than those prescribed in the Practice D7007 standard may be required. A comprehensive training program is required for operator proficiency.

7.4 *The Earthen Material-Covered Geomembrane Method*—This method is to test the geomembrane while it is covered with earthen material, with a sufficiently conductive material below the geomembrane. Practice D7007 contains a standard practice for this method. An electrical power supply is connected to one electrode which is placed in the earthen material above the geomembrane and another electrode is placed in contact with the sufficiently conductive material under the geomembrane. The voltage impressed across the geomembrane produces a low current flow and a relatively uniform voltage distribution in the material above the geomembrane. An electrical current flowing through the leaks causes localized anomalies in the electrical potential at the location of the leak. As shown in Fig. 7, it is similar to the water-covered geomembrane method except the geomembrane is covered with earthen material, and point-by-point measurements are made on the surface of the earthen material. The earthen material must have adequate moisture, but the earthen material does not have to be saturated with water. It requires a sufficiently conductive material above and below to test the geomembrane. The most common implementation of this method is to make dipole measurements using two moving electrodes spaced a fixed distance apart. Pole measurements can also be made by making potential measurements on the earthen material cover using one moving electrode referenced to a second distant stationary electrode. The data can be taken on a grid or at regular points along parallel survey lines. The data is recorded and analyzed post-survey to locate areas displaying a characteristic leak signal. The data can be analyzed in graph form or by using voltage contour plots.

7.4.1 *Features*—This method has the distinct advantage of locating leaks that are made during the placement of the earthen material layer above the geomembrane after material placement. These leaks, due to construction damage, have been found to be the most significant type of damage to geomembranes and are difficult to witness during construction quality assurance activities. This technique can be used in wet conditions. Practice D7007 specifies setting the measurement spacing based on detecting a 6.4 mm diameter actual or artificial leak for surveys with 600 mm of cover material. Leaks much smaller than that are typically found, but adverse site conditions can compromise this sensitivity. The survey rate depends on the sampling density of the measurements. The rate of testing also depends on data acquisition and interpretation methodology. The approximate survey rate for a survey taking one measurement every square meter is 400 to 1000 m^2/h per person, including establishing the survey lines. Survey speeds of up to 4000 m^2/h per person can be achieved by using a dipole measurement grid spacing of up to 3.05 m if allowed by the maximum leak detection distance. Setting up the equipment and electrodes typically requires 1 to 2 h. Sensitivity testing can take an additional 2 h.

7.4.2 *Limitations*—The overlying and underlying earthen material must have adequate electrical conductivity to perform the leak location survey. In cases where the earthen material is not sufficiently conductive (typically because it is desiccated), the earthen material should be wetted with water, or upper layers of the desiccated soil could be scraped away at the measurement points. Free-draining material such as gravel must be wetted immediately before the method is applied. Unless a geomembrane manufactured with a conductive layer in intimate contact with the insulating geomembrane is being tested, leaks may not be detected in poor contact situations such as at the peak of a wrinkle and in any area where the subgrade is not in intimate contact with the geomembrane. The cover material should be electrically isolated from the conductive layer underlying the geomembrane to be tested. Typically a perimeter isolation trench is created in the cover material, leaving the geomembrane exposed around the perimeter of the survey area. Large sources of current leakage such as access roads and metal or concrete objects traversing the geomembrane can prevent the effectiveness of the method. A comprehensive training program and substantial field experience is required for operator proficiency.

7.5 *The Permanent Monitoring System*—This permanent monitoring system has been developed to monitor leaks during construction, after construction, throughout the operational life, and during the post-operational life of a geomembrane under bottom liners and lined final covers of landfills. Fig. 8 shows a diagram of a typical installation. An electrical power supply is connected to sensor electrodes placed in a regular or irregular grid in the sufficiently conductive material above or below the geomembrane. Electrodes placed underneath the geomembrane require installation before the geomembrane is installed. Reference electrodes may be placed above or below the geomembrane, or in the earth outside of the geomembrane installation. The voltage impressed across the geomembrane produces a low current flow and a relatively uniform voltage

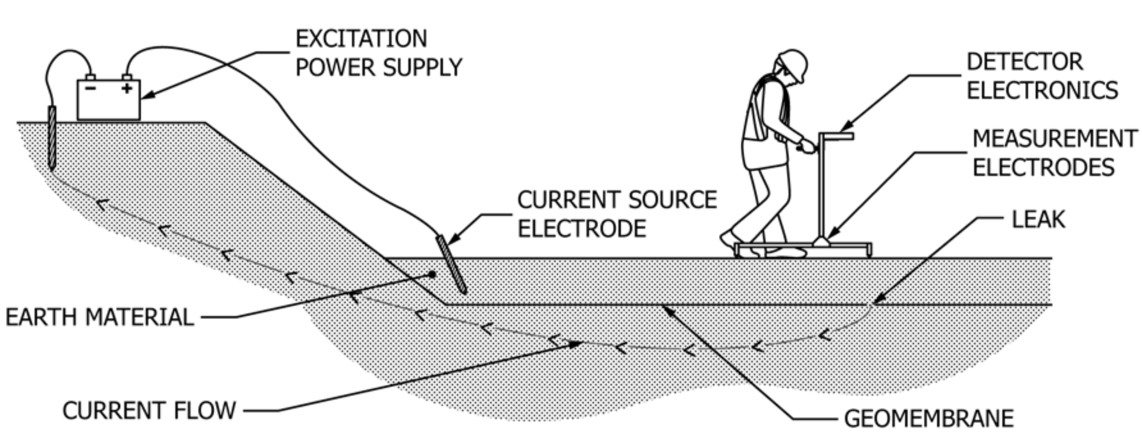

FIG. 7 Schematic of Earthen Material-Covered Geomembrane Method

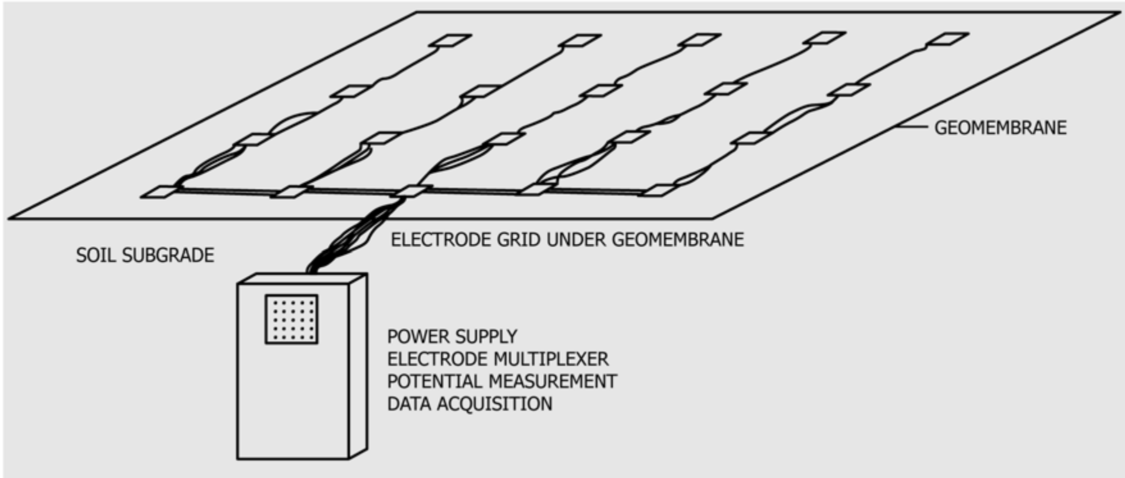

FIG. 8 Schematic of the Permanent Monitoring System

distribution in the material above the geomembrane. An electrical current flowing through the leaks causes localized anomalies in the electrical potential at the location of the leak. The leaks are located by taking potential measurement via a widely spaced grid of sensors under the lined area. The collected data are then processed to determine the location of the leak relative to the installed grid.

7.5.1 *Features*—This system is used principally as a permanent monitoring system. It can alert an operator on a continuous or periodic basis. The technique permits isolating the general location of a leak. It can be used under earthen material cover and with waste or any liquid stored in the application, even when the depth of the cover material exceeds the effective depth of the mobile leak location methods. Telemetry can be used for remote or ongoing monitoring, or both. The survey time can be very fast and depends on the degree of automation of the data acquisition system.

7.5.2 *Limitations*—The main limitation is related to the placing of the sensors under the floor area, which must be performed as part of construction. Because of the large amount of wire needed for large grids and the sophistication of the data analysis, the system requires a capital investment as part of construction. The buried components of the system must be designed to survive for as long as the system is needed. This system is sometimes used in tandem with the mobile leak detection methods to gain precise leak locations in the case of multiple leaks after the initial facility construction. The precision of the leak detection is a function of the installed grid spacing. Highly specialized knowledge is required for proper installation.

8. System Functionality and Reporting

8.1 A realistic test of the leak detection sensitivity is performed and documented as part of every leak location system or method. An actual or artificial leak is used as detailed in the relevant ASTM Standard Practice for each system or method. A final electrical leak location report is to be prepared per the relevant standard practice(s).

9. Considerations

9.1 In selecting one of the many methods described in Sections 6 and 7, the following considerations should be taken into account:

9.1.1 Subgrade restrictions (conductivity, moisture content, etc.),

9.1.2 Geosynthetics underneath or above the geomembrane,

9.1.3 Uncovered material restrictions (waves, wrinkles, steep slopes, etc.),

9.1.4 Cover material restrictions (conductivity, water saturation, etc.),

9.1.5 Water requirement (depth necessary, quantity of water needed, bottom slope),

9.1.6 Protruding accessories (pipes, steel bars, access platforms, etc.),

9.1.7 Economic factors, and

9.1.8 Intent and desired sensitivity of test.

10. Keywords

10.1 bare geomembrane survey; covered geomembrane survey; damage; electrical leak detection method; electrical leak location; electrical leak location method; electrical leak location system; exposed geomembrane; geoelectric leak location; geomembrane; leak detection; leak location survey; leak survey; liner integrity survey; permanent monitoring system; soil-covered geomembrane; water-covered geomembrane