

Enhanced Geomembrane CQA Through Proper Application of Geomembrane Leak Location Surveys

Bradford L. Smith, P.E., BCEE, Stearns & Wheeler, LLC; Glenn T. Darilek, P.E, Leak Location Services, Inc.; Daren L. Laine, Leak Location Services, Inc.

ABSTRACT

Historically, geomembrane construction quality assurance (CQA) has focused on destructive testing of welded seams to verify seam strength and integrity. Paradoxically, seams are not subject to significant stress and practically never fail in service, while holes and construction damage in the geomembrane are a much more widespread problem. The historical approach fails to evaluate how well the geomembrane performs in providing a liquid barrier, which is the primary function of a geomembrane. More recently, CQA efforts have focused on verifying liquid barrier performance using electrical leak location surveys. Engineers, installers, regulators, and owners are starting to rely on these surveys to evaluate geomembrane performance. The only function of a geomembrane is to prevent liquid flow. It is certainly prudent to spend a fraction of a percent of the construction cost of a landfill to test the performance of the geomembrane. So now a total approach is needed that incorporates a sound design that considers the most relevant and cost-effective CQA requirements, construction monitoring and testing, proper preparations for leak location surveys, and effective geomembrane leak location surveys.

Geomembrane leak location surveys using electrical methods have been used commercially for more than 20 years. Leak locations surveys are conducted on bare geomembranes, geomembranes covered with soil, and geomembranes covered with water. Industry standards have been developed for all the major electrical methods. Optimum leak detection sensitivity depends not only on the proper performance of the survey itself, but also on the design of the liner system and the proper preparation of the liner system prior to testing. The electrical method is used to detect electrical current flowing through holes in the geomembrane. The liner system design and leak location preparations should take this into consideration. Certain landfill liner designs can reduce leak detection sensitivity and hinder the detection of holes. At the same time, the detection of smaller holes requires special preparations and considerations. This paper discusses a total approach to geomembrane CQA from design to pre-construction preparation to leak location field surveys, and makes specific recommendations for enhanced geomembrane leak detection performance.

GEOMEMBRANE CQA PROBLEM ANALYSIS

More than fifteen years ago, geomembrane construction quality assurance guidelines were written to perform tests of the material suitability and physical properties of the geomembrane and to perform destructive testing of geomembrane field seams. These guidelines were incorporated into regulatory requirements, and the geomembrane industry had their “marching orders.” Soon after that, the industry realized that landfill leachate had negligible effect on the

most popular geomembrane materials, and the geomembranes rarely failed the physical tests. At the same time, with the introduction of the double wedge fusion welder, with a testable air channel, seam strength was no longer an issue. Many in the geomembrane industry feel that the current protocol of destructive testing of seams actually does more harm than good because each destructive seam test removes 1 to 1.5 meters (3 to 5 feet) of double wedge weld and requires a patch using 3.5 to 4.5 meters (12 to 15 feet) of inferior manual extrusion welding.

The only function of a geomembrane is to prevent liquid flow to the environment. Therefore, the quintessential test should be to test for liquid leakage. Although seam strength and material suitability are factors to consider, the CQA guidelines have completely disregarded the problem of holes in the geomembrane. Holes in installed geomembranes have always been a problem. Geomembrane leak location contractors have found tens of thousands of leaks in geomembranes, and the contractors have typically tested only a very small percent of the geomembrane being installed. Landfills with regulatory CQA had 4.2% of the leachate leaking through the primary geomembrane before the leachate could be pumped off the geomembrane. (Tedder). Construction damage while emplacing protective earth materials on the geomembranes is the major quality problem. One leak location contractor reported that 73% of the leaks were caused by construction activities. (Nosko). A momentous consideration for installations where an underlying geosynthetic clay liner (GCL) is used instead of a thick compacted clay liner is that construction damage that causes damage to a geomembrane will most likely also breach the GCL.

Electrical leak location surveys have been used for more than two decades on a variety of single and double lined facilities – from farm ponds to hazardous waste landfills. The methodology and results of the methods have been described in the technical literature including Laine (1989), Laine (1993), and Rollin. The number of leaks found using electrical leak location methods, and the characteristics of these leaks have been documented in many publications. Colucci reported a leak density of 15.31 leaks per hectare (6.20 leaks per acre) for geomembranes in Italian landfills. Laine (1993) reported 22.5 leaks per hectare (9.11 leaks per acre) for impoundments filled with water in the United States. Rollin reported 2.03 leaks per hectare (0.82 leaks per acre) for bare geomembranes in Canada and France. These statistics do not convey the variability of the density of leaks found using electrical leak location methods. No leaks are found during some leak location surveys, but some surveys find literally hundreds of leaks in a single facility.

Design engineers have been aware of the availability of the technology for use in the event that problems arise during construction. The experience of the primary author is that electrical leak location surveys are most common with double lined or double composite lined landfills, where a defect in the primary geomembrane may readily result in an unacceptable action leakage rate detected in the secondary collection system. The design of these facilities, while still meeting federal and state criteria, can be optimized to produce highly sensitive, and therefore accurate, leak location surveys. As more state regulatory agencies require electrical leak location in their regulations or as a standard permit condition for lined landfill facilities, the need to design the multiple component liner systems to compliment the performance of the electrical leak location survey becomes more important.

The technical guidelines for geomembrane CQA promulgated years ago were intended as a starting point, and were never intended to be permanent. Nonetheless, they have been adopted

into the regulations for every state in the United States, and similar measures were adopted throughout the world. It is time to reexamine geomembrane CQA practices and update historical practices with productive measures that test the true function of the geomembrane. Revised CQA guidelines should be adopted by the regulatory agencies and the geomembrane industry.

COMMON SENSE TESTING OF A GEOMEMBRANE

The overall goal of geomembrane construction quality assurance (CQA) should be to provide a geomembrane system that has no leaks and has very low potential for developing leaks during the lifetime of the lined facility. The best approach to improving our ability to detect defects in the geomembrane liner is to implement a total approach that incorporates design, construction, and CQA components.

After two decades of emphasis on destructive testing of seams, the industry has learned that Seams are generally quite reliable; however seams are an ineffective measure of geomembrane performance. Most protocols for destructive testing of seams may result in more harm than good. (Kerkes) (Koerner) (Thiel). Recent suggestions to reduce seam testing based on improved liner installation performance, while a step in the right direction, still ignores testing the fundamental function of the geomembrane. Some destructive testing of seams will always be needed to verify that seaming machines are operating properly and to compel quality workmanship. Making use of the essentially nondestructive pressure testing of double welded seams is a very effective measure to test seams for defects. But it does not make sense to spend project resources testing a problem that rarely arises while ignoring a problem that exists with practically every geomembrane installation. The emphasis on destructive seam testing has focused attention away from the most significant problem, which is liquid leakage through holes in the geomembrane liner.

Within the last few years, regulators and the industry are realizing the need for more effective geomembrane CQA (Phaneuf). Almost no one is challenging the need to reduce destructive testing. Many engineers and regulators are realizing that the most relevant test for a component whose function is to prevent leakage is to test for leaks. Leak location testing technology using electrical methods were developed at Southwest Research Institute in San Antonio, Texas under cooperative contracts with the U.S. Environmental Protection Agency. Commercial geomembrane leak location services using those methods have been available for more than 20 years.

Several states have adopted regulations or guidelines that require electrical leak location testing, and several other states are considering that measure. Presently there are at least 14 companies in the United States that offer electrical leak location surveys, and at least that number more internationally. The typical construction cost for a double composite landfill liner system is USD\$108 per square meter (\$10 per square foot), of which \$22 per square meter (\$2 per square foot) is spent for CQA (Duffy). It does not make sense to skip a electrical leak location survey which typically costs less than \$0.65 per square meter (\$0.06 per square foot).

DESIGN AND CONSTRUCTION PREPARATIONS FOR ELECTRIC LEAK LOCATION TESTING

The goals of a total approach to geomembrane CQA are:

- * Provide a sound design that will facilitate and enhance CQA;
- * Specify the measures to properly implement the design;
- * Monitor the construction to be sure the facility is constructed as designed; and
- * Implement and facilitate relevant testing to be sure the facility will perform as designed.

An essential part of this total approach to CQA is to perform relevant destructive and non-destructive testing of the geomembrane liner. This testing includes performing an electrical leak location survey of the installed geomembrane. Therefore, the design and the construction of the geomembrane lined facility must take into account the guidelines for best performing this type of test. This will improve the quality of the electrical leak signal, the leak detection sensitivity, and the efficiency of the electrical leak location survey. By accomplishing these goals, we can enhance the results for the electrical leak location survey and obtain the best value for the CQA investment.

The design of the geomembrane-lined facility should be considered to facilitate and enhance electrical leak location surveys to be consistent with the improving performance of the liner system. In order for electrical current to flow through the leaks, electrical continuity must exist from the material above the geomembrane, through the leaks, and to a return electrode in contact with the conducting material below the geomembrane. Therefore, there should not be an electrically-insulating layer above or below the geomembrane and the leak must have some conductive material in it. Likewise, the geomembrane must provide an electrically insulating layer with no electrical conduction paths through the seams or around the geomembrane.

The following factors provide some general guidelines for optimizing the leak detection process. In many cases it is not necessary to require the most optimal design in order to successfully perform an electrical leak location survey. In less than optimal designs the leak detection sensitivity might be decreased, but in most cases, larger leaks and construction damage caused by heavy equipment will be detected. It is important to realize that just because every small leak may not be found, that does not mean that one does not want to find any leaks. Small leaks are anticipated, as evidenced by an allowable leakage rate in regulations.

Layers and Conduction

The basic design concept behind a composite liner section consists of a drainage layer overlying a barrier layer. The barrier layer is further divided into geosynthetic barrier component overlying a soil barrier component. For double composite liner systems the designs of the primary and secondary composite liner are usually different. In order to enhance the geomembrane CQA process, the selection of each of these components must keep in mind the conditions required to improve electrical leak location survey sensitivity.

Barrier Layer. The soil component of the barrier layer of a composite liner system typically consists of low permeability soil or a geosynthetic clay liner. Either material can successfully be used in a composite liner system and provide the electrical continuity required. Earth materials generally meet these requirements if they have some moisture, and some fines or moisture content above field capacity to enter the defects in the geomembrane. One can imagine that

large, dry gravel could bridge smaller defects in the geomembrane and prevent electrical current from flowing through the defect to create a leak. This would not be a problem if water or rainfall wets the gravel to field capacity or sufficient fines with some moisture fill the defect to create continuity (a leak).

If the manufacturers' recommended minimum moisture level is maintained, geosynthetic clay liners have sufficient moisture for performing electrical leak location surveys of an overlying geomembrane. Exceptions include instances when the GCL is installed in an arid environment, and the moisture is evaporated before the GCL can be covered with geomembrane and there has been no rainfall on the geomembrane or water percolating through the cover materials. In these cases, the bare geomembrane or material-covered geomembrane must have water added to allow moisture to penetrate through the leaks. The moisture will penetrate the geotextile component and hydrate the clay component. The hydrated clay swells into the leak and also provides a larger contact area with the clay layer to establish sufficient electrical conductivity.

GCLs that include a geomembrane substrate can hinder leak detection. Construction damage (larger defects) to the geomembrane will most likely also breach the GCL, but smaller holes caused by small rock punctures or installation activities are more difficult to detect. To a lesser degree, the woven geotextile side of some GCLs can also insulate a smaller leak. If possible, the nonwoven side of the GCL should be installed away from the geomembrane if the design will permit.

Drainage Layer. The drainage component of the liner system provides the greatest variety in materials of construction and the greatest potential impact to the quality of electrical leak location surveys. In order to detect a leak, some moisture must be present in the layers above and below the geomembrane, and within the leak itself. One way to enhance these conditions is to have water present on the geomembrane surface, creating a small hydrostatic head that allows water flow through the defects to the layers below. The design intent of drainage layers is to remove water from above the liner system, reducing the head on the liner and therefore reducing the action leakage rate. However, with proper design and proper preparations, both functions can be implemented.

The primary component of many drainage layers is sand or gravel. Although coarse sands may meet most minimum permeability requirements of 1×10^{-3} cm/sec, many designs utilize an even higher permeability of up to 1 cm/sec. This permeability can only be met with clean gravel. Shredded tire material can also be used, but they are a special situation. Gravel in direct contact with geomembrane might lead directly to holes in the geomembrane. Therefore, a geotextile cushion layer is often used immediately above the geomembrane to protect it from installation damage. This cushion geotextile can provide enough water holding capacity to create the small head required to create the electrical conduit necessary to enhance geomembrane CQA. Geotextiles are usually installed dry, and if covered with dry earth materials will also create an insulating layer. Therefore, if rainfall does not wet the geotextile, the geotextile or material above the geotextile (or both) should be pre-wetted with water to provide electrical continuity through the smaller defects. Construction damage will likely force earth materials through the leak, so larger leaks would be detected without the need for added water.

Geocomposites provide another potential for providing an electrically insulating layer above the geomembrane. Some designs use a geosynthetic drainage composite immediately above the geomembrane to increase the lateral flow capacity above the geomembrane and to reduce the water head on the liner, thus reducing action leakage rates. The geonet component of a geocomposite does not, by itself, usually retain sufficient moisture. For this design approach the drainage composite should include a geotextile on the bottom of the composite, adjacent to the geomembrane to provide the electrical continuity required for enhanced electrical leak location testing if the design allows. For optimum results, measures should be taken to maintain adequate moisture in the geotextile components.

While geomembrane leaks can be detected under geocomposites, but the conditions must be controlled. Another approach for designs with a thin insulating layer above the geomembrane is to conduct an initial electrical leak location survey on the bare geomembrane to detect small leaks caused during installation, followed by a second survey with earth materials covering the geomembrane and the thin insulating area. Construction damage to the geomembrane would also breach the thin insulating layer. This approach has also been used for landfills in arid areas to enhance CQA.

Because slope areas drain much more quickly, the hydrostatic head on slopes cannot be maintained as well. Therefore, extra measures should be taken to provide moisture on the side slopes. Fortunately, smaller leaks are not as prevalent on the side slopes because there is less construction traffic and fewer seaming details on the side slopes. The primary area of concern with side slopes is near the bottom of the slope where it is difficult for equipment operators to judge where the geomembrane transitions from the flat floor to the slope. However, damage in these areas is typically more significant and can be detected without the need for additional moisture.

Leak Detection Layer. Often in a double-geomembrane system, there is often only a geonet leak detection layer placed between the geomembranes. For these installations, the layer between the geomembranes is typically flooded with water during electrical leak location surveys. However, a GCL, a sand layer, or other conductive layer will facilitate the leak location survey without having to flood the leak detection zone with water. Consideration can be given to using the proprietary conductive geomembrane with the conductive side up for the secondary geomembrane to create a suitable electrical environment. EPDM geomembranes are electrically conductive, and they could be used as the secondary geomembrane if otherwise suitable. Conductive geotextile has been used between geomembranes to provide a conductive layer, but their cost has been about three times the cost of the leak location survey and cannot be justified if a geotextile is not otherwise needed. Conductive foil with a substrate such as that used for a radiant barrier has been used in some installations to provide the electrical path. Measures must be taken to ensure the conductive sheets are connected together.

If flooding the leak detection layer with water is required, this approach can be facilitated through proper design. For the case of a water-covered geomembrane, flooding the geomembrane is routine. Measures should be taken to ensure the water level in the leak detection layer is slightly lower than the water in the impoundment to prevent the geomembrane from floating. However for the case of a soil-covered geomembrane, the water head pressure in the

leak detection layer must be less than the pressure of the soil on the geomembrane to keep it from floating. Water can be added above the primary geomembrane to provide additional downward pressure.

As an example, assume the geomembrane is covered with 600 mm (2 feet) of earth materials that have a relative density of 1.6 Mf/m^3 . (100 pcf). When the water level in the leak detection layer reaches an elevation of 960 mm (3.2 feet) above the lowest point on the geomembrane the geomembrane will just begin to float. Therefore, the primary geomembrane up to an elevation of 960 mm (3.2 feet) could be surveyed. To test above that elevation, an equivalent level of water must be added above and below the primary geomembrane. Because of the amount of water that is needed to flood the leak detection zone and counter balance the effects of liner uplift, only the floor is surveyed in these situations. Testing this system would be routine if the floor had only 960 mm (3.2 feet) of slope. So reducing the amount of slope on the floor would facilitate leak location surveys. There are minimum slopes that are required for proper drainage. However, the total amount of elevation difference on the floor can be minimized if:

- * Leak detection sumps are put in the middle of the facility if feasible;
- * The leak detection sumps are put on the longer axis of the facility; and
- * Multiple leak detection and leachate collection sumps are used.

When the leak location survey is completed, the water between the geomembranes should be removed first to prevent floating the geomembrane. This procedure also minimizes “squeeze-out”, which is the flow of residual water into the leak detection sump.

There have been a few liner installations where the leaks were so numerous and closely spaced that the signals from the individual leaks could not be differentiated. A leak signal occurs over a distance of several times the depth of the overburden. Therefore, if there are multiple closely-spaced leaks, the superimposed signals from offset leaks will augment and cancel each other to produce a signal that cannot be easily be recognized as a leak signal. The combined leak signals can appear to be background noise. Only the signals from the largest leaks can be differentiated from the mixed signal background. Good practice dictates isolating the leaks that are found and making additional measurements to see if other leaks are nearby. However, if the additional leaks are numerous, the process must be repeated many times, and individual, small leaks may not be recognized. When there are that many leaks, it is usually more economical and sound practice to replace the geomembrane and correct the conditions that caused the numerous leaks.

Extraneous Conduction Paths

Darilek (1989), Peggs (1999) and Peggs (2006) described many other design factors to facilitate electrical leak location surveys. In order to provide electrical continuity through any holes, the use of geomembrane rub sheets and protective sheets installed on the geomembrane should be avoided. If there is a leak under the rub or protective sheet, one might detect signals around the edges of the sheet where electrical current is flowing under the sheet, but the actual leak could not be located. A geotextile rub sheet would not have this problem because it is porous.

In addition, electrical isolation should exist between the conducting materials above and below the geomembrane. The electrical leak location method detects electrical current flowing through leaks in the geomembrane. Other conduction paths will also conduct electrical current and provide a large signal that will prevent the detection of smaller leaks in their vicinity, and may decrease the leak detection sensitivity to some degree throughout. Therefore, the design should consider this wherever practical.

In the case of single geomembranes, grounded structures through the geomembrane should be avoided, such as the use of metal pipe penetrations. Plastic pipe can be used, but one must also consider that the water in the plastic pipe may be grounded at a grounded metal valve or pump. Plastic pipes can be isolated using a non-conducting plug or by draining the water from behind a partly-conductive plug.

For lined concrete structures, battens should be covered with geomembrane or cast-in embedment strips can be used. Columns or stanchions or any other conductive structures should be booted with geomembrane to a level above the water or earth material. If a leak detection or leachate collection pipe drains to a wet well, the design should consider how to isolate the water in the pipe from earth ground. An isolation valve or plug can be incorporated. Underwater conductive structures such as metal grates or screens should be avoided, if possible.

In the case of a single geomembrane with earth materials placed on the geomembrane, the earth materials on the geomembrane should be isolated from earth ground by leaving a narrow width of the geomembrane exposed around the perimeter of the cell during the leak location survey. This can be accomplished by delaying the complete backfilling of the anchor trenches or leaving a strip of geomembrane exposed at the inside edge of the trench. Haul roads or earthen ramps should be designed to allow temporary isolation during the leak location survey. Otherwise, the road will provide a large interfering signal. To electrically isolate the ramp, a trench can be excavated down to the bare geomembrane to expose the bare liner. Typically, a geotextile covered with plywood is placed on the bare liner to protect the liner during the excavation process. Another approach is to have a vertical flap of sacrificial geomembrane placed on the bare geomembrane and designed to protrude from the road. The edge of the flap would need to be excavated and exposed during the leak location survey, or the flap can be welded to a length of plastic pipe that barely protrudes from the road.

Floating aerators, pumps, or suction barges in water-filled installations must be removed or insulated from earth ground. Electrical lines and conducting pipes must be disconnected. Nonconductive mooring lines can be used for electrical isolation in some cases, but if a towed probe is used to survey the geomembrane covered with deep water, the mooring lines will probably interfere with the survey.

For double-lined systems, the leak detection sump and layer between the geomembranes should be electrically isolated from the material on the primary geomembrane. If the materials between the geomembranes are effectively insulated from earth ground, then the edges of the primary geomembrane can be covered with earth materials during the leak location survey. The primary and secondary geomembranes should be welded together, or carefully buried in close contact with each other, with no GCL or other material between the geomembranes.

Means must be provided to isolate leak detection pumps and instrumentation lines from earth ground. In some cases, temporarily removing the pump is the easiest method. In other cases, disconnecting the grounding wire is sufficient, but the power conductors should be also disconnected for safety. Metal cables used for pump removal and leachate line camera inspection should also be isolated from ground during the leak location survey.

Wherever practical, for the water puddle method, the edges of the geomembrane should be propped up to prevent a signal when the water puddle overflows the edge of the geomembrane to earth ground. Likewise, grounded battens can be encapsulated with geomembrane, or a flexible flap can be installed under the batten to form an isolating barrier to allow a leak location survey up to the very edge of the geomembrane.

Other Factors

Electrical current cannot flow through the air. The quality of the survey will be impacted if the subgrade has voids or the geomembrane is bridging at the bottom of the slope. Tire ruts or track ruts placed in a wet subgrade can also result in air voids under the geomembrane. Therefore, the subgrade should be smoothly graded to eliminate air gaps.

Water puddle surveys should be conducted with the geomembrane lying flat on the conducting substrate. In particular, wrinkles are to be avoided during the survey. Wrinkles not only create an air gap but, depending on their size, may also prevent water from puddling on them. Often the flexible geomembranes can be flattened during the survey, but stiffer geomembranes such as high density polyethylene cannot be easily flattened. Therefore water puddle surveys should be accomplished in the night or early morning before wrinkles form. On the other extreme, water puddle testing on bridging geomembranes should not be attempted.

For large cells, installing a suitable current electrode between double geomembranes will enhance the sensitivity of electrical leak location surveys. The number and placement of the electrodes depends on the design. A qualified leak location contractor should be consulted. The ends of the wires to the electrodes must remain exposed, and should be protected from burial or damage. A good design is to have the ends of the wires permanently available in case subsequent operations damage the geomembrane and another leak location survey is needed.

Sandbags, scraps of geosynthetics, and other large debris should be removed from impoundments for surveys in deep water to allow a probe to be towed across the bottom with no obstructions. Scraps of metal, particularly wires, can provide false signals that may not be discerned particularly in deep water. Vegetation and thatch should be managed to allow measurements to be made on the underlying earth materials.

The final factor involves project planning. Electrical leak location surveys cannot be conducted if the water or soil is frozen.

Again, these factors provide for enhanced electrical leak location surveys. However, one need not forego a electrical leak location survey because one or more of these recommendations cannot be implemented. If these recommendations can be implemented in the design and construction stages then the sensitivity of the leak location survey can be increased. However, successful leak locations survey results have been obtained under less than ideal conditions. For example, excellent results have been obtained at large single-geomembrane installations and landfill caps where none of the edges of the geomembrane were isolated.

EFFECTIVE LEAK LOCATION SURVEYS

Specifications

Obviously, as with any technology, perfection can seldom be obtained. It is naïve to specify that the leakage through a primary liner system be zero. Fortunately, the regulations recognize that and define acceptable performance of the liner system in terms of allowable leakage rates. If we specify leak detection sensitivity for holes that are too large, the number of smaller defects that are missed may impact performance. If action leakage rates obtained after the completion of the electrical leak location are unacceptable, our CQA work becomes largely ineffective, and must be corrected. The overriding goal of the total approach is to balance the electrical leak location survey design to focus on the goals of the project.

Leak location surveys must be performed effectively and in accordance with the project specifications by a qualified electrical leak location contractor. Fortunately, the industry has established ASTM standards for the various electrical leak location methods. ASTM Standard Guide D 6747 describes the various implementations and applications of the methods. ASTM D 7002 is a standard practice for leak surveys on bare geomembranes. ASTM D7007 includes standard practices for leak location surveys with water on the geomembrane and with earth materials on the geomembrane.

The ASTM standards are performance-based standards that specify leak detection performance. Artificial or actual leaks are used to verify the leak detection sensitivity of the equipment and field procedures. Leak detection sensitivity is the smallest leak that the leak location equipment can detect. It is not sufficient to be able to detect the leak when the measurements are made directly on or over the leak. The field procedures must be tailored to allow meeting the leak detection sensitivity under worst-case measurement spacing conditions. The ASTM standards recommend leak detection sensitivities that usually can be economically met. When considering the smallest size leak that one wants to find, the obvious answer is every hole, no matter how small. While properly performed electrical leak location surveys can produce impressive results, one must temper the requirements to be realistic, attainable, and economical. Specifying the ultimate in leak detection sensitivity will require that the site conditions be near perfect, and that the leak location measurements be made at closely-spaced intervals. This mentality will greatly increase the time for and cost of locating and repairing leaks that may not significantly improve the performance of the lining system.

Contracting

The owner and design engineer have two primary options available for implementing the geomembrane CQA process. The geomembrane CQA firm can be retained by the contractor through the contract documents or they can be retained by the engineer or owner directly. Both approaches have advantages and disadvantages. Regardless of approach, it has been theorized that by knowing that geomembrane CQA will be required on the project the contractors are more careful and perform better. It has been shown that knowing that electrical leak location survey will be required on the project, contractors are more careful and perform better (Darilek 1995). Better performance of the liner system should be the goal of everyone on the team.

Having the contractor retain the geomembrane CQA and leak location firms has the disadvantage of loss of control over qualifications. The construction bidding process typically places a premium on cost and the lowest cost usually wins. This may result in some contractors searching out lower cost, but less experienced geomembrane CQA providers. There have been at least 34 companies that have performed electrical leak location surveys in the United States. Twenty of these no longer offer leak location services or are no longer in existence. Selecting a leak location contractor with experience in successful geomembrane leak location surveys is important. The results, performance, and time required to perform a leak location survey is highly operator dependent and less experienced providers may not produce the same quality field data. This may result in more time and cost, and damaged reputations in the long run.

Another potential disadvantage of this contractual relationship is that there may be the appearance of a conflict in interest because the CQA and leak location contractors are paid by the contractor and are therefore not entirely independent. At the same time, by having the contractor responsible for the entire geomembrane CQA process, the owner and engineer remove themselves from having to coordinate the process with ongoing construction activities. This is even more important if both the secondary and primary geomembranes are to be tested.

Having the geomembrane CQA implemented through either the engineer or directly by the owner under the guidance of the engineer allows a more selective process that focuses on experience and quality. This follows a quality based selection process similar to that used to select engineering firms. By selecting a geomembrane CQA firm prior to construction, specific design and construction requirements can be incorporated during the design process, thus improving the quality of the electrical leak location survey. However, any components of the electrical leak location system that are required by the geomembrane CQA firm to be installed during construction must be properly incorporated into the contract documents. The engineer's field representative must make sure that electrical leak location system preparations are properly performed during construction. And, most importantly, the owner and engineer assume the responsibility for coordinating their subconsultant with the construction activities of the contractor. Without proper communication and coordination, the contractor may be entitled to delay claims if the CQA and leak location requirements are not properly incorporated into the project schedule. Properly specifying the contractor's obligations and time allowances during the geomembrane CQA and electrical leak location will alleviate these problems.

Having the owner/engineer contract the geomembrane CQA firms directly seems to be the best way to ensure that there is no conflict of interest and that the design and specification process incorporates the electrical leak location components to enhance geomembrane CQA..

Construction Requirements

Regardless of who retains the geomembrane CQA firm, there should be several field requirements specified by the geomembrane CQA firm. These include:

- * The number and location of electrodes (location in both plan and within the liner system);
- * Routing of electrical lines to the perimeter of the cell for future electrical leak location survey connections;
- * The level of assistance from the general contractor in establishing field control and other related tasks;
- * The need for additional water to wet the liner surface. If the geomembrane and layers above the geomembrane have not had sufficient rain, one can assume that water will be needed;
- * Whether the leak detection system will need water added to it to improve continuity below the liner system; and
- * Whether the geomembrane installer should be on site during the electrical leak location survey so that repairs can be immediately made and retested.

Electrical Leak Location Field Survey Criteria

Because the most significant geomembrane damage is caused by construction machinery while placing earth materials on the geomembrane, it is most important to conduct a leak location survey after earth material is placed on the geomembrane. If more than one layer of earth materials is placed on the geomembrane, it is technically better to perform the leak location survey after the first layer is installed. However the moderate gain in the leak detection capability is usually negated by scheduling requirements. To be efficient, contractors overlap the installation of multiple layers. Therefore, to perform the leak location survey on the first layer would require the leak location contractor to be on site longer, and at least a part of the leak location survey to be in the critical path of the project schedule.

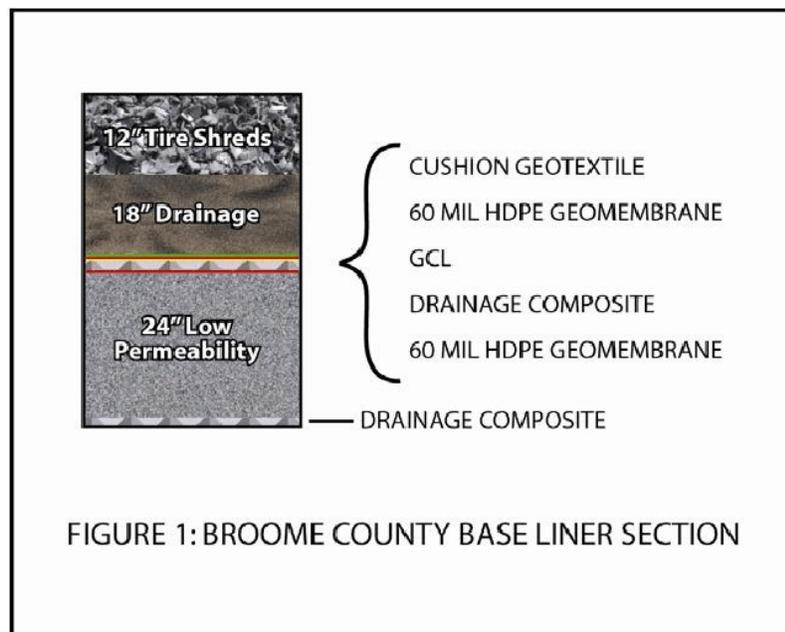
As previously mentioned, particularly for installations with a geocomposite above the geomembrane and at arid sites, the most thorough rationale is to perform a leak location survey of the bare geomembrane to detect smaller leaks, and then perform a leak location survey after the earth materials are installed to detect construction damage. The water puddle method must be performed on the bare geomembrane. The geomembrane must remain exposed with no cushion geotextile, drainage composite, etc. installed. This approach also allows for quick repair of

defects as the geomembrane is already exposed. Covered liners require the careful excavation of soil and the removal of geosynthetics prior to making repairs.

Some designs now include the use of shredded tires to provide some or all of the drainage capacity, physical separation between waste and the liner system, and frost protection in colder climates. While the shredded tire insulates the liner system from cold temperatures, they also insulate the liner system from the electrical signal that we are trying to measure. Therefore, unless extraordinary measures are attempted, testing must be performed prior to placing the shredded tires. Some designs have a final filter geotextile installed on the uppermost earth material layer. Electrical leak location surveys should be conducted before the geotextile is installed. This sequencing also facilitates repair of the leaks.

CASE HISTORY

The Broome County, New York Section IV Landfill Expansion provided an excellent example of using a total approach to enhance geomembrane CQA (Smith). The Broome County Section IV expansion consisted of approximately 4.8 hectares (12 acres) of double composite liner, 4 hectares (10 acres) of which comprised the floor of the cell. The base liner section is depicted in Figure 1.



The entire cell drains by gravity through a single, HDPE pipe penetration. The owner-engineer agreement specified that the engineer would retain the geomembrane CQA firm. Qualifications and quotes were solicited and the engineer worked directly with the selected geomembrane CQA firm during design of the cell. The contract documents specified that geomembrane CQA, including an electrical leak location survey, would be performed on the primary liner and also incorporated installation of required electrical leak location system components as part of the contract. The contractor was diligent while placing the drainage material, using a minimum of 0.9-meter (3-foot) thick haul roads for truck traffic and placing material in the morning. The

contractor also used an excavator to place the drainage material instead of pushing the material with low ground pressure bulldozers and risking the possibility of creating wrinkles in the liner system (even though this approach wasn't specified in the contract documents). Communication was maintained with both the contractor and the geomembrane CQA firm. The contractor provided laborers to assist the CQA firm with establishing field control and with adding water to the liner system ahead of testing. The electrical leak location results identified a total of 8 leaks in the liner system or less than 0.4 leaks per hectare (< 1 leak per acre), which is much better than previously reported data. All of the leaks were smaller than 6 mm (0.25 inches) and were the result of construction activities. One leak was a scratch that was most likely caused by a dropped piece of geomembrane installation equipment. One leak, although identified by the electrical leak location survey and checked twice during the survey process, was never visually identified. This may have been a broken needle in the underlying GCL penetrating the geomembrane from below. Even though this signal may have been weak, it could be detected because a total approach was used to enhance geomembrane CQA.

The action leakage rate for the primary liner system has been less than 1 liter/hectare/day (less than 0.1 gallons/acre/day.) The only time that higher leakage rates were observed was when the liner was purposely flooded with 1.5 to 1.8 meters (5 to 6 feet) of water at the pipe penetration, even though it is highly unlikely that the leachate head during operations would ever reach this level. There was a minor defect in the pipe boot, which was repaired, and the system has performed as designed and well below regulatory limits since.

CONCLUSIONS

The primary function of a geomembrane is as a liquid barrier. Historic CQA practices have focused on testing geomembrane seams rather than detecting leaks in the sheet. Electrical leak location surveys are the only commercially proven method to detect leaks through geomembranes. It is time to adopt a total approach to enhancing geomembrane CQA.

A total approach to geomembrane CQA should include electrical leak location surveys and the process should incorporate liner system design, contracting, leak location survey specifications, survey system preparation during construction, and the performance of the survey. Specific measures can be taken to enhance the electrical leak location signal and improve the quality of the survey. Electrical leak location surveys should be required after the placement of the overlying earth materials for the primary geomembranes of all landfills. Consideration should also be given to testing the secondary geomembranes for leaks. In dry areas and for certain designs, the primary geomembrane should be tested before and after earth materials are emplaced. Both geomembranes of liquid impoundments should be tested for leaks using electrical methods.

Several other factors should be considered during the total approach to enhance geomembrane CQA. These factors are intended to improve leak signal sensitivity so that smaller defects can be more readily and cost effectively detected. However, regardless of the number of these factors that can be incorporated into a given design, the benefits of an electrical leak location survey make it a prudent step for any geomembrane installation.

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CONTACT:

Mr. Bradford Smith, PE, BCEE

Stearns & Wheler, LLC

One Remington Park Drive

Cazenovia, NY 13035

Phone: 315-665-8161

Email: blsmith@stearnswheler.com