Title: CCR Barrier Systems: Mitigating Risk from Leakage with Proven Advanced Technologies

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ABSTRACT

In order to limit liability and provide maximum protection to the environment and human health, state-of-the-practice technologies must be applied to large-scale containment facilities. This paper focuses on the advanced technologies that can be applied to barrier systems at coal ash containment facilities. These methods include electrical leak location (ELL) and Leak Location Liner (LLL), which enhances ELL method capabilities and overcomes some of the method limitations in order to provide a leak-free barrier layer. After LLL installation, the spark testing ELL method is used to find even the smallest of leaks after the geomembrane installation and the dipole ELL method is subsequently used to locate the larger leaks created during cover material placement. Together, these three technologies should result in a leak-free containment facility. After the successful demonstration of the materials and methods chosen for a case study project on a small-scale test pad, the challenge was then to apply the materials and methods to a very large construction project on a disposal area using gypsum as the protective cover layer. The damage successfully located during the ELL methods for this case study is detailed. This type of damage is typical for disposal pads of this scale, as reported by dipole ELL survey results from several other coal ash landfill construction projects. Leak Location Liner installation, spark testing method performance, site preparation for the dipole method, and performance of the dipole method are all detailed and discussed.

BACKGROUND

Climate change may still be debatable. Carbon dioxide emission sources may be difficult to track and control and the enforcement of emissions is politically dicey. Groundwater contamination, however, has a clear and traceable path to its source. Allowable limits for groundwater degradation are not negotiable. Tampering or falsifying records such as groundwater quality testing is an offense that can be criminally prosecuted. Even when owners construct a facility in accordance with regulatory guidance, it still does not remove liability from the owner if groundwater contamination
occurs. One infamous case of groundwater contamination from hexavalent chromium has cost the owner more than $1.5 billion in settlements and remediation costs, decades of legal battles, and even still, remediation efforts are expected to continue until 2053. This is in spite of the fact that the facility was built to the acceptable containment standards of the time.

Coal ash residual has remained a hot topic since the TVA’s Kingston Plant failure resulted in a $1.2 billion clean-up effort. The heavy metals that can be found in coal ash include hexavalent chromium and vanadium, the former deemed carcinogenic and the latter linked to nausea, diarrhea, cramps and neurological effects. Coal ash disposal facilities must take responsibility for proper storage of coal ash waste in order to protect the lives of facility neighbors and protect their corporate reputation.

Since the inception of the idea of using geomembranes to prevent groundwater contamination, materials, installation methods and testing methods to increase geomembrane effectiveness have evolved immensely. In recent years, the recognition that electrical leak location (ELL) technology is essential to ensure the functionality of a geomembrane-lined facility has given rise to novel materials and methods to support this technology. The latest advancements in materials and methods have only recently begun their application on a large scale.

Geomembranes are an effective barrier system with extremely low permeability values. However, the integrity of the low permeability geomembrane has a high probability of being compromised during the construction phase of the project during installation of the geomembrane and cover soil placement on top of the geomembrane. In a 1996 survey (Nosko et al., 1996), it was reported that 73% of geomembrane damage occurs during cover soil placement, 24% occurs during geomembrane installation, and 2% occurs during the post-construction phase. These experiences from past projects solidify the need to have stringent construction quality assurance (CQA) practices and perform post-construction leak location surveys to ensure the integrity of the barrier system. The presence of stringent CQA can reduce the leaks in an installed geomembrane by 82% (Forget et al., 2005), and the use of both a bare geomembrane ELL survey and a soil covered ELL survey can potentially reduce leakage to zero (Beck et al., 2015).

**ELECTRICAL LEAK LOCATION**

Electrical Leak Location is a field-proven technology and currently the only economically practiced method of locating leaks in installed geomembranes both before and after cover material placement. Various ELL methods are available, but all operate on the principal that geomembranes are electrically isolative and when electricity is applied to the surface of the geomembrane and grounded to the layer beneath the geomembrane, then the path of electricity can be traced directly through any leaks present. ELL methods are typically more sensitive before the cover material is placed, which is why it is essential to leak test the geomembrane before cover material placement to find the
smallest defects incurred during geomembrane installation. The dipole method is used after cover material placement in order to locate the damage incurred during cover material placement.

Conductive-backed geomembranes were developed in response to the need to test bare geomembranes for leaks, especially double-lined facilities where the primary geomembrane is not underlain by an electrically conductive medium. The Spark Testing Method (ASTM D7240)\textsuperscript{6} was developed for leak testing conductive-backed geomembranes. Geomembranes placed on an electrically conductive layer such as subgrade can be tested for leaks using the water puddle, water lance or arc testing methods (ASTM D7002, ASTM D7703, ASTM D7953)\textsuperscript{7 8 9}. All ELL methods require a semi-conductive layer directly underneath the geomembrane to be tested to complete the circuit with the applied voltage source. The advent of conductive-backed geomembrane places that semi-conductive layer in intimate contact with the geomembrane. This ensures excellent contact between the geomembrane being tested and the “return path” of the electricity required for leak detection. Thus, even if a leak is located on a wrinkle or an area with poor contact with the subgrade, then the conductive backing of the geomembrane can carry the electricity for detection. Leaks on wrinkles can increase leakage by several orders of magnitude, and wrinkles are a ubiquitous reality for most geomembrane-lined facilities (Rowe 2011)\textsuperscript{10}. The ability to detect leaks on wrinkles can be critically important for the successful performance of a containment facility (Beck, 2014)\textsuperscript{11}.

However, one issue with conductive-backed geomembrane is that fusion-welded seams cannot be reliably tested (ASTM D7240). At the panel overlap of a fusion-welded seam, a layer of conductive material can remain intact through the fusion weld. This can carry current through the seam, which is difficult to impossible to distinguish from an actual hole through the seam. The major issue with this product is that once a geomembrane is covered with soil or water, the conductive fusion welds can compromise the electrical isolation required to perform a dipole survey (ASTM D7007)\textsuperscript{12}. Since the majority of major damage is caused during placement of soil cover material, being able to apply the dipole method is essential. Therefore, the use of conductive-backed geomembrane was previously limited to sites that would only be tested before being covered.

**LEAK LOCATION LINER**

In order to address the issue with fusion-welded overlaps, new installation guidelines were developed and a new product was coined “Leak Location Liner” for its ability to be tested using any of the ELL methods rather than only the spark testing method. The product utilizes proprietary technology, which allows seams to be reliably tested by eliminating the electrical leakage that also causes other ELL methods to be compromised or ineffective. Therefore, the dipole method can be performed on a conductive-backed geomembrane when the Leak Location Liner installation guidelines are followed, which is essential for the quality control of soil-covered geomembranes.
The Leak Location Liner installation guidelines incorporate four main points. The first is that the conductive backing of the geomembrane must be broken inside the fusion welds. This is achieved with a proprietary wedge called an “iso-wedge”. The second criterion is that extrusion-welded patches must also be isolated from the overlap flap of any fusion welds covered by the patch. This is done by cutting off and then grinding down the overlap flap until there is no longer electrical continuity from the overlap flap into the underside of the patch. Third, the extrusion-welded patches and the fusion welds must then have continuity across the back side of any separate geomembrane sheets or pieces. This is achieved by placing inverted scraps of conductive-backed geomembrane upside down across any weld or patch locations underneath the installed geomembrane. This bridges the conductive-backed layer across the discontinuity of the electrically isolated panels and patches. Lastly, the overlap flaps of the fusion welds must be cut and ground down before entering the anchor trench. This last criterion keeps the current applied above the geomembrane from traveling to the ground via fusion welds buried in the anchor trench.

CASE STUDY

The owners of a gypsum containment facility set out to apply the industry's best approach to minimize leakage for a gypsum containment application. The Leak Location Liner system was of interest due to its ability to perform all of the bare geomembrane ELL methods such as the spark testing, water puddle, water lance, and arc testing methods. The Leak Location Liner system also provides the ability to perform covered electrical leak surveys such as the dipole method. The representative of the facility was unsure of the product’s ability to perform with the gypsum cover on top of geomembrane. Therefore, a field demonstration was conducted to provide confidence in the materials and methods to the representative of the facility and the project engineer. The representative of the facility requested COMANCO Environmental Corporation as the installer to work with GSE Environmental the manufacturer and TRI Environmental the ELL testing company to setup a field demonstration. A test pad was agreed upon to test the Leak Location Liner system with a bare leak location survey and soil covered leak location survey. The facility owner representative, engineer, installer, and manufacturer agreed upon the test pad construction and testing protocol for the field demonstration.

TEST PAD

The test pad was constructed with Leak Location Liner, which was a 60 mil white double-sided textured high density polyethylene (HDPE) geomembrane with dimensions of approximately 66 ft. in width and 100 ft. in length as shown in Figure 1. These dimensions were achieved by seaming three 22.5 ft. wide panels together that were 100 ft. in length with two fusion welds.
After a bare electrical leak survey was performed, then the test pad was covered with gypsum to prepare for the covered ELL survey. The test pad was covered by two different thicknesses of gypsum. A 30 ft. width and 100 ft. length was covered with 2 ft. of gypsum while the other half was covered with 4 ft. of gypsum as shown in Figure 2.

The ELL surveys were performed in two phases. The first phase was a bare geomembrane electrical leak location survey. The engineer placed 11 defects into the geomembrane, and the installer used the spark testing method per ASTM D7240 to perform survey. All defects were repaired in preparation for the next phase of testing. The second phase of the test pad consisted of performing a dipole test per ASTM D7007. The project engineer placed 7 blind leaks in the test pad underneath the 2-foot and 4-foot cover of gypsum.

Phase 1 – Bare Geomembrane Survey. The installer utilized spark testing equipment from Tinker & Rasor in order to perform the spark testing survey. The 11 holes placed in the geomembrane were placed in different areas of concern. The defects were comprised of five 47-mil diameter holes, two 10-mil diameter holes, two punctures made with No. 2 Phillips screw driver, one 47-mil diameter hole at edge of extrusion weld on a patch, and one 47-mil diameter hole under the upper flap of a fusion weld. Nine of the eleven defects were successfully located by the installer during spark testing. One Phillips screw driver tip puncture and the 47-mil diameter hole at the edge of the extrusion weld on a patch were not detected, so the reason they were not detected was investigated.

One undetected hole was close to an area where a generator and other equipment was placed, so this area was initially not tested. Once COMANCO was notified that they had missed a leak in that area, they performed the spark testing in that area and located the previously undetected hole. The hole next to the extrusion bead on a patch did not have an audible alarm during the initial spark test but on closer inspection, there was a spark going to the hole without the audible alarm. It was explained to installer, engineer, and facility representative that testing around extrusion patches may need to
be focused on visual observation of the spark rather than the dependence on an audible sound, since it is difficult to place both the grounding pad and the spark test wand on a small patch at the same time.

Phase 2 – Soil Covered Survey. A total of seven blind leaks were installed in the test pad before the soil-covered dipole survey. The number of leaks, type of leaks, and locations of leaks were completely unknown to the dipole testing technician. The dipole method survey was performed on the test pad with a measurement density of five feet by five feet. The test pad was divided into the “North” and “South” survey areas, since the current injector electrode must be moved at least once during the survey in order to cover the entire area and one voltage map per current injector location is created. Approximately two feet of gypsum material was present on the left side of the test pad and approximately four feet of gypsum material was present on the right side of the test pad.

After the survey was completed for both the North and South ends of the test pad, the data was analyzed, as shown in Figures 3 and 4. The North and South areas were overlapped slightly in order to avoid missing details in the middle section of the test pad, so that holes 2 and 3 can actually be seen in both voltage maps.

In order to “read” a dipole voltage map, a leak signature consists of a positive peak on top of a negative peak, separated by closely spaced voltage contour lines. The positive voltage values are denoted by green, yellow and white in order of increasing magnitude. The negative voltage values are denoted by red, blue and black in order of increasing magnitude. It is the abrupt, localized change from a positive to a negative value in the direction that the data was collected that signifies a leak (in this case up and down on the presented map). If a leak signal is weak, it may still exhibit the characteristic shape of a leak signal without changing sign. This was the case for damage numbers 2 and 3, which can be seen in the first phase of mapping in the Southern area by shape only. The locations indicated by the voltage anomalies on the maps were then excavated and exposed, revealing damage locations 1 through 5 listed in Table 1.

Since electricity always follows the path of least resistance, a larger leak can mask the presence of a smaller nearby leak. Since five hole locations were excavated and isolated from the cover material, some of the locations a significant source of leakage, the entire test pad was then resurveyed, resulting in the voltage map presented as Figure 5.

Figure 5 reveals a large anomaly centered on an area where no anomaly had been detected during the initial survey of the North end of the test pad, since at that time all the current was traveling to the other, larger leaks in the pad. This anomaly turned out to be a ½” diameter leak on the four-foot thick section of the test pad. No other anomalies were noted and the survey was not repeated once the ½” diameter leak was uncovered.
It was reported after the dipole test was complete that one ¾” long knife slice was not
detected by the dipole survey. It is stated in the ASTM that knife slices cannot reliably
be located by the soil-covered dipole method. The dipole method requires that soil
and/or water is traveling through the leak to carry the electrical current in order to
enable detection. This shows the importance of performing a bare geomembrane ELL
method before the placement of cover material in order to locate installation damage
such as knife slices.

Figure 3. Voltage Contour Map of North Side of Test Pad

Figure 4. Voltage Contour Map of South Side of Test Pad
Figure 5. Voltage Contour Map of Resurvey of Entire Test Pad

Table 1. List of Holes Found During Dipole Survey

<table>
<thead>
<tr>
<th>Damage Number</th>
<th>Description of Damage Found</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>~1/2&quot; x ~2-1/2&quot; puncture</td>
</tr>
<tr>
<td>2</td>
<td>Rip/slice under fusion weld flap</td>
</tr>
<tr>
<td>3</td>
<td>(5) ~4&quot; long knife slices</td>
</tr>
<tr>
<td>4</td>
<td>Multiple punctures, ~6&quot; long</td>
</tr>
<tr>
<td>5</td>
<td>Multiple punctures, ~3&quot; long</td>
</tr>
<tr>
<td>6</td>
<td>½&quot; diameter hole</td>
</tr>
</tbody>
</table>

LARGE-SCALE TESTING

A 200-acre containment facility with a variable two to four-foot gypsum cover material thickness was specified to be constructed using Leak Location Liner. It was tested for leaks immediately after geomembrane installation using the Spark Testing Method, then tested for leaks using the dipole method after placement of the cover material.
For the dipole method, a direct current voltage is applied to the material covering the geomembrane and the current source is grounded to the semi-conductive layer beneath it. A roving dipole is used to measure and record voltage potential in a grid pattern throughout the survey area. The voltage potential measurements are observed in real time and recorded by a data acquisitioner. The data can be analyzed in graphical format or as a voltage contour map for post-survey data review.

Applying this method to a large scale site, especially one that does not have tidy square or rectangular geometry, can be a daunting task when it comes to data organization. Data is typically collected along string lines throughout the survey area and each line is manually organized in order to be able to return to any locations with a suspected leak. GPS-based data acquisition allows the survey to be efficiently completed on any geometry. Additionally, the GPS-based data can be easily organized into a voltage contour map and the GPS-guided measurement locations can be displayed on the map to show that the survey area was completely covered. This type of map provides extreme comfort to all parties involved that the method is being performed accurately and thoroughly. GPS-based data acquisition is also much faster than manually mapping out an area with string lines. For large sites, survey speed becomes an important factor. Dipole surveying would likely not be feasible with manual string line mapping due to its slow progression resulting in excessive construction delays.

The sensitivity of the soil-covered dipole method varies wildly and is mainly a function of site conditions. Pinholes have been found through 0.6 meters of well-watered gravel material, but at other sites a one meter diameter hole can barely be detected. Even though a minimum detectable hole size is prescribed by the ASTM, actual survey area sensitivity cannot be controlled by how the test is conducted. A few things can be done to slightly increase the chance of locating a hole such as increasing the measurement density, but these few things can only help so much to mitigate poor site conditions. The required site conditions mainly entail sufficient moisture content in the cover and subgrade material and survey area isolation. Since moisture can always be added to the cover material during the survey, the most important aspect of preparing a site for a dipole survey is cover material isolation. What is meant by this is that the soil covering the geomembrane cannot be in contact with the subgrade soil anywhere except for where there is a leak. Electricity always travels the path of least resistance and if the perimeter of a survey area is not isolated (i.e. an access road is in place), electricity will preferentially flow through the larger mass of soil at the perimeter rather than the small leaks in the geomembrane. Survey area isolation is typically achieved by placing the cover material just short of the perimeter terminations so that a strip of geomembrane about a half meter wide is left open along the entire perimeter of the survey area. ASTM D7007 is set up to reliably detect leaks as small as 6.4mm (1/4") in diameter, but this is only possible if the site has been prepared per ASTM recommendations including survey area isolation.

If an access road needs to remain in place, which is common for large sites where the dipole method is sometimes performed while construction is ongoing, then the access road needs to be electrically isolated. This can be achieved by inserting a scrap of
geomembrane across the road, bisecting the soil material so that the soil can remain in place but electricity cannot travel through it.

Before beginning construction, several educational meetings were held in order to help the earthworks contractor understand the isolation requirement for the dipole testing. A plan was created for the sequence of areas to be tested while maintaining electrical isolation and surface water drainage paths away from the working area and the isolation trenches. To address safety concerns, the dipole method ELL contractor committed to using a current limiter for the direct current power source in order to keep the applied current below the level that could potentially stop the human heart in the case of poor operator adherence to internal standard operating procedures.

DAMAGE AVOIDED

Small holes caused during geomembrane installation were located during the spark testing method, but it is the holes encountered during the dipole method that take the spotlight. The damage shown in Figure 6 was found during the second mobilization at the case study site. The electrical response of this damage location is shown in Figure 7. This damage was caused even when every precaution was taken to prevent damage to the liner and the contractor knew that a leak location survey would be performed behind him.

Figure 6. Damage Found During Dipole Method Survey at Case Study Site
This type of damage is, unfortunately, not uncommon at coal ash facilities. Figures 8 through 10 show damage encountered during dipole method leak location surveys at various coal ash facilities. Note that in Figure 7, the GCL underneath the geomembrane was also torn by the equipment blade, leaving a direct path through both barrier layers of the lining system.

Figure 8. Damage Found During Dipole Method Survey at Coal Ash Landfill
Figure 9. Damage Found During Dipole Method Survey at Coal Ash Landfill. Photo Courtesy of Tony Oberhausen

Figure 10. Damage Found During Dipole Method Survey at Coal Ash Landfill. Photo Courtesy of Tony Oberhausen
CONCLUSIONS

The test pad constructed before beginning of this case study project served two important goals. The first was for the owner of the facility to gain confidence in the materials and methods subsequently employed in the large-scale containment facility. The second was to understand both the abilities and limitations of all of the materials and methods applied. The ELL methods can be 100% effective on the Leak Location Liner product, but certain site conditions and locations and geometries of the actual holes themselves can preclude detection. If these limitations are well understood, they can be mitigated.

The construction of the 200-acre facility proved that these materials and methods can be successfully applied on a large scale without compromising the construction schedule. The damage located during the ELL surveys proved how essential these technologies are in order to construct a leak-free containment facility which can mitigate the risks on CCR barrier systems.

The effectiveness of an installed geomembrane varies depending on the site design, material, installation practices, testing methods and maintenance practices during the life of the site. By using currently available technologies, regulators, design engineers and site owners can specify a system like the one described in this case study in order to ensure that the highest possible level of containment is achieved. Currently, ELL is the best method available to check an installed geomembrane for leaks. It makes no sense why anyone would venture to install a geomembrane whose sole purpose is to prevent liquid migration without checking it for leaks after decades of reports of construction damage, welding issues, and other causes of geomembrane failure. With the invention of Leak Location Liner, ELL has become even more effective. It is perhaps impossible to know for certain if a project like this will achieve the goal of zero leakage, but the methods described here can be systematically applied, even at the large scale of the project in this case study, in order to achieve the lowest possible leakage with currently available technologies.

With global shortages in quality drinking water, the protection of groundwater should be of utmost importance. It is every engineer and site owner’s moral imperative to employ every effort to protect Earth’s most precious resource.

REFERENCES


