Conditions Required for the Successful Performance of Geoelectric Liner Integrity and Leak Location Surveys

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ABSTRACT
The regulatory needs for geoelectric liner integrity surveys as the final stage of geomembrane CQA are increasing. Statistics show the unquestionable benefits of such surveys, even when experienced CQA has been performed. However, there are a number of controlling factors that determine whether a survey can effectively be performed. It is essential that these controlling factors be understood by design/CQA engineers and regulators who require surveys to be done as the final stage of CQA. They must also be understood by engineers and survey providers wanting to locate problematic leaks in existing systems. The former must design a system that can be surveyed. Without this knowledge a survey may be performed, there may appear to be no holes or leaks, but they may simply have been missed. The controlling factors and the principles for performing effective surveys are presented.

1. INTRODUCTION

All geomembrane lining systems cannot be successfully surveyed by the applied potential geoelectric method. If such systems are surveyed no leak indication signals will be generated and the liner will appear to be in good shape when it may not be. New lining systems must be carefully designed for the performance of geoelectric integrity surveys as part of the construction quality assurance (CQA) program, and existing lining systems must be carefully assessed for the performance of successful leak location surveys (problem resolution).

There are typically three types of surveys that are increasingly being specified by engineering consultants and regulators:

- Liner integrity surveys (LIS) as the last stage of new construction CQA
- Liner condition surveys of existing facilities on a periodic (4 or 5 year) basis, and
- Surveys to locate and repair problematic leaks that otherwise might cause facility shutdown

2. SURVEY REQUIREMENTS

Whether the liner is covered by soil or water both require the same simple controlling factors (boundary conditions) for meaningful results to be obtained:

1. There must be an electrically conductive medium above the geomembrane being surveyed.
2. There must be a conductive medium through the holes being sought.
3. There must be a conductive medium directly underneath the geomembrane.
4. Current must only flow from one side of the liner to the other through the holes being sought.

The two areas where these requirement cause most difficulty are in soil-covered single liners where the soil above the liner should not be in electrical contact with the subgrade soil at the periphery of the cell, and in double liners, when there is only a geonet or geotextile/geonet/geotextile composite (geocomposite) in the leakage detection system (LDS) between the geomembrane. The soil-covered liner contravenes Condition 4 and requires a channel exposing the geomembrane to be left or excavated around the periphery of the cell during the survey. The geocomposite-only LDS contravenes Condition 3, and can only remedied by backfilling the LDS with water or by allowing leaking water to accumulate in the LDS. But then the liner can only be surveyed where there is water in contact with the liner. Clearly, it is better to design the LDS with a conductive layer in it – damp sand, GCL, conductive geomembrane, or conductive geotextile.

3. SURVEY TECHNOLOGY

The survey technology is based on the assumption that the geomembrane is an electrical insulator. A direct current (DC) potential is applied across the liner from a current injector electrode (CIE) in the water or soil cover, to a current return electrode (CRE) in the subgrade soil or attached to the conductive layer in the LDS (see Figure 1). The potential gradients in the water or soil cover are surveyed to locate the unique signal (Figure 2) that occurs where the current density increases to pass through a leak. Therefore, it is necessary that there be a continuous circuit between the current injector and current return electrodes.

A simple analogy is measuring the water surface elevation gradient in a pond with a large whirlpool over a leak. Well away from the leak the surface gradient is essentially zero. As the leading electrode approaches and enters the whirlpool the gradient increases until it becomes a maximum when the leading electrode is directly over the hole. When the two electrodes are equidistant astride the hole the gradient is zero. Then, when the trailing electrode moves directly over the hole there is another maximum gradient but of the opposite sign to the previous maximum. Finally, as the survey probe climbs out of the whirlpool the gradient decreases to zero, as shown in Figure 2.

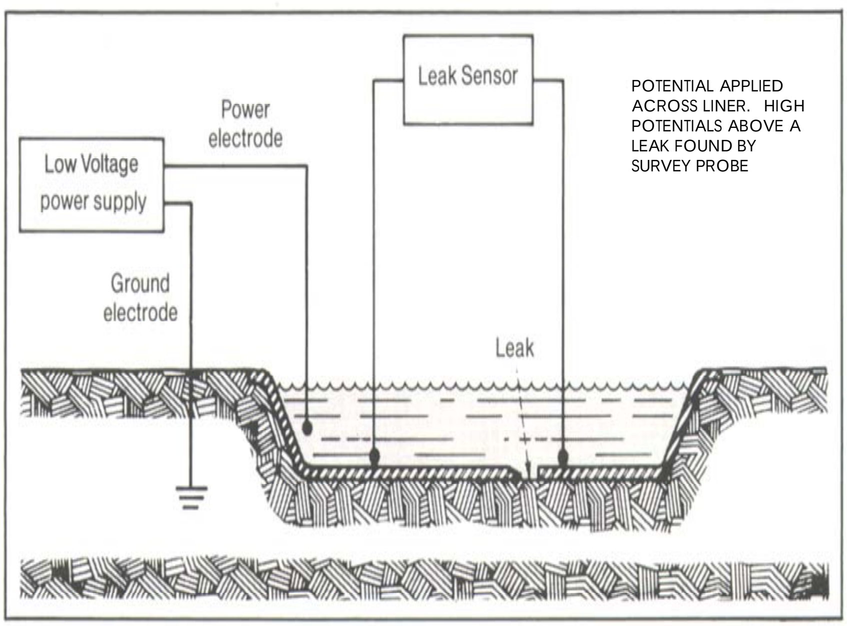

Figure 1. Patent sketch showing electrode and dipole (two-electrode) survey probe. Scale is misleading – survey probe electrodes are about 1 m apart.

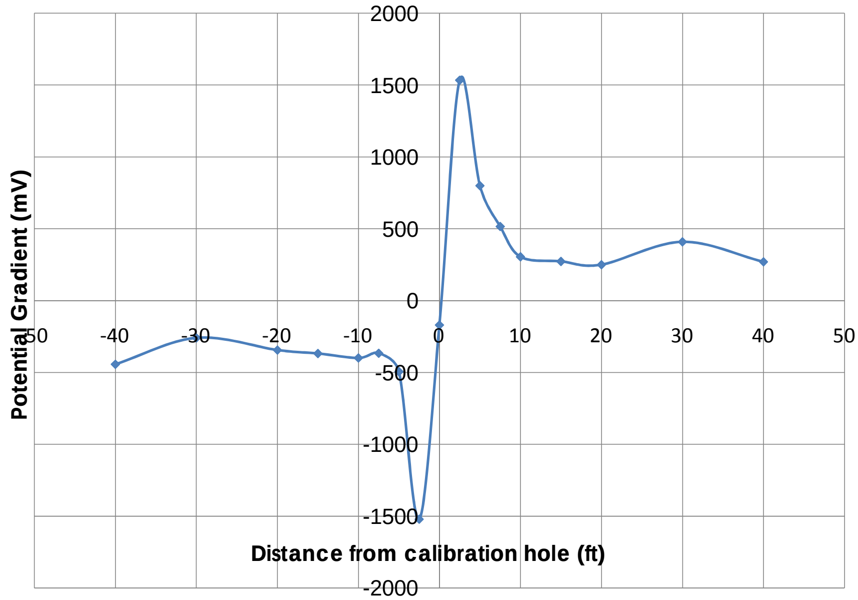

Figure 2. Characteristic potential gradient signal at a leak.

In a landfill double lining system this might require the following for example:

- Injector electrode firmly embedded in, and in good contact with, soil protective layer
- Moist (conductive) protective layer soil
- Moist separation geotextile between protective layer and drainage gravel
- Moist drainage gravel
- Moisture in, or adequately wet, primary drainage geocomposite
- Water or soil through any leak. No cavities under, or air bubbles in, leaks
- Conductive medium under the primary geomembrane from any leak to wherever the current return electrode can be placed. For a single liner the CRE will be in the soil, or attached to a metal fence surrounding the cell. For a double liner the CRE will typically be in the water/leachate-filled secondary sump. It has been found that the leaking water pathway from hole to secondary sump may not be sufficiently conductive to rely upon.

If there is not good contact between electrodes and soil, or if any of the layers are too dry, current will not flow, and any holes that are present will not be detected. A good example follows.

4. PROBLEMATIC CALIBRATION

Liner damage was suspected in the primary liner of the following new lining system, from the top down:

- 450 mm clayey protective/operations layer – quite wet
- Separation nonwoven geotextile
- 150 mm gravel drainage layer
- Geocomposite
- Primary HDPE geomembrane
- GCL
- Geocomposite (LDS)
- Secondary HDPE geomembrane.

The current injector electrode (CIE) was placed in the clayey operations layer. The current return electrode (CRE) was placed through the primary geomembrane into the GCL at the edge of the cell, as shown in Figure 3.

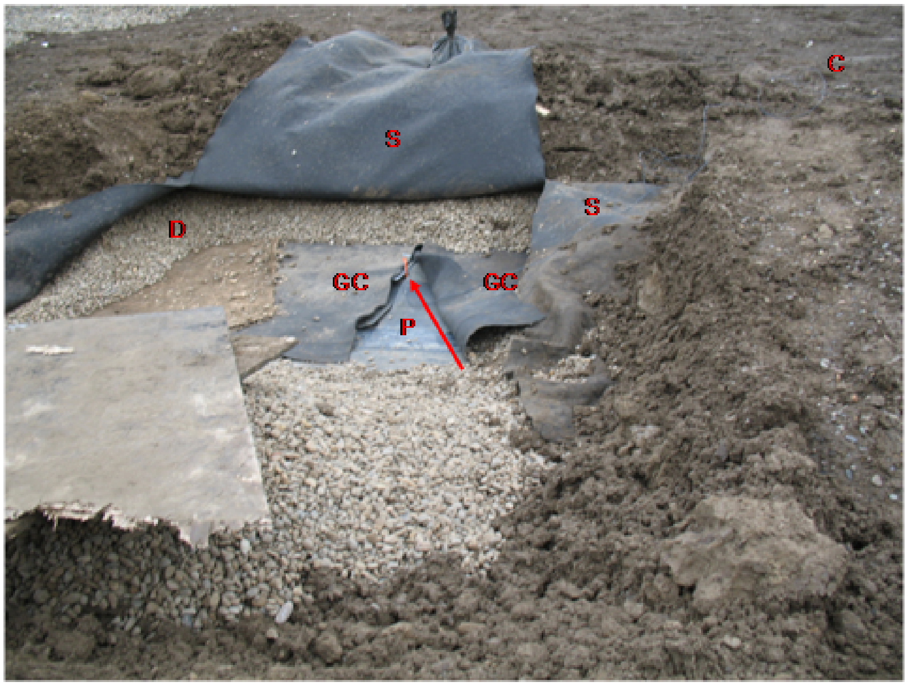

Figure 3. CRE (arrowed) attached to GCL under primary geomembrane (P). Primary geocomposite (GC), gravel drainage layer (D), separation geotextile (S), clay operations layer (C)

An artificial calibration hole (ACH - the end of a cut wire) was buried on top of the geomembrane. A potential was applied between the CIE and the ACH, but there was no current flow down through the cover layers. Clearly there was an insulating barrier in the lining system between the CIE and the ACH. At this point the CRE was not involved with the survey – it would become involved after calibration. The ACH was moved up to the bottom of the protective layer. As expected there was ample current flow through the wet soil. The ACH was moved down into the middle of the separation geotextile. There was no current flow – the geotextile was too dry, despite the wet soil above. The ACH was moved down into the gravel drainage layer. Again, but as expected, there was no current flow. To confirm the condition of the gravel layer, the ACH was left in place and the CIE moved into the gravel layer at the edge of the cell, to check current flow within the gravel layer itself. There was no current flow – the gravel was too dry. Therefore an effective survey could not be made through this lining system.

Watering the surface would not help since the operations layer would not allow such water to penetrate through it. It was suggested the operations layer be removed since the area of concern was not too large. The owner asked if a survey would be successful if that was done. To confirm that the GCL was adequately conductive (occasionally a GCL dries out) both the CIE and ACH were placed in the bentonite of the GCL some distance apart. Current flowed indicating that the GCL would not be a problem. The owner was assured a survey would be successful.

The protective layer and the separation geotextile were removed, and the gravel was thoroughly watered to ensure the geocomposite and top of the geomembrane would also be wetted. The CIE was placed in the wet gravel above the geomembrane, and the ACH was placed on top of the primary geomembrane under the geocomposite. Current flowed, indicating that a successful survey would be possible. A calibration traverse over the surface of the gravel generated the characteristic leak signal above the ACH. Therefore the system was working satisfactorily. The production survey was performed with the potential applied between the CIE in the gravel and the CRE in the GCL. No damage was found. The owner and engineer were satisfied. This is a good example of what can prevent a successful survey and the features that should be considered to enable a survey to be performed. Thus calibration is extremely important.

5. DESIGN AND SURVEY CONSIDERATIONS

Other features that need careful consideration at the design stage or when trying to find that troublesome leak include:

- Metal pipes (conductive) penetrating a single liner, which appear as large leaks, and which may swamp signals from a real leak in the boot welds/clamps.
- Plastic pipes penetrating a single liner, since the water in the pipe will likely make contact with a grounded valve some way down the pipe. This can be resolved by placing an inflatable rubber bung in the pipe opening to isolate the pathway through the water in the pipe. However, do not use a mechanically expanding plug that is expanded by screwing plates on each face together – the bolt through the centre is conductive.
- Pipe penetrations at concrete thrust blocks, or any concrete structure penetrating the liner, since concrete is conductive. Concrete structures should be covered with liner.
- Metal batten strips, since they too will appear as leaks, thereby preventing the detection of small leaks at locations where they might be prevalent.
- Aerators and other electrical equipment in ponds. Not only should they be switched off, they should be disconnected.
- Stainless steel cables tethering aerators in ponds that sag into the water should be lifted or replaced with plastic ropes
- Manholes for monitoring leakage. Are they plastic, concrete, coated concrete, or does it matter whether or not they go to ground?
- Haul roads into the cell, since they may need cutting at the top to isolate above and below liner soils
- Leakage removal pipes entering manholes – plastic or metal? Do pipes enter above or below sump water level If above the water level is there a continuous stream (conductive) or is the water only dripping (nonconductive)?
- Concrete columns and walls – fasten liner above water line rather than below water line
- Obstructions to probes and tripping hazards on liner – avoid where possible
- Conductive geomembrane – consider the possibility of false positive readings along the free flap of fusion welds (see ASTM D7240). Extrusion welds do not have the same concern. Also consider the need to ensure the continuity of the conductive layer from panel to panel in double lining systems with only a geocomposite LDS (nonconductive). This is not a problem in single liners on soil (conductive).
- GCL moisture content – ensure they do not dry out and become nonconductive, particularly in an LDS between two geomembranes. May need irrigating before covering
- Primary leachate geocomposite drainage layers - in new installations may need wetting to make conductive before covering. Established systems should not be a problem
- Double geomembranes in anchor trench – welded together or not? Ensure conductive GCL is not in subgrade contact
- Cell contents – if totally contained and isolated it is immaterial what happens outside liner
- LDS system – if totally contained and isolated it is immaterial what goes to ground from water or soil in the cell
- Large area liners such as for heap leach pads and in mine tailings, ash, and evaporation ponds – may need several CREs installed under the liner during construction.
- GCLs – while a GCL under a geomembrane can facilitate a successful survey, a GCL liner alone (conductive) cannot be surveyed by the applied potential method.
- If a single exposed liner is being surveyed and it rains, the survey will become ineffective since current flows from the pond water through the wet film on the slopes to ground.
- If it rains on the exposed primary liner of a double liner, the survey may be continued if the conductive contents of the LDS are fully isolated from ground.

- Protective layer – if a sacrificial geomembrane is used to protect the liner, for example under a leachate drain pipe, a hole in the liner will only be signalled weakly at the edge of the sacrificial panel. However, if a geotextile is used, the hole will be accurately located.
- Landfill cap – if welded to the bottom liner a hole will have to be made through the cap to insert the current return electrode in the substrate soil.
- Landfill cap – if the cap is an umbrella-type cap the periphery of the cap will have to be exposed to isolate the cover soil from the peripheral soil

6. MAXIMUM ALLOWABLE LEAK FLOW RATES

It is now accepted liner design practice to assume that all single liners leak to some degree, therefore the maximum allowable hole size should be specified, and this will vary with depth of soil, but not water, above the liner. If no hole size is specified, ASTM D7007 recommends 6 mm diameter. On the other hand it is unreasonable to use anything less than 2.5 mm for calibration purposes. If no minimum hole size is specified there can be much discussion about what constitutes a hole? Typically the maximum allowable leak flow rate for a liner covers the very small holes (Figure 4), while the surveys are used to find the larger holes, such as that in Figure 5, of which there are a disappointingly large number.

Figure 4. Small hole (at pen tip top right and left) found under 600 mm sand cover, and particle making it (bottom right).

Figure 5. Typical large hole caused by mechanical equipment.

In US landfills the primary liner typical maximum allowable leak flow rate, the Action Leak Rate (ALR), above which the leak(s) must be found and repaired, is typically 200 litres per hectare day (lphd). The hydraulic head on the geomembrane should not exceed 300 mm. In municipal waste water treatment ponds under a 2 m head the typical ALR is 5000 lphd. This is too high. It could be closer to 2000 lphd. However, an ALR of 65,000 lphd under a 5 m head has also been seen. This is way too high.

7. CONCLUSIONS

- When performed properly geoelectric integrity and leak location surveys are extremely successful and cost effective. However, it is easy to do them incorrectly and to achieve the appearance of a non-leaking liner. Rarely is a survey performed that finds no leaks.
- The three essential boundary conditions required for a successful survey are conductive media above the liner, through holes, and below the liner. Also there should be no, or little, contact between the media above and below the liner.
- Proper calibration is extremely important.