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Study of the use of electrical leak/damage detection and location systems around the world

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ABSTRACT: The role of electrical leak location/damage detection (ELL) systems is increasing hand in hand with sales of low permeability geosynthetic membrane or "geomembrane", used to for many purposes including the containment of hazardous materials in landfills, leachate lagoons and underground storage tanks. Being able to gauge the integrity of the installed geomembrane allows owners, operators, installers and local authorities to make a more competent assessment of the quality of the installation thus facilitating the permitting process.The integrity of the geomembrane may be monitored off-line, typically when measurements of the electrical parameters are performed at the request of client or interested third parties such as a regulator, or on-line, where measurements are collected automatically by an integral computer. The processing software analyses the data and can be used to trigger an alarm to alert the operators of the facility if a leak is suspected. The frequency of measurement is typically predefined and based on various factors including regulator or permit requirements, waste type, aquifer vulnerability and risk modelling assessments.

1 INTRODUCTION

Today, we are seeing the increasing application of electrical leak location/damage detection (ELL) systems for the detection and location of penetrating defects in geomembranes. Over the last several years, there has been a step-by-step acceptance of their because ELL systems provide additional and valuable control of the quality of geomembrane installation. Their purpose is not to provide the standard Quality Control (QC) techniques but to bring additional value especially in the construction period where classical QC is limited. Once the geomembrane is covered with any material (sand, gravel, concrete, water, etc.), nobody can declare that the covered part of geomembrane is free of any damage. Thus the main role of ELL systems is to confirm and insure the integrity of the geomembrane after the construction of the facility. A second valuable advantage is the possibility to control the integrity of the geomembranes through part or all of the facility's lifetime e.g. operation of landfill lagoons, etc.

Generally, these systems are applied in two ways: either as a mobile ELL survey system and/or a permanent ELL system. In the case of landfills, the mobile ELL system is applied just after the facility has been constructed and the cover soil or drainage layer placed on the geomembrane. Electrical measurements are systematically collected across the top of the cover material and the data are analyzed to assess the integrity of the geomembrane, with respect to penetrating damage present at the time of the survey. In the case of the permanent ELL systems, data are collected from a permanently installed array or network of sensors, typically installed beneath the geomembrane (case of single geomembrane) or in between the geomembranes (case of double geomembrane), during the construction of the facility. Data can be collected by a permanent ELL system at any time after geomembrane installation and especially during the early operational life of the landfill, to assess the integrity of the geomembrane as waste, liquid or any material is placed in the containment.

1.1 *Brief evolution of the Electrical systems*

The first references to ELL type methods appeared in the early 1980's simultaneously in Europe and USA. In Europe it was team of researchers (Mazac et.al., 1990) from the Czechoslovak Republic who in 1980 carried out experiments to monitor leaks through manmade pond in Slovakia. They used a grid of permanently installed twin electrodes to monitor changes in self-potential due to the leak of water through the PVC geomembrane. They also tested active current type geophysical methods to test the integrity of the geomembrane. Unfortunately, funding was curtailed and the research had to stop. In the USA, the initial work, carried out by the Southwest Research Institute (SRI) on behalf of the US Environment Protection Agency (EPA), showed that the electrical resistivity technique was able to assess the integrity of geomembranes used in fluid impoundments and landfills (Shultz et al., 1984, 1985). The second phase of this research project established the Electrical Leak Location method and covered the development of portable systems (Shultz et al., 1986). This work was completed in December 1987 and published in an EPA report in 1988 (Darilek and Parra, 1988). The theory was published by Parra (1988), Parra and Owen (1988) in the same year. In 1989 the EPA and SRI both presented papers at Geosynthetics '89 Conference in San Diego (Darilek et al., 1989, Landreth, 1989). At the same time, the Foote Mineral Company privately developed and patented an electrical method for locating leaks in fluid impoundments using the same approach as EPA/SRI (Boryta and Nabighian, 1985).

In Europe. the Sensor Company introduced the first permanent ELL system in the early 1990's. The first prototype of their Damage Detection System (DDS) was installed in 1991 at Budmerice chemical and waste disposal near Bratislava in Slovakia (Nosko and Andrezal, 1993). Fabric based ELL systems, with wires woven into the geotextile, appeared in Germany and Belgium in 1994 (De Meerleer, 1994, Merlevede, 1996, Rodel, 1996).

In Asia the permanent ELL system was introduced by Maeda Corporation (Arai et al., 1994). Since then, several other providers have introduced permanent ELL type systems.

Since the 1980's, the application of this technique has evolved to cover the electric leak location of almost any geomembrane system, from single geomembranes to multiple geomembranes, from exposed geomembranes to soil or waste covered geomembranes. In parallel with the development of the portable systems, permanent systems were and are being developed for *in-situ* installations beneath or between geomembranes. These permanent systems are being used in landfills (both in basal geomembranes and in closure cap lining systems), in the mining industry for either long term systems for continuous monitoring of the structure, or as cheaper short term systems for monitoring the first few meters of waste deposition. The mobile surveys are being used across the whole spectrum of impoundments, from domestic landfills to sanitary landfills in the waste industry, from barren ponds and tailings ponds to heap leach pads in the mining industry, to evaporation ponds in the food industry and brine ponds in the oil and gas industry.

1.2 *Terminology of electrical monitoring system*

It is necessary to make an analysis of what a system used for monitoring failures in a geomembrane actually does. Based on the results of such an analysis that the terminology of electrical monitoring systems is very important for the understanding of a client to enable him to choose the right one for his purpose. A table can be constructed to describe any system. The main parameters are words or sentences used for its description e.g.:

Damage detection - possibility of detecting any damage without specification whether or not the contaminants are flowing through the geomembrane (at present time or in the future).

Damage location - possibility of detecting and find the position of any damage without specification whether or not contaminants are flowing through the geomembrane (at present time or in the future).

Leak detection - possibility of detecting any leakage through a geomembrane.

Leak location - possibility to detect and find the position of any leakage through a geomembrane.

Sensors - used for the reception of an electrical signal.

Electrical source - used for the creation of an electrical field by injection of a current and voltage into the ground.

There are several other terms to be clearly explained for a client to enable him to understand the principles of such systems available on the market. Such as: *direct/indirect detection/location of leak/damage/failure, portable systems, static systems, permanent systems etc.*

2 THE BASIC PRINCIPALS OF THE ELECTRICAL SYSTEMS.

The basic principle of an ELL system is the creation of an electric field on one side of a geomembrane and the measurement of the resultant potential difference (PD) by sensors located on the other side of the geomembrane. The technique exploits the insulating properties of the plastic geomembranes, which if whole, will let very little current pass through them. However, if there is a penetrating defect in the geomembrane, a defect that conducts electricity, then current will flow through the hole creating an electrical anomaly at that point. This is the anomaly that is measured by either the sensors of a mobile or permanent ELL system. In the case of a mobile system, the PD is measured by one or more pairs of sensors that are moved sequentially across the surface materials of the facility. In the case of a permanent system, the sensors are permanently installed within the facility. and the PD is measured by one pair of sensors at a time, with all pairs of sensors scanned in turn during a survey. Typically, the series of PD measurements are stored in a portable computer in the case of mobile surveys with data analyzed off-line. In the case of permanent installations, data are collected by either portable (off-line analysis) or desktop computers (on-line data analysis), the approach dependent on the type of system. At the Photo No.1-3 there are view of the “on-line” configuration of the terminals installed for Otaru municipal landfill in Hokaido, Japan. The terminals (Photo 1 and 2) are permanently installed at the site and the remote PC-computer is on-line connected to them through the modem line. The measured data are automatically transferred from terminals to the remote PC computer. After several steps of processing and analysis, the data are interpreted and displayed on the screen of a computer with the locations of the detected anomalous areas indicated. Once located, a small section of the geomembrane is exposed, and the defect repaired.

3 DESCRIPTIONS AND COMPARISONS OF THE ELECTRICAL SYSTEMS WHICH ARE COMERCIALLY USED

The ELL systems can be divided into two basic groups, permanent or fixed systems and mobile systems (Nosko,1999, Nosko et al., 2000). The fixed systems can be further divided into three groups depending on the relative positions of the sensors in relation to the geomembrane:

- sensors are located under a geomembrane,
- sensors are located above a geomembrane,
- sensors are located between a primary and secondary geomembrane.

In general, most ELL systems measure the PD (potential difference) between two sensors. Other systems take measurement of the variation of capacitance, measurement of changes of resistivity/conductivity of the subgrade under the geomembrane caused by the introduction of contaminated (typically) water through holes in the geomembrane.

The sensors are made of metal, plastic or ceramics. The shape is very similar but basically, looks as a point (square, rectangle, cylinder) or line (very long wire made of cooper or any conductor, or carbon belt).

3.1 *Advantages and disadvantages or limits of the electrical systems*

Every system has certain limits or boundary conditions under which they work. It is necessary to be aware of such boundary conditions to be able successfully detect and locate failure in a geomembrane.

3.1.1 *Permanent systems where sensors are situated under a geomembrane*

Advantages:

Sensors are situated outside of the contaminated and often corrosive materials located above the geomembrane.

The subgrade beneath the geomembrane is electrically homogeneous which improves the ability to locate penetrating defects

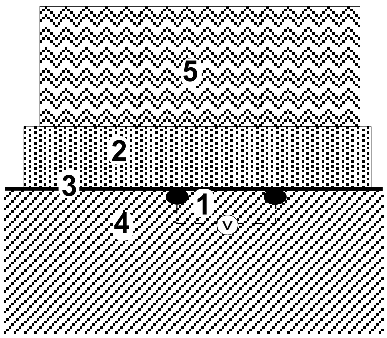

Figure 1. System with fixed sensors under a geomembrane (1 – sensors; 2 – fluid, soil, drainage layer, etc.; 3 – geomembrane; 4 – subgrade; 5 - waste).

Sensors are close to the geomembrane and therefore the signal coming from a failure is sufficiently strong to be measured.

There is no dependence on the thickness of the layers above the geomembrane

Rapid measurement of large areas e.g. 10,000 m^2 in 10-15 min. It is possible to repeat the measurements immediately after repairs to verify integrity.

Rapid measurement of large areas e.g. 10,000 m^2 in 10-15 min. It is possible to repeat the measurements immediately after repairs to verify integrity.

Measurement can be repeated at any time when required.

Disadvantages:

It is necessary to be on site twice, once for the installation of the hardware parts (sensors, cables, monitor boxes, electrical sources) and a second time for the measurement of the integrity of the geomembrane by this hardware using special equipment.

However, new technology is allowing these systems to be run remotely and controlled over the internet.

3.1.2 *Permanent systems where sensors are situated above a geomembrane*

Advantages:

Sensors are situated above the geomembrane inside the contaminated area in a material that is electrically homogeneous which improves the ability to locate penetrating defects

As the sensors are typically adjacent to the geomembrane the signal coming from a failure is sufficiently strong and is decreased only by distance between sensors to be measured.

No dependence on the thickness of the layers above a geomembrane.

Rapid measurement of large area e.g. 10,000 m^2 in 10-15 min. In the case of detection of a failure and after repairs of revealed failures, it is possible to repeat measurement immediately after such activity many times per day, thus saving cost.

There is also the possibility of repeating of measurements at any time when required.

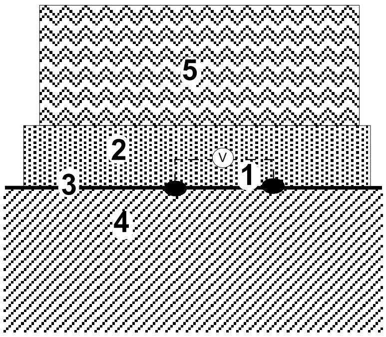

Figure 2. System with fixed sensors above a geomembrane (1 – sensors; 2 – fluid, soil, drainage layer, etc.; 3 – geomembrane; 4 – subgrade; 5 - waste).

Disadvantages:

Sensors are situated inside a potentially highly contaminated area where there is a significant possibility of rapid corrosion of the hardware parts of a system (sensors, cables, and connections).

Due to very high conductivity of material where the system is situated, the interpretation and computer determination of the position of failures is less precise and more problematical. The location of two or more failure situated near to other, where the distance between the failures is less than the distance between the two nearest sensors is difficult or if not impossible to resolve.

It is necessary to be on site twice. Once for installation of the hardware parts (sensors, cables, monitoring boxes, electrical sources) and a second time for the measurement of the integrity of a geomembrane by such hardware using special equipment.

3.1.3 *Systems where sensors are situated above and under a geomembrane*

Advantages:

Because sensors are at both sides of a geomembrane the sensitivity is relatively high. Sensors are situated in and outside the contaminated area in the layers which are electrically homogeneous to leading and spreading electrical parameters.

Sensors are at the nearest position to the geomembrane and therefore the signal coming from a failure is strong and is decreased only by distance between sensors to be measured.

Higher amount of sensors (because both side of geomembrane) allows gain higher density of useful information.

There is no dependence on the thickness of the layers above the geomembrane.

Rapid measurement of large area e.g. 10,000 m^2 in 10-15 min. In the case of detection of a failure and after repairs of revealed failures, it is possible to repeat measurements immediately after such activity many times per day, thus saving cost.

There is also the possibility of repeating measurements at any time when required.

Disadvantages:

It is necessary to be on site three-times. Once for each of the installation of the hardware parts (sensors, cables, monitoring boxes, electrical sources) above and below the geomembrane and third time for the measurement of the integrity of the geomembrane by such hardware by using special equipment.

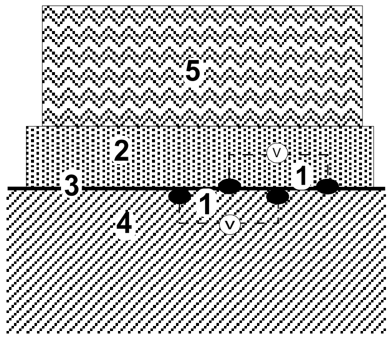

Figure 3. System with fixed sensors above and under a geomembrane (1 – sensors; 2 – fluid, soil, drainage layer, etc.; 3 – geomembrane; 4 – subgrade; 5 - waste).

3.1.4 *Systems with "mobile sensors or probes"*

Advantages

The survey is carried out by moving probes scanning electric signal distribution on a top of the protective/drainage sand/gravel layer.

There is no necessity for the complicated installation of permanent sensors

Data acquisition and equipment is less sophisticated.

An experienced operator can identify the major penetrating defect during the acquisition.

Disadvantages

This survey itself is relatively time-consuming requiring a very skilful operator to take measurement, detect and located position of the failure.

The significant disadvantage is the thickness of the protective/drainage layer placed on top of the geomembrane. Generally, for most surveys where mm sized holes need to be located, the limit is about 50-60 cm depending on the electrical quality of this material. Larger holes can be detected beneath thicker layers of cover material (Snow et al., 1999).

Climate variations such as rainfall or hot conditions will alter the homogeneity of the protective/drainage layer (puddles (conductive), dry surface (resistive))

Surface infrastructure such as road access, drainage pipes the use of different material for protection and for drainage layers can and do cause ambiguities in the electrical potential field.

Advantage/Disadvantage

Depending on whether you are the owner or the regulator, repeat surveys (i.e. monitoring) are almost impossible once the facility becomes operational, especially in the case of landfills where significant volumes of inhomogeneous waste material are deposited on to the cover material.

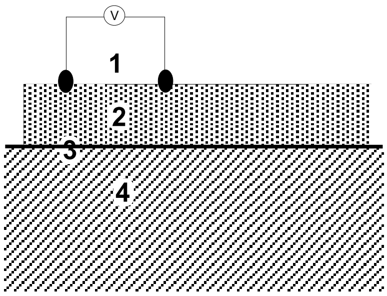

Figure 4. System with mobile sensors (1 – moving sensors; 2 – fluid, soil, drainage layer, etc.; 3 – geomembrane; 4 – subgrade).

From above written text we can see that every system has certain advantages and disadvantages. The use of system basically depends on the case of its application.

3.2 *The purpose of use of the ELL systems.*

Mostly the ELL systems are used for detection and location of the failures in the geomembranes. Contrary to that some clients require only detection or indication of the failure. The precise location is not so interesting for them. Therefore, should be acceptable to unify the terminology and allows client to specify more precisely what is their needs. Some explanations are written in the section 1.2.

3.3 *Data recording, processing and display of useful information.*

The measurement can be collected by digital multimeters or data loggers. The use of a standard multimeters typically means that the reading has to be written down on paper (and entered into a computer manually), while a data logger stores the reading in its memory for later download to a computer (case of manual reading with data logger). Other ways, which are mainly use in case of permanent systems, are the off-line and on-line measurements. The main difference is that in case of off-line measurement we use measuring equipment where portable computer is implemented. The measurement is done from time to time and equipment is connected only during the time of measurement. In case of on-line monitoring of integrity of the geomembrane the measuring equipment and all electronic parts are permanently connected to the sensors. The desktop computer drives the measurement remotely or through the cable connection. The results are immediately displayed on the screen of the computer. In case of any useful anomaly is detected, the precise location of the failure is computed and displayed. The co-ordinations (X,Y) are showed to the operator automatically.

The way of operation depends on type of specification. For example in Japan mainly on-line systems are used. It means, the detection and location of any failure must be done automatically without any human assistance. Another on-line version of the ELL system is detection system for lagoons and for double lining sealing. The mostly only detection of failure is required by on-line way, means the automatic equipment continuously controlling the integrity of geomembrane. In case of any failure appears the alarm is switching on and operator is informed by acoustic or visual signal. This signal could be transmitting by radio or modem line to any place where it is required.

4 DO THE ELL SYSTEMS PLAY IMPORTANT ROLE WITHIN CONVENTIONAL QC?

Inside section 1.1 we briefly described the evolution of the ELL systems. It is incontestable that uses of ELL around the world are increasing. We did study of use of the ELL systems in some specific countries.

Inside USA mostly mobile systems are used but sometimes permanent one are applied as well. Contrary to that mostly permanent systems are used in Europe and Asia.

Within west part of Europe the UK market is the one where the mobile systems are very extensively used. Since last 2 years the permanent systems grow there due to the possibility to be used not only once but several times within early stage of operation of the controlled landfill. Contrary to that, France and Belgium mostly adopted the permanent systems and use of mobile ones are in minority. Within Spain and Portugal the permanent systems dominate. Italy has similar tendency like UK market. Germany is very specific country within Europe because the ELL systems are mainly used for checking of integrity of the closure cap lining systems for landfills. The permanent systems dominate there.

In the central and east part of Europe the permanent systems are mostly used. Mobile systems are used from time to time. Almost every newly constructed landfill is equipped by permanent system in Slovakia. Very high amount of newly constructed landfills are controlled by permanent systems in Czech republic, Hungary and Poland as well. This trend is increasing.

Sporadically, the ELL systems are used in other European countries like Finland, Sweden, Holland or Croatia.

In African continent we have information about use of permanent system in South Africa.

In Asia, the Japan is country where the permanent systems dominate. There are mostly on-line controlling systems (see photo 1, 2 and 3). Similar situation is in South Korea except on-line applications, means basically permanent systems are used there. In Hong Kong the ELL was used as well.

Based on this study we can claim that use of ELL systems rapidly grows around the world. We can see that traditional QC is at the end of the development and cannot bring more informations. ELL systems are developing and bring more and more informations even under the very difficult site conditions. Through our practice and from many other published facts done by Nosko & Touze-Foltz (2000), Rollin et al. (1999), Nosko et al. (1996), Colucci & Lavagnolo (1995), Crozier & Walker (1995), Laine & Darilek (1993) it can be seen that mostly the problems with failures cumulate during the placing the protective drainage material on top of geomembrane. The problems within the seams (double wedge weld or extrusion weld) are negligible compare to other failures created during the construction. Another very important fact is that conventional QC has information only about a few percentages of surfaces of the geomembrane after its installation. Contrary to that, the use of ELL systems can give almost 100% information about integrity of controlled geomembrane. Therefore, if we compare the cost of the traditional QC per "really" controlled surface and cost of ELL per m^2, we can recognize that ELL systems are very effective and not costly procedure. In plus, it brings information under the condition where no other method are able to do that. If we adopt permanent version of ELL system we have tool, which has possibility to give us informations very long time even during the operation of site. Darilek, Laine (2001), published the important comparison of common CQA and QC test method (see table 1).

5 CONCLUSION

The geomembrane market stabilized the quality of material produced by producers. The conventional CQA propose standard procedures, which always gives standard results. The history shows that it plays very important and irreplaceable role. But the present time shows as well that it has one limit, means once the geomembrane is covered it cannot give any useful information about integrity of geomembrane. Regular using the ELL systems and their acceptance within CQA can fulfill this gap.

Table 1. Common CQA and QC Test Methods (Darilek & Laine 2001)

Method	Area Tested (Percent of Liner)	Speed	Test Under Load	Test for Construction Damage	Features and Limitations
Air Lance	Seams (0.5%)	Fast, 3 to 10 m per minute	No	No	Economical QC test used on very flexible liners only. Tests for unbounded areas only. Requires operator skill and experience.
Air Pressure	Double wedge weld seams (0.5%)	Setup time plus about 10 minutes per seam	No	No	Economical QC test for double wedge weld only. Welds tested at a fraction of their strength.
Conductive sheet	Primarily for panels, limited test on seams (99%)	Very rapid, 1 to 2 hectares per day	No	Yes, but prior to placement of drainage material	Rapid QC test of panels and areas that cannot be tested with vacuum box, requires installing proprietary geomembrane.
Destructive Seam Testing	0.2% of seams (0.0015%)	Very slow turn-around, days	Yes	No	Test for maximum seam strength, about 4 m of inferior extrusion weld needed to repair each test point, may delay project.
Electrical Leak Location	100% of liner (100%)	About 0.5 to 1 hectare per person day (*)	Yes	Yes, after drainage material placement	Only test conducted after potential for construction damage has occurred.
Vacuum Box	Primarily for extrusion welded seams (0.2%)	Slow, labor intensive	No	No	QC test, operator dependent. Cannot be used on wrinkles and corners. Leak may not be indicated with clay or water under liner. Primarily used for extrusion welds.

(*) Means ELL system with mobile sensors. In case of permanent ELL system the speed is 10 minutes per 1 hectare (Nosko et al. 1996)

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Photo 1. Permanent ELL system at on-line configuration. (Otaru municipal landfill, Japan – 80,000 m^2). 4 central boxes comprising of 11measuring units are situated outside and located at perimeter of landfill. The communication between these units and PC desktop computer located at control room is through cable by modem line.

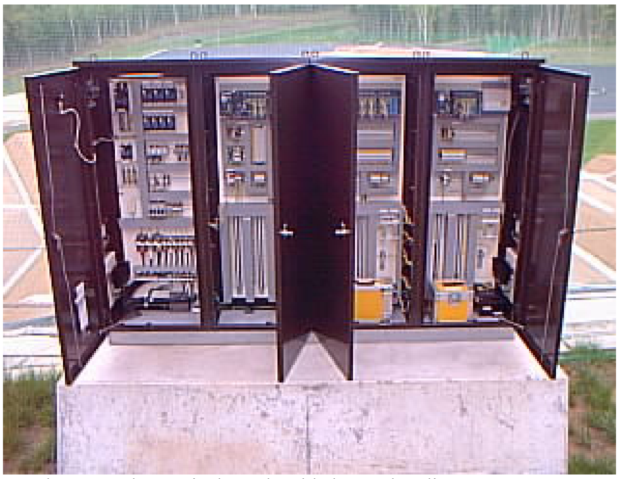

Photo 2. Permanent ELL system at on-line configuration. (Otaru municipal landfill, Japan – 80,000 m2). View to the inner parts of the one of the central boxes. This box comprise of 4 measuring units.

Photo 3. Permanent ELL system at on-line configuration. Desktop PC computer at control room 24 hours drives the 11 measuring units situated outside and located at perimeter of landfill. The failure is immediately detected and its position is precisely computed and displayed on the screen. The alarm is appeared at the same time.