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Importance of Planning Prior to an ELL Dipole Survey on Covered Geomembrane: Overview of Two Very Different Project Cases

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ABSTRACT

The dipole method (Electrical Leak Location) has been used on various types of civil engineering works in the last 20 years. The principle is well known and in good conditions it can detect pin hole faults in geomembrane materials and defects in extrusion seams.

In the first part of this paper, the basic principles of the dipole method will be introduced. In the second part, two case studies of dipole leak locations will be presented. The first of these studies describes a multi-layered, 122,000 m^2 mine capping project, the design of which was made to accommodate dipole leak location methods in terms of electrical isolation, thickness of material layers, and surface watering. The second case study describes a pulp mill landfill project that encountered contingencies during construction leading to changes in the project's overall design.

Dipole surveys for both of these projects underwent significant adjustments to adapt to project conditions, but in the second case study the geomembrane had suffered damage to the extent that a new dipole leak location protocol was required in order to ensure that acceptable quality standards were met.

The goal of this paper is to educate engineers and leak location practitioners and to share valuable data about the dipole leak location method. This paper will also highlight the importance of including leak location in civil engineering projects early in the design stage, in order to prevent contingencies from negatively effecting survey performance and to ensure reliable survey results.

1. INTRODUCTION

In the last 20 years electrical leak location methods have grown in both popularity and effectiveness. Statistics show that increased installation experience and the adoption of installation technologies have contributed to a gradual reduction in leaks recorded on worksites, but the geomembrane barrier is not the only factor in ensuring the impermeability of a given site. Regardless of the efficacy of quality control procedures during the installation of the geomembranes, the addition of the drainage or protection layer can cause a variety of problems. The dipole method has been performed since 1985 (Darilek et al. 1999). It allows for the verification of the impermeability of the geomembrane material following the installation of covering materials, as well as permitting the localisation of faults for repair. The traditional alternative to the dipole method was to fill the basin with water (load test), but this method gives no indication of the number or location of faults and the volume of water required can be significant on larger sites, resulting in delays whilst filling, testing and emptying is completed. In addition, the traditional alternative is not suitable for capping projects.

In favourable conditions, the dipole method can localise faults as small as 1mm². However, on sites that are poorly adapted to the method faults of up to 30 cm^2 may generate a signal too weak to be detected. It is therefore important that the method is understood by the technician responsible for the survey and that the suitability of the site is considered from the start of the design phase. If the project engineer is not familiar with leak location requirements, an expert firm can be contracted to ensure the rapidity and precision of the survey. This article will present two (2) case studies of dipole method electrical leak location surveys completed in 2018. In the first case study, the integration of the dipole method was considered from the initial design phase. In the second case study, the dipole method was applied as an attempt to compensate for various problems arising during site construction. A brief summary of the dipole method is presented in the next section, followed by the presentation of the two case studies.

2. DIPOLE METHOD DESCRIPTION

The dipole geoelectrical method (ASTM D7007) relies on the intrinsic insulation properties of geomembranes for the detection of faults created during the installation of covering materials (see figure 1 below). Geomembranes that are themselves electrically conductive, such as EPDM (Ethylene Propyl-ene Diene Terpolymer) due to its large concentration of carbon black, or that are impermeable but non-isolating, such as geocomposite clay liner (GCL), are therefore incompatible with the Dipole method.

To perform a dipole survey, a current of approximately 500 V DC (direct current) is passed into the covering material (usually sand, clay, gravel or crushed stones), and a grounding electrode is placed outside the limits of the geomembrane. Whilst under normal circumstances electricity will flow from a different potential to ground in order to discharge and reach equilibrium, the presence of a non-conductive geomembrane prevents this discharge and the electrical current is confined within the cell. However, if a fault is present in the geombrane, the current will pass through the fault to reach the grounding electrode. This in turn generates a distinct electrical signature that can be identified and located by a specialized technician.

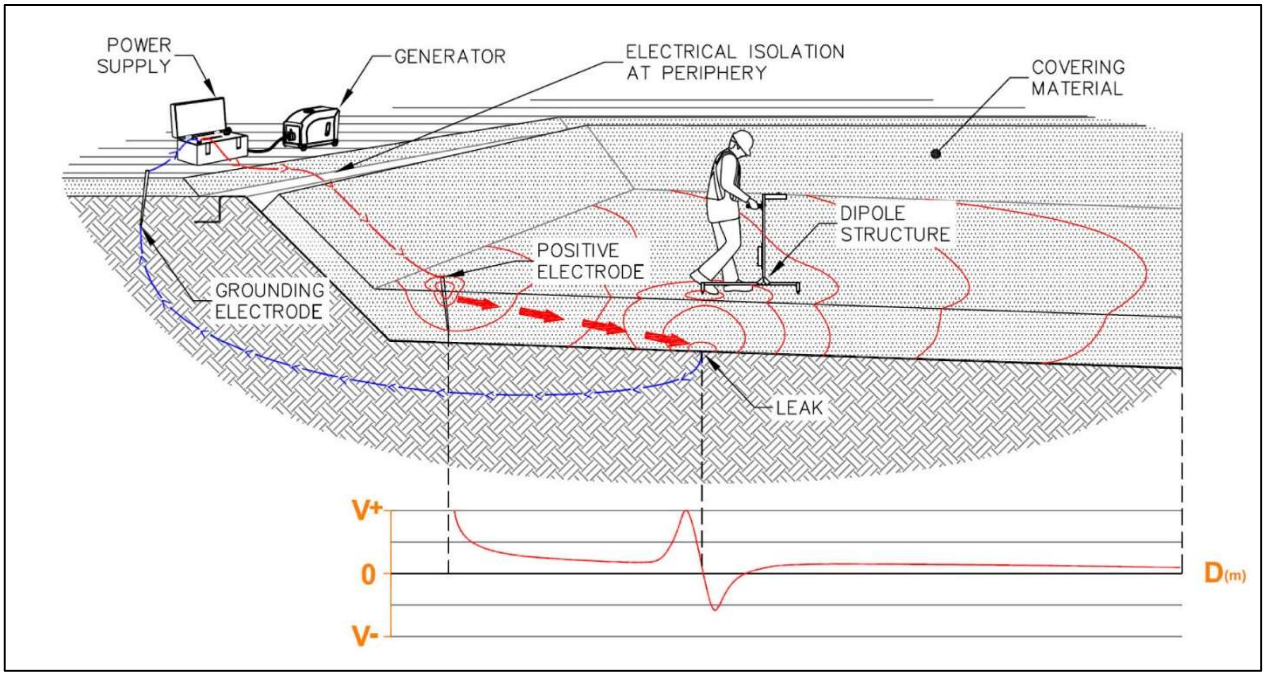

Figure 1. Dipole method schematic.

3. PROJECT DESCRIPTIONS

3.1. Project 1: Mining Cap Designed for Leak Location

The first case study concerns a permanent mine capping project. This was a large-scale project with a geomembrane surface of 120,000 m. Dipole leak location surveys were carried out across this entire surface. The project site is located in Canada and was constructed in the second half of 2018, during which it was exposed to summer and autumn weather conditions typical of eastern Canada. A layer of sand for the drainage of biogas was installed on the base tailings layer, followed by a PEHD geomembrane layer. A capping layer of at least 700 mm was required to ensure protection from frost, which was in turn composed of a layer of drainage sand and topped with topsoil.

Dipole electrical leak location had been planned long in advance of the construction works, allowing for all project contributors to understand the importance of their respective tasks in relation to how the dipole method works. It was decided that the dipole method would be applied on the first sand layer, as this provided a homogenous surface whose thickness (300 mm) allowed for optimal survey precision. A 3m buffer of geomembrane material was installed all around the site to allow for the installation of the sand layer without compromising the site's electrical insulation, which is essential to a successful dipole survey. A boundary trench and the geomembrane anchoring system were installed on the other side of this geomembrane buffer.

3.2. Project 2: Landfill Extension

The second case study concerns the expansion of a landfill site. The capacity of the site's first operational cell was soon to be reached and an expansion to the side of the cell had been planned to allow for additional waste layers to be added to cell 1. A PEHD geomembrane layer had been installed across the surface area of the expansion, totalling around 32,000 m^2. The subgrade of the geomembrane material was very irregular due to its proximity to an underlying rock layer and the impossibility of dynamiting the area to flatten the rock. A pierce resistant geotextile was installed before and after the installation of the geomembrane layer, as well as a 300 mm layer of crushed stone to allow for drainage at the base of the cell. Electrical leak location services were requested a few weeks prior to the start of site surveying works, allowing for the contractor to dig an insulation trench around the entirety of the cell expansion.

4. SURPRISES, CHALLENGES AND ADJUSTMENTS

4.1. Project 1

Various challenges were encountered during construction, but only those related to electrical leak location will be discussed in this article.

4.1.1. Lack of Water

The summer prior to construction had been very hot and dry. It was possible to perform the dipole survey on the sand layer as it had been recently installed and had retained its humidity, but the conditions posed problems for surveys on trench areas that dried quickly in the sun (the trench areas were covered with “wrip-wrap” and filled with large stones). It was therefore necessary to dampen these areas to ensure the conductivity of electrical signals at the surface. Restrictions on the supply of water had been put in place as a result of the dry season, and the site’s water truck was limited to two (2) loads per day for all of the site’s water requirements (including the watering of access roads to limit dust dispersal). It was therefore necessary to limit surveys on the trench areas during this period. As the trenches were already completed, this limitation did not cause a delay for the contractor.

4.2.2. Excess Water

Following a dry summer, a wet autumn filled the trench areas with rainwater. It was therefore necessary to clear rainwater from 120,000 m^2 of geomembrane whilst keeping the water level in the trench areas below the level of the drainage layer to allow for continued testing. As time passed, the testing of trench areas became a challenge to ensure that the site would be delivered on time. A 1 in 100 years weather event further complicated the situation, and the volume of water on the geomembrane was large that a part of the geomembrane layer slid towards the bottom of the slope, requiring heavy machinery to repair the sector. The circulation of heavy machinery on damp and soft sand necessitated an additional dipole survey to reverify the sector.

4.2.3. Sectors to Survey to Allow for Work fo Continue

The contractor regularly required access to different sectors for the installation of drainage sand, filler materials and topsoil, and of stones in the drainage trenches installed on the slope. To facilitate this access, the contractor required that dipole surveys be completed quickly at a given sector to allow for the construction of access routes without having to remove them later. Whilst this request is normal, it considerably increases the time required for the validation of the site due to the additional time required to continually uninstall and reinstall the testing equipment, often to validate relatively small areas of the site.

4.2.4. Insulation of Access Roads

As the worksite covered a large area, a system of access roads had been constructed to facilitate site access for trucks carrying covering materials. There were seven (7) access roads in total, and they had a significant adverse effect on the electrical insulation of the site, preventing an acceptable signal from being recorded during simulated leak tests. Each access road had been excavated to the level of the geomembrane and waste geombrane had been placed vertically through a cross section of the road to prevent the electrical current from reaching the exterior of the site. Each road was regularly checked to clear this vertical geomembrane from the road surface and to ensure the best possible electrical insulation.

4.2. Project 2

4.2.1. Presence of Rock

The first unanticipated challenge of the project was the presence of rock significantly higher than the planned geomembrane layer. An initial idea was to dynamite the rock layer to the correct level, though this was quickly abandoned due to anticipated costs and delays. An alternative idea was to add a sand layer to protect the geomembrane and avoid significant changes in relief, which require the installer to make multiple extrusions adapted to the profile of the bedrock. Unfortunately, this option was also rejected because the rock presented near vertical reliefs, requiring a significant amount of sand to fill the contour. The final decision was for the geomembrane to be installed following the contour of the rock, with a thick geotextile layer installed first to protect the geomembrane.

4.2.2. Variable Contour of Site Base Level

The installation of the geomembrane layer on a non-flat surface may long term repercussions in terms of earthworks and the tension present in the geomembrane. Best practice dictates that geomembrane layers should be installed flat and free from stress. An immediate consequence of this variable depth was the exceptional difficulty experienced by the contractor in the installation of a 300 mm thick pebble layer: even with GPS integrated into the contractor's machinery, it is difficult to the establish the depth of the geomembrane layer once it is covered by pebbles. This resulted in a variable depth of 100 mm to 700 m in the pebble layer, leading to faults in the geomembrane where heavy machinery had passed over areas whose covering layer was too thin.

4.2.3. Problems Related to the Number of Faults

From the moment that the dipole equipment was calibrated by testing on several simulated faults, it was clear that this would be a complex project. Exceptionally, the simulated faults generated no signal despite the insulation of the surrounding area. There were so many real faults onsite that very little electrical current was passing to the simulated faults, even when a large 300 mm x 300 m plate was used for the simulated fault. It was therefore decided that the survey should begin by identifying the largest faults, ensuring their excavation and isolation, and then passing again over the same area to identify the large number of smaller faults hidden by the large faults.

This in turn required that an excavation protocol be implemented to reduce the time lost for the dipole survey operator. When a fault signal was found, the dipole source had to be switched off and the area around the fault was excavated with shovels. At the start of the project it was common to turn the dipole source back on and immediately find a fault in the same area next to the excavation. This was because the faults were generally caused by the covering layer being too thin, leading to a high number of faults in the same area. It was therefore established that during each excavation, an additional area of one metre should also be excavated around the fault, and this should be repeated until no fault is discovered in the additional area. This method meant that the excavated areas were sometimes up to 10 metres wide.

4.2.4. Faults Caused by Heavy Machinery

Certain sectors presented such a high density of faults that it was impossible to excavate the faults by hand. In many cases, an excavator was called to the sector to remove the crushed rock covering layer, allowing the installer to repair the faults with patches of extrusions. A new puncture-proof geotextile was then placed over the zone and the excavator replaced the crushed rock layer. Unfortunately, in one area where eight (8) faults had been located, excavated, repaired and covered, a further dipole test discovered six (6) new faults. This incident made it clear that the presence of the excavator was sufficient to pierce the geomembrane and that it would be challenging to ensure an acceptable level of impermeability across the landfill site.

5. RESULT OF DIPOLE SURVEYS

5.1. Number of Total Faults, Ratio of Faults by Hectare

5.1.1. Project 1

For the tailings capping project presented in project 1, the design of the geosynthetics and the covering layers was conceived to minimise the stress applied to the geomembrane. The roof of the cap had a slope of 4% and the base had a slope of gradient 6:1. Heavy vehicles were restricted to moving on specially designed 1.2m access roads. The total number of confirmed fault signals was 20 across a total survey area of 122,800 m^2 (slightly larger than 30 acres). Internal data gathered over 8 years and almost 1.5 million square meters of dipole surveys show that on average the dipole method discovers 3.2 faults per hectare. On this project, the average was around 1.63 faults/hectare, or half of the expected average. This low ratio of faults can be explained by various reasons, including the simplicity of the design, the experience of the installer and the general contractor, and the rigour of the on-site quality control team.

5.1.1. Project 2

As everybody should know by now, "all geomembranes leak" (Giroud 1984), but sometimes they leak so much that the installed geosynthetics barely do anything at all, as in this case. The number of faults discovered on the second project is very significant: a total of 396 faults were repaired across the site area. This number greatly exceeds any project the author has seen before and is in no way representative of a typical leak location survey. It was ultimately impossible to provide a definitive number of leaks discovered during the survey. In some sectors, excavations reached up to 30 metres wide and exposed over 30 leaks. As the leak location team were required to continue the survey, the excavations were completed by a team provided by the general contractor, principally using shovels rather than heavy machinery. The geomembrane installer then proceeded to repair the faults. As some patches were used to cover multiple faults the number of leaks is in reality much larger than 396, but this is the total number of reparations confirmed by the geomembrane installer.

The work required to excavate these zones was significant, but the survey also brought various challenges including the identification of fault signals. Prior to the excavations, the large number of faults caused the electrical signals to be weak and variable. Following the excavations however the electrical current was forced to pass through zones that had been disturbed by numerous excavations and fillings, leading again to erratic electrical signals. The goal of the dipole method is to identify electrical anomalies in an otherwise uniform electrical profile. Variable electrical signals resulting from anomalies in the covering layer poses a significant challenge to successful leak location.

The total area of the landfill site extension was 32,000 m^2, providing a ratio of 124 faults/hectare. Our internal statistics show that the previous leader for the highest ratio of faults was 72 faults/hectare. This was across a surface of 5,000 m^2, giving a total of 36 faults. The previous leader for the highest number of faults was 203 across a total area of 171,000 $m^{2,}$ this being around half the number of faults located in an area 5 times larger.

5.2. Duration of Leak Location Surveys, Speed in m^2/day

5.2.1. Project 1

The main features of this project from the leak location perspective were the multi-layer design with a total of three layers above the geomembrane and the 1.2 m minimal thickness of the access roads. In order to work on the secondary layer, access roads had to be installed on the primary layer, but the contractor did not want to wait for the completion of the first layer across the entire before beginning work on the second layer, as this would have taken too much time. The decision was therefore made to complete the three layers in parallel, requiring the leak location technician to prioritise sectors where the next access roads were to be installed.

The result was that the dipole survey was slowed down in order to expedite the work of the general contractor, which is normal practice on sites in Canada. In total, 57 days were required on site to survey the entire 122,800 m^2 of covered geomembrane. This represents a survey speed of around 2,154 m^2/day, with a dipole length of 1 m and a grid resolution of 1 m. This speed is comparatively low in relation to industry standards, which vary between 4,000 m^2/day and 40,000 m^2/day in accordance with the ASTM standard D6747 “Standard Guide for Selection of Techniques for Electrical Leak Location of Leaks in Geomembranes”. This variation can be explained by the grid resolution used, which is in turn a result of the signal quality established during calibration testing. The grid resolution varies normally between 1m and 3m. Comparing a 3 m x 3m grid resolution to a 1 m x 1m grid resolution, the difference in speed (m^2 / day) can vary by an order of ten.

5.2.2. Project 2

For project 2 the situation was completely different. The project was already finished when the dipole survey began, and no accommodations had been made in the design of the site to facilitate electrical leak location. After a few days of the survey had confirmed 89 faults, it was decided that numerous passes would be required to ensure the impermeability of the site. This meant that the largest faults, or the sectors containing the highest density of smaller faults, were excavated and repaired first, allowing for a second survey to more precisely validate the same areas. It was ultimately impossible to estimate the number of additional surveys that would have been required to obtain a satisfactory result.

The first survey was completed in a few days and was followed by a second, more detailed survey. As the client required for the cell to be put into operation quickly (with the existing cell being at maximum capacity), it was decided to prioritise the delivery of a third of the new cell with minimum faults, before continuing to survey the rest of the cell. It became clear that this result would be difficult to achieve following an incident where a sector around 15 m in diameter was excavated, repaired, and recovered with a gravel layer by an excavator. An additional survey performed to verify the impermeability of the repairs in this sector revealed the location of seven (7) new faults. These new faults were probably caused by the presence of the excavator, which had possibly damaged the geomembrane layer with its bucket or applied excessive pressure on the geomembrane resulting in punctures from the stone layer below.

Ultimately budget constraints resulted in the remaining two thirds of the site not being verified by a second survey. The second survey was instead limited to 4 m wide areas directly above drainage trenches. The dipole leak location activities lasted a total of 39 days with a dipole length of 1 m and a grid resolution of 1 m, resulting in an average speed of 821 m^2/day for an incomplete survey.

5.3. Type and Size of Defects Located

The following table 1 presents the type and size of faults located. Faults in the “puncture” category are mostly caused by small stones that pierce the geomembrane. Whilst puncture faults are occasionally caused by surveyors’ poles, or by waste materials when an operational landfill cell is nearby, such faults were not found in either of the case studies presented in this article. The “tear” category includes faults made my heavy machinery, such as damage from a bulldozer or excavator buckets. The “knife cut” category is self-explanatory, but whilst knife cut faults and similar “extrusion” faults are usually located with an exposed membrane leak location method (such as the water jet or spark test method), the dipole method is also capable of locating these smaller faults.

Table 1. Types of defects found.

Type of defect	Project 1	Project 2
Puncture (%)	85	99,5
Tear (%)	10	0
Knife cut (%)	5	0
Extrusion (%)	0	0,5

Table 2 shows the size of defects, sorted in four (4) categories: small (less than a square centimeter), average (one to five square centimeters), big (five to ten square centimeters) and very big (more than ten square centimeters).

Table 2. Size of defects found.

Size of defect	Project 1	Project 2
Less than 1 cm² (%)	5	5
1 cm² to 5 cm² (%)	40	44
5 cm² to 10 cm² (%)	20	15
More than 10 cm² (%)	35	36

It is very interesting to observe that the faults are of similar sizes across the two projects, despite the differences in project area (project 1 being almost 4 times larger than project 2) and the difference in the number of faults located (20 faults in project 1, over 400 in project 2), It should be noted that for project 2, only a portion of the excavated leaks (196) were measured and recorded. This remains a significant number of the total located faults, allowing for an adequate picture of the general situation on site.

5.4. Portion of Budget Reserved for Leak Location

It is often said that electrical leak location services are expensive. This section of the article aims to show the difference between a well-planned leak location campaign in the context of a project which incorporates leak location design from the outset, and a leak location campaign which aims to simply troubleshoot issues arising during construction works. The aim of leak location is to validate that constructions works have been completed to a satisfactory level and to identify accidental faults, not to provide a quality level equivalent to that found on well managed projects.

Without presenting budgets or professional services fees, it is possible to present the percentage of the total project budget that was spent on dipole leak location surveys. According to our internal statistics, the cost of leak location is generally around 0.5% and 1% of total project costs. Given the importance of guaranteeing impermeability in the cases of environmental confinement or the retention of mine tailings, this cost is far from excessive.

For the two projects presented in this article, the speed of the survey was far from optimal and the costs associated with the onsite technician were therefore above average. For project 1, this allowed for the general contractor to advance other site activities and generated significant savings in the availability of staff and vehicles. For project 2, work on site had already been completed, and the only factor that slowed the progress of the survey was the exceptionally large number of faults discovered. For project 1, leak location represented 1.39% of total project costs. For project 2, leak location represented 3.01% of total project costs.

6. CONCLUSION

Beyond economic factors, the importance of effectively integrating leak location into construction works is shown in the final project quality delivered by such an initiative. It is clear that effective planning allows for a quick and efficient intervention in the location and repair of faults, reducing leak location costs, but in controlled conditions, the dipole method can achieve the level of precision required to locate extremely small faults in a geomembrane layer.

Electrical leak location does not however provide a method for the transformation from a site by faults to a durable and impermeable

Electrical leak location does not provide a method for transformation compromised installations into durable and impermeable confinement sites. Leak location provides a general overview of the state of a site of a given time, and does not provide information on the long term durability of a geomembrane layer. A site like that presented in project 2 can also exhibit a large number of superficial faults, where the geomembrane has been rendered fragile without being actually perforated in a way detectable by leak location methods. It is likely that the geomembrane layer will fail in these areas during site operation. Ensuring the long-term reliability of sites using geomembrane layers for confinement is the job of a dedicated quality assurance team, which can apply laboratory tests and on-site procedures to ensure that installation works have been completed in conformity with site plans and specifications.

REFERENCES

ASTM D 7007. Electrical Methods for Locating Leaks in Geomembranes Covered with Water or Earth Materials, *American Society for Testing and Materials*, West Conshohocken, Pennsylvania, USA.

ASTM D 6747. Standard Guide for Selection of Techniques for Electrical Leak Location of Leaks in Geomembranes, *American Society for Testing and Materials*, West Conshohocken, Pennsylvania, USA.

Beck. A. (2016). Best Practices for Groundwater Protection, *GeoAmericas 2016*.

Beck. A. (2014). Designing to minimize geomembrane leakage, *Geosynthetics Magazine*, August/September Issue.

Darilek, G.T. and Laine, D.L. (1999), *Performance-based specification of electrical leak location surveys for geomembrane liners*, Geosynthetics '99, Boston, Massachussetts, USA, April 1999, pp. 645-650.

Darilek, G.T. and Laine, D.L., (2010). Leak Location Surveys, The Past, The Present, The potential, *GSI Annual Meeting 2010.*

Forget, B. et al., (2005). *Lessons Learned from 10 Years of Leak Detection Surveys on Geomembranes*, Sardinia Symposium, Sardinia, Italy.

Giroud, J.P., (1984). “Impermeability: The Myth and a Rational Approach”, Proceedings of the International Conference on Geomembranes, Vol. 1, Denver, CO, USA, June 1984, pp. 157-162.

Thiel, R., Beck, A. & Smith, M.E. (2005). *The Value of Geoelectric Leak Detection Services for the Mining Industry*, Geofrontiers, ASCE, Waste Containment and Remediation. pp. 1-6.

Touze Foltz. N. (2002). *Méthodes de détection et de localisation de défauts dans les géomembranes*. Ingénieries, E A T, 2002, pp. 17-25.