GEO12-FW-020 - Suitability of a Semi-automatic Mobile System for Detecting Defects of Different Sizes and Shapes in Landfill Liners

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ABSTRACT
Landfills are engineered facilities construct with a barrier system (lining system) intending to ensure the protection of the environment. The effectiveness of lining systems depends, above all, of the performance of the GM. A critical issue in their performance is the defects caused by construction activities. Thus, a research program is in progress with the purpose of developing a semi-automatic mobile system to assess the integrity of the GM after the placement of the PLCS, in a quick and accurate way, and overcome the disadvantages of existing methods. The first stage of the research program is accomplished. In this stage, the functionality of a prototype was tested in a small scale pilot plant. This paper reports the results of tests carried out on the pilot plant. Conclusions are drawn about the suitability of the prototype to detect holes of different sizes, shapes and with different spacing intervals, as well as about the influence of water content on materials located below and above the GM.

RESUMO
A eficácia do sistema de confinamento dos aterros de resíduos depende sobretudo do desempenho da GM. A ocorrência de orifícios na GM parece inevitável, designadamente, durante a colocação da camada de drenagem. Assim, está em curso um projecto de investigação com o objectivo de desenvolver um sistema móvel semi-automático de detecção de orifícios em GMs, mais expedito e económico que os métodos já existentes e que supere alguns dos inconvenientes destes. Nesta fase já foi desenvolvido o protótipo, dotado de meios que permitem a detecção semi-automática de localização dos orifícios e está a ser testada a sua funcionalidade em escala reduzida, numa instalação piloto no ISEL. No presente artigo descreve-se a instalação piloto realizada no laboratório do ISEL e apresentam-se as conclusões sobre a capacidade do protótipo para detectar orifícios de diferentes dimensões, formas e distâncias, bem como a influência do teor em água dos materiais localizados sobre a GM.

1. INTRODUCTION

Landfills are engineered facilities designed and constructed with a barrier system (lining system) intending to ensure the protection of the environment. This system includes active and passive barriers. The passive barrier comprises a compacted clay liner (CCL) and/or a geosynthetic clay liner (GCL), while the active barrier includes a geomembrane (GM), protected by a geotextile (GTX), and a drainage layer known as primary leachate collection system (PLCS).

The effectiveness of lining systems in service conditions depends, above all, on the performance of the GM. A critical issue in their performance is the defects, which, unfortunately, seems to be unavoidable (Nosko and Touze-Foltz 2000; Peggs 1996; Peggs and Wallance 2008; Rollin *et al.* 2004). Most of these appear during the placement of PLCS (Barroso *et al.* 2007; Colucci and Lavagnolo 1995). Indeed, data reported by Nosko and Touze- Foltz (2000), collected at more than 300 sites, from 16 countries, showed that 71% of the damages were caused by stones during PLCS installation.

Although there are some test methods do detect and locate defects in GM liners after the placement of the PLCS, as stated by Beck *et al.* (2008), namely the soil-covered GM method (mobile probe) and the grid method (permanent), the existing methods present some disadvantages. They are laborious and time consuming and, so, very expensive. Also, they were developed for liner systems consisting of GM+CCL, which is neither the case of Portuguese landfills (GM+GCL+CCL), nor the recommended for hazardous landfills, which typically include double liner systems. The disadvantages of the existing methods have made them infeasible for Portuguese landfills. Hence, there is a risk of potential environment damage, due to the lack of a feasible practical method.

Thus, to avoid the potential environment damage a research program is ongoing with the purpose to develop a semi-automatic mobile test method to assess the integrity of the GM after placement of PLCS, in a quick and accurate way. The test method is intending to overcome the disadvantages of the existing methods, and provide a tool to be used, not only in bottom liner systems, but also in cover systems. The methodology used consists in the development of a prototype, endowed with functionalities that allow the semi-automatic data acquisition (detection and location of the defects) and real time processing. The functionality of the prototype will be verified, in two pilot plants: an indoor first stage (ISEL´s laboratory) and an outdoor second stage (LNEC's campus). It will be finally checked in situ, at a true landfill.

This paper reports on the pilot plant developed at ISEL's laboratory and presents the test results. Conclusions are drawn about the ability of the prototype to detect holes of different sizes, shapes and different spacing intervals, as well as about the influence of water content on materials located below and over the GM.

2. EXPERIMENTAL WORK

2.1 Prototype and Test Methodology

The prototype is based on the device used in electrical resistivity test to carry out tests based on the principle of the mobile probe method (ASTM D 7007).

The prototype, developed to work in laboratory, consists of 21 electrodes mounted on a bar and assembled in order to measure the electrical potential induced by the electrical current injected into the soils above and below the GM by two remote electrodes. The apparatus moves along two orthogonal directions across the pilot plant and the measurements are carried out between pairs of electrodes (dipoles) along several parallel profiles in each of these directions (Figure 1).

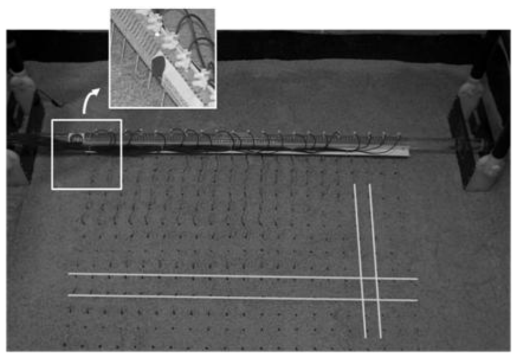


Figure 1. The prototype.

2.2 Pilot Plant

The pilot plant (Figure 2) consists of a pad area with 1.8×1.8×0.8 m^3 in which the bottom was leveled by a screed with a slope of about 2% to replicate the bottom of a landfill. Then a layer of 0.3 m fine grained soil (more than 80% smaller than #200) was compacted ($\gamma_{dmax} = 17.1$ kN/m^3 and $w_{opt} = 17\%$).

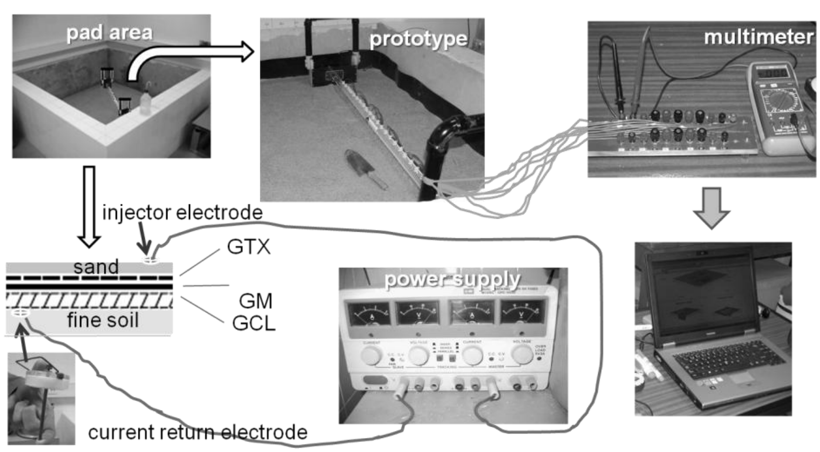
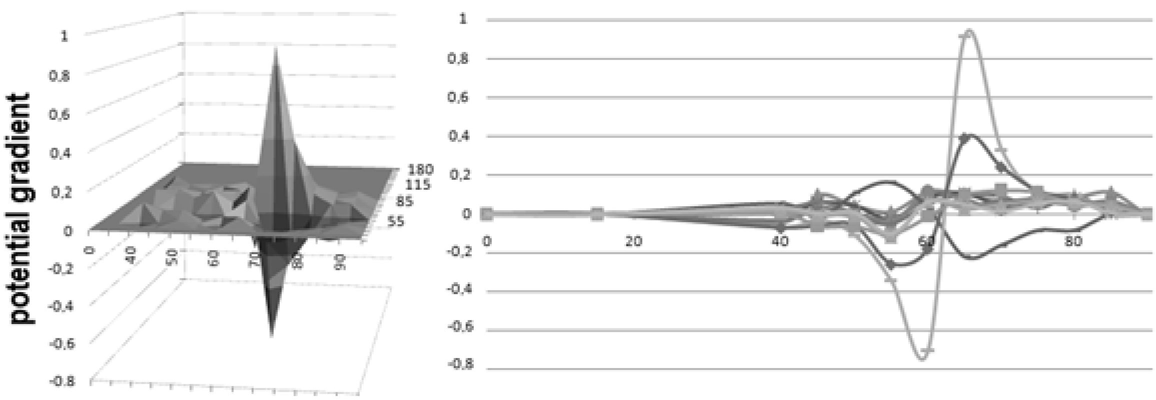


Figure 2. The pilot plant.

Over the soil a GCL was placed. The GCL is composed by a core of a sodium bentonite encapsulated between a non-woven and a woven geotextiles, with a mass per unit area of 5000 g/m^2, and a natural water content of 11.4%. A high-density polyethylene (HDPE) geomembrane 2 mm thick was then placed. To ensure no electrical connection between the soils above and below the geomembrane, extrusion seams were made in the corners of the geomembrane. Above the GM were placed: (a) a needled punched geotextile with a mass per unit area of 300 g/m^2; and (b) a uniform sand layer with an average grain size of 950 µm.

The power supply is an independent voltage source of 60 V DC, having two terminals: (a) an injector electrode placed in the soil above the geomembrane and (b) a current return (ground) electrode in the medium below the liner. The prototype is used to measure the potential gradients on the surface of the overlying medium (sand, in this case) and to identify the steep characteristic gradient associated with a leak. The voltage measurements were collected by a digital multimeter connected by cables to the device that allows the readings of potential gradient between the electrodes of the prototype.

A graphical interface, developed for the purpose of allowing to visualize the output potential gradient, displays the output on a 3D or 2D graph in a laptop computer as shown in Figure 3.



a) 3D graph b) 2D graph

Figure 3. Illustration of the output potential gradient displays (one hole in the GM).

2.3 Testing Program

The purpose of tests on the pilot plant is to evaluate the accuracy of the prototype to detect holes of different sizes, shapes and at different spacing intervals in the GM, as well as verifying if the equipment is operational in different conditions of saturation, for the different materials above the GM. For this purpose a set of different tests were programmed as shown in Table 1.

Table 1. Test program.

tests type	materials layers	purpose
A	fine soil+GM+GTX (wet)	• to check the minimum size of the holes that can be detected by the prototype
B	fine soil+GCL($w_{natural}$)+GM+ GTX ($w_{natural}$/wet)	• to check the suitability of the prototype to detect holes if a GCL layer is placed under the GM
C	fine soil+GM+ GTX ($w_{natural}$)+sand ($w_{=0,15\%}$)	• to check the suitability of the prototype to detect holes if the materials above the GM have a natural water content
D	fine soil+GM+ GTX (wet)+sand ($w_{increasing}$)	• to check the minimum sand layer water content in order to detect an electric current flow
E	fine soil+GCL($w_{natural}$)+GM+ GTX (wet)+sand ($w_{=0.15\%}$)	• to check the suitability of the prototype to detect holes if the materials above the GM have a natural water content, in the presence of a GCL layer placed under the GM
F	fine soil+ GCL($w_{natural}$)+GM+ GTX (wet)+sand ($w_{increasing}$)	• to check the minimum water content and thickness sand layer in order to detect an electric current, in the presence of a GCL layer placed under the GM • To check the suitability of the prototype to detect holes of different sizes, shapes and at different spacing intervals

Note: GM – geomembrane; GCL – geosynthetic clay liner; GTX – geotextile; w – water content

3. TESTING AND RESULT ANALYSIS

The results from the A, C and D-type testing are not reported because they are not always consistent, due to the difficulty in having a small resistance for the electric contact between the GM and the fine soil (thus hindering the flow of electric current), due to the rigidity of GM and to the small size of the pad area.

For the B-type testing, in a first step, tests were carried out with a circular hole in the GM. The 2 mm diameter hole is the minimum diameter detected by the prototype (figure 4).

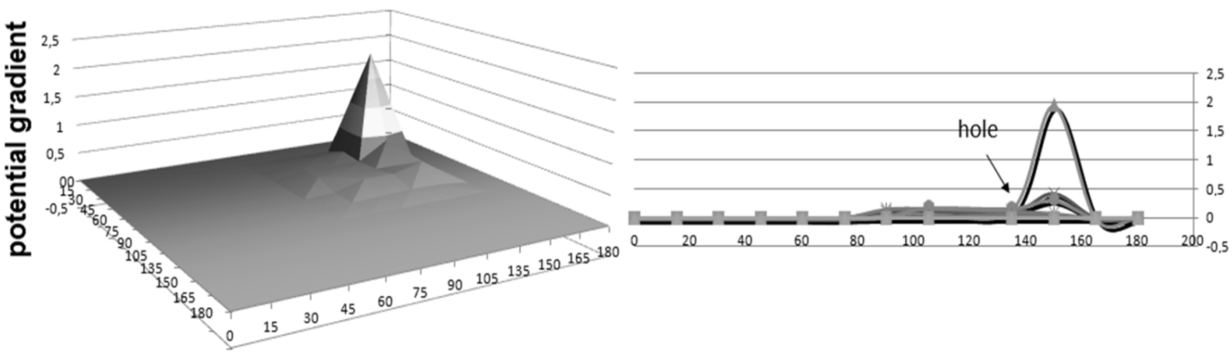


Figure 4. B-type test: detection of a circular 2 mm hole in the GM.

In a second step, tests were carried out with two circular 2 mm holes in the GM. Tests carried out with two holes spaced less than 0.5 m, showed that the holes interfere each other and it is not possible to determine their respective locations. Figure 5 shows that the prototype can detect and accurately locate two holes 0.5 m apart (Figure 5).

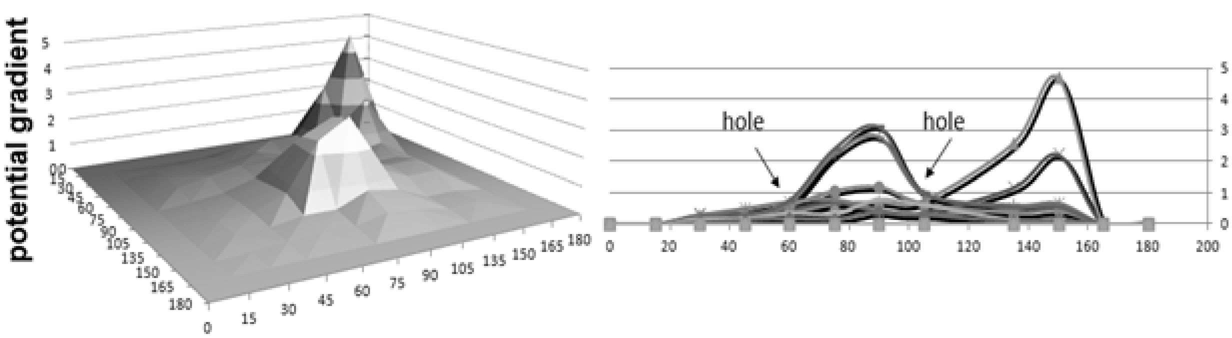


Figure 5. B-type test. Detection of two circular 2 mm holes in the GM.

For the B-type testing, it was found that the existence of electric current depends on the wetting of the geotextile.

With regard to results of the E-type tests, it was found that no electric current flow was detected, when the sand layer (0.08 m thick) presented a water content about 0.15% (as it was provided).

For the F-type testing, in a first step, tests were carried out with a 2 mm diameter circular hole in the GM. The water content of the sand layer was increased until the hole was detected. After increasing the average water content to 3.5%, the hole was detected (Figure 6), but the hole location was less accurate than in the B-type tests.

Subsequently, in the GM two 2 mm holes were made 0.5m apart, because due to the pad area size it was not possible to perform tests with holes spaced more than 0.5 m apart. The second hole was not detected (Figure 7).

Then, several tests were carried out by changing the supply voltage, the water content, the thickness of the sand layer and by enlarging the diameter of holes, but the results were inconclusive. Then, another attempt was done by changing the shape of the hole, to simulate a 0.09 m long tear (Figure 8).

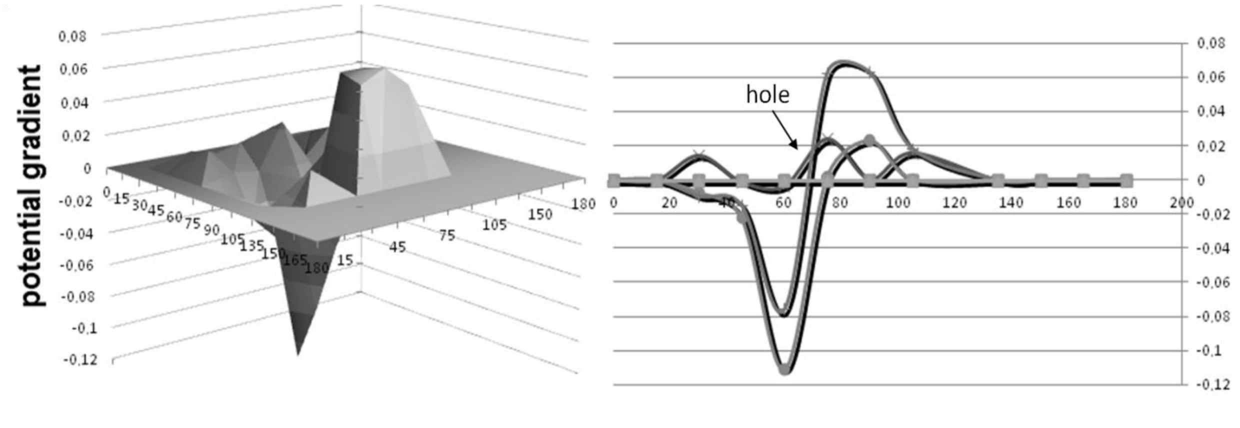


Figure 6. F-type test: detection of a circular 2 mm hole in the GM.

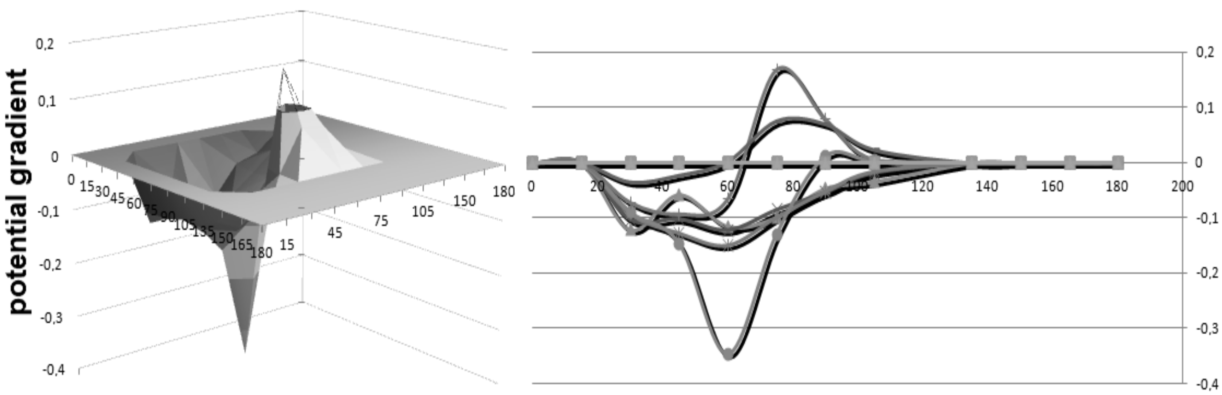


Figure 7. F-type test: detection of two circular 2 mm holes in the GM.

Figure 8. Shape and dimension of the tear.

First, tests were carried out only with one tear (0.09 m long) in the GM, in the following conditions: GCL with natural water content of 11.4%, GTX wet and sand layer (0.15 m thick) with a water content about 4%.

As shown in Figure 9 the prototype can detect and locate the hole. But when the tests were carried out with two tears 0.05 m apart, the second one was not detected, although it was 0.09 m long (Figure 10).

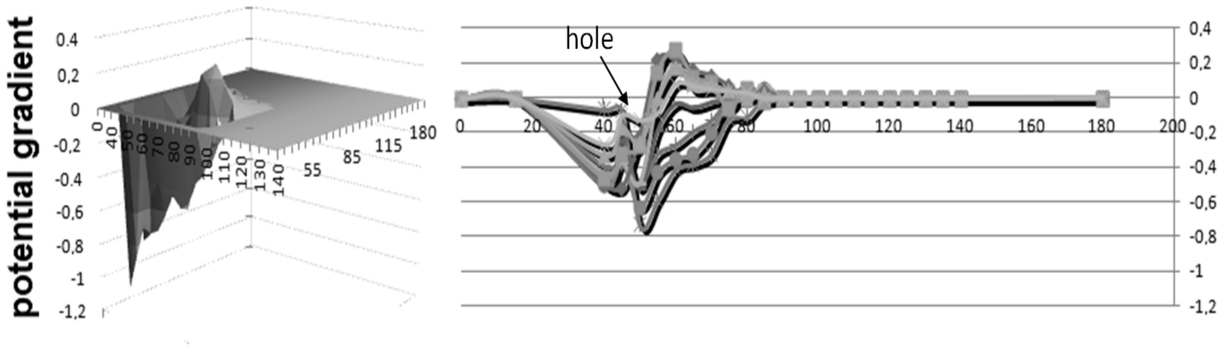


Figure 9. F-type test: detection of a of 0.09 m long tear in the GM.

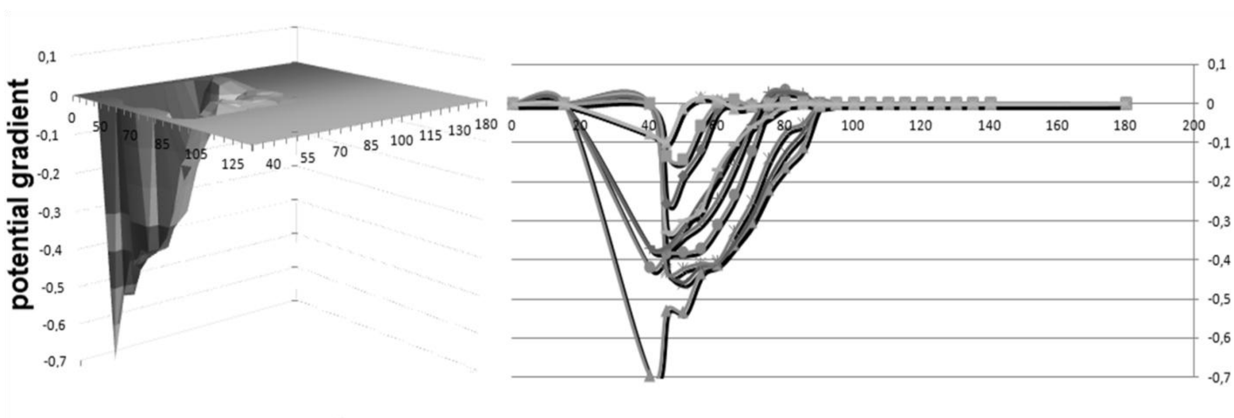


Figure 10. F-type test: detection of 0.09 m long tears in the GM.

4. CONCLUSION

This paper describes the research program carried out in order to study the suitability of the prototype to detect holes of different sizes, shapes and at different spacing intervals, as well as the influence of water content of the materials located below and above the GM.

The first stage of the research program, the indoor stage at ISEL´s laboratory, is accomplished. From these tests, it is possible to draw the conclusion as follow:

- If the geotextile above the hole is dry, then not enough current flows through the circuit to allow the detection of holes, due to the occurrence of a high electric circuit resistance;
- If the sand layer above the hole has a water content around 0.15%, then not enough current flows through the circuit. Again, due to the occurrence of a high electric resistance;
- If the tests are performed with the GCL at a natural water content (around 11.4%), the GTX wet and the sand with a water content greater than 3.5%, then the prototype is able to detect holes greater than 2 mm, independent of the sand layer thicknesses (0.08 and 0.15 m);
- If the thickness of the sand layer increases, then the accuracy of the prototype to locate the hole decreases, but for the set of tests carried out the deviation was less than 0.2 m;
- If two holes are placed too close to each other, then one hole may mask the other. This is due either by producing a significant smaller resistance electric circuit, or because the electric gradients at the level of the readings can be interpreted as the detection of only one anomaly.

In this stage it was not possible to carried out tests with holes spaced more than 0.05 m apart due to the pad area size. These tests will be carried out in the outdoor second stage of the research program, a larger facility to be held on the campus of LNEC.

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