Leak detection through geomembrane liner using electrical resistivity method

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ABSTRACT: Liners comprising of geomembrane layer placed over soil layer, are extensively used in waste containment systems for the prevention of soil and groundwater contamination. These liners operate in harsh physicochemical and mechanical conditions. Hence, their performance tends to get compromised over the intended design life. Defects often develop in the geomembrane due to poor placement practices and severe operating conditions. Subsequent environmental pollution ensues because of such defects. Therefore, it becomes critical to detect leakage issues as soon as they arise. The early leak detection is of vital importance for timely and economical hazard mitigation. Many different methods for leak detection are available, however, the electrical resistivity method is most feasible owing to its low operational cost and easy operability. Most soils have very high electrical resistivity values compared to that of contaminating fluids such as landfill leachates. Consequently, the leakage of even a small amount of leachate may cause significant rise in the electrical conductivity of the soil which can be easily detected. This paper outlines the development of an innovative system for the detection and localization of leaks in geomembrane liner placed over soil using the electrical resistivity method. Leak was introduced intentionally in the geomembrane and the resulting changes in the electrical resistivity of the underlying soil were observed. The newly developed system has been found to effectively detect and locate leakage in the geomembrane liner. The technique can find application in the effective handling, storage and management of wastes by waste containment facilities.

Keywords: electrical resistivity; geomembrane; leak detection; leaks; liner; soil

1 INTRODUCTION

The effective control of pollutants for the prevention of contamination is the most pressing concern faced by the waste storage and handling operators, such as landfilling facilities, tailing dams, leachate collection ponds, sump wells, underground storage tanks, etc. (Rowe 2012, Shukla and Yin 2006, Bouazza and Impe 1998). Lining systems are used by waste containment facilities to minimize potential contamination issues arising from the contact of pollutants with soil and groundwater (Shukla 2016, Daniel 1993, Daniel and Koerner 1991).

Liners are engineered systems with low permeability, designed to control the movement of liquid effluents out of the containment units. Geomembrane (GMB) liner placed over the soil is used extensively for this purpose (Rowe 2012, Shukla and Yin 2006, Shukla 2016). Figure 1 shows a typical geomembrane liner used at a landfilling facility.

Although the lining systems are designed to be intact over their planned lifespan, harsh physicochemical operating conditions and poor placement assurance tend to cause damages to the liners. Subsequently, "all liners leak" (Giroud 1984). Defects are observed to develop in the liners leading to the leakage of liquid contaminants (Ben Othmen and Bouassida 2013, Giroud and Bonaparte 1989). These leakage issues must be located and repaired timely, to ensure minimum environmental impact. Large time lags in detection lead to unacceptable increase in the contamination of soil and groundwater (Giroud 1984). Hence, this leads to more damage to the environment and significantly greater costs of hazard mitigation. Therefore, putting in place a system for the early detection of geomembrane defects and leakage issues becomes critical for any waste storage and handling facility (Oh *et al.* 2008).

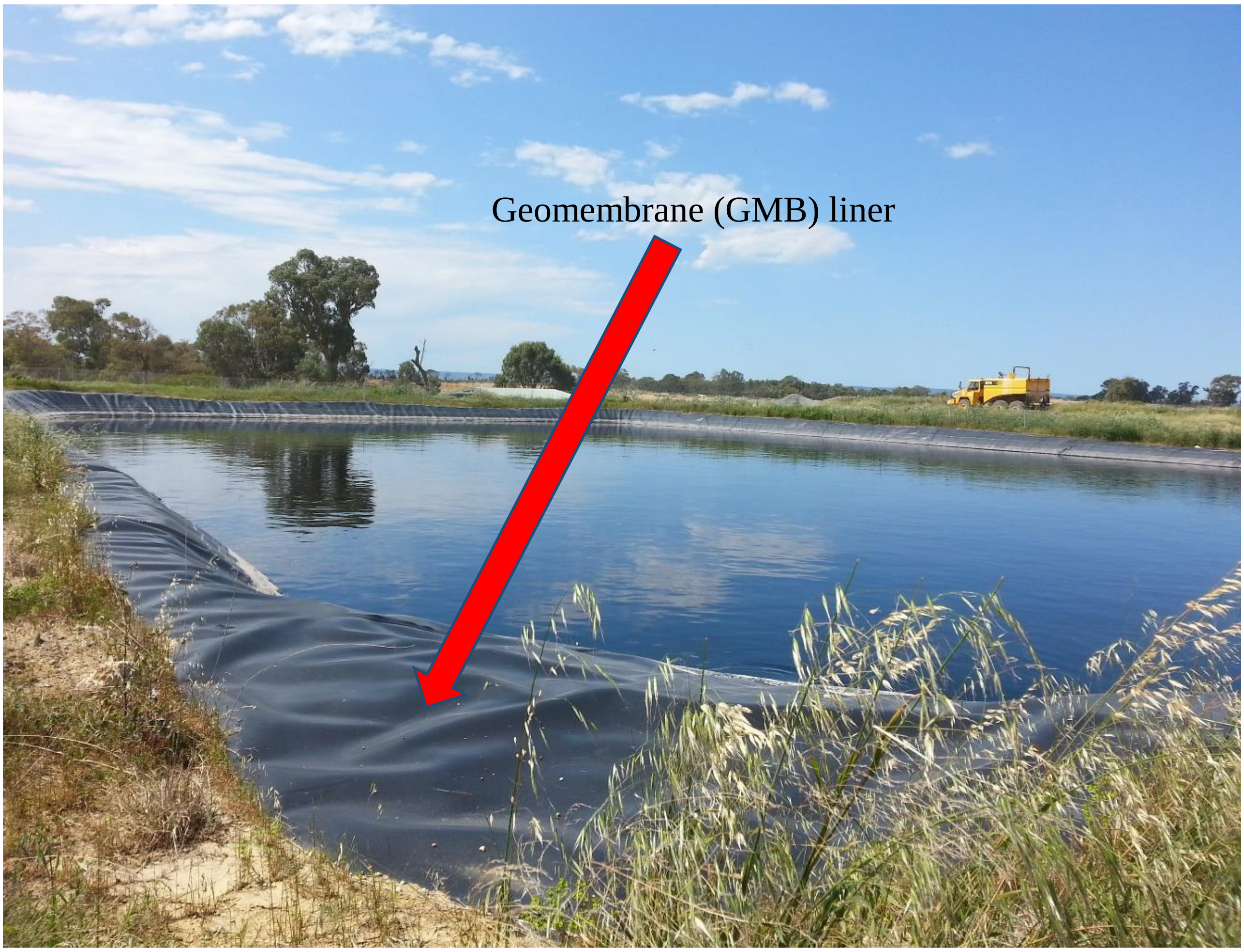

Figure 1. Leachate collection pond at Millar road landfill and recycling facility, Perth, WA, Australia.

2 METHODS FOR DETECTION OF LEAKAGES IN LINERS

Table 1 lists the various conventional methods that are used for the detection of leakage across liners resulting from the different types of defects based on existing research work (Pandey *et al.* 2015, Ben Othmen and Bouassida 2013, Oh *et al.* 2008, Hix 1998). The associated advantages and disadvantages have also been summarized.

These methods make use of the changes in the properties of soil and groundwater, produced due to their contamination by leachates, to detect liner defects. It is important to note that early detection of leakage and the timely repair of liner is critical to minimize the hazardous impact of leachate contamination (Ben Othmen and Bouassida 2013, Giroud 1984). The use of conventional methods listed in Table 1, generally increase the time period for leak detection. A solution to this problem is the use of the electrode grid method which locates leaks in active and closed solid waste landfills, monitors the entire area below the liner and, can detect holes in the liner during the construction phase. However, this method is relatively new and is limited by high installation costs. For the effective use of any leak detection technique using electrical resistivity sensing system, it is essential to have thorough understanding of the parameters controlling the resistivity of that specific soil such as various soil parameters, type of defects and type of contaminants. Hence, there is a significant scope of research to establish an effective method to obtain this background data.

The main purpose of this research work is to develop a new and innovative technique, based on the electrical resistivity method, with a view to its application in various waste containment facilities to detect soil contamination and therefore, to assist in determining leakage issues in their lining systems. This newly developed apparatus can be applied for the development of sensors for real-time monitoring of lining systems. In addition, it can be used by practicing engineers for the design and management of the lining systems in waste containment facilities. Furthermore, this methodology can be adopted as a standard method for soil testing by the Australian government and Standards Australia, in accordance to their policies. Additionally, this work will have several other applications, such as soil and corrosion studies, anomaly detection, subsurface water profiling and prospecting.

Table 1. Leak detection methods.

Leak detection methods	Advantages	Disadvantages
Groundwater monitoring wells	Detects contaminant plumes	Does not prevent groundwater contamination, expensive, can only detect plumes that pass by the line of wells
Lysimeter	Detects contamination	Requires laboratory testing, high operating cost, cannot pinpoint the location of the leak
Diffusion hoses	Widely available components, automatic, low operational cost	Ineffective if leachate does not produce vapor
Capacitance sensors	Readily available, automatic	Measures all moisture, not specifically leachates
Tracers	Can be used at any stage of landfilling, leachate composition not required	Operational cost high due to manual collection and testing, does not locate exact leak point
Electro-chemical sensing cables	Widely available	Detects very narrow range of contaminants, site specific, must be installed during construction phase
Two electrode method	Especially useful for detecting leaks in pre-existing landfills	Indicates only the existence of a leak, cannot be used for active landfills

3 DEVELOPMENT OF LEAKAGE DETECTION SYSTEM

An innovative leakage detection system (LDS) was developed with a view to its application in the electrode grid method of liner leakage detection. It consisted of a soil box as shown in Figure 2 and an AEMC ground resistance testing machine (Figure 3).

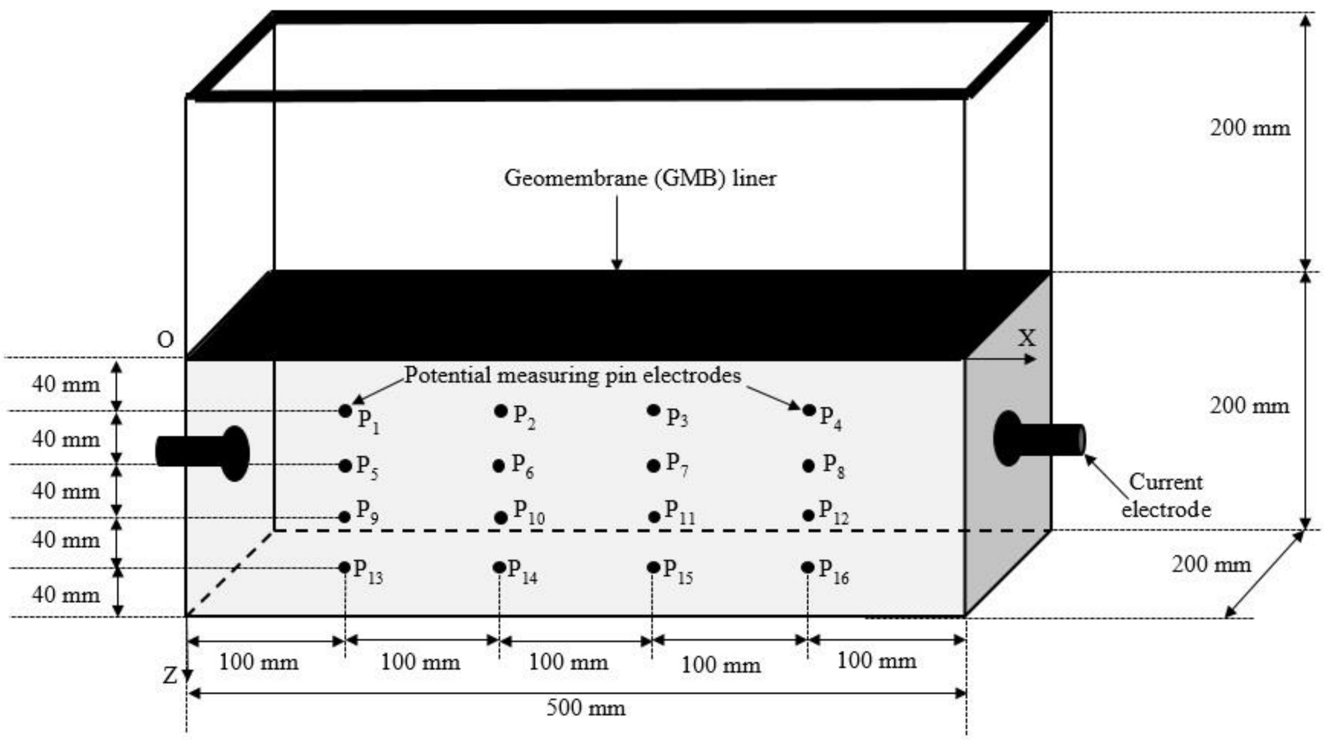

Figure 2. Soil box used for the leak detection system.

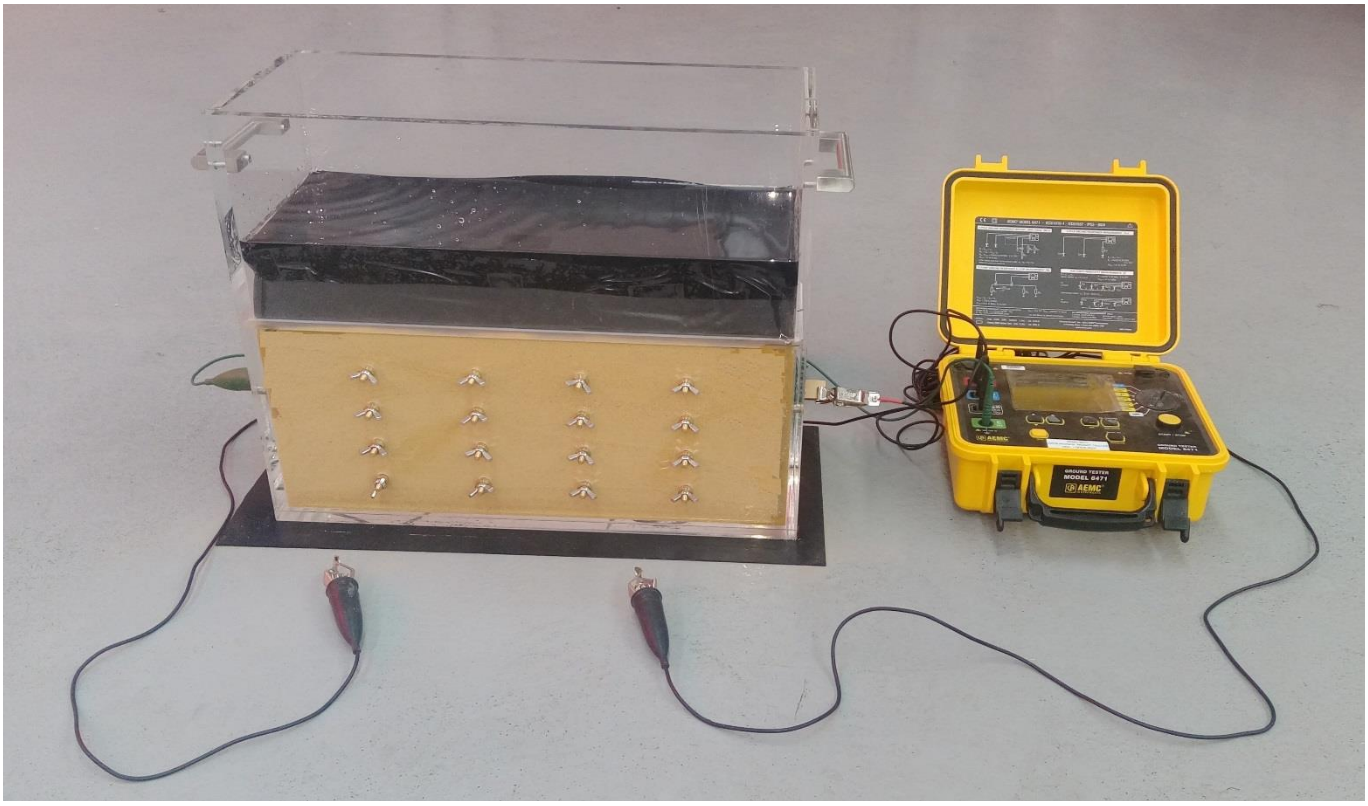

Figure 3. Experimental setup for the leak detection system.

The experimental apparatus has been developed based on the Australian standard AS 1289.4.4.1-1997 (Standards Australia, 1997). The main setup was a box (internal dimensions as 500 mm length, 200 mm width and 400 mm height) fabricated using 12 mm thick non-conducting perspex sheet. All joints were waterproofed. Two brass current plate electrodes of dimensions 200 mm by 200 mm and 16 brass potential measuring pins of 4 mm diameter, were installed in the box (Figure 2). A groove of 8 mm diameter was made all around the box, with its center at a height of 200 mm from the bottom. Complete details about the development of the test apparatus with technical analysis have been presented recently by Pandey, Shukla and Habibi (2017).

4 TEST METHODOLOGY

A 220µ thick geomembrane (GMB) layer was used in this test. The GMB of 550 mm length and 250 mm width was cut out. A puncture defect was intentionally made in the center of the GMB with an angular gravel-size particle to replicate actual landfill conditions. The defect was covered initially with a piece of tape and uncovered at the beginning of the test, that is, at time $t = 0$. Here, the leakage duration, t (min) is the time period for which the leakage through GMB was allowed, and the resistivity of the soil was measured.

The soil specimen used in this study is representative of the Perth metropolitan region. It is classified as poorly graded sand (SP) with a specific gravity of 2.68. The minimum and maximum dry unit weights were 14·02 kN/m^3 and 15·56 kN/m^3, respectively.

The soil was oven dried overnight at 110°C. It was then filled into the box up to a height of 200 mm, to achieve a relative density of 100%. The soil was then covered with the precut GMB layer to simulate a landfill liner (Figure 3). A rubber gasket (8-mm diameter) was fitted into the groove over the GMB layer to hold it in place and to ensure that there are no leakages, apart from the leakage through the intentionally introduced defect.

A constant head of 100 mm of potable tap water, used as the leaching liquid in this experimental demonstration of the leak detection system, was maintained over the geomembrane for the test. The motivation behind using tap water was that any leachate contaminant generally possesses conductivity greater than that of tap water. So, if the developed leak detection system is sensitive enough to detect the tap water, it can easily detect the leakage of any other leaching fluid.

After the water was filled in the box, the tape which covered the defect was removed and the water was allowed to leak out to the underlying soil. This time at the beginning of the test was recorded as $t = 0$. Electrical resistance of soil, R (Ω), was obtained at various time intervals using the AEMC 6471 ground resistance testing machine. Current was injected through outer plate electrodes and the potential drop across each pair of pin electrodes was measured as shown in Figure 3.

Figure 4 is a representation of the soil box used in this study. Here, x (mm) is the distance and z (mm) is the depth of the mid-point of each pair of electrodes, respectively. Twelve resistance readings were obtained as shown in Figure 4. Resistance between each electrode pair was assumed to be situated at the mid-point of the two electrodes, for the analysis of results. This research is ongoing, and as an example, the results obtained at one time interval $t = 30$ min, have been presented here.

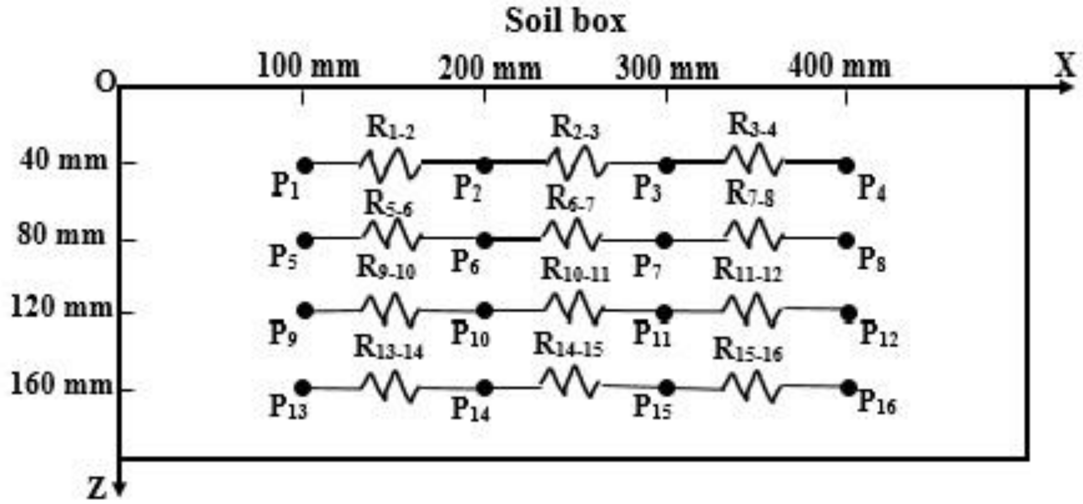

Figure 4. Representation of the soil box.

5 RESULTS AND DISCUSSION

Figure 5 shows the variation of the measured soil resistance for a leakage duration, $t = 30$ min.

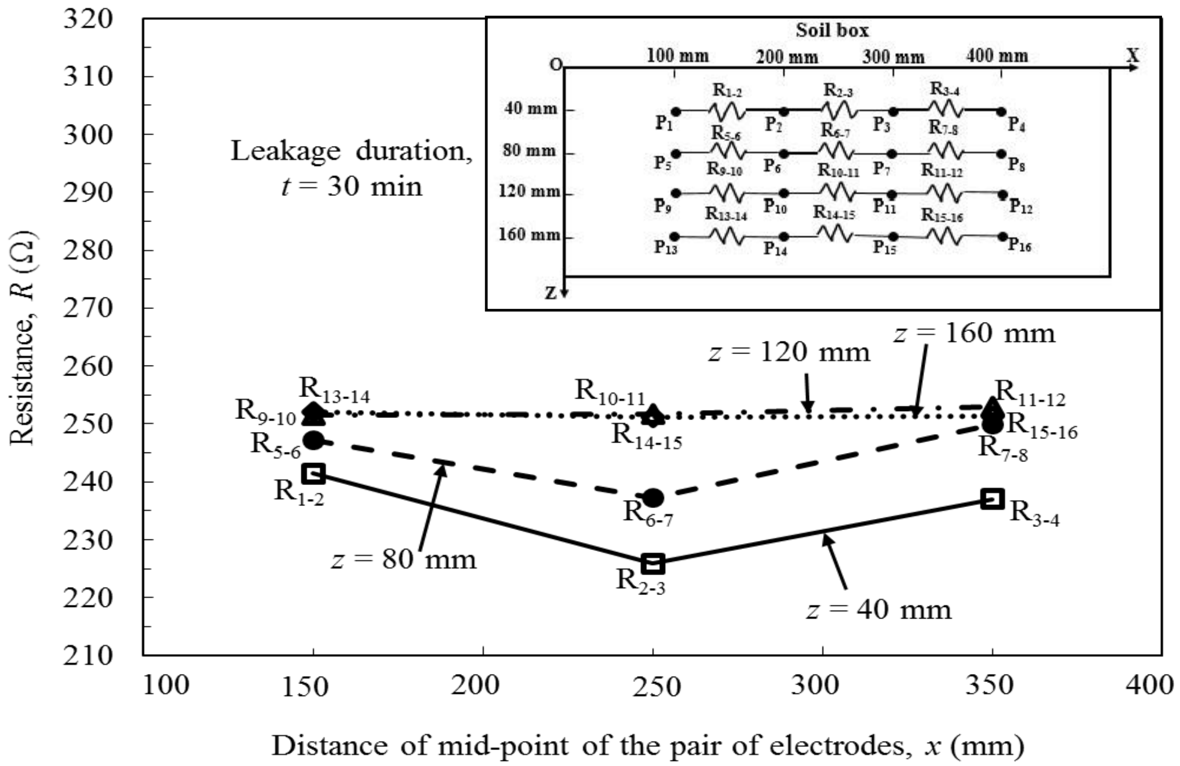

Figure 5. Variation of resistance in the specimen.

It can be noted that at a depth $z = 40$ mm, the resistance (R) first decreased and then increased with an increase in the distance of the mid-point of electrodes (x). This observation has been as expected. The hole in the geomembrane (GMB) liner was positioned directly above resistance R_{2-3}. Hence, the amount of water between the potential measuring electrodes, P_2 and P_3, would be greater than the amount of water between the adjacent electrode pairs. Therefore, R_{2-3} was expected to be lower than R_{1-2} and R_{3-4}. Similar observations were made for the resistance at a depth of 80 mm from the GMB liner.

It can be seen from Figure 5 that at a given x, soil resistance R increases with an increase in the depth z. This observation also complies with the expectation that with an increase in z, the amount of water in soil would decrease, and consequently R would increase.

It can be noticed that with an increase in the distance or the depth from the hole, the resistance of the soil shows an increase. Therefore, the location of the liner leak can be ascertained based on the resistance profile of the soil. Based on these observations, it can be concluded that the newly developed leak detection technique is reasonably effective for detecting and locating leakages through liners.

Furthermore, for t = 30 min, these changes in soil resistance are noted to be negligible with increase in depth. At the depths of 120 and 160 mm, the effect of x and z was found to be insignificant. This observation would differ with increase in leakage duration t.

6 CONCLUSIONS

Investigation of electrical resistivity of the liner base soil is highly useful in detecting leakage issues in geomembrane liners placed over that soil layer. Based on this fact, an innovative leak detection system has been developed as mentioned. Results have also been given for the leak detection test for a leakage duration of 30 min. The resistance of the soil increased with an increase in the depth or the distance, of the mid-point of the pair of electrodes, from the liner leak. The effect of distance and depth was found to be negligible at higher depths, for leakage duration of 30 min. It was observed that the newly developed system can be used by different types of waste containment systems to effectively detect and locate leakages in liners. This innovative methodology for the testing of the electrical resistivity of soils can be adopted as a standard method for soil testing by the Australian government and Standards Australia, in accordance to their policies. Furthermore, this work will have numerous applications in several areas, such as soil and corrosion studies, anomaly detection, subsurface water profiling and prospecting.

REFERENCES

Ben Othmen, A. & Bouassida, M. 2013. Detecting defects in geomembranes of landfill liner systems: durable electrical method. International Journal of Geotechnical Engineering, Vol. 7(2), pp.130-135.

Bouazza, A. & Van Impe, W.F. 1998. Liner design for waste disposal sites. Environmental Geology, Vol. 35(1), pp.41-54.

Daniel, D.E. 1993. Landfills and impoundments. Geotechnical practice for waste disposal, Springer, USA, p. 97-112.

Daniel, D.E. & Koerner, R.M. 1991. Landfill liners from top to bottom, Vol. 61, Issue 12, pp. 46-49.

Giroud, J.P. 1984. Impermeability: The myth and a rational approach. Proceedings of the International Conference on Geomembranes, Vol. 1, p. 157-162.

Giroud, J.P. & Bonaparte, R. 1989. Leakage through liners constructed with geomembranes—Part I. Geomembrane liners. Geotextiles and Geomembranes, Vol. 8(1), pp.27-67.

Hix, K. 1998. Leak detection for landfill liners. National Network for Environmental Management Studies Report. National Service Center for Environmental Publications, USA. [Accessed online on 15-06-2017: https://clu-in.org/download/studentpapers/leaklnfl.pdf]

Oh, M., Seo, M.W., Lee, S. & Park, J. 2008. Applicability of grid-net detection system for landfill leachate and diesel fuel release in the subsurface. Journal of Contaminant Hydrology, Vol. 96(1), pp.69-82.

Pandey, L.M.S., Shukla, S.K., & Habibi, D. 2017. Resistivity profiles of Perth soil in leak detection test. Geotechnical Research, Vol. 4(4), pp. 214-221.

Pandey, L.M.S., Shukla, S.K. & Habibi, D. 2015. Electrical resistivity of sandy soil. Geotechnique Letters, Vol. 5(3), pp.178-185.

Rowe, R.K. 2012. Geotechnical and geoenvironmental engineering handbook, Springer Science & Business Media, Berlin, Germany.

Shukla, S.K. 2016. An introduction to geosynthetic engineering, CRC Press, Taylor & Francis Group, Florida, USA.

Shukla, S.K. & Yin, J.H. 2006. Fundamentals of geosynthetic engineering, Taylor & Francis, UK.

Standards Australia 1997. AS 1289.4.4.1: Methods of testing soils for engineering purposes. Sydney, NSW: Standards, Australia.