

Field Model Tests for Landfill Leachate Leakage Detection System using Grid-net Electrical Resistivity Measurement Method

격자형 전기비저항 측정기법을 이용한 매립지 침출수 누출감지시스템에 대한 현장 모형시험

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개요(SYNOPSIS) : 격자망식 전선배치에 의한 전기비저항 측정기법을 이용한 침출수 누출감지시스템을 개발하여 그 적용성을 평가하기 위하여 현장모형시험을 수행하였다. 현장모형시험을 수행한 결과 침출수 누출지점에서 전기비저항이 크게 감소하여 누출지점을 정확하게 감지할 수 있었다. 격자망식 전선배치에 의한 전기회로적인 효과로 인하여 전기비저항이 감소된 지점과 동일 전선상에 연결된 다른 센서에서의 측정값도 다소 감소하는 경향을 나타내었다. 이를 보정하기 위하여 P-SPICE를 이용하여 전기회로 시뮬레이션을 수행하여 전기회로 효과를 정량적으로 평가하였다. P-SPICE 시뮬레이션의 결과를 토대로 보정계수를 도출하여 현장모형시험결과를 보정하였으며, 보정된 결과에 의하면 전기회로적 특성에 의한 영향을 효과적으로 제거되어 누출지점에서의 전기비저항 감소가 명확하게 나타났다.

주요어(Key words) : 전기비저항, 매립지, 침출수, 누출감지시스템, P-SPICE

1. Introduction

Soil and groundwater can be easily contaminated by the landfill leachate induced from the damage of liners. To prevent contamination of soil and groundwater, geomembrane liners are often used to enclose and contain the landfills. Although most manufacturing defects and construction flaws in the geomembrane liner should be detected and repaired prior to operation of landfill, leakage may develop due to inferior workmanship during field construction, deterioration of the geosynthetic material after prolonged exposure to corrosive chemicals, or physical contacts by humans and animals during operation. Laine and Darilek(1993) reported that it has detected an average of 22.5 leaks per 10,000m² of geomembrane liner in landfill. Although the problems are considered seriously

so far, there have been no statistics on leakage in landfills reported in Korea as yet. However, it is still considered serious.

The conventional methods to characterize subsurface contamination involve collecting representative samples of soil and pore fluid and analyzing them in the laboratory (Okoye et al. 1995; Kaya and Fang, 1997). However, sample collection and analysis method has significant problems: (1) sampling of the soils is extremely time consuming and expensive; (2) sampling is destructive in the case of removing the soil samples; and (3) samples can be contaminated during sampling, transportation, and analysis (Kaya and Fang, 1997). Also, this method can only detect leakage after the long-lasting contamination, because it is not continuous with time. Therefore, in landfills, it is necessary to replace and repair liner system after finding out when liner is broken as soon as it leaks. Leakage detection system can be effectively used for early detecting the leak point through continuous monitoring. It can make the minimum of the environmental damage caused by leachate.

The concept of which the electrical properties of subsurface material can be affected by the introduction of contaminants might be applicable for developing the leakage detection system using electrical resistivity measurement for leachate coming from landfill. Electrical resistivity surveys are a particularly useful technique for examining the possible subsurface distribution of contamination plume (Brandl and Robertson, 1997). Every soil type possesses a natural resistivity within certain limits; deviations may suggest possible pollution. It is known that contaminants influence the bulk resistivity of soil because they change the electrical properties of the groundwater and soils (Abu-Hassanein et al., 1996; Yoon et al., 2002). In this study, grid-net leakage detection system was designed, in which, electric wires were set up horizontally with specific intervals and other wires in perpendicular to these wires in the same way and every cross point had the electrical resistivity sensor. The field model tests were performed to evaluate the applicability of the grid-net landfill leachate leakage detection system using electrical resistivity. P-SPICE (Professional Simulation Program with Integrated Circuit Emphasis) simulations were also carried out to investigate and calibrate the expected electric circuit effects of grid-net leakage detection system.

2. Overview of Leakage Detection System

Leakage detection system is able to locate leak points without laboratory analysis. Several different types of sensors provide such benefits, including electrical methods measuring the voltage or current density, and chemical methods analyzing soil vapor or reacting directly to leachate or using tracer chemicals to detect leaks. Currently, leakage detection system based on using the electrical method is the most widely researched out of the many other leakage detection systems. The established electrical method utilizes the insulative properties of geomembrane liners. This method requires installing electrodes inside and outside the landfill. It detects the electrical current flow from one electrode to another through a hole developed in the insulating liner (White and Barker, 1997). However, these methods are applicable to landfills where insulating geomembrane liner is installed. In addition, even if geomembrane liner is installed, exact monitoring is not at ease because there is a possibility of current movement at landfill boundaries. Furthermore, installation of outside electrodes that must be located far away from landfills is difficult, considering the limited land use in reality.

Various types of leak detection tools are available for identifying leaks right after their development. But the use of these technologies is not widespread, mainly because of economical efficiency. Each leakage detection system has different advantages and disadvantages. The ideal

detection system should be sensitive to small holes, able to detect breaks in the liner without a significant loss of leachate, accurate in locating leakage, yield a minimum of false alarms, sufficiently durable to last through the life of the landfill, automated, and be inexpensive to installation and operation (Frangos, 1997). It must provide complete spatial monitoring for the entire area below the landfill. However, the perfect monitoring system has not yet been designed. Further research and development is necessary to create a system with these attributes.

3. Description of Grid-net Leakage Detection System

The grid-net leakage detection system developed in this study consists of three parts; grid-net electric circuit, electrical resistivity measuring sensors and measurement system including connection system and data storage system as shown in fig. 1. The concept of grid-net electric circuit is based on installing two perpendicular sets of horizontal electric wires in specific intervals with sensors at their intersections. This system detects leakage location by the analysis of electrical resistivity or electrical conductivity that can be measured at sensors. Electrical resistivity measurement is achieved by measurement system including current source and voltage meter. Resistivity measurement at sensor is performed by connecting each of both horizontal and vertical wires to measuring instrument in connection system. Namely, connecting the selected two horizontal and vertical wires to either a (+), (-) terminal of source meter creates a closed electric circuit that enables measurement at the sensor. By connecting other wires to source meter, measurements at all sensors are accomplished.

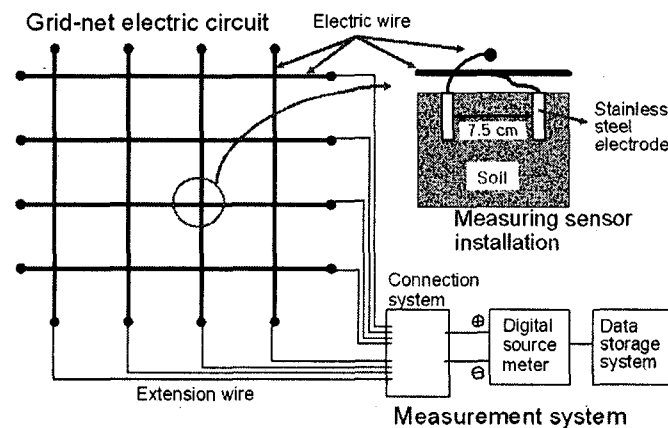


Fig. 1. Schematic diagram of grid-net leakage detection system

4. Experimental Section

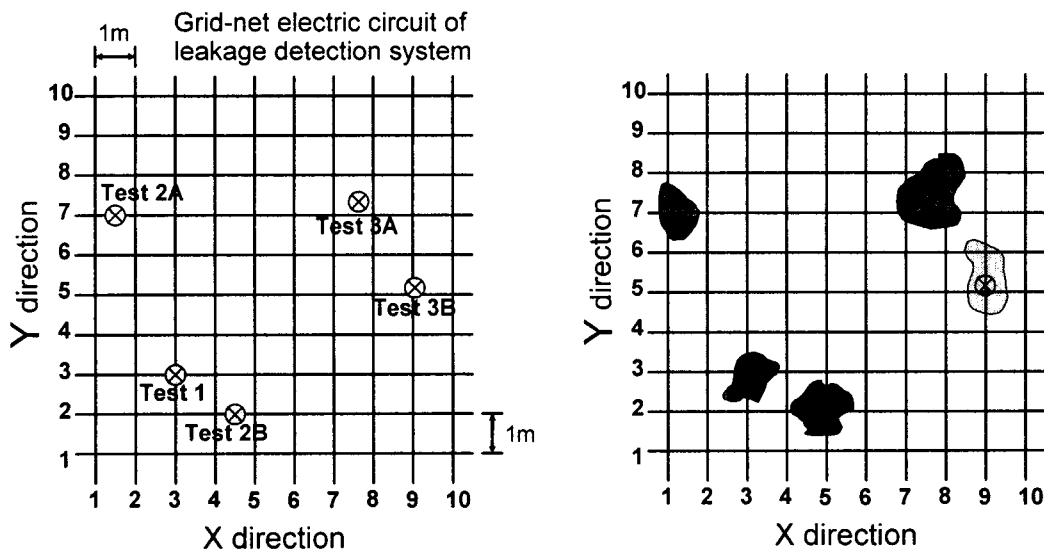
4.1. Field Model Test

A field model test was performed in order to evaluate the effectiveness of detecting landfill leachate using grid-net detection system based on electrical resistivity measurement. The prepared field site for the test was a 11m×11m foundation that had been compacted after excavation and back filling with field soil. After field compaction, ten wires at 1m spacings were installed at both horizontal and vertical directions. In addition, electrical resistivity measurement sensors were

installed at each intersections. After the installation of the grid-net electric circuit and sensors, test site preparation was completed by covering with geosynthetic sheets.

The experiment is performed by measuring the initial electrical resistivity at all sensors before leachate introduced. Then, the electrical resistivity of all sensors are measured after injecting leachate at a specific location within the test area. Electrical resistivity measurement was achieved by measuring the electrical potential under supplying a 0.1mA current by current source(Keithley 220). Table 1 shows the leakage conditions of field model tests and fig. 2. describes the leakage locations of this study and leachate distribution results from leachate leakage.

Soil sampled from experimental site is weathered granite soil that is classified as well graded sand(SW) under the Unified Soil Classification System. Landfill leachate used in this study was collected from Kimpo landfill, and its electrical conductivity measured by the conductivity meter(Orion 550A, USA) was 20.58mS/cm(=0.486Ωm).



(a) grid-net electric circuit and leak point (b) contaminant distribution due to leakage
 Fig. 2. leaking point of field model test and leachate distribution due to leakage

Table 1. Summary of field model test conditions

	Leaching solution	Leaching time (hour)	Total leaching amount (L)
Test 1	Kimpo landfill leachate	9	7.5
Test 2	A Kimpo landfill leachate	5.5	7
	B Kimpo landfill leachate	6	7
Test 3	A Kimpo landfill leachate	2	7
	B tap water	2	7

4.2. P-SPICE Simulation

P-SPICE(Professional simulation program with integrated circuit emphasis) simulation was performed to verify the electric circuit effect of grid-net configuration of leakage detection system and to calibrate the measured resistivity of field model test. It is frequently used to simulate the performance of an electronic circuit.

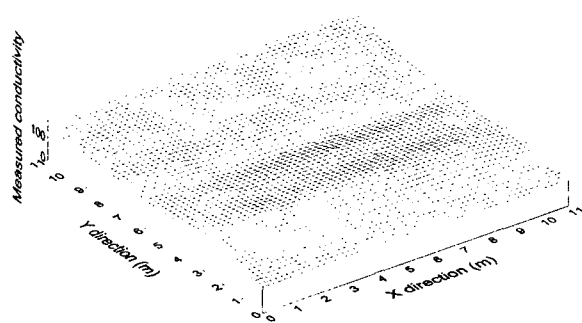
10×10 grid-net electric circuit is constructed in a same way with field model test to analysis

electric circuit with P-SPICE. Under the assumption that electrical resistivity of subsurface is constant before leakage development, one hundred $10k\Omega$ resistors were installed as a substitute of all sensors. In order to simulate the change in electrical resistance due to leakage, resistor at a selected point replaced by $0.1k\Omega$ in sequence. And then resistance of all resistors were measured.

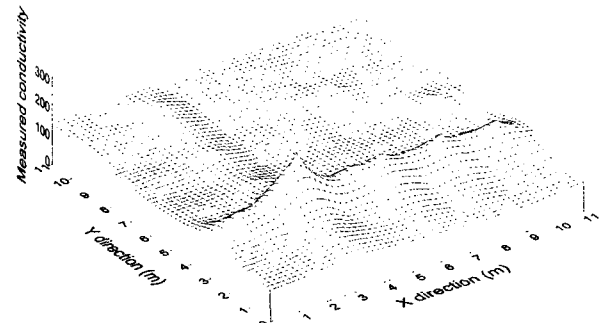
5. Results and Analysis

5.1. Field Model Test Results

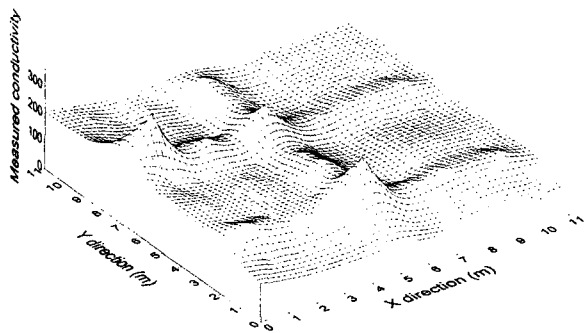
Fig. 3. shows the distribution of electrical conductivity that have been measured from field model tests. The graphs present electrical conductivity, the inverse of electrical resistivity, for a clear visualization because resistivity decreases with leakage development. The electrical conductivity of subsurface before leachate injection lie within a small range of $123.9\mu S/cm(=80.7\Omega m) \sim 197.2\mu S/cm(=50.7\Omega m)$ as shown in Fig. 3(a). Fig. 3(b),(c),(d) shows that an increase in electrical conductivity is evident at leakage locations. However, unexpected conductivity increases are developed at sensors connected to wires containing the increasing point of electrical conductivity due to leachate. It may be caused by the electric circuit effects of grid-net electric circuit configuration. Although the unexpected electric circuit effect is developed in field model test results, it is not significant in determining the location of leachate leakage. In order to obtain the clear information about leachate leakage, the quantitative analysis of electric circuit effects is necessary.



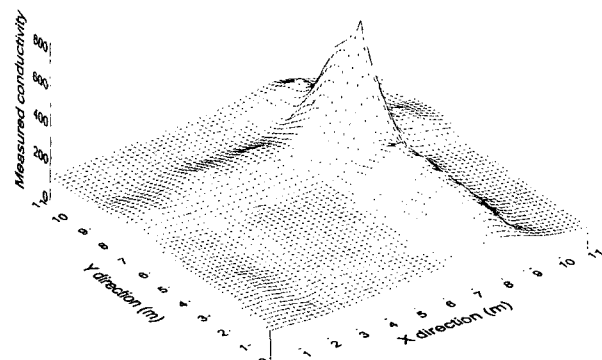
(a) before leakage



(b) test 1 results



(c) test 2 results



(d) test 3 results

Fig. 3. Measured electrical conductivity distribution of field model test

5.2. P-SPICE Simulation Results

When $10k\Omega$ resistors are installed at all intersections, P-SPICE simulation results give a $1.9k\Omega$ resistance measurement at all resistors. This can be explained that the grid-net electric circuit operates in an identical principle to that of the parallel circuit.

when resistance decreases at a specific location (i,j) , P-SPICE simulation results can be categorized into three different groups according to their electrical resistance measurements. The first is the resistance of decreased resistor $R(i,j)$, Second group is located at $R(i,y)(y \neq j)$, $R(x,j)(x \neq i)$, which are the points that lie on the same wire with $R(i,j)$. the rest of the measurements can be categorized into final group which contains all measurements at $R(x,y)(x \neq i \text{ or } y \neq j)$.

In fig. 4, resistance values of $R(x,y)(x \neq i \text{ or } y \neq j)$ are not influenced due to $R(i,j)$ variations. However, at resistors $R(i,y)(y \neq j)$ and $R(x,j)(x \neq i)$ which lie on the wire that contains decreased resistor $R(i,j)$, resistance measurements showed a tendency of gradual decrease. Such result is identical with the field test result. This phenomenon reveals the fact that electric circuit effects from grid-net circuit configuration accounts for the electrical resistance decrease at locations on the wire that contains the specific location of electrical resistance decrease.

Fig. 5 shows the resistance changes at $R(i1,j2)$ and $R(i2,j1)$ which lie on the intersections of wires that contain the two specific locations when $R(i1,j1)$ and $R(i2,j2)$ are simultaneously decreased. With resistance changes at the two specific positions, measurements at $R(i1,j2)$ and $R(i2,j1)$ were the same; the effect of resistivity changes at $R(i1,j1)$ and $R(i2,j2)$ gave smaller resistance measurements of $R(i1,j2)$ and $R(i2,j1)$. Such results explain that the unexpected electrical conductivity increase of test 2 in fig. 3(c) is due to electric circuit effects.

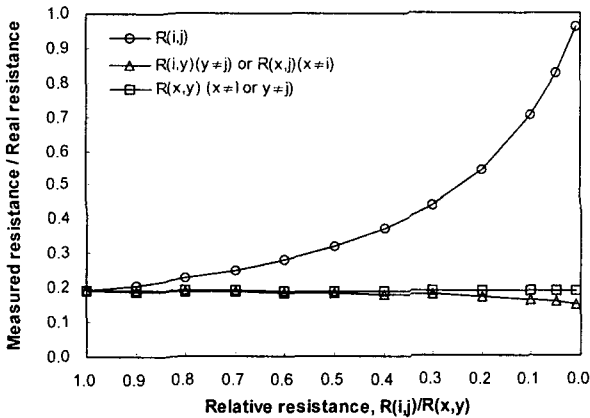


Fig. 4. Measured resistance variations of all resistors due to decreased resistance of a specific resistor at (i,j)

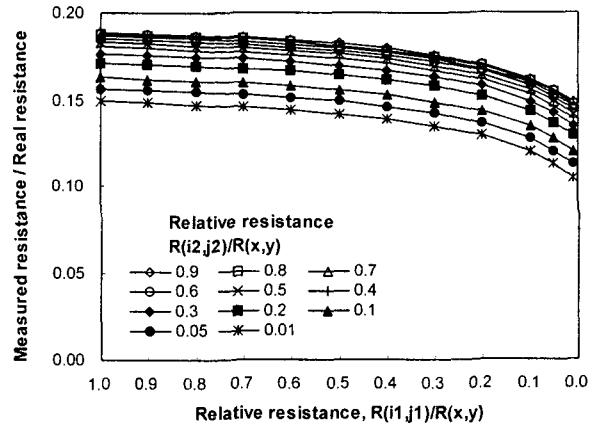


Fig. 5. Measured resistance variations of $R(i1, j2)$ or $R(i2, j1)$ due to decreased resistances of two specific resistors at $(i1,j1)$ and $(i2,j2)$

5.3. Calibrated Results of Field Model Test using P-SPICE Simulation

The electrical conductivity that have been measured in field model test was calibrated by using the P-SPICE simulation results. Fig. 6 shows the calibrated electrical conductivity distribution of field model tests. In fig. 6, circuit effect of grid-net electric circuit configurations is effectively

removed from the process of calibration using the P-SPICE simulation. This is indicated that the unexpected increasement of electrical conductivity at sensors connected the detecting point is caused by electric circuit effects. Electrical conductivity of subsurface before any leakage was within the $24.8 \mu\text{S/cm}(=403.0\Omega\text{m}) \sim 43.0 \mu\text{S/cm}(=232.7\Omega\text{m})$ range. However, electrical conductivities of leaking point after leachate leakage were $572.1 \mu\text{S/cm}(=17.5\Omega\text{m})$ for test 1, $632.1 \mu\text{S/cm}(=15.8\Omega\text{m})$ and $547.6 \mu\text{S/cm}(=18.3\Omega\text{m})$ for test 2. These values are approximately more than 15 times the conductivity values of subsurface where no leakage is present. This clearly indicates that leachate leakage detection using grid-net detection system is accurately achieved. In test 3, electrical conductivity at leachate leakage locations were within the $638.1 \mu\text{S/cm}(=15.7\Omega\text{m}) \sim 1812.9 \mu\text{S/cm}(=5.5\Omega\text{m})$ range and electrical conductivity at tap water leakage location was $160.1 \mu\text{S/cm}(=62.5\Omega\text{m})$. Although the electrical conductivity is slightly increased at tap water leakage location, it can be differentiated with electrical conductivity at locations where leachate leakage is present. This result implies that the heavy rainfall and rise in the level of the water table are expected to be insignificant in detecting leachate leakage using grid-net detection system based on electrical resistivity measurements.

These results show that the grid-net leakage detection system using the method of measuring electrical resistivity is effective to locate the leachate leakage in landfill site.

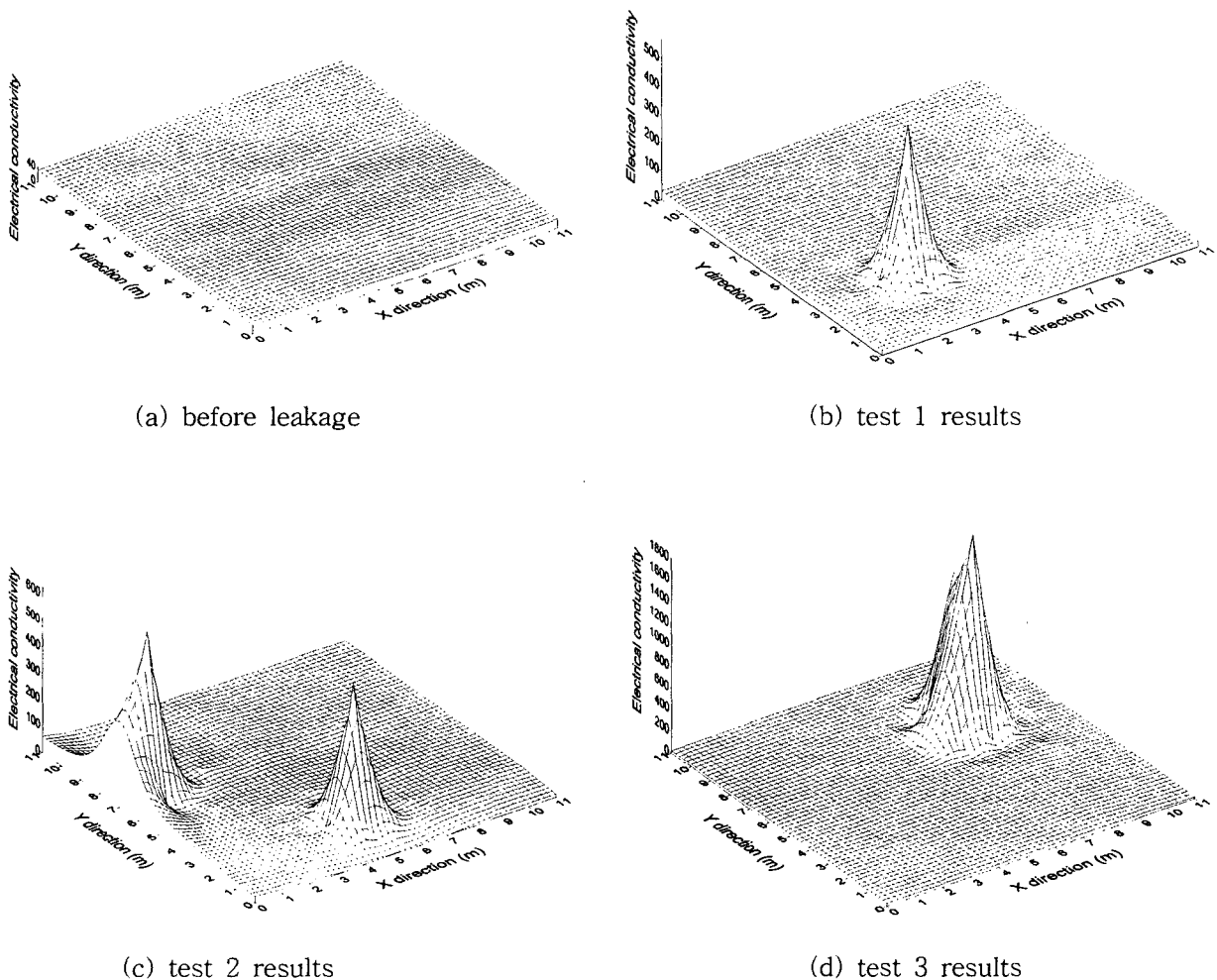


Fig. 6. Calibrated electrical conductivity distributions of field model test

6. Conclusion

The following conclusions are drawn from field model tests and P-SPICE simulations for grid-net electrical resistivity measurement leakage detection system.

1. Electrical conductivity increases (electrical resistivity decreases) at subsurface where leachate is introduced, because leachate contains a significant amount of ionic constituents as charge carriers. By analysing the distribution of electrical conductivity (the inverse of electrical resistivity) over the entire area, leakage location could be detected accurately by locating points with a significant increase in electrical conductivity.
2. The unexpected slight increases of electrical conductivity develop at sensors connected to the wire which contains a specific location of conductivity increase due to leachate leakage. This can be explained as an electric circuit effects caused by the parallel circuit of grid-net circuit configuration. The effects of electric circuit can be evaluated quantitatively by P-SPICE simulations. And these effects of field model tests results were effectively removed by calibration using the simulation results.
3. Field model test results calibrated by P-SPICE simulation showed that leachate leakage locations can be detected effectively using the grid-net leakage detection system based on electrical resistivity measurement method. Therefore, grid-net leakage detection system developed in this study has a high potential in its applicability to landfill site.

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