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# A preliminary study on evaluating the performance of aged landfill covers using DC and CC resistivity methods

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ABSTRACT: A preliminary study, using the electrical resistivity tomography, was conducted to evaluate the performance of landfill cover in response to different weather conditions at an aged landfill site in Hong Kong. Both the direct current (DC) resistivity method and the capacitively coupled (CC) resistivity method (with line antenna) were adopted. The measured results suggest that both the DC and CC resistivity methods can be used to effectively monitor the ground resistivity change of a landfill cover in response to different weather conditions. Besides, the DC resistivity method can be used to identify the location of geomembrane layer and then examine the associated deformation since a clear boundary, below which there exists a high resistivity regime due to the presence of nonconductive geomembrane to hider to DC transmission, was found. As to the CC resistivity method, it can be used to investigate the electrical resistivity distribution and associated changes for the regimes above and below the geomembrane layer since the alternative current (AC) can be capacitively coupled into the ground below the geomembrane.

## 1 INTRODUCTION

Many landfills have been built for the disposal of municipal solid waste. When landfills are closed, landfill covers are commonly put to minimize the quantity of surface water infiltrating into the waste deposits and then protect waste containment system from rainfall percolation (e.g, Benson et al. 2001). However, since the local conditions, such as seasonal weather conditions and the growth of vegetation roots, etc., will change the pores and peds in the cover soils (Buol et al. 2011; Henken-Mellies & Schweizer 2011), the hydraulic properties of the cover soils, e.g., the saturated hydraulic conductivity (Ks), may change with time (Meiers et al. 2006). Benson et al. (2007) carried out a long-term monitoring on the hydraulic properties of water balance covers using a flexible-wall permeameter, and the results indicated that Ks could increase as much as 10,000 times four years after the construction of those covers. Such an increase in Ks was also reported in Henken-Mellies & Schweizer (2011). They found that the hydraulic conductivity in a simple soil barrier and in compacted clay liners may increase considerably with time if there was no long-lasting protection method. Such an increasing trend of Ks may weaken the performance of the landfill covers.

In addition to the increase in Ks of the cover soils, the properties of the geomembrane liner in the landfill cover may also deteriorate with time as a result of exposure to the field conditions. This in turn may also affect the long-term performance of a landfill cover. Therefore, there are concerns on the performance of the aged landfill covers, especially those more than 20 years old.

In Hong Kong, there are 13 closed landfills aged from 20 to 41 years. Considering the large amount of stored waste in those landfills, which is about 66 megatons, to assess the performance of those aged landfill covers in order to better control rainfall percolation into the underlying waste is crucial to Hong Kong.

Compared with the traditional sampling method to determine soil properties, geophysical methods, e.g., electrical resistivity tomography (ERT), have non-destructive, low-cost and fast speed features. The direct current (DC) ERT method (termed as DC resistivity method in the following discussion) has been successfully applied to detect defects and heterogeneity in loamy-clay cover (Genelle et al. 2012), to trace subsurface migration of contaminants from landfill (Bahaa-eldin et al. 2011), and to investigate top cover effectiveness and internal structure of sealed landfill (Hermozilha et al. 2010). Hence, it seemly feasible to apply DC resistivity method in assessing the performance of aged landfill covers. In addition to the DC resistivity method, capacitively coupled (CC) ERT method (termed as CC resistivity method in the following discussion) can also be used in the assessment. A CC resistivity system, usually working at kilohertz frequency, can inject an electrical current into the ground and measure the potential of the ground surface capacitively without galvanic coupling. That is, there is no need to install electrodes while using the CC resistivity method. Indeed, the CC resistivity method has a higher ratio of measurement speed to data density compared with DC resistivity method (Niu et al. 2014). In this context, the CC resistivity method seems to be economically preferred to evaluate the performance of aged landfills because this method, compared with the DC method, is less time consuming and relatively easy to be operated (to be further discussed later).

In summary, this study aims to evaluate the performance of aged landfill covers using both the DC and CC resistivity methods. A series of resistivity surveys was carried out at Tseung Kwan O (TKO) Stage II/III Landfill, which is an aged landfill site in Hong Kong, to evaluate the landfill cover performance in response to different weather conditions. In addition, for the same survey line, comparisons between the measurements obtained from the two methods are made to highlight the different features between them.

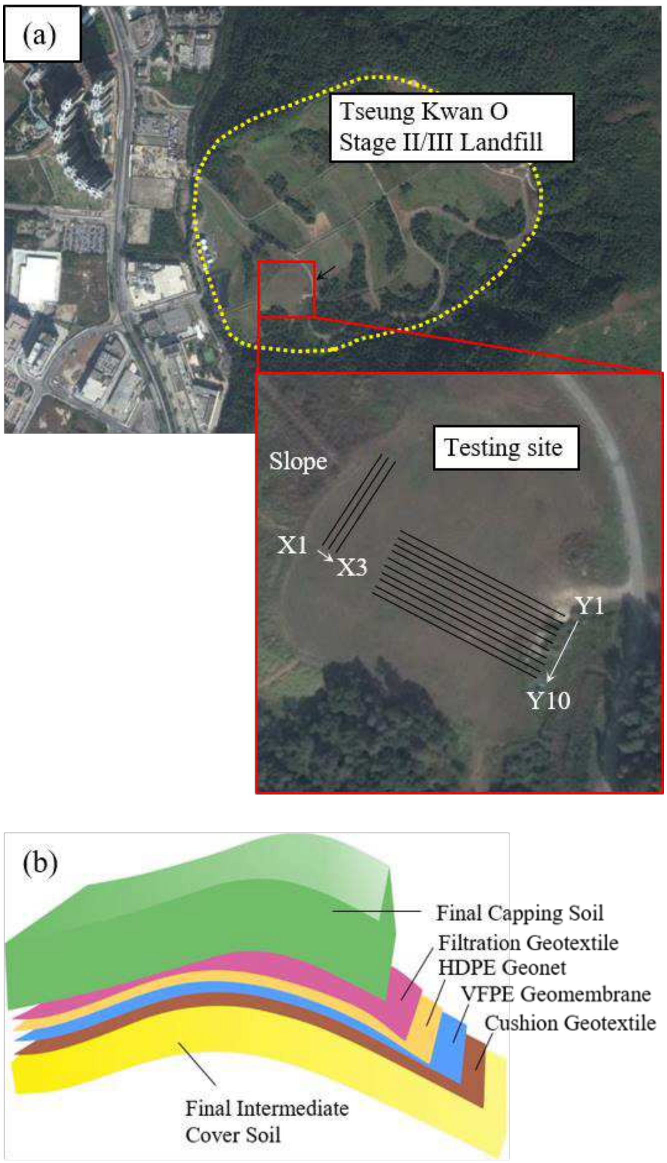
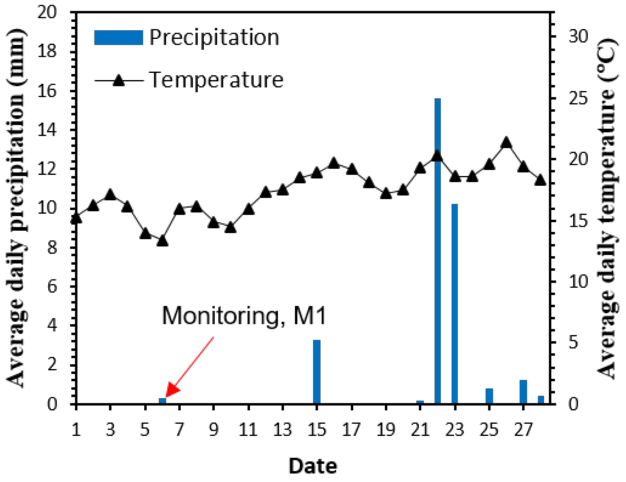
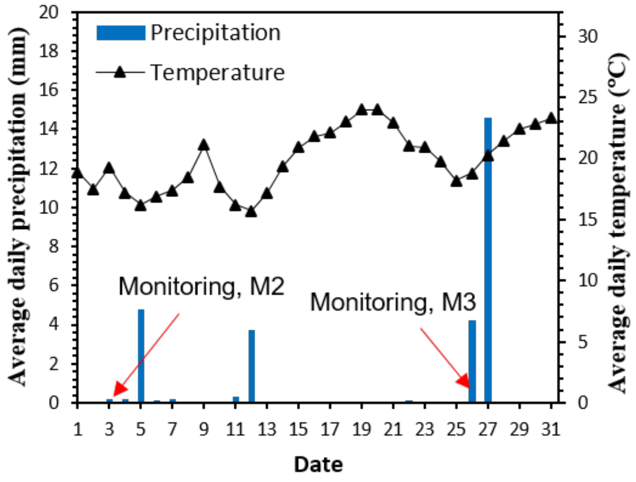


Figure 1. Landfill site: (a) location of test site and measurement lines and (b) profile of landfill cover.

(a) February, 2015



(b) March, 2015



(c) July, 2015

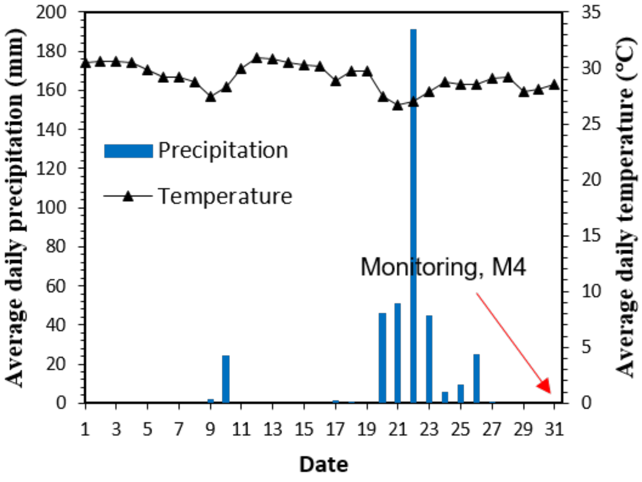


Figure 2. Weather conditions, in terms of the daily averaged precipitation and temperature, for each measurement. Note that the scale set for precipitation is different in order to show the details.

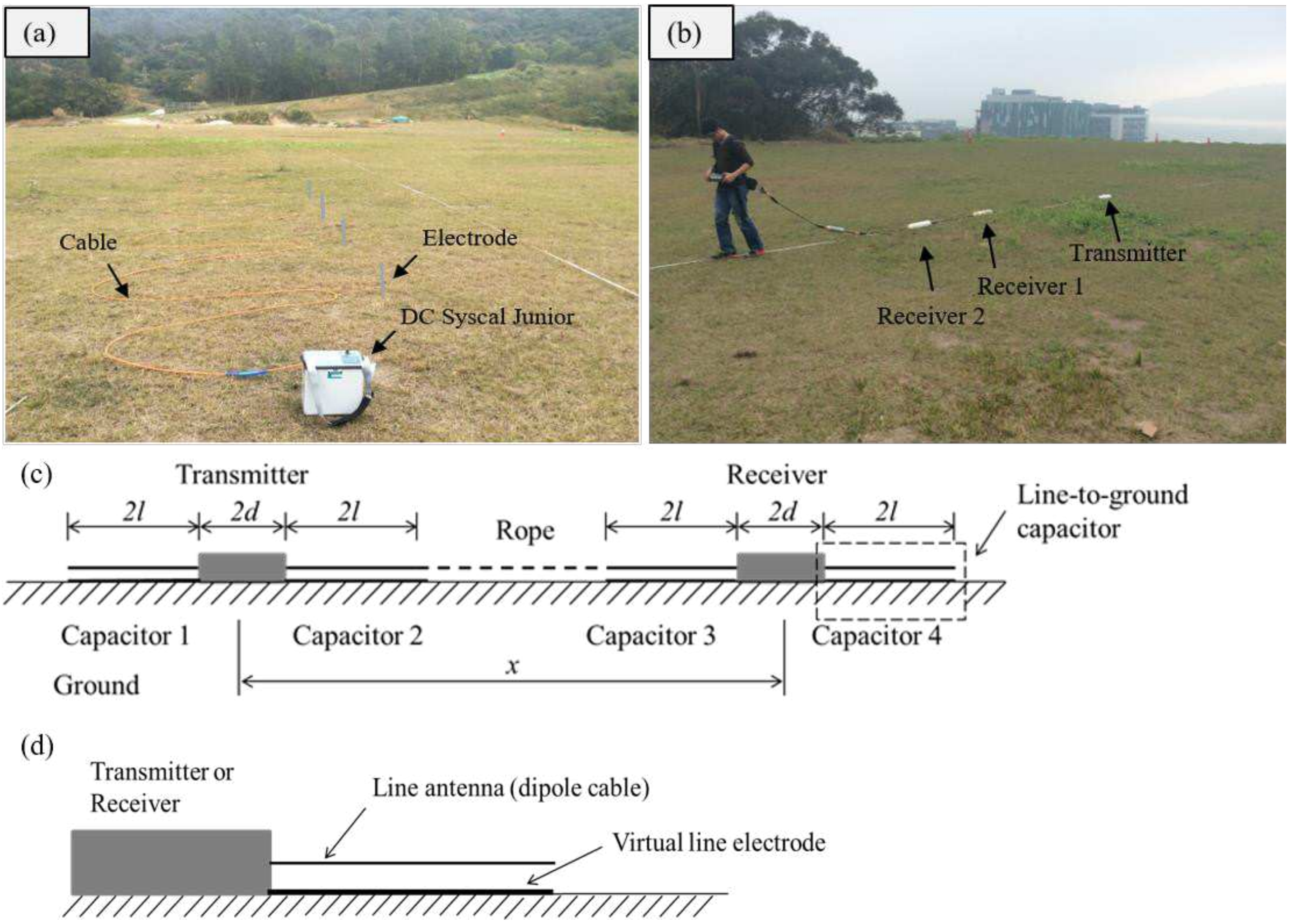


Figure 3. Instruments used in the resistivity surveys: (a) for the DC method; (b) for the CC method; (c) a schematic diagram with one transmitter and one receiver; and (d) the line-to-ground capacitor (b, and c are adopted from Niu and Wang 2013).

## 2 SITE DESCRIPTION

Figure 1a gives a satellite image of TKO Stage II/III Landfill. The landfill is located at TKO development area 105, New Territories, Hong Kong. The landfill site is subjected to a monsoon-influenced humid subtropical climate. The average annual precipitation ranges from 1400 to 3000 millimetres, and the daily mean temperature ranges from 16.3 to 28.8 °C. The landfilling operation of TKO Stage II/III Landfill commenced in 1989 and ceased in 1994. The flat area of the landfill is approximately 42 hectares, and the amount of stored waste is about 12.6 megatons, which accounts for 19% of the total amount of stored waste in the closed landfills in Hong Kong. As shown by Figure 1a, a platform, which is approximately 0.7 hectares large, is selected as the testing site, because this area is flat enough to carry tests.

Figure 1b presents the cover profile of TKO Stage II/III landfill. The designed thickness of the final capping soil is about 0.8 m

## 3 EXPERIMENTAL DETAILS

Four different surveys have been carried out using SYSCAL Junior Switch 48 resistivity meter and OhmMapper at different weather conditions. 10 lines (from Y1 to Y10) in y direction and 3 lines (from X1 to X3) in x direction were monitored as shown in Figure 1a. RES2DINV inversion software (Loke and Barker 1996) was used to interpret the measured resistivity data by two dimensional (2D) resistivity tomography. The absolute error of each inversion result is less than 5%. Details are described in the following.

### *a. The DC resistivity method*

As shown in Figure 3a, in the DC resistivity survey, the dipole-dipole array with equal electrode spacing of 2 m for the survey lines Y1 to Y10 and 1m for the survey lines X1, X2 and X3 was adopted. The SYSCAL Junior resistivity meter was used and each measurement array consists of 24 electrodes.

### *b. The CC resistivity method*

In the CC resistivity survey, as shown in as shown in Figure 3b, the OhmMapper (Geometrics, CA, USA) was used. The OhmMapper is a CC resistivity system (meter), which consists of one transmitter and several receivers as also shown in Figure 3b. The receivers and transmitter are linked by a nonconductive rope and therefore the whole equipment can be towed by an operator at a walking speed. As shown

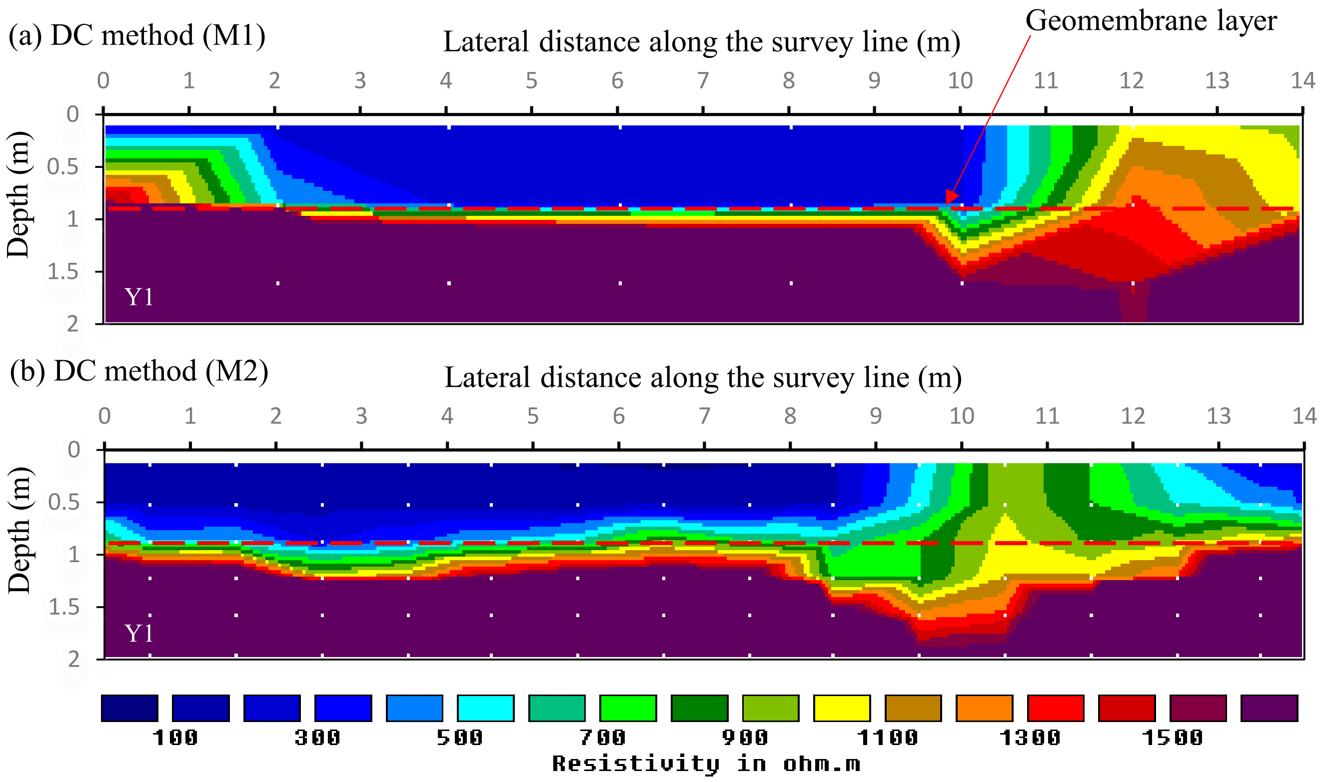


Figure 4. Results of ground resistivity measured by the DC resistivity method along the survey lines Y1 for (a) measurement M1 and (b) measurement M2.

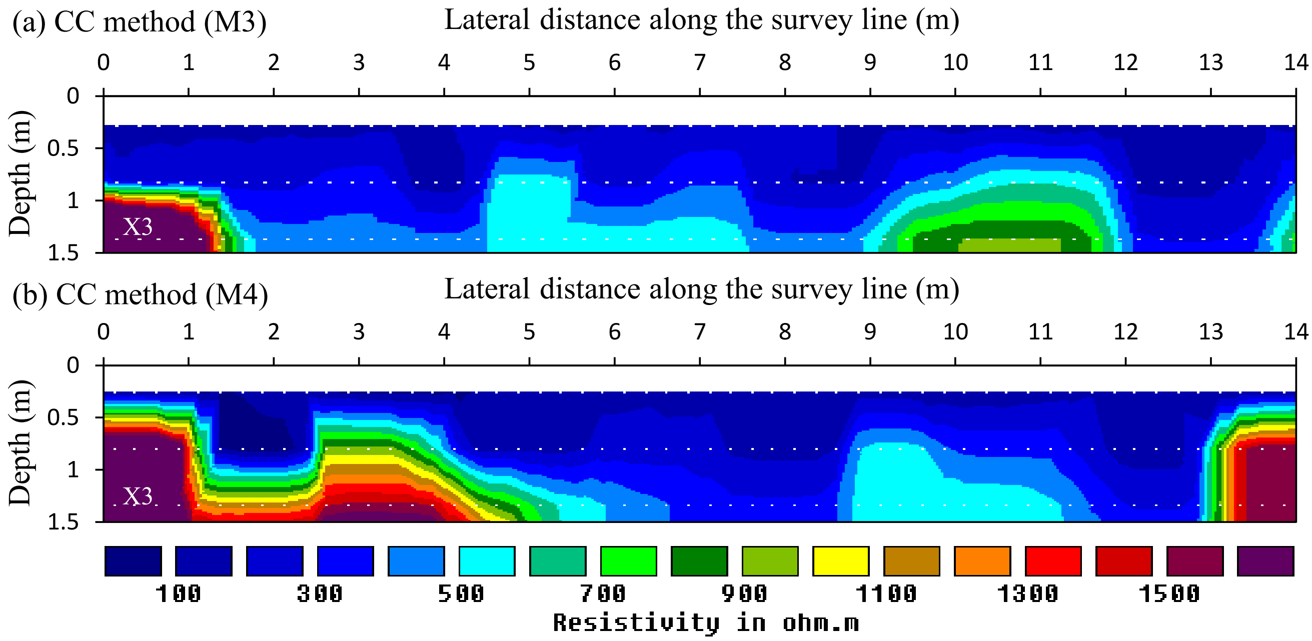
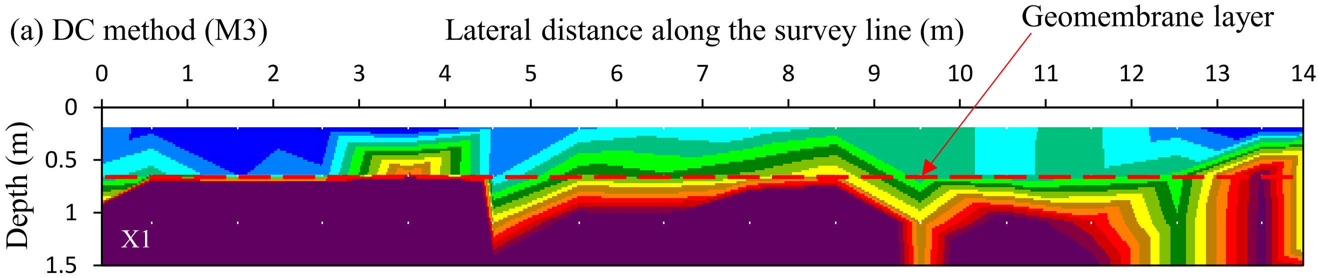


Figure 5. Results of ground resistivity measured by the CC resistivity method along the survey lines X3 for (a) measurement M3 and (b) measurement M4.

(a) DC method (M3)



(b) CC method (M3)

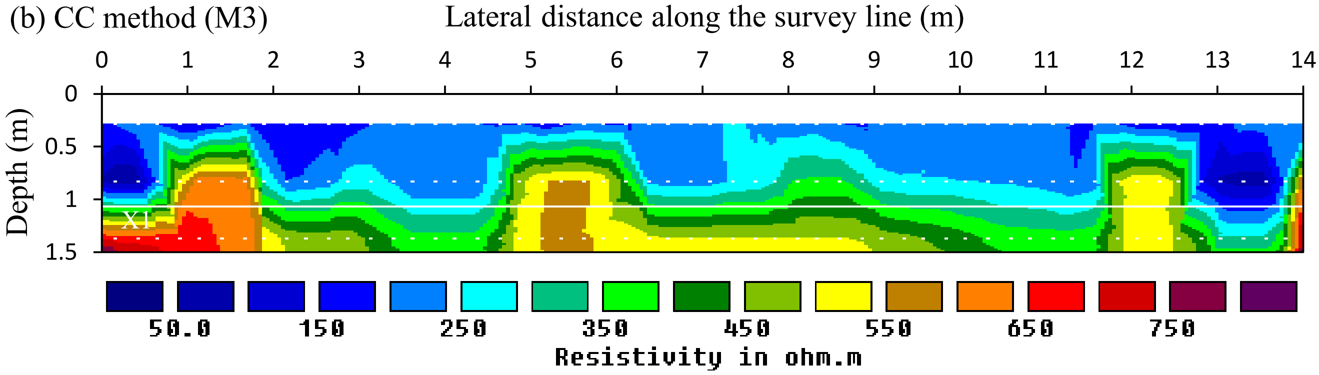


Figure 6. Results of ground resistivity along the survey line X1 for measurement M3 using (a) the DC resistivity method and (b) the CC resistivity method.

in Figure 3c, each transmitter or receiver has two line antennas (i.e., the dipole cables) and each line antenna together with the ground surface forms a line-to-ground (or cable-to-ground) capacitor as illustrated in Figures 3c, d. That is, the upper plate of the capacitor is formed by the line antenna (dipole cable), and the lower capacitor plate is established by the ground surface and is envisaged as a virtual line electrode herein to facilitate the discussion. During the measurement, the alternating current (AC) generated from the transmitter can be capacitively coupled into the ground through this virtual line electrode, which has galvanic coupling with the ground. In the same principal, the potential on the ground surface (see Figs. 2c, d) can also be measured by the receiver. Note that the current frequency is fixed at 16.5 kHz for OhmMapper. In this study, the dipole length is selected as 2.5 m and the rope length between the receiver and transmitter was 1 m for all measurements. The equivalent dipole length used in the inversion should be corrected by a factor 0.74 as suggested in Niu and Wang (2014).

### *c. Measurements*

The weather conditions, in terms of the daily averaged precipitation and temperature for each measurement are indicated in Fig. 2. As shown in Figure 3a, the first measurement (M1) was carried out after a long arid weather condition. The second measurement (M2) was carried out two days after several rainfall events with ~30 mm precipitation in total (Fig. 2b), the third measurement (M3) was carried out right after a rainfall event with 4.2 mm precipitation (Fig. 2b), and the fourth measurement (M4) was carried out four days after several rainfall events taking place within 10 days with 379 mm precipitation in total (Fig. 2c).

## 4 RESULTS AND DISCUSSION

The center parts of some tomography results are compared together. Figure 4 compares the tomography images measured by the DC resistivity method along the survey line Y1 for the first and the second measurements (i.e., M1 and M2). It can be found that both images show a sudden resistivity increase area about 0.9 m beneath the ground surface, and this phenomenon should be caused by the presence of the geomembrane layer. The region above the geomembrane layer has the electrical resistivity about 300 Ω.m, and the electrical resistivity suddenly reaches a quite high value in the regime below the geomembrane layer. This is due to that the direct current is difficult to flow through the non-conductive geomembrane during testing, thus the area below the geomembrane is considered as media with a high resistivity value based on the measurement. Besides, an area with relatively high resistivity on the right side above geomembrane can be observed. This phenomenon is supposed to be caused by the existence of a concrete exhaust shaft. When comparing the two measurement results, it can be found that the resistivity value of the region above the geomembrane is higher in the measurement M2 (see Fig. 4a) than in the measurement M2 (see Fig. 4b). This is consistency with the precipitation conditions that the weather is drier during measurement M1 than during measurement M2.

Figure 5 presents the results along the survey line X3 from the measurements M3 and M4 using the

CC resistivity method. As shown in the figure, the geomembrane layer cannot be clearly identified and the ground resistivity below the geomembrane can still be measured. This is because an alternative current was used by OhmMapper and the current can also be capacitively coupled into the ground below the membrane. When comparing the two measurement results, the ground electrical resistivity is decreased after a heavy rainfall (see Fig. 5b), even for the region beneath the geomembrane.

Figure 6 compares the results along the survey line X1 measured by both the DC and CC resistivity methods. Once again, the DC resistivity measurements, as shown in Figure 6a, can clearly identify the location of geomembrane below which the resistivity suddenly jumps to a high value. It can also be found that the boundary that separates the low and high resistivity regime due to the presence of geomembrane wavy along the survey line. This might be caused by the ground settlement and movement since line X1 is near the slope along the test site. For the CC resistivity measurement, as shown in figure 6b, the ground electrical resistivity can be detected for the regimes above and below the membrane. The comparison between the results shown in Figures 6a and 6b suggests that the DC resistivity method is good to identify the location of geomembrane and then check the deformation and condition of the geomembrane layer, and the CC resistivity method is good to survey the ground resistivity changes below the geomembrane layer.

## 5 CONCLUSIONS

A preliminary study, using the electrical resistivity tomography, was carried out on an aged landfill site to evaluate the performance of landfill cover. Four different resistivity surveys were carried out at different weather conditions. Both the direct current (DC) resistivity method and the capacitively coupled (line antenna) resistivity method were adopted in the monitoring. The testing landfill site is located at Tseung Kwan O development area 105, New Territories, Hong Kong; the landfilling operation commenced in 1989 and ceased in 1994.

The measured results suggest that both the DC and CC resistivity methods can be used to monitor the ground resistivity change of landfill covers in response to different weather conditions. Besides, the DC resistivity method can be used to detect the location of geomembrane layer and then examine the associated deformation since a clear boundary, below which the resistivity value suddenly jumps to a high value due to the DC cannot penetrate through the nonconductive geomembrane, can be identified in the survey results. As to the CC resistivity method, it can be used to investigate the electrical resistivity distribution and associated changes in response to different weather conditions for the regimes above and below the geomembrane layer. The alternative current (AC) used by OhmMapper can also be capacitively coupled into the ground below the geomembrane.

## 6 ACKNOWLEDGEMENTS

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