Rapid near surface resistivity survey using the capacitively-coupled resistivity system：OhmMapper

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ABSTRACT

The capacitively-coupled resistivity(CCR) experiments were conducted using the multi-channel OhmMapper TR5 in Japan. In the CCR method, there is no need to plant electrodes into the ground. With CCR, very rapid near surface surveys are possible compared to conventional D.C. resistivity survey. Through our experiments, the CCR method with a multi-channel OhmMapper system worked successfully on the cohesive soil and at the levee. It would be a useful tool when the survey line is very long, such as for example, a line along a levee. On the other hand, on conductive soil or in urban areas where there are many utilities underground, the CCR would be difficult to apply. It is important to consider the capabilities and limitations of the CCR method for successful results.

KEY WORDS: resistivity, multi-channel capatively-coupled resistivity, near surface,

INTRODUCTION

In disaster mitigation or for environmental survey it is important to understand the geologic structure of the near surface to a depth to around 10 m. In such surveys rapid and cost-effective survey methods are needed. Some geophysical techniques have been developed for these types of surveys. For example, the land streamer technique was developed and applied in seismic surveys(Inazaki, 2002). In electrical surveys, the capacitively-coupled resistivity survey (CCR) was developed and applied(Timoffev et al, 1994; Shima et al, 1995). In a CCR survey, because it is not necessary to use ground stakes to measure the resistivity of the ground, and for this reason very rapid measurement is possible compared to the D.C. galvanic-resistivity technique. The CCR survey has the advantages that data acquisition is possible in highly resistive areas. Values of apparent resistivity greater than 10,000 ohm-m, such as in permafrost, may experience severe contact resistance problem with using a conventional galvanic resistivity meter(Timoffev et al, 1994).

We have tested the multi-channel CCR system, the OhmMapper manufactured by Geometrics, Inc. The CCR survey and a conventional D.C. galvanic survey were performed at our test field in Tsukuba, Japan, and also at the levee.

METHOD

The concept of the capacitively-coupled resistivity measurement is shown in Figure 1. When voltage is applied to the conductor inside the CCR transmitter an electric charge appears between the conductor and the ground which are separated from one another by the insulation. The conductor and the ground act as two plates of a capacitor separated by a strong dielectric resistor(the insulation). This capacitance between the conductor and the ground acts as a path for an A.C. current to flow into the ground from the conductor. According to the same principle, it is possible, with a CCR receiver, to detect the A.C. voltages in the ground generated by the transmitter. In this manner the resistivity of the ground can be acquired.

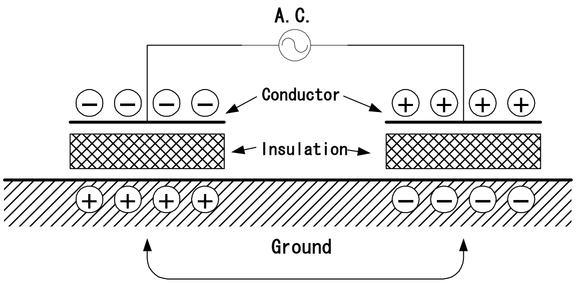

Figure 1. A conceptual model of the capacitively-coupled resistivity measurement

EQUIPMENT

Figure 2 shows the appearance of the five-receiver OhmMapper TR5, and Figure 3 shows the schematic diagram of the OhmMapper. The receivers are connected to each other by shared "dipole cables", and the transmitter is connected to the receiver array by a nonconductive rope. The transmitter/receiver array is towed by a person or a vehicle.

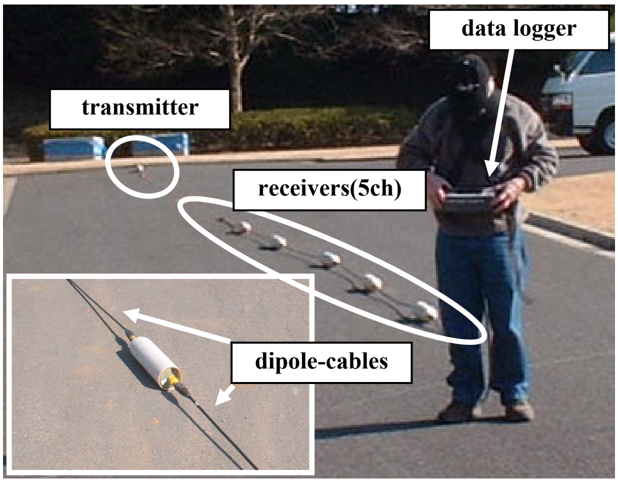

Figure 2. Appearance of the 5-receiver OhmMapper TR5

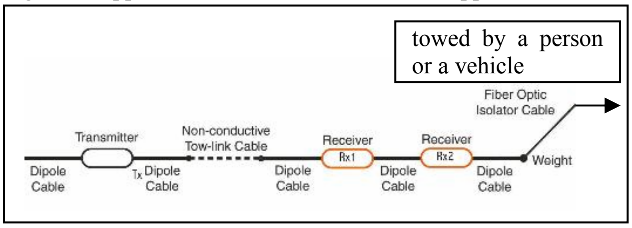

Figure 3. Schematic of the OhmMapper

Figure 4 shows how the dipole cables work as capacitive electrode. Internally they have a twisted pair of two wires of modest gauge, a nonconductive filter to pad the diameter out to the desired size and then a copper braid wrapped over the filter. Over the copper braid is placed an outer insulating covering. It is this copper braid that acts as the electrode for the OhmMapper. The capacitive coupling from the copper braid to the ground couples the transmitter's current from its electrodes to the ground. The voltage in the ground is then capacitively coupled into the braid on the receiver's electrodes. Two dipole cables are connected to the transmitter and also two dipole cables are connected to each of receivers in the multi-receiver array. The electrode configuration is equal to a dipole-dipole array. The depth of investigation can be controlled by changing the length of the dipole cables and the spacing between the transmitter and the receivers. The transmitter- receiver separation should not exceed one skin depth. The skin depth, in meters, is approximately 503*sqrt(rho/freq) where rho is the resistivity of the ground and freq is the transmission frequency. That is, the maximum depth of investigation for the OhmMapper increases as the square root of the ground resistivity. Table 1 shows the main specifications of the OhmMapper.

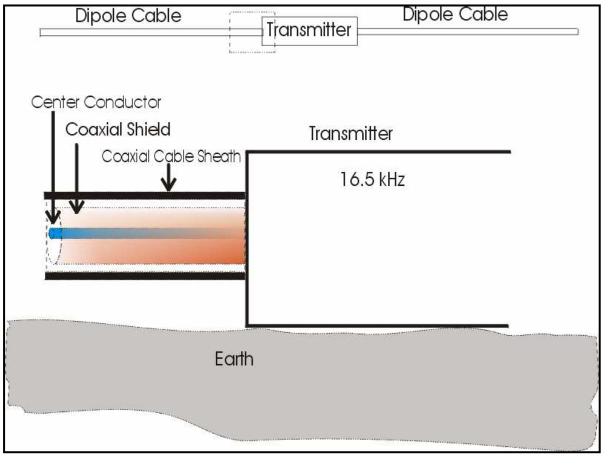

Figure 4. Schematic of the dipole cable working

Table 1 Specifications of OhmMapper

Principle	Constant-current, capacitively coupled, dipole-dipole resistivity
Operating Range	From 3 to 100,000 Ohm-meters
Cycle Rate	Selectable data logging up to 2 scans/sec
Data Storage	2 Mbytes of non-volatile RAM
Transmitter Specification	Frequency : approx. 16.6 kHz Output Power : Up to 2 Wats Output Current : 0.125 mA to 16 mA
Receiver Specification	Cable Lengths : 1, 2.5, 5(standard), 10 m Input Impedence : >5 M Ohm Measured Voltage Accuracy : Better than 3 % Input Voltage Range : 0-2 V RMS

FIELD EXPERIMENT

We conducted the OhmMapper measurements at three sites.

site(1) The first experiment was to compare the conventional galvanic resistivity survey and the OhmMapper survey.

site(2) The second experiment was to confirm the reliability of the OhmMapper on pavement.

site(3) The third experiment was to examine the applicability for a survey on a levee.

Table 2 shows the overview of the field experiments.

Table 2. Overview of the field experiment

Location	(1)Compare Line on the cohesive soil (Tsukuba city Ibaraki Pref, Japan)	(2)Survey line on the pavement and the grass (Tsukuba city Ibaraki Pref, Japan)	(3)River bank (Kokai river, Ibaraki Pref, Japan)
Experiment description	* OhmMapper Survey * D.C resistivity Survey (Pole-Pole array)	*OhmMapper Survey	* OhmMapper Survey * D.C resistivity Survey (Pole-Pole array)
Surface condition	* grass	* Asphalt pavement * grass	* Asphalt pavement

Site(1) **Comparison to the D.C. resistivity survey**

The OhmMapper and a traditional resisitivity survey were conducted on the same survey line for comparison.

The site is located in Tsukuba city in Ibaraki Pref., Japan. The comparison line was 250 m long on cohesive soil. The surface of the survey line was the grass. Table 3 shows the soil structure near the surface at this site. The OhmMapper measurement used 5 m dipole cables and the separation between the transmitter dipole and the receiver dipoles was from 5 m at minimum to 35 m at maximum. The electrode array of the D.C. resistivity survey was pole-pole array. The minimum electrode spacing was 1 m and the maximum was 15 m. The OhmMapper data set was processed with the 2D resistivity inversion software RES2DINV by Geotomo software. The D.C. resistivity data set was processed with the ElecImager by OYO Corporation.
Figure 5 shows the results of the OhmMapper and the D.C. resistivity from the comparison line. There is a resistive layer of more than about 140 ohm-m, and below this layer, is a less resistive layer of less than 60 ohm-m. Although there are differences at the surface, the OhmMapper result roughly agrees with the D.C, resistivity result. The differences in the very near surface may be caused by the difference in the type of electrode array.

Site(2) Measurement on the asphalt pavement

In this experiment, two survey lines were set parallel to one another. One was on the grass and the other was on the asphalt pavement. Each survey line was about 8 m apart with a length 125 m. The thickness of the pavement is 50 mm and there is a crushed run layer below the pavement. The thickness of crushed run layer was 200 mm from 0 to 40 m along the survey line, and 350 mm from the 40 m point to the end of the survey line. Figure 6 shows the photo of the survey line. In this survey, 2.5 m dipole cables used. The minimum dipole spacing between transmitter and the receiver was 5 m, and the maximum 20m. Figure 7 shows that the measurement results are very similar to each other. The influence of the difference of the crushed run layer thickness near surface seems to be little.

Site(3) Experiment at the levee

In this experiment, we applied the OhmMapper to the levee survey. The experiment site was the Kokai river in the Ibaraki Pref., Japan. The survey line was on the crown of the levee along the Kokai river. The length of the survey line was 1200 m. The 5 m dipole cables were used. The surface of the survey line was asphalt pavement. The minimum dipole spacing between transmitter and the receiver was 5 m, and the maximum was 35m. The sensor array was towed by a car on this site(Figure 8). For comparison, a conventional D.C. resistivity survey was done from 0 m to 250 m along side the same suvey line at the top of slope of the levee. The electrode array of the D.C. resistivity survey was pole-pole array. The minimum electrode spacing was 1 m and the maximum 15 m.

Figure 9 shows the OhmMapper survey result of the whole of the survey line. Figure 10 shows the comparison of the OhmMapper result and the Pole-Pole array resistivity result. There was a highly resistive zone above 1000 ohm-m where the OhmMapper can collect good S/N data. The result of the OhmMapper survey roughly agreed with the result of the pole-pole array resistivity survey. In this survey, the total length of the survey line for obtaining the 2D resistivity image was 4,800 m. It took about 75 minutes to measure the whole survey line. The working efficiency was actually good comparing the D.C. resistivity survey in this site.

SUMMARY AND CONCLUSIONS

The CCR experiments were conducted using the OhmMapper TR5 in Japan. Through our experiments, it was confirmed that the CCR could be applied on the cohesive soil where the ground resistivity is around 100 ohm-m or less. The CCR also applied to the survey of the levee and we obtained the 2D resistivity image successfully. With the multi-channel CCR method, very rapid surveys are possible. The CCR method would be a great advantage when the survey line is very long, such as one along the levee, for example. On the other hand, on the conductive soil or in an urban area where there are many utilities underground, the CCR method would be difficult to apply. It is important to consider the merits and limitations of the CCR method for successful results.

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Table 3. Typical near surface soil structure of site(1).

back filling soil thicknes:0.5 m
loam thickness:1.1-1.4 m
coarse sand thickness:3.1-4.3 m
tuffaceous clay thickness:1.5-2.3 m
fine sand thickness:1.4-1.8 m

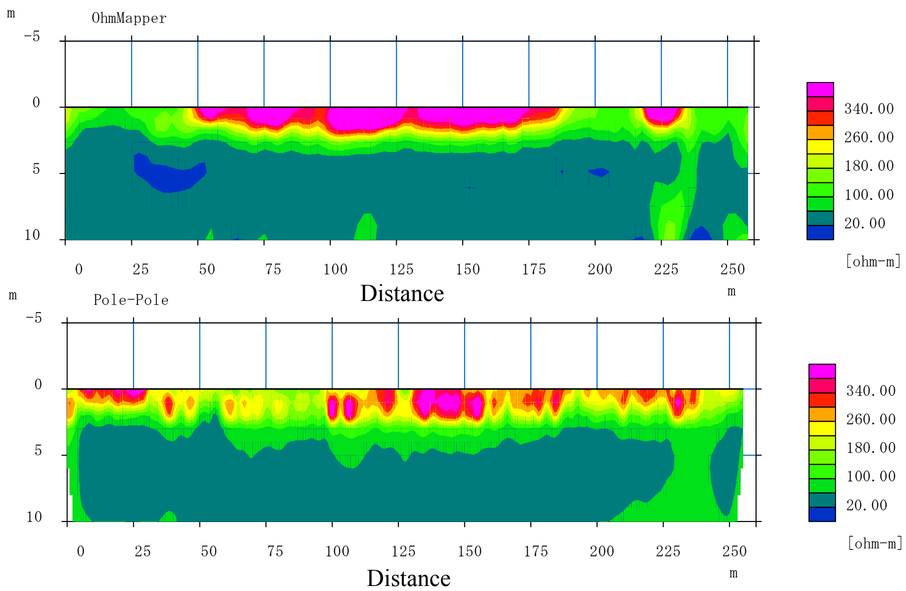

Figure 5. Results for site(1); the OhmMapper survey(top) and the D.C. resistivity survey(bottom)

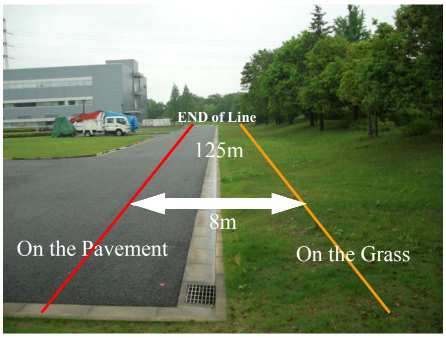

Figure 6. Photo of site(2); The survey line on the asphalt pavement and the grass.

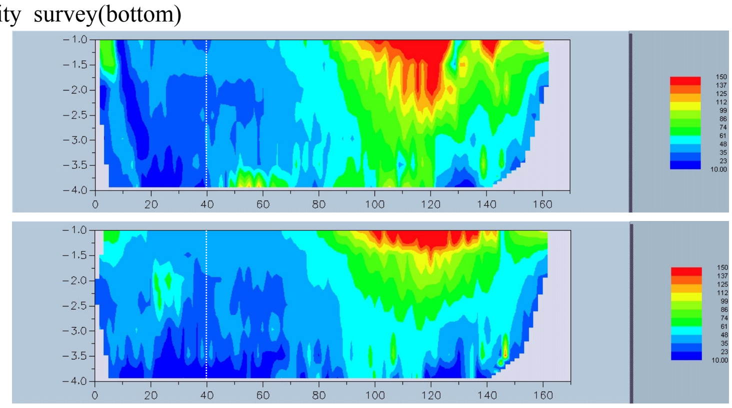
Figure 7. Results for site(2); Apparent resistivity pseudo section obtained from OhmMapper. On the asphalt pavemen(top) and on the grass(bottom).

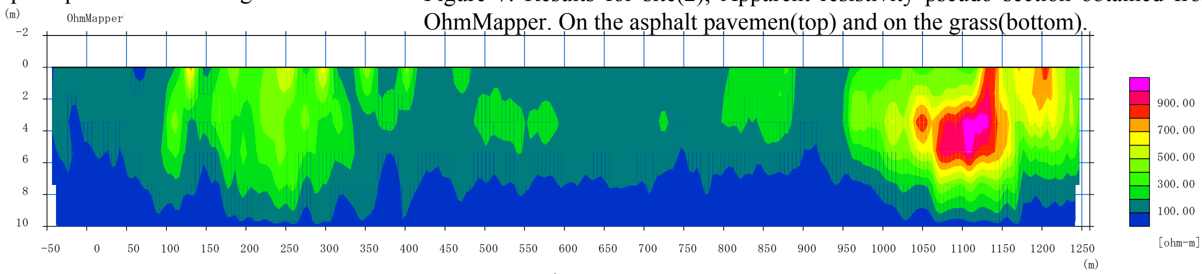

Figure 9. Result for site(3); The result of the OhmMapper survey at the levee of the Kokai river.


Figure 8. Photo of site(3); The OhmMapper in operation on the levee of the Kokai river.

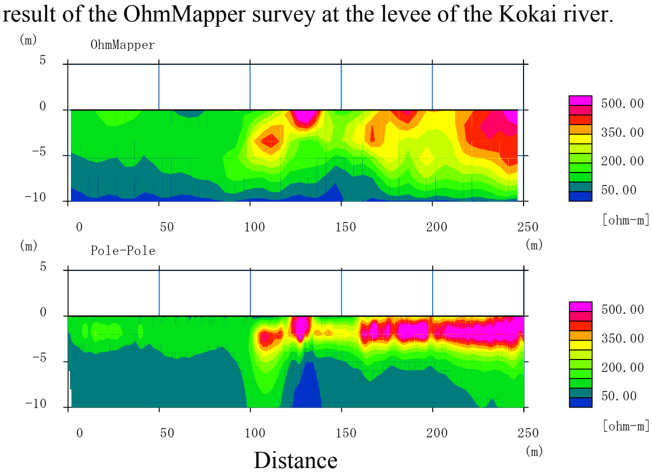

Figure 10. Comparison at the part of the levee survey line between the OhmMapper survey result; (top) with D.C. Pole-Pole array resistivity survey result(bottom).