Appendix C

Textbook for Water Resources Institute

ELECTRICAL SURVEY METHOD
FOR
GROUNDWATER EXPLORATION

CONTENTS

1 PRINCIPLE OF ELECTRICAL SURVEY

1.1 Introduction

Electrical survey is a geophysical method to investigate subsurface electrical property. There are many kind of electrical survey methods, e.g. Resistivity method, SP method, IP method and Electromagnetic method. The most commonly method used for water resource investigation is Resistivity method. In this method, current is injected through the ground using a pair of electrodes, and the resulting distribution of the potential (voltage difference) in the ground is measured by using another pair of electrodes. And, we can estimate subsurface resistivity from the current value and the voltage difference.

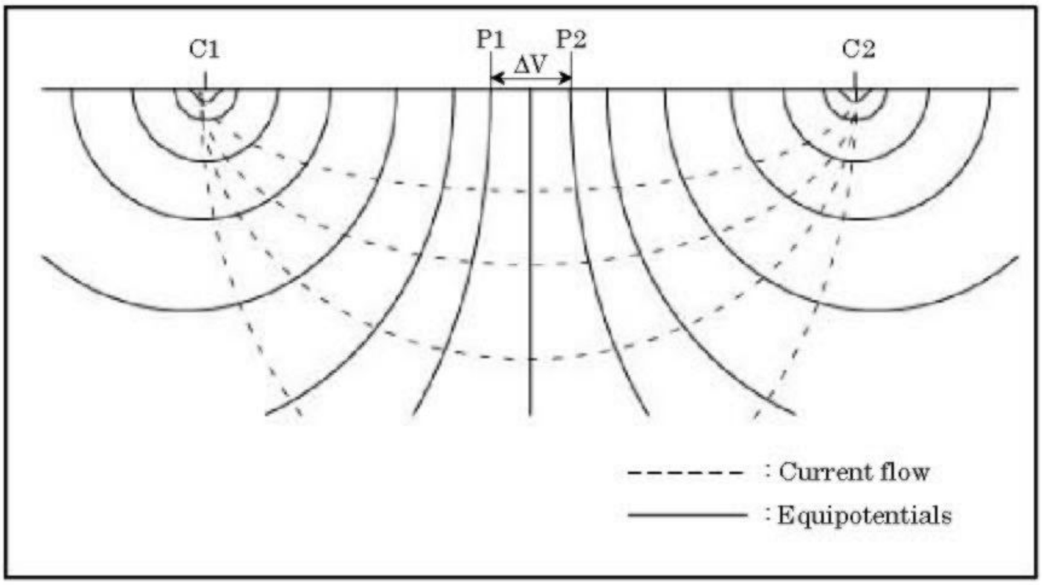


Figure 1.1 Schematic section showing lines of current flow (dotted) and equipotentials (solid) between two electrodes (C1, C2) in the homogeneous ground.

Most rocks show high resistivity in dry condition, because most mineral grains (except metallic ores and clay minerals) are insulators. The current flows through water contained in pores and fissures. Hence the resistivity of a rock formation generally depends on the resistivity of contained water, porosity and water content.

Resistivity is, therefore, an extremely variable parameter, not only from formation to formation but even within a particular formation. Nevertheless, a broad classification is possible according to rock types. Figure 1.3 shows the approximate resistivity ranges of common rock types. It shows that clay, sand, sedimentary rocks, metamorphic rocks and igneous rocks stand in order of increasing resistivity.

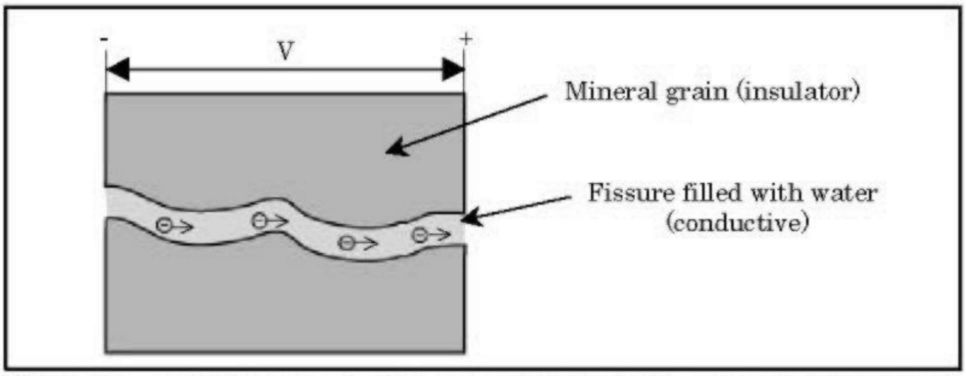


Figure 1.2 Current flows through pore water in rock. The resistivity of rock depends on the resistivity of pore water, porosity and water content.

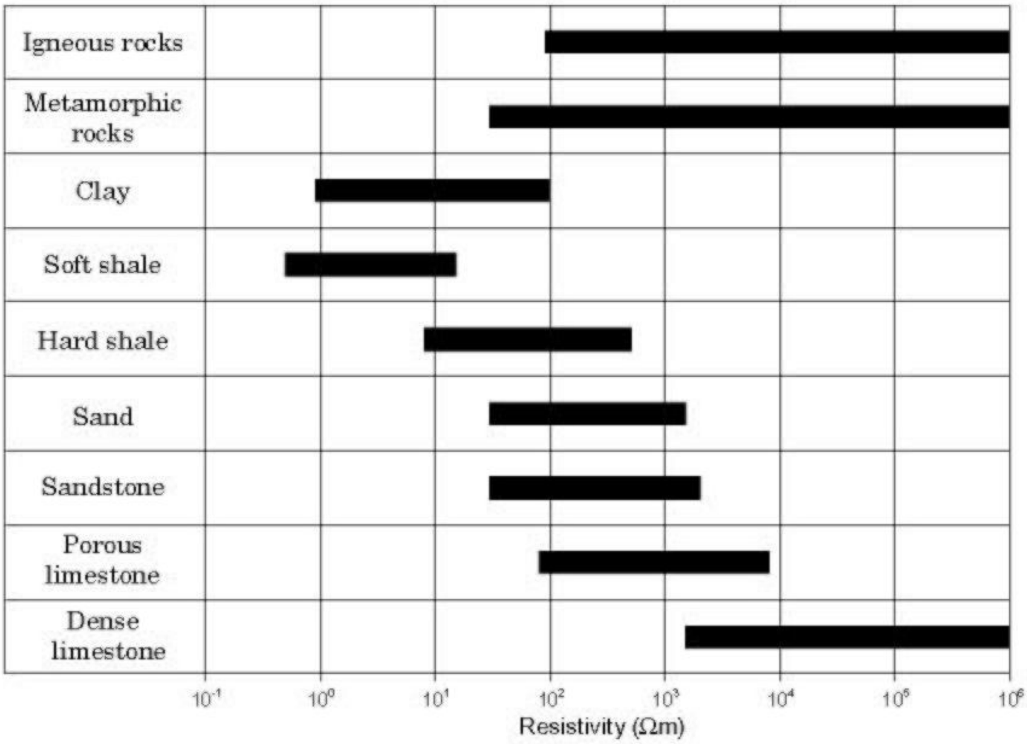


Figure 1.3 Approximate resistivity ranges of some rock types. The resistivity increase in order of clay, sand, sedimentary rocks, metamorphic rocks and igneous rocks.

1.2 Resistance and Resistivity

The electrical property of a material is usually expressed in terms of its resistivity. If the resistance between opposite faces of a conducting cylinder of length l and cross-sectional area A is R, the resistivity is expressed as

$$\rho = RA / l. \quad (2.1)$$

The unit of resistivity is ohm meter (Ωm). The conductivity of a material is defined as the reciprocal of its resistivity.

As mentioned above, the electrical property of a material is expressed not by its resistance but by resistivity because the resistance vary with volume of the material (see figure 1.4). When we identify a material by some physical property, the physical quantity should be constant even if the size of the material changes. Therefore, we use the resistivity instead of the resistance in electrical survey as the density (g/cm^3) is used instead of the mass (g) in gravity survey.

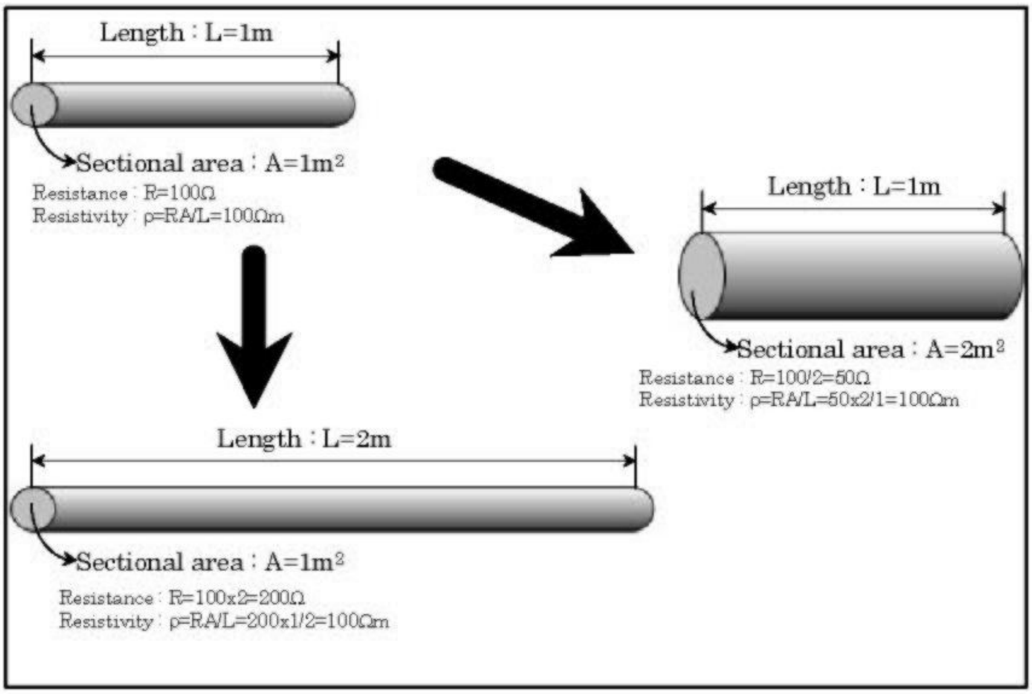


Figure 1.4 Resistance varies with the size of material, on the other hand, resistivity shows constant value even if the size changes.

1.3 Resistivity and Apparent Resistivity

If the underground is homogeneous, the resistivity is expressed as

$$\rho = GV / I, \quad (3.1)$$

where, V is voltage difference between potential electrodes (P1, P2), I is current injectd from current electrodes (C1, C2) and G is called geometric factor depending on the configuration of electrodes. Figure 1.5 shows commonly used electrode configurations and geometric factor corresponding to each configuration.

The resistivity calculated by equation 3.1 is true resistivity provided that the underground is homogeneous. For inhomogeneous underground, the resistivity calculated by equation 3.1 varies with the position of the electrodes and dose not show true resistivity, therefore this resistivity is called the apparent resistivity.

The apparent resistivity is a formal and artificial concept and it should not be considered to be some sort of average of resistivities of inhomogeneous underground formations. Nevertheless, the apparent resistivity is very useful concept for interpretation of the result of electrical survey.

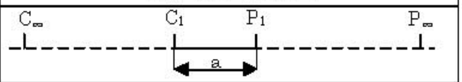
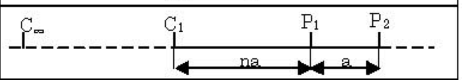
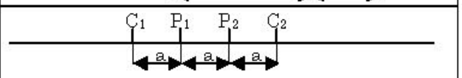
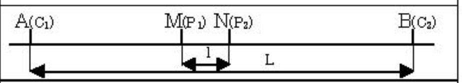
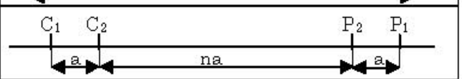
Name of configuration	Geometric factor	Configuration
Pole-pole	$2\pi a$	
Pole-dipole	$2n(n+1)\pi a$	
Wenner	$2\pi a$	
Schlumberger	π (L2-l2)/(4l), [L≧5l]	
Dipole-dipole	$n(n+1)(n+2)\pi a$	

Figure 1.5 Commonly used electrode configuration and the geometric factor corresponding to each configuration.

1.4 Electrical Sounding

When the underground consists of a number of horizontal layers, the vertical variation of resistivity is investigated by electrical sounding method. Electrical sounding method is based on the fact that the current penetrates continuously deeper with the increasing separation of the current electrodes. Figure 6 shows the principle of electrical sounding. When the electrode separation, C_1C_2, is small compared with the thickness, h, of the upper layer, the apparent resistivity would be the same as the resistivity, ρ_1, of the upper layer. This is because the current flows only within the upper layer, and the underground is considered approximately as homogeneous. As the electrode separation is increased, the current will penetrate deeper, and the apparent resistivity approaches ρ_2.

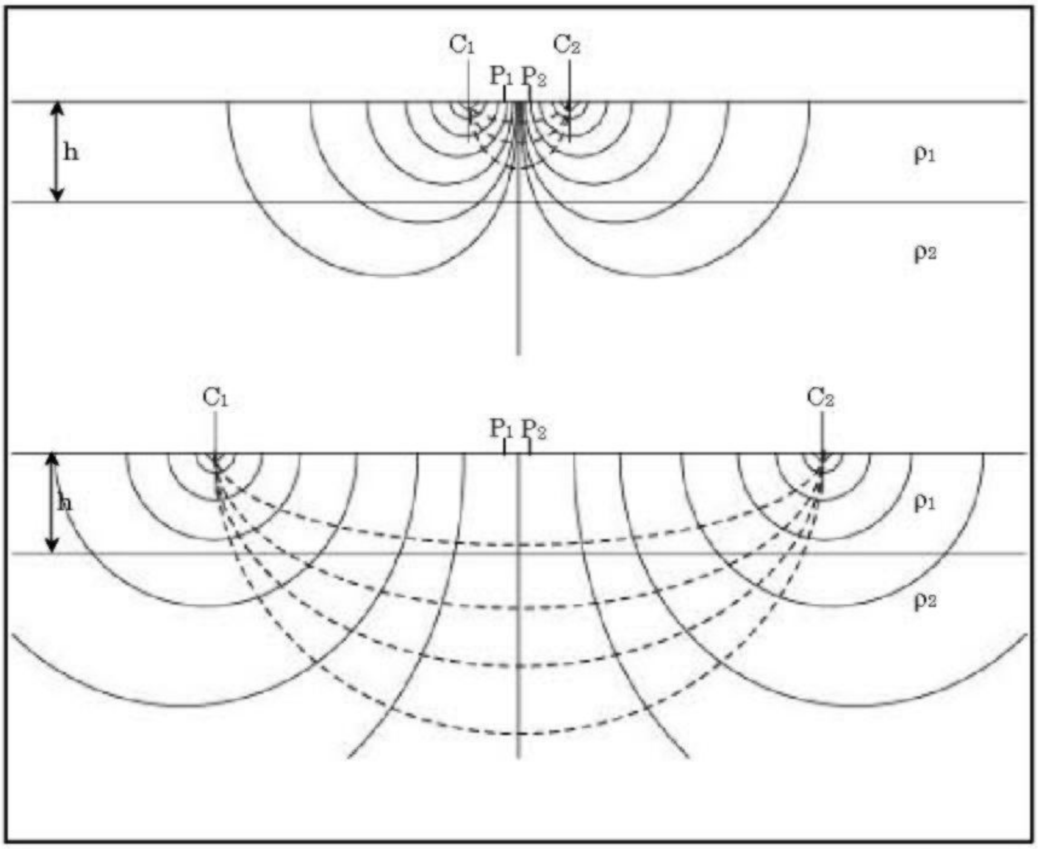


Figure 1.6 Principle of electrical sounding. For small electrode separation (C_1C_2<h), the current is confined to the upper layer. As the separation C_1C_2 increases, the current penetrates deeper in the second layer.

Figure 1.7 shows typical two- and three-layer curves for the variation in apparent resistivity as a function of the current electrode separation.

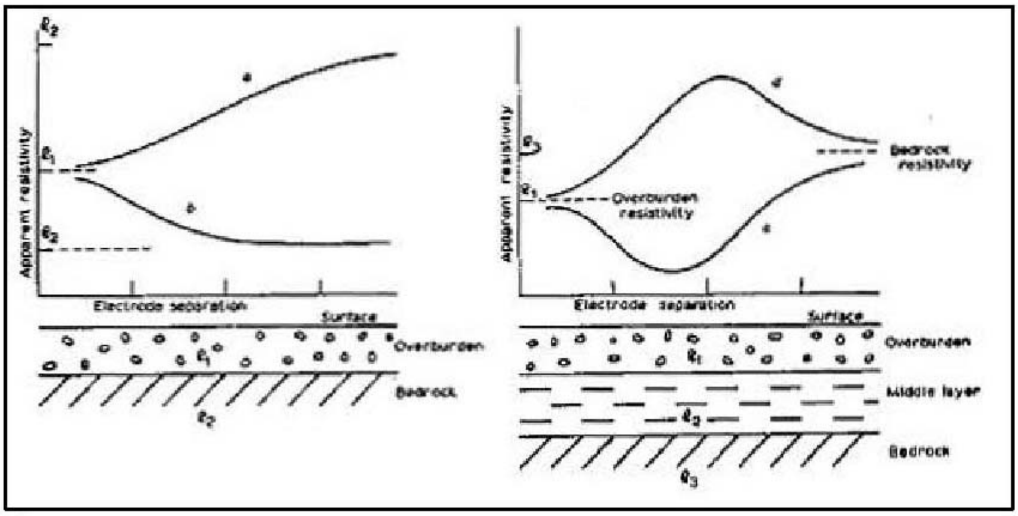


Figure 1.7 Schematic electrical sounding curves over a horizontally stratified earth. The apparent resistivity curves are shown for the following cases: (a) $\rho_2 > \rho_1$, (b) $\rho_1 > \rho_2$, (c) $\rho_3 > \rho_1 > \rho_2$ and (d) $\rho_2 > \rho_3 > \rho_1$. (After Parasnis, 1973.)

2 McOHM-EL

2.1 Introduction

McOHM-EL is a geophysical equipment for electrical survey and electrical logging manufactured by OYO Corporation (Japan). Maximum output current and voltage are 120mA and 400V respectively. A floppy disk drive and a thermal printer are built in this equipment.

Available method are as follows,

Electrical survey ……DC resistivity method, e.g. Schlumberger, Wenner, etc.

Electrical logging ……Normal logging, Temperature logging and Caliper logging.

The system consists of mainframe and other accessories as follows,

McOHM-EL,
12V battery,
Power supply cable,
Resistance for test,
Electrode,
400m and 200m cables,
Hammer.

When this equipment is used for electrical logging, the following optional accessories are required.

Normal probe,
Temperature probe,
Caliper probe,
Borehole frame,
Sheave and
Power winch.

Table 2.1 shows the specification of McOHM EL.

Table 2.1 Specification of McOHM EL

<table>
<tr><td colspan="2">Transmitting section</td><td colspan="2">Data memory section</td></tr>
<tr><td>Output current</td><td>2, 20, 60 or 120mA</td><td rowspan="3">RAM capacity</td><td rowspan="3">98kB (approximately 4000 data can be stored</td></tr>
<tr><td>Max output voltage</td><td>400V</td></tr>
<tr><td>Duration time</td><td>2, 3 or 4sec</td></tr>
<tr><td colspan="2">Data acquisition section</td><td rowspan="4">FDD capacity</td><td rowspan="4">512(Header) + 48 x N(Data numbers) [bytes]. In case of 1.2MB disk, max N is about 26200.</td></tr>
<tr><td>Input impedance</td><td>10MΩ</td></tr>
<tr><td>Max input voltage</td><td>±5V</td></tr>
<tr><td>Min detective voltage</td><td>1μV</td></tr>
<tr><td>Stacking</td><td>1, 4, 16 or 64</td><td></td><td></td></tr>
</table>

Current

Output current is selected on the menu. Output voltage is settled automatically according to the current and the contact resistance between the electrode and the ground. It is based on the Ohm's Law, V=RI. For instance, if 120mA is selected as output current, the contact resistance needs to be less than 3kΩ (400V divided by 0.12A is equal to 3333.3Ω).

Duration time

The wave form of output current is square wave as shown in figure 2.1. Time of one cycle is called duration time. The user can select three kind of duration time, 2, 3 or 4sec.

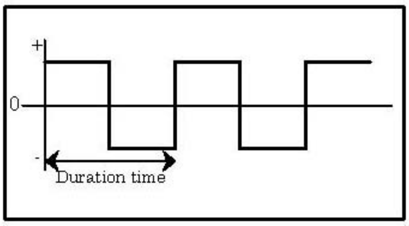


Figure 2.1 The waveform of output current

Stacking

The S/N ratio is improved by averaging two or more data. It is called stacking. Figure 2.2 shows the effect of stacking. The stacking number should be set as at least 4.

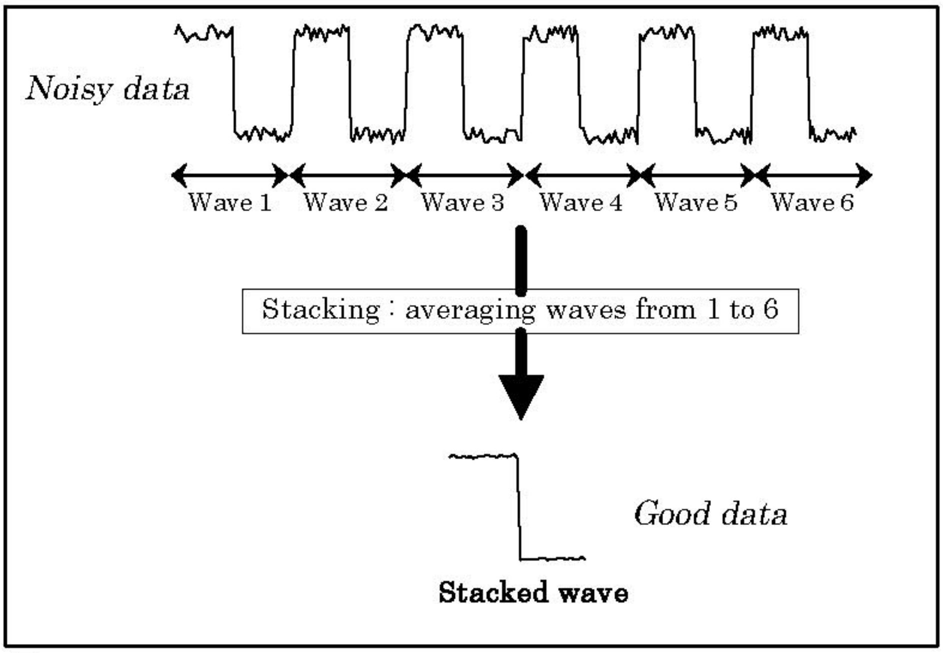


Figure 2.2 Random noise is canceled by stacking, and the S/N ratio is improved.

2.2 General Procedure

General procedure of McOHM EL is as follows.

(1) Connection

1) Connect the 12V battery to the power supply connector.
2) Connect wires from four electrodes to the current (C1, C2) and the potential (P1, P2) terminals.

(2) Setting Parameter

1) Turn on the power supply switch.
2) Press [F1] key to display VES menu.
3) Set parameter of CURR., PERI., WAVE, STACK and PRINT.

(3) Measurement

1) Press [ENTER] key after setting parameter to start measurement.
2) The measurement will be done in several seconds, and the result is displayed on the LCD
3) Press [ENTER] key to save the data into the memory. Pressing [CANCEL] key causes returning to the setting parameter menu without saving the data.

Table 2.2 indicates the detail of parameter.

Table 2.2 Details of parameter

Item	Remarks
CURR.	Select suitable current so that sufficient input potential can be measured. The input voltage value depends on the current and the resistivity. Generally, start measurement with minimum current, and if the input potential is too small, increase the current value. Sufficient input potential value is 1mV or more, in general.
PERI.	Select [2]sec usually.
WAVE	Select [+-] for usual measurement. [+--+] wave is useful for improving the S/N ratio in case that the SP indicates the linear variation.
STACK	Select [4] at least in order to improve the S/N ratio.
PRINT	If [ON] is selected, the measurement result will be printed out after each measurement. Select [OFF] usually.

3 SCHLUMBERGER METHOD

3.1 Introduction

Schlumberger method is most commonly used for vertical electrical sounding.

In this method, four electrodes are placed in the ground on one line symmetrically around the mid-point, the measurement point.

The Current is injected through the outer electrodes (A, B), and the potential difference between the inner electrodes (M, N) is measured simultaneously.

The electrodes are moved out around the midpoint and a new measurement is taken.

The apparent resistivity is calculated as,

$$\rho = \pi \left(L^2 - l^2 \right) / (4l) \frac{V}{I} \quad [\mathrm{L} = 5\mathrm{l}]$$

where L and l are the length of AB and MN, respectively. V is the potential difference between the electrodes M and N. I is the current injected through the electrodes A and B. L must be grater than $5l$. Figure 3.1 shows Schlumberger configuration and measurement procedure.

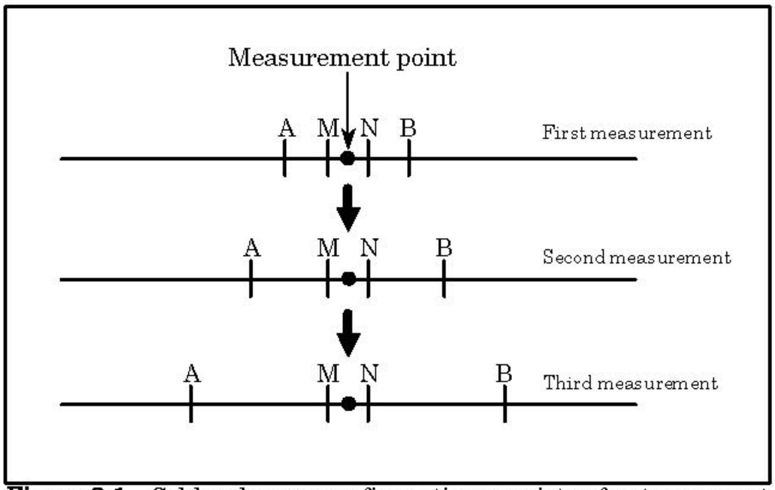


Figure 3.1 Schlumberger configuration consists of outer current electrodes and inner potential electrodes placed symmetrically around the measurement point. The measurement is carried out one after another by moving the current electrodes outside.

3.2 The procedure of Schlumberger method

The items for Schlumberger method are listed in Table 3.1.

Table 3.1 List of items for Schlumberger method

Item	Quantity
McOHM EL	1
12V battery with cable	1
Wires	400m x 2, 200m x 2
Electrode	5
Hammer	4
Measuring tape	100m x 2
Calculator	1
Tester	1
GPS	1
Field note	Depending on number of measurement points
Water container	4
Umbrella for sunshade	1 (at least)

General procedure

(1) Stretch two measuring tapes along the line as putting 0m on the mid-point.

(2) Place the electrodes in the ground at predetermined spacing (Start from small separation). ***The spacing of electrodes should be set up so as to satisfy the conditional equation, L = 5l.***

(3) Connect the electrodes and the terminal on McOHM EL with four wires.

(4) Taking data. ***Plot data on a double logarithmic diagram in order to ensure data quality***.

(5) Move the current electrodes outside, and take new data.

(6) Save the data into the floppy disk when the measurement is completed.

Parameter for normal condition

CURR. : Set low current like [2] or [20]mA when the current electrodes are close together. As the separation of AB increases, the signal decreases. Therefore, you should set high current like [60] or [120]mA.

PERI. : Select [2] seconds.

WAVE : Select [+ -].

STACK : Select [4] (at least).

PRINT : Select [OFF].

Helpful hints for successful survey

- Try to separate the potential and current cables as much as possible to prevent error caused by "cross-talk" between the cables
- Try to reduce the contact resistance between the electrodes and the ground. If the contact resistance is high, push the electrode deeper into the ground or pore saltwater on the ground where the electrode is placed.
- When you have to select the measurement point close to a power line unfortunately, try to set up wires in the direction perpendicular to the power line.
- Plot data on a double logarithmic diagram in order to check the data quality. The curve connected each plotting point should be smooth generally. If the data is remarkably different compared with the last data, check the electrode, the wires and also the contact resistance, and measure again.
- Stop the measurement during rain or thunder.
- Make sure that the electrodes are free from dirt and corrosion where it makes contact to the ground and the wire.