SALESIAN COLLEGE PHYSICS DEPARTMENT

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GEOPHYSICAL SURVEYING PROJECT

ELECTRICAL RESISTIVITY SURVEYING

You are to conduct CST and VES electrical resistivity surveys of the Salesian College lawns to produce CST electrical resistivity survey line graphs and a VES graph and interpretation of all the results.

This project will demonstrate a practical application of a concept in Physics, develop your data-collection and teamwork skills, enable you to use of Microsoft Excel to process your data and produce line graphs, and use computer modelling software to interpret the VES data.

You will produce an A2 or A1 poster of your work for display to communicate your findings and explain the physics behind the survey.

This instruction booklet will explain how an electrical resistivity survey can be carried out, the equipment and circuitry required and how to analyse and interpret the data obtained.

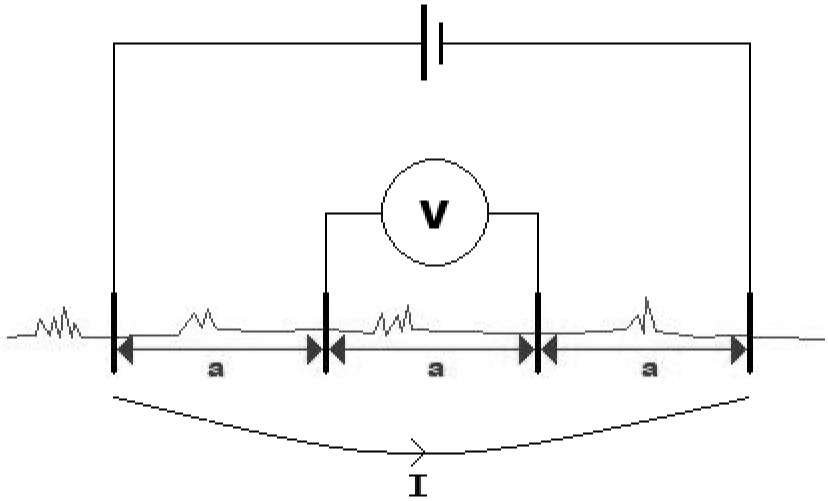
Contents:

Theory

Resistivity is a physical property of materials related to how well current can pass through the material. Most materials are insulators so the resistivity is normally controlled by the water content of the subsurface material. Materials with high water content have a lower resistivity because the ions in the water allow current to flow more easily.

Resistivity can be measured by passing a current into the ground and measuring the potential difference. Separate pairs of electrodes need to be used for both functions because of high contact resistances at the probes. A reversing square wave current source is applied to the ground to stop the build up ions at the probes, and this also nullifies the effect of telluric currents. Telluric currents are naturally occurring currents that usually flow parallel to the surface. When a reversing current is applied they add on when the current is in the same direction, and take off with the current is in the opposite direction. This just shifts the measurements taken up or down so the telluric current effect can be removed.

There are several different geometrical arrangements of electrodes to pass the current into the ground and to measure the voltage. One of the most common arrays used is called the Wenner array and this is the configuration that will be used, because it leads to the simplest calculations. The Wenner array is set up with two outer probes to apply the current and two inner probes to measure the potential difference. The electrodes are placed in the ground with a constant separation between them (shown below).



Now we have this basic configuration we can look at the different applications. The Vertical Electrical Sounding (VES) method uses the Wenner array by keeping the central point in the same position and increasing the separation (*a*) taking readings with every different separation. This allows you to look at horizontal layers under the surface because the larger the separation the deeper the current penetrates into the ground. This is useful to determine depth to buried objects or sub-surface geology.

The Constant Separation Traversing (CST) method keeps the separation (*a*) constant and moves the whole array over the ground. This is a quick technique to survey and map a large area and therefore is an ideal technique for archaeological geophysical surveying.

The apparent resistivity can be calculated for the Wenner array using the following formula.

$$\rho_a = 2\pi a \frac{\Delta V}{I}$$

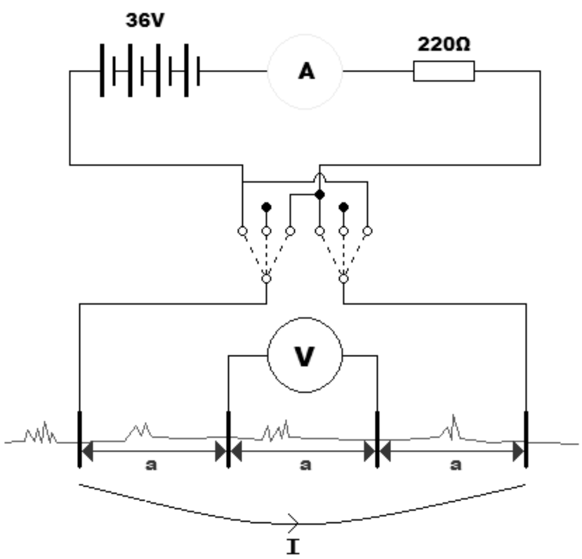
The apparent resistivity is calculated not the actual resistivity because the value calculated depends on a function of what is under the ground, unless this is all the exactly same material, which is almost never the case.

Design of Equipment

The major variation from common resistivity devices is that we are not using a reversing square wave current. We will be using DC current. This choice has been made to simplify the problem and reduce costs of the current source and measuring devices. So our results are also not effected by telluric currents, we will reverse the direction of the current as well manually; taking a reading with the current flowing in one direction (up) and then taking a reading with the current flowing in the opposite direction (down). To get the correct voltage reading we need to calculate the difference between the two measured potential differences and then halve this value to give the amplitude of the potential difference with the telluric currents removed. This is then a good approximation for the measured voltage using a reversing current supply.

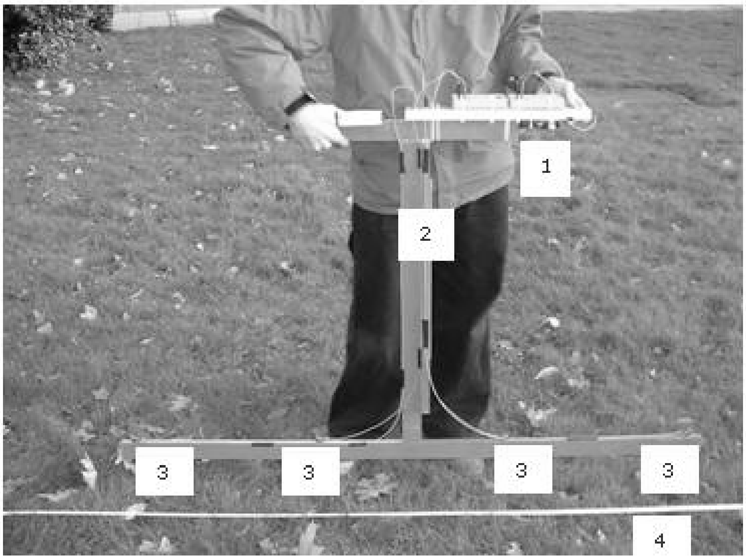
Our circuit has a double pole mom – off – mom switch switching mechanism so the direction of the current can be varied. This means when you flick the switch on it clicks back to off this ensures battery power is not wasted and that the two terminals of the battery can't accidentally be joined together. Double pole means that when you flick the switch it makes two connections not just one. We are using four 9V batteries giving us a voltage of 36V.

To measure the current and the potential difference we will use two standard digital multimeters. One down side of the multimeters though is that the fuses can easily be blown to stop this happening we have connected a resistor in series with the multimeter and batteries to stop the fuse rating of 200mA being exceeded.



CST Surveying

For the CST survey, the circuitry is mounted onto a wooden frame so all four probes can be moved in unison. The frame has a 1.2m base section to allow for the four probes to be attached with a constant 0.30m separation between them. The probes are thick 6” nails attached through the base section with the nail-head proud so that wires can be attached.



Picture of finished CST frame 1. mounted device, 2. frame, 3. probes, 4. tape measure

Carrying out the survey

Lay out a tape measure the length of your surveying line. Place the central point of the array of probes on the 0.0m mark. Take a reading in the up direction by pushing the switch up. Record the ammeter and voltmeter readings in the results table. Then push the switch in the opposite direction, i.e. down and take readings again and record them. Now move the midpoint of the array to the next surveying point (1.0m) and continue along the survey line in 1.0m increments.

When you have completed taking readings along your first survey line, move the tape along to another line and carry out the same procedure to obtain data for this line. Continue with further lines until results for the whole survey area has been obtained.

Processing, analysing and interpreting the data obtained

To process and analyse the data use the prepared CST spreadsheet downloadable from www.fizix.info. Input your data into the four empty columns for each survey line (on a separate sheet in the workbook) and the spreadsheet will calculate the apparent resistivity and a plot graph of the apparent resistivity along a CST survey line. You will need to add additional sheets and graphs to the workbook for the other lines. It is important you understand what the spreadsheet is doing and how the formulas work so that you can add additional sheets and graphs and check the calculations.

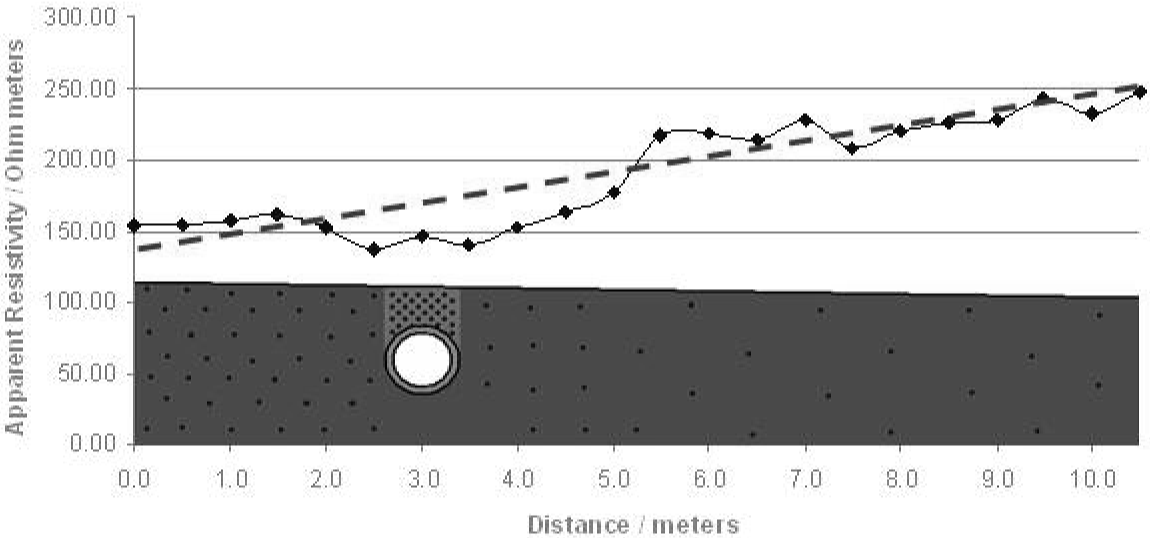
The spreadsheet is calculating the difference between the two measured voltages and average current magnitude. One current will be negative one positive so need to make both the same sign to calculate an average. It uses voltage and the average current to calculate the apparent resistivity, using the following formula. Where *a* is the separation, *ΔV* is the voltage difference (this needs to be divided by two to give the amplitude of the potential difference with the telluric currents removed) and *I* is the average current. Make sure all the average current calculations and voltage differences are positive to ensure accurate results.

$$\rho_a = 2\pi a \frac{\Delta V / 2}{I}$$

To analyse the CST data a graph of apparent resistivity *vs* distance along the profile is plotted by the spreadsheet. You are looking for changes in the resistivity value to interpret it.

Sample CST interpretation

Below is an example of some data collected from a CST survey. The survey was carried out over a known submerged pipe.



Results and interpretation from a CST survey

There was a general trend of data over the whole profile line, increasing from left to right and when the pipe was passed over there was a low resistivity anomaly noticed. A typical low resistivity anomaly looks similar with a drop in resistivity with a rise in the centre and a drop to the other side, a positive resistivity anomaly is the inverse. A positive anomaly was expected over the pipe because it is filled with air so would have a high resistivity, but the current penetration with the small electrode separation must not have penetrated that deep meaning a low resistivity anomaly was noticed from the disturbed soil that must have been dug up to bury the pipe, or from water sat above it. The general trend is thought to be caused by the pipe as well. There was a slight downhill slope to the right, so extra water would be expected down hill making the resistivity lower but this was not the case, a possible explanation of the anomaly is that water builds up, on the uphill side of the pipe because it cannot pass through causing a lack of water the other side.

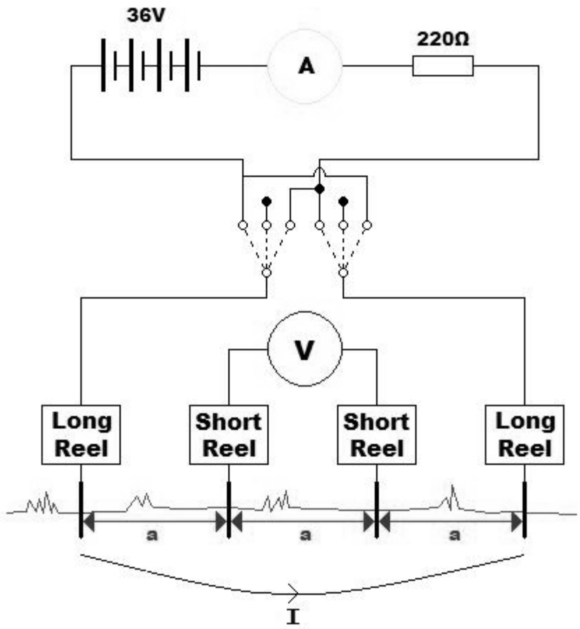
In the interpretation of the data some imagination is needed!

VES Surveying

For the VES survey, the circuitry is mounted onto the same wooden frame, but this is placed at the point under investigation and connected to brick pin electrodes away from this point.

Carrying out the survey

Place the wooden frame is placed at the point under investigation and run the tape measures stretched out in two directions along a straight line from this point. Place the brick pin electrodes well into the ground at the required electrode spacing, but leaving enough to clip the wire onto the head. Disconnect the connections to the nail electrodes and connect to the reels of wire, and then stretch out the wire to connect to the electrodes in the ground.



Take readings of current and voltage in the up and down directions of the switch. Record results in the VES table. Then move the brick pin electrodes to the next electrode separation and repeat until you have readings for all your separation distances.

You can then move to another point to investigate, or onto analysing your results.

Processing, analysing and interpreting the data obtained

To process and analyse the data use the prepared VES spreadsheet downloadable from www.fizix.info. Input your data into the four empty columns and it will calculate apparent resistivity and plot a graph. Once again, it is important you understand what the spreadsheet is doing and how the formulas work so that you can add additional sheets and graphs and check the calculations.

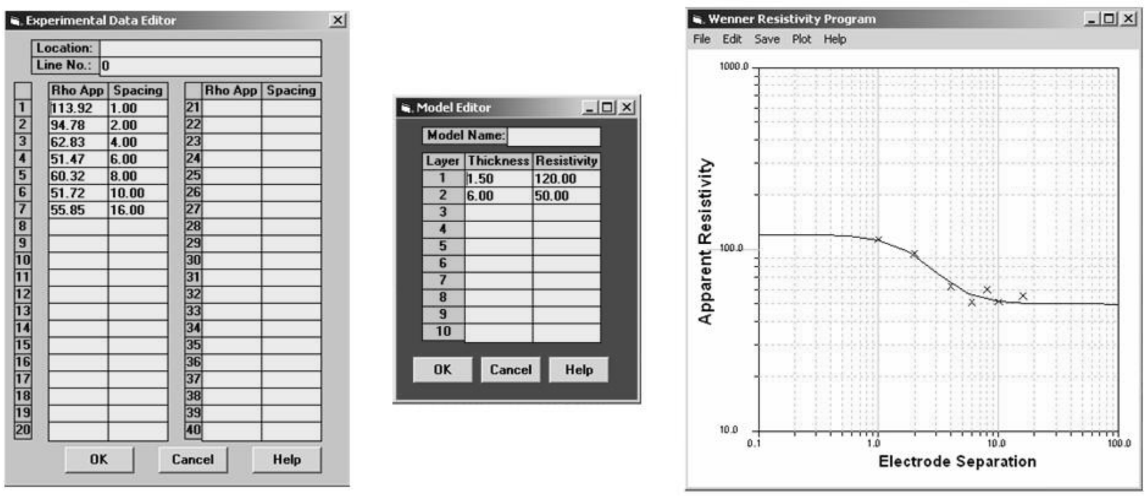
To interpret the VES data you need to load the program Wenner Resistivity (Start ➔ Programs ➔ Physics ➔ Wenner. This program is used to analyse data from expanding Wenner array surveys, and is produced by Liverpool University, Earth and Ocean Sciences Department. You can download it to your home PC from:

http://pcwww.liv.ac.uk/~sg01/software/

A blue intro screen should appear click ok to get into the program. Now the program is running and you should see a blank box with just the title menus. Click on File ➔ Create Profile this allows you to enter your collected data into the program. Type in your apparent resistivity values calculated using the spreadsheet and their corresponding separations. When you have entered the entire dataset, click on ok. Next you need to enter your initial guess for what the structure under the ground is like. To do this click File ➔ Create Model. You need to type in the thickness you think the layer might be and its apparent resistivity. A good initial starting point is to enter your resistivity value for the shortest spacing as the resistivity for the first layer and your lowest resistivity as the value for the second layer. Then guess a thickness probably somewhere below 10 meters for the first layer (the thickness of the bottom layer is not important because the model extends it to infinity). Next click Plot ➔ Rho App vs Spacing a plot should then appear on the screen. The crosses represent the data points and the line is the model that you have guessed. If the model line does not look to fit the data click Edit ➔ Edit model and try altering your model to make it a better fit to the data.

Sample VES Interpretation

Below is an example of some data that was collected using the device constructed during testing.



Results, model and apparent resistivity vs spacing plot for data collected

The data collected is to the left and the model that best fits the profile is in the centre. The fit to the data can be seen in the screen shot of the Wenner resistivity program on the right. From the model this data is thought to represent a two layer case. There is a thin top layer 1.5m thick with a resistivity of 120Ωm and a layer below with a resistivity of 60Ω. The interpretation of this data is that there is a thin dry top layer and then below this there is a more water rich layer that causes the low resistivity, because water content has the greatest variation on resistivity, from this data it is unknown if there is a change in rock type or the water table has been found, and this is often the case that only a qualitative assessment can be made. If there are more layers the differences could be from changes in rock type and changes in water content in the rock type.

Acknowledgements

This booklet contains text, pictures and diagrams developed from a resource produced by Christopher Watts at the University of Liverpool Department of Earth and Ocean Sciences: http://www.liv.ac.uk/Geomagnetism/schools/

Thanks to Mr R Walker, Physics Technician at Salesian College for his help sourcing and constructing the equipment and circuitry used in this survey.

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CST Survey Line: Time: Date:

Surveyed by: Probe no:

Distance from origin, d / m	Current up, I_{up} / mA	Current down , I_{down} / mA	Voltage up, V_{up} / mV	Voltage down V_{down} / mV
0.00				
1.00				
2.00				
3.00				
4.00				
5.00				
6.00				
7.00				
8.00				
9.00				
10.00				
11.00				
12.00				
13.00				
14.00				
15.00				
16.00				
17.00				
18.00				
19.00				
20.00				
21.00				
22.00				
23.00				
24.00				
25.00				

VES Survey Time: Date:

Surveyed by: Probe no:

Electrode separation, a / m	Current up, I_{up} / mA	Current down , I_{down} / mA	Voltage up, V_{up} / mV	Voltage down V_{down} / mV
0.20				
0.50				
1.00				
2.00				
4.00				
6.00				
8.00				
10.00				