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A Description of Field Setup and Common Issues in 2-D Electrical Resistivity Tomography Data Acquisition

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Abstract: ***Electrical resistivity tomography is a geophysical imaging technique utilized commonly for shallow subsurface investigations in support of civil structural, environmental, utility and archaeological investigations. For engineering consulting businesses that use this survey method extensively, the acquisition of reliable resistivity data using proper equipment in a timely manner is crucial for data processing, interpretation, and overall client satisfaction. Tough site conditions and human errors can negatively affect the speed of acquisition, data quality and hence affect the overall project timeline and cost. Based on the extensive use of an AGISuperSting resistivity meter system, this paper addresses the general surveying procedures with emphasis on common problems encountered and offers solutions accordingly. The most common issues are improper connections, hard or dry ground, overgrown vegetation and rain at the surveying site. Operations that could speed up the process can also be beneficial for engineers and researchers who acquires the data in a similar setting.***

Keywords: electrical resistivity tomography (ERT), data acquisition, subsurface, AGISuperSting, geophysical investigation

1. Introduction

As one of the geophysical surveying tools, the electrical resistivity tomography (ERT) maps variations in resistivity of the target, by injecting electrical current and measuring the resulted potential. Resistivity is dependent on the lithology, clay content, porosity, permeability, fluid saturation and fluid salinity of the target. Clay, which contains moving ions (electrolytic conduction), has relatively low resistivity values. Therefore, earth materials that contain clay generally have relatively low resistivity values. Figure 1 lists the resistivity ranges of some of the most common earth materials, where variations of resistivity between materials can be seen[1]. The outcome from ERT surveying is usually 2-Dresistivity images of the subsurface(Figure 2).

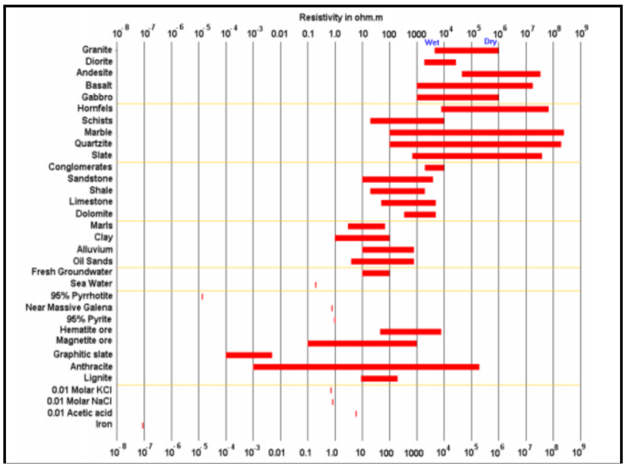

Figure 1: Resistivity values of common rocks, soil materials and chemicals (Keller and Frischknecht, 1966).

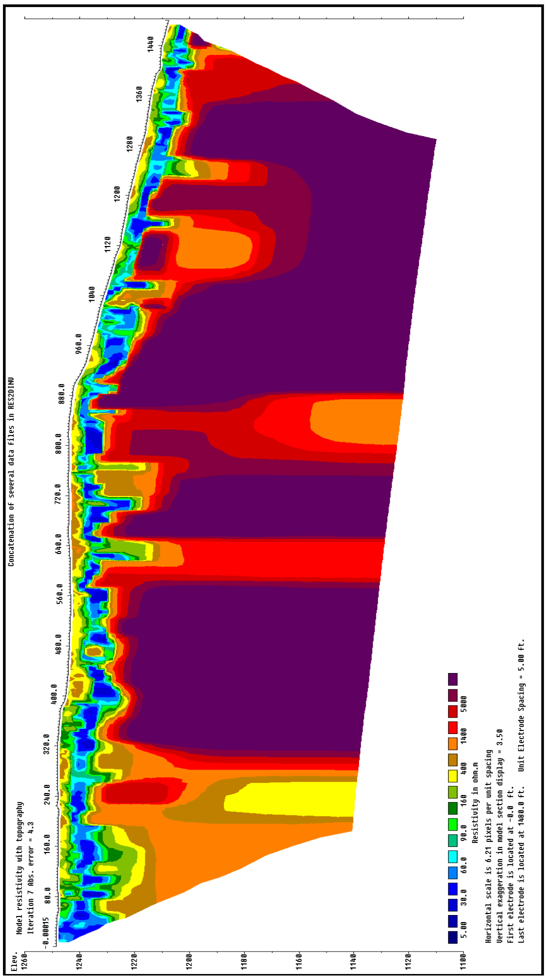

Figure 2: Example 2-D ERT profile showing resistivity variations of the subsurface.

An AGISuperStingR8 system was used by the authors to acquire over 100, 000 ft of data in tough topographic settings. Although the use of the equipment has been widely taught in academia, workshops and through owner manuals, in reality, personnel can face many challenges in the field, especially in a consulting business setting where quality data needs to be collected in a timely and cost-effective manner. This paper addresses several aspects of the data acquisition process and discusses related common issues. Solutions to these issues are suggested based on the field experience of the authors and can serve as guidelines for researchers and engineers who acquire ERT data in a similar setting.

2. Data Acquisition Equipment

As shown in Figure 3, the primary equipment the authors used included an automated 8-channel resistivity meter AGISuperStingR8 system, deep-cycle marine batteries, switch boxes, multiple ERT cables with electrodes attached, a large number of stainless-steel stakes and a laptop.

Figure 3: ERT data acquisition equipment.

3. Pre-planning

The amount of ERT data that can be acquired per day or per week and the size of the field crew should be determined ahead of time. This is partially determined by the client needs and site size but also determined by the weather and site conditions. For example, to investigate the subsurface to the depth of 100 ft, assuming a 4 person crew using a 168 electrode array and working on a relatively flat surface with no overgrown vegetation and relatively moist soil, and without weather interpretations, it can typically take up to 5 hours to acquire 835 ft of ERT data along a single traverse (including equipment setup time, data recording time and equipment take-down time). In contrast, using the same equipment and crew on an irregular surface (e.g., steep incline) with overgrown vegetation (which needs to be cleared) and dry soil (which needs to be wetted for conduction), with weather interruptions, it can take 7-8 hours or more. The equipment setup process (e.g., driving stakes into the ground, transferring equipment, connecting cables, wetting stake/ground contact) is largely affected by the terrain conditions and can take a much longer time to complete than the actual data recording process.

Weather conditions affect ERT data acquisition. Rain will potentially damage the electrodes, and jeopardize crew safety (e.g., working in a thunderstorm can be dangerous). Moisture damage to equipment results in delays and financial loss, therefore, ERT data acquisition is paused during rainstorms. It is advised to check weather radar periodically before and throughout the investigation and make changes to the survey schedule accordingly. Tarps, plastic bags (such as Ziplocs) should be used to cover the equipment/electrodes during the data recording process, as weather can change suddenly despite the frequent checking of weather radars. In the event of an unexpected thunderstorm, equipment should be covered and transferred to a dry location as soon as possible. It is crucial to inform the client(s) of weather-related issues prior to the project to avoid unrealistic expectations. (e.g., continue acquiring data when there is a thunderstorm).

Surprisingly, a common issue researchers and engineers might encounter is accessibility. Although information regarding site location, site history, accessibility is generally obtained before fieldwork, such information can be inaccurate and incomplete as they are provided by clients who do not have a geophysical surveying background. This can happen in projects to be carried out at locations far away (e.g., in another state), when the preliminary site assessment cannot be done by the researchers and engineers in person. More than often, field crew can find themselves in a situation where part of the ERT array needs to be extended off-site, meaning setting up stakes and operating equipment on a neighboring property that the client does not own. In this case, prior authorization needs to be obtained from the property owner to avoid trespass issues.

Uneven ground, steep incline, and overgrown vegetation slow down the equipment setup process significantly. In these areas, access is typically limited, and it is often difficult to walk, set up and take down equipment. It is also very common for field personnel to carry all the equipment in person and walk to the investigating target, instead of transporting equipment via trucks. As a precaution, it is advisable to walk slowly and carry relatively heavy equipment, such as the resistivity meter, stainless-steel stakes, cables, and batteries separately and take separate trips as needed. An all-terrain vehicle (ATV), although often not available, is found to be very helpful in transporting equipment/personnel in tight spaces and along steep inclines.

Ideally, any overgrown vegetation should be cleared prior to data acquisition as they affect the connections between electrodes and stakes as leaves tend to get in between. It is important to communicate with client(s) to have the vegetation cleared prior to acquisition so that the field crew does not have to do additional clearing. However, field crew may carry necessary tools for simple cutting and clearing of vegetation (e.g., tree branches) if the area is not completely cleared out of such obstacles. The site should be surveyed and the starting and ending point of an ERT traverse should be determined ahead of time. Prior to equipment loading, equipment should be checked for damage, batteries should be fully charged, meetings within crew members should be held to ensure the full understanding of the site conditions, the correct use of equipment and survey objectives. Additional items, such drills (for drilling holes on pavement), battery chargers, tarps, plastic bags, and smaller electronic tools (for fixing the equipment), should be prepared along with the primary survey equipment.

Equipment are usually loaded onto a truck to be transported to the survey location. As an example, a common type pickup truck manufactured in the USA can usually hold two boxes of a total of 8 cables, two buckets of approximately 200 stainless-steel stakes, one resistivity meter, two switchboxes and small tools such as hammers, tape measures, tarps, etc. It is important to note that the resistivity meter, switch boxes, and cables should be stored and transported in hard-shelled plastic boxes for protection and therefore they can take up most of the space on the truck.

4. Data Acquisition Procedure

In an ERT survey, the order of electrode spacing affects the lateral resolution of the 2-D ERT profile. As distance between the electrodes increases, the depth of investigation increases but lateral resolution decreases. During data processing, as an example, when using a 5 ft electrode spacing, the subsurface is divided into rectangular areas that are 5 ft wide with an apparent resistivity assigned to each. By doubling the spacing to 10 ft, the rectangular areas are essentially quadrupled, hence the decrease in lateral resolution on the 2-D ERT profile.

Generally, ERT can investigate the subsurface to deeper depths if the ERT array length increases. The total depth of imaging is approximately 20% of the ERT array length (distance between the very first electrode and the very last electrode)when using a dipole-dipole array. As lateral resolution generally decreases with increasing depth, vertical resolution also decreases with increasing depth and is comparable to lateral resolution. As an example, a dipole-dipole array with the use of 168 electrodes with 5 ft electrode spacing can yield an investigation depth of approximately 167 ft (835 x 20%=167).

Depending on the size and accessibility of the investigating target, lengths of acquired ERT profiles vary. Generally, one or several “roll-alongs” of one ERT array and additional test(s) are conducted to achieve the desired investigating coverage. For example, while the initial ERT array covers 835 ft of investigating surface, by rolling the first half of the array (4 ERT cables)to the end of the second half of the array (4 ERT cables) and conducting a second test, an overall of 1250 ft of investigating coverage can be achieved (835 + 415 =1250).

The equipment setup process starts with rolling a tape measure along the predetermined ERT traverse (Figure 4). Wind can always be an issue preventing crew from stretching the tape measure along a straight line. As the tape measure is for the correct installations of the stakes with accurate intervals (e.g., 5 ft), it is advised to install a stake every 100 ft along the traverse for the tape measure to hold onto. A very common issue associated with stake interval often rises when acquiring data on an incline (Figure5). On the curved surface, if one drives stakes at intervals shown exactly on the tape, such as 5 ft, the produced 2-D ERT image will not be accurate in terms of electrode spacing. The proper way is to slightly increase the intervals to make stake intervals greater than 5 ft, to ensure that the correct electrode spacing is shown on the final resistivity profile.

Figure 4: Tape measure stretched along the ERT traverse for the correct installations of stakes at set intervals.

As Figure 6 illustrates, based on the tape measure, stainless-steel stakes are then driven into the ground with set intervals, using a 5 lb. hammer. The stakes are routinely cleaned and sharpened to ensure excellent conductivity and are carefully examined each time before installation.

The conduction between the electrodes and the subsurface is achieved by attaching electrodes to the stakes using rubber bands (Figure 6). There are commercially available products (such as metal springs) designed for this particular purpose, but in practice, the rubber bands are found to be a better choice over metal springs, as it generally takes less effort and time (e.g., rubber bands are easy to put on and take off, are lightweight and take up less space) to achieve a reliable connection. Regardless of the choice, the connections between the electrodes and stakes should be carefully examined to ensure eliminate loose connections.

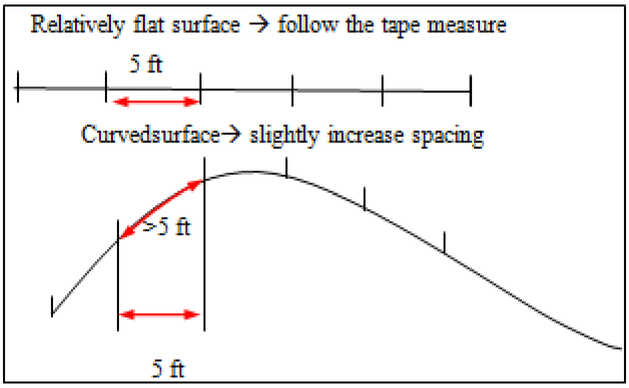

Figure 5: Electrode (stake) interval adjustment on an incline

To ensure sufficient conductivity, water is manually added onto the stake/ground contact (Figure 6). In areas that could be accessed by a truck, the stake/ground contact can be wetted effectively using a hose connected to a water tank, which is usually mounted on the back of the truck. More than often, water is added using a bucket as a result of restricted truck access. For example, if data are to be required on a steep incline with overgrown vegetation, the use of water buckets seems to be the only option. Additionally, if time is an issue, it is common to wet several stake/ground contacts on the array where electrical current is initially injected into the subsurface. The rest of the stake/ground contacts can be wetted after data recording starts.

The completed ERT array layout is shown in Figure 7. The resistivity meter (SuperSting) controls the electrodes (e.g., injecting current and measuring voltage) by attaching to two switch boxes (SB1 and SB2) that switch four cables each. Cables 1 to 4 are switched by SB1 while cables 4 to 8 are switched by SB2.

In an ideal terrain setting with no weather interruptions, the installation of the stakes, connection of cables, attaching electrodes, adding water, and setting up resistivity meter/ switch boxes, usually takes about 1-1.5 hours to complete. Again, this can vary significantly between a terrain that is rather flat and easy to walk on, and a terrain that is inclined, with overgrown vegetation.

For quality control, prior to actual data recording, any loose connections at the electrode/stake contacts occurred during or after the setup process are carefully examined by conducting a contact resistance test. Loose connections could have been a result of human mistakes but are mostly caused by wind disturbance and animal interactions. The contact resistance test measures the resistivity between stake 1 and stake 2, stake 2 and stake 3 and so on, and the resistivity values should be overall consistent. Extremely high or low values most likely are attributed to the following:

- Electrodes are not properly connected to the stainless-steel stakes.
- Separate ERT cables are not correctly connected to each other, the pins of the cable connectors can be dirty from dust and soil clod.
- Loose connections or wrong connections (reversed connections) at the switch boxes.
- The contact between the stakes and ground are poor (e.g., stakes are not firmly pushed into the ground, and insufficient amount of water is added).

Driving stakes into the ground using 5 lb. hammer

Attaching electrode onto the stakes using rubber band

Pouring water onto stake/ground contact to ensure conductivity

Figure 6: Stake driving, electrode connecting and water adding process.

Field personnel locate the problematic electrode(s) or cable connection(s) and fix the issues accordingly. A second contact resistance test will follow. The actual data recording should not be initiated until all readings on the contact resistance test become normal. Once the actual data recording process begins, field personnel routinely checks physical connections of all parts of the array and monitors readings on the resistivity meter closely. Following the completion of data recording, raw ERT data are transferred to the laptop. Raw ERT data are general unprocessed resistivity images of the subsurface and they enable field personnel to locate potential data acquisition errors, this is only to ensure the collected data are of satisfactory quality, and the raw ERT data are not the accurate resistivity representations of the subsurface. Data acquired in the field are further processed in the lab using commercial software.

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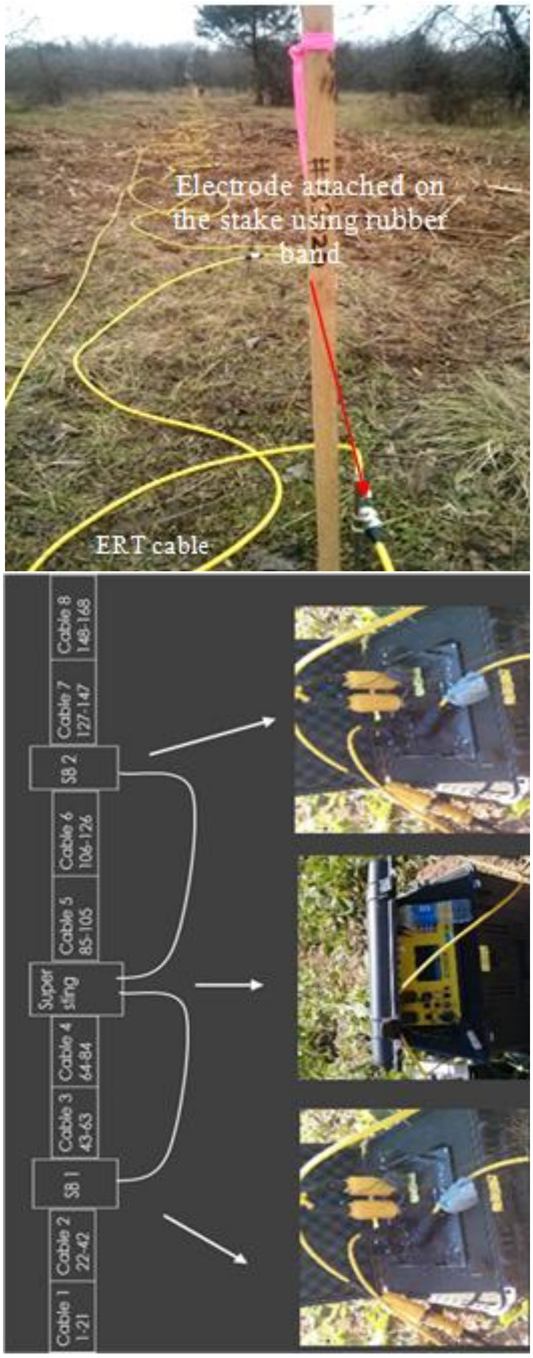

Figure 7: ERT cable and equipment layout

Field experience has shown that it is beneficial to check data quality at regular intervals during the data recording process, which involves the temporarily pausing of the resistivity meter and the attaching of laptop to download and check data points. This process can take up to 10 minutes before data recording can be resumed. Data checking is usually conducted at 30-min intervals. If data are found to be of poor quality, connections are checked, and data recording is repeated with subsequent data checking. In the unfortunate event that the data are found to be of poor quality after several repeated tests, data recording at that location is usually abandoned.

The power source of the resistivity meter, which in this case, a deep cycle marine type battery, should be fully charged prior to data acquisition. It is ideal to carry two or more fully charged batteries to the site as backups. In tests conducted in a cold climate, battery usually drains faster and requires periodical battery swaps.

Experience has shown that several factors negatively affect the quality of the acquired ERT data. The most common issue is the unsatisfactory connection/conduction between the stakes and ground. Sometimes, it is difficult to firmly drive stakes into the ground when the ground is hard and dry. Inexperienced field personnel may only drive the stakes in a few inches without realizing the connection between the stakes and the ground is not of satisfaction. Experienced crew members would use portable drills to drill holes in the hard/dry ground (e.g., on a pavement), prior to pushing stakes in, and add an adequate amount of water onto the stake/ground contacts.

As previously discussed, the electrodes, resistivity meter, batteries, switch boxes, cables should always be protected from rain and moisture. In addition, in areas where water bodies such as creeks and ditches are present, plastic covers (e.g., Ziplocs) are applied onto the equipment (usually the cable connectors) that contact with water to prevent moisture damage. In areas where a more significant water body is present, ERT data are usually acquired using specially designed marine cables.

For researchers, wearing proper personal protective equipment (PPE) in the field is highly suggested. For consulting business, usually the wearing of PPE is a common practice and a general requirement. Throughout the test, signs should be available on-site to avoid unexpected interruptions. For example, if acquiring data across a roadway, road should be blocked properly, and signs should be put up to warn motorist. Field personnel should be available at the site for emergencies. In addition to rain, equipment should always be monitored and protected from animals (Figure 8), wind damage and theft.

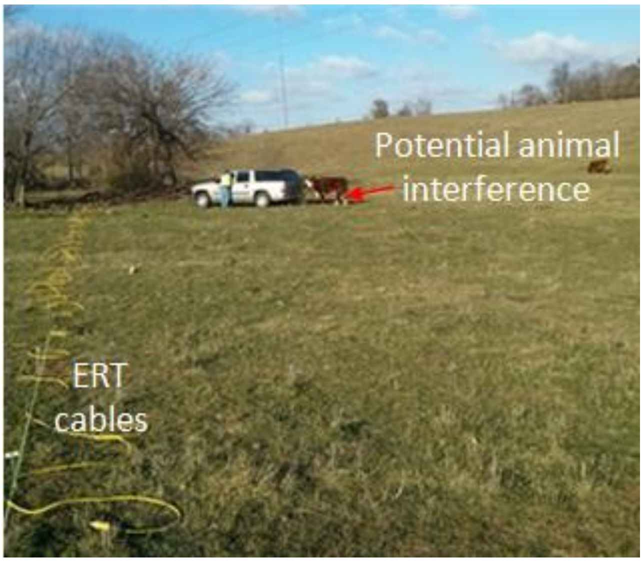

Figure 8: Field personnel on-site monitoring data acquisition and preventing animal interference to the ERT cables.

Figure9 illustrates the issues field personnel may encounter at the site. Table 1 lists the suggested solutions. It is important to note that researchers and engineers can encounter a combination of the listed issues in a single project.

Figure 9: Common issues at the surveying site

Table 1: Common issues and solutions

Common Issues	*Effect*	*Solutions*
Hard Ground (e.g., pavement)	Stakes are unable to be driven into the ground by hand	Use drills to drill holes, and add a large amount of water onto stake/ground contacts
Dry Ground (Soil is dry)	Poor conductivity between stakes and ground	Pour water over stake/ground contact, repeat as needed and carefully check values during contact resistance test.
Uneven Ground & Slopes & Hills	Difficult to walk on and set up equipment	Walk cautiously and slow down, take additional trips for equipment transportation
Rock Piles	Very difficult to drive stakes in	Pick out rocks and make space to place stakes
	Very poor conductivity	Pour a significant amount of water at stake/ground contact
Overgrown Grassy Ground	Grass can get in between electrodes and stakes. Stake are difficult to locate, may cause tripping	Clear the grassy spot with a truck or other tools
Rain	Moisture damage to equipment	Cover equipment and connectors with tarp and plastic covers, transfer equipment to a dry location
Poisonous Animals & Herbs	Cause injury/ could be fatal	Work cautiously and always carry first-aid kit
Fences & Obstacles	Unable to get through to set up equipment	Use tools to cut & clear fences and obstacles before setting up

References

[1] Keller G.V. and Frischknecht F.C., 1966.Electrical methods in geophysical prospecting. Pergamon Press Inc., Oxford.