EARTH RESISTIVITY TESTING SWP

1. PURPOSE AND SCOPE

The purpose of this Standard Work Practice (SWP) is to standardise and prescribe the method for implementing an 'Earth Resistivity Test' for the purpose of determining the earth resistivity at a particular site.

This applies to the soil testing of new earthing systems, with the purpose of providing accurate soil models to achieve acceptable safety criteria designs. It is also used to provide data when testing existing earthing systems for safety criteria compliance. The testing procedure is limited to the "Wenner" method of resistivity testing.

2. STAFFING RESOURCES

Adequate staffing resources with the competencies to safely complete the required tasks as per 8 Level Field test Competency Reference - 2597616.

These competencies can be gained from, but not limited to, any or all of the following:

- Qualifying as an Electrical Fitter Mechanic.
- Qualifying as a Technical Service Person.
- Training in the safe use of relevant test equipment.

Requirement for all live work:

- Safety Observer (required for all "live work" as defined in the Managing electrical risks in the workplace).

All resources are required to:

- Have appropriate Switching and Access authorisations for the roles they are required to perform and have the ability to assess and maintain relevant exclusion zones form exposed live electrical apparatus
- Hold current licences for any vehicles and equipment they may be required to operate

Required Training

Staff must be current in all Statutory Training relevant for the task. All workers must have completed Field Induction or have recognition of prior Ergon Energy Field Experience. Contractors must have completed Ergon Energy's Generic Contractor Worker Induction.

3. DOCUMENTATION

8 Level Field test Competency Reference - 2597616.
Electrical Safety Rules 2022 – 6503074.
Energex Safety Manual – 2951572
Environmental Management System – Environmental Standard – 2947192.
EQL SWMS – Safe Work Method Statements
HazChat – On-site Risk Assessment
Health and Safety Policy – 692225
Procedures for Safe Access to High Voltage Electrical Apparatus (SAHV) – 2904212.
Substation Primary Plant and Secondary Systems Field Testing – 2902800.
Standard for Maintenance Acceptance Criteria - 2928929

SP0510C07. Substation Earth System Injection Testing Analysis Tool
SS1-7.3. Substation Standards - Soil Resistivity Testing.
Maps and site plans – use these for marking where test readings were taken, these may include but not be limited to:

- Local map – Can give useful information on surrounding area.
- Geological / Soil survey map (Should be available from local council).
- Civil Works - Site Clearing Plan.
- Civil Works - Earth Grid Plan.
- Google earth EC (Will show existing network).

Geotechnical Report
Test Equipment Manuals

4. KEY TOOLS AND EQUIPMENT

All equipment used is to be calibrated and within test due date.

- Earth Resistivity Testing
- Earth Resistivity Tester / Injection test unit.
- Ground Grid Conductor Locator.
- Flexible Insulated Wire on Easy-to-Spool Reels.
- Earth test electrodes (stake).
- 240V Portable Generator.
- Measuring Wheel/Measuring tapes (100m).
- Hammers.
- Suitable barriers and warning signs for erection at the source and the remote end to prevent inadvertent contact with 'LIVE' equipment, if deemed necessary.
- PPE including full-length protective cotton clothing, safety footwear, safety helmet. All PPE to be inspected and confirmed within test date (where applicable) prior to use.

<u>Additional PPE Required</u>

- Additional PPE as required: brim for safety helmet, leather work gloves, class 00 gloves, hearing protection, safety eyewear, high visibility clothing when working on or near roadways.
- Sun protection to be used when working outdoors.

5. TEST METHOD DESCRIPTION

For the purpose of this SWP only the Wenner method of testing shall be described.

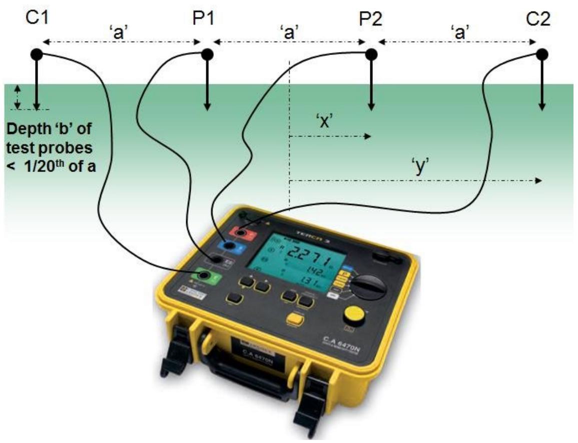


Figure: 1

Figure 1. The earth tester pictured injects an AC current into the earth under test from terminal C1 to C2 utilising the outer driven metallic stakes. The inner stakes shown measure the potential difference, and are connected to terminals P1 and P2. The meter will display a resistance measurement. This resistance, R, is used in the formula:

$$\rho=2\pi aR$$

Where, ρ (Rho) is the average soil resistivity to depth a, π being the constant 3.1416. 'a' is also the distance of spacing between the electrodes used in the measurement, which must be equal between each electrode as shown in Figure 1.

The depth shown 'b' must be less than a/20. E.g. at 0.5m spacings, the electrodes can only be driven into a depth of 2.5cm; at 10m they can be driven to 50cm, but can be less.
By completing this testing accurately, and with spacings as large as practically possible, we obtain details about the soil such as whether it is homogenous or has multiple layers, and the apparent resistivity of those layers. This provides valuable information when designing earthing systems for maximum performance economically.

6. WORK PRACTICE STEPS

6.1. Prior to testing

- Gather as much information regarding the proposed site where the soil resistivity will be carried out. This should include site maps, maps of surrounding areas, soil surveys, geo-tech reports and previous test results. Using this information, an estimated model of the soil can be produced (see Appendix for common values of soil resistivity), and proposed test lines can be marked out.
- A minimum of two traverses shall be carried out at the proposed site or as close as possible. Further traverses can be carried out remote to the proposed site to reinforce test results.
- Factors limiting physical extent of testing should be identified. These factors may include housing developments, metallic fences, water courses/dams, vegetation and the existing electrical network. Other

comparable sites can be identified from the soil survey map to enable thorough testing to acceptable soil depths.

Tip: Make sure your earth resistivity meter has a fully charged battery before leaving for site. If possible, have two available.

6.2. Carry out an onsite risk assessment

- Prior to performing this activity, any hazards associated with pre-requisite tasks at the worksite shall be identified and assessed with appropriate control measures implemented and documented in accordance with the HazChat – On-site Risk Assessment and using reference document EQL SWMS – Safe Work Method Statements.
- If any risks cannot be managed or reduced to an acceptable level, do not proceed with the task and seek assistance from your Supervisor.

6.3. On site testing procedure

After completion of the HazChat and arrival at the site to be tested, the following steps should be followed to obtain satisfactory test results:

- Identify the first straight line to be traversed from your drawings / maps. Stake the centre point of the line.

  Tip: Run out 2 100m tape measures in opposite directions from the centre point to guide the placement of your electrodes.

- Estimate maximum spacing of your electrodes (you should be prepared to go as far as your equipment allows) and run out your current and potential leads to a distance allowing that measurement. Eg. 30m spacings require a minimum of 45m current leads and 15m potential leads. The current and potential leads shall be run on opposite sides of the straight line being measured and as far from each other as practical. This will reduce any inductive effects. Bring both ends of the leads back to the centre point.

Note: Care must be taken if using spools wound around metallic drums with magnetic properties. Place current and voltage spools at 90º angles to each other to reduce any transformer effect.

- Starting at a spacing of 0.5m, place the 4 electrodes in a straight line taking care not to exceed the a/20 depth. This would place your current electrodes at 0.75m from the centre point and your potential electrodes at 0.25m from the centre. Connect the electrodes to the meter as shown in Figure 1 and measure the resistance, record on the test report. See below for common troubleshooting.

Note: When the meter is on, all electrodes should be treated as live unless proven otherwise. The meter should be turned off between measurements and before anyone touches exposed conductors or electrodes.

- Reverse your Current and Potential leads at the meter, ie. C1-P1, P1-C1, C2-P2, P2-C2 and measure the resistance again and record on the test report. This is a check of the setup and equal spacing of the electrodes. You should get approximately the same result.

- Repeat the two steps above at increasing electrode spacing distances, each spacing distance and resistance measured should be noted on the test report.

Tip: Doubling your spacing each time allows a quick check of the soil homogeneity. If your resistance reading halves each time you move your spacing out, you are measuring a homogenous layer.

- If possible, enter the data into the electronic copy of the Substation Earth System Injection Analysis Tool - 2941578. Analyse the graph of apparent resistivity vs spacing. This graph will tell you if you have gone to a large enough spacing. Refer Figure 2, this suggests a homogenous soil (approximately 350Ωm to a depth of at 64m). No further testing would be required. Figure 3, however, shows a change in layer, but further spacing would be required to try and determine the resistivity of the lower layer.

Note: This is not as critical if testing for upper layer resistivity for step and touch voltage criteria.

- Repeat this process again for another traverse. You should measure the second traverse line at 90º to the first. Inconsistencies between the two line traverses could suggest buried conductors, adjacent metallic interference or poor test setup. Carry out extra traverses until confident of your results.
- Ensure you have recorded weather conditions including recent patterns and mark your traverse lines on a site plan.

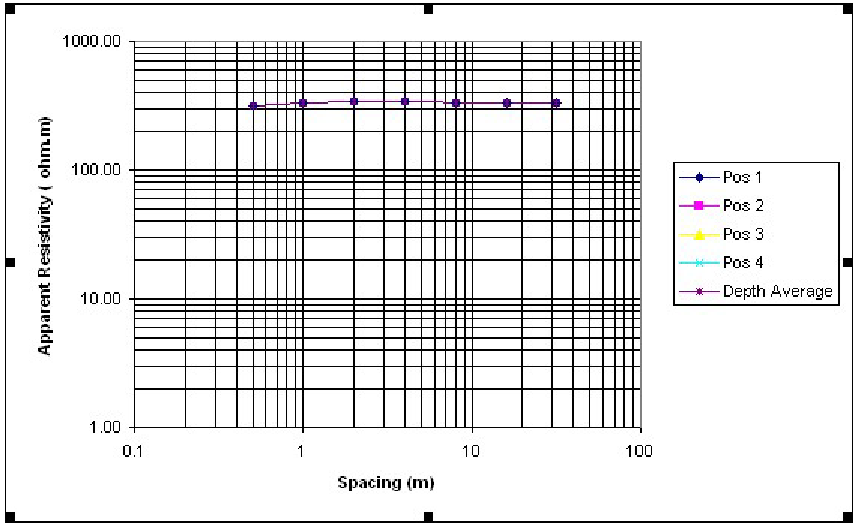


Figure: 2 – Homogenous Soil

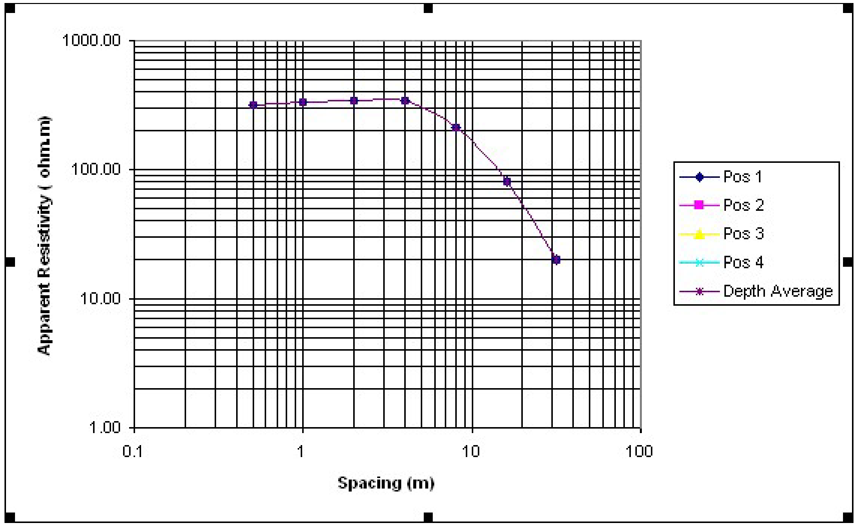


Figure: 3 – Two Layer

7. INTERPRETATION OF RESULTS

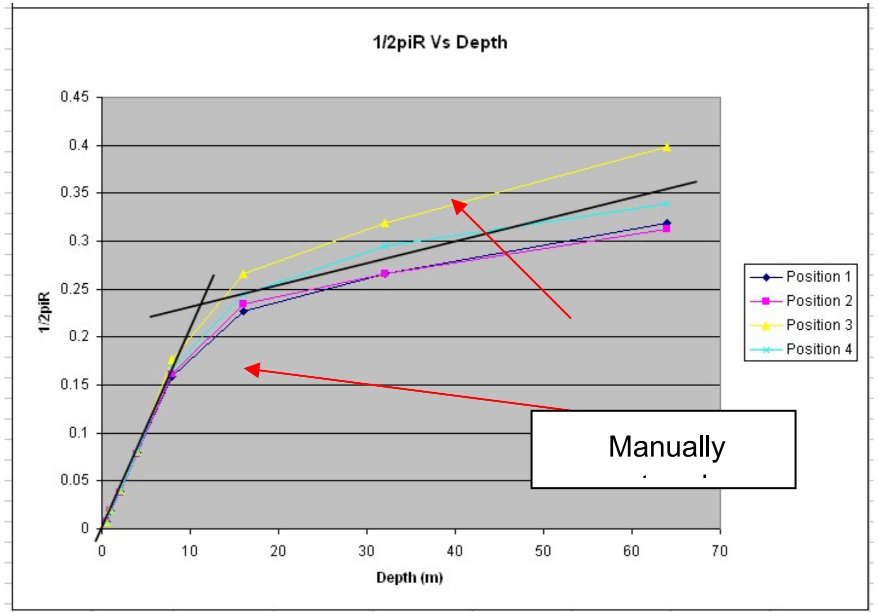
7.1. Resistivity-Depth Curve

A quick assessment of the layering of the soil model can be obtained from Resistivity-Depth graphs as shown in Figures 2 and 3. However, this is not always the preferred method for determining resistivity value.

7.2. Inverse Slope

The following is an extract from SS1-7.3. Substation Standards - Soil Resistivity Testing. It describes a process of using a graph of $1/(2\pi R)$-Depth to determine soil layer depths and resistivity.

"The equation $\rho=2\pi aR$ can be written as $a/\rho=1/(2\pi R)$
The graph of $1/(2\pi R)$ (vertical axis) against a (horizontal axis) will yield resistivity (from reciprocal slope) as a function of depth. Straight line approximations are drawn through the points obtained; the abrupt changes in slope being designated as 'Breakpoints' indicate the change in resistivity layering. Inverse slopes of each straight line segment and the breakpoints give resistivity and layer depth values, respectively."
By interpreting the graph provided on Substation Earth System Injection Analysis Tool – 2941578, and entering the upper and lower points of the slopes the test report will provide the upper and lower layer resistivity values as shown in Figure 4.



DETERMINATION OF UPPER LAYER THICKNESS & RESISTIVITIES FROM 1/(2πR) Vs DEPTH GRAPH
(Refer to SWP for direction)

Upper layer thickness from average curve (where the slope changes)				10	m
Best fit points of upper layer at	8	m	Average 1/(2pR) value =	0.1661562	
	0.5	m	Average 1/(2pR) value =	0.0079381	
			Upper layer resistivity=	**47.40**	ohm-m
Best fit points of lower layer at	64	m	Average 1/(2pR) value =	0.3418967	
	16	m	Average 1/(2pR) value =	0.2430051	
			Lower layer resistivity=	**485.38**	ohm-m

Figure: 4 – Determination of layer depth and resistivity by inverse slope

8. TESTING TROUBLESHOOTING

Problem	Possible solution
Meter reports High impedance at close spacings	Use water (saltwater if you can) to help lower electrode contact resistance. You can also use extra electrodes connected together. Note: The distance between the extra electrodes needs to be kept to less than a/20.
Meter reports High impedance at far spacings	Drive electrodes deeper without exceeding a/20. Use water. Try another meter, different type of meter.
Resistance measurement is different (>5%) when current and potential leads are crossed.	Spacing of electrodes is probably not equal.
Physically cannot increase electrode spacings to get satisfactory results.	If testing for earthing design, it is important to try and get lower layer resistivity. Try and locate an area nearby that has similar soil qualities where you can increase the electrode spacings. Use geo-tech data if possible. Core sample if necessary (inner city).
Soil appears to be very low resistivity and homogenous	Could be buried services, do second traverse at 90º.

	Could be correct, compare to known soil type.
Differing apparent resistivity between traverses.	Could be buried services. Could be angled layers of soil, check for large land formation nearby. Continue with traverses until confident of soil model.
Apparent resistivity is very high, but ground is wet.	Testing has shown that areas of high rainfall may have high resistivity soil. This has been concluded to be a result of dilution of the salinity of the soil.
Apparent resistivity seems too low as test is in arid area.	Similar to above, in dry conditions soil salinity can be much higher, and the water table should also be considered.

9. REFERENCES

ESAA Safe Earthing Systems Design.
ANSI / IEEE STD 80 – 1986.

10. APPENDIX

Typical Resistivity Values

Material	**Resistivity (Ωm)**
Sea Water	0.1 – 1
Loam, Garden soil	5 – 50
Clay, Chalk	10 – 70
Ground water, Spring water	10 – 150
Clay/sand mixtures	4 – 300
Peat, marsh, mud	5 – 250
Lake, river water	100 – 500
Shale, sandstone, limestone, slate	100 – 500
Rainwater	100 - 1000
Sand	1000 – 3000
Distilled water	5000
Coarse sand, gravel	1000 – 10,000
Igneous rock, granite	10,000 – 400,000
Ice	10,000 – 100,000