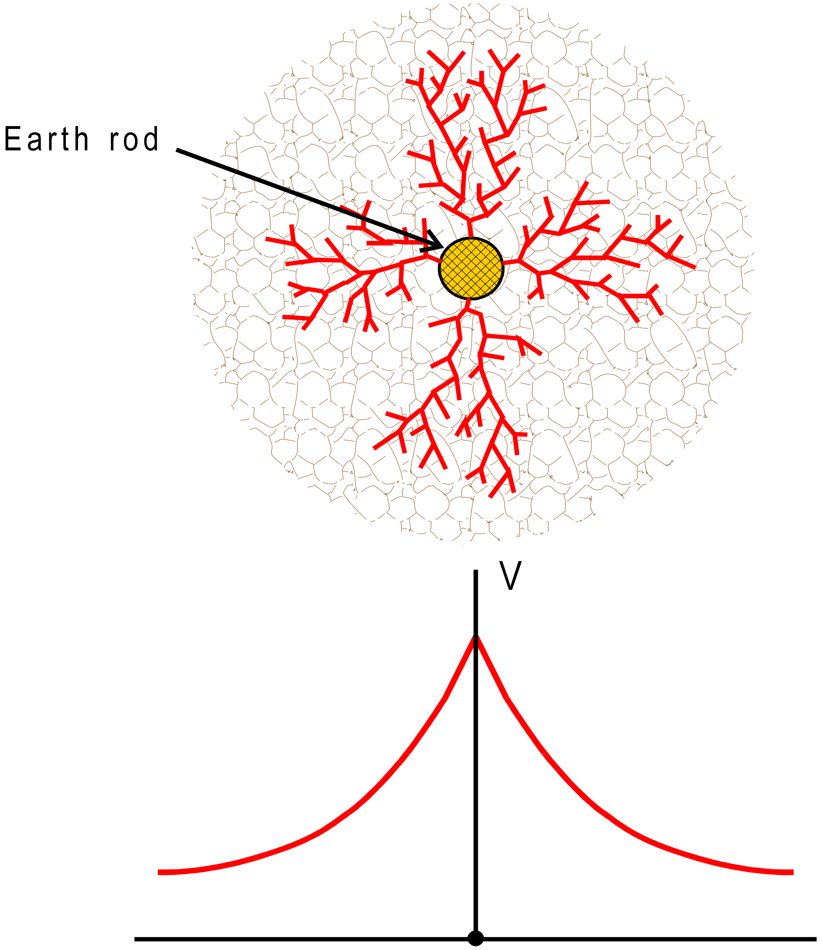
Hands-On Demonstration: Ground Resistivity and Ground Resistance Measurements

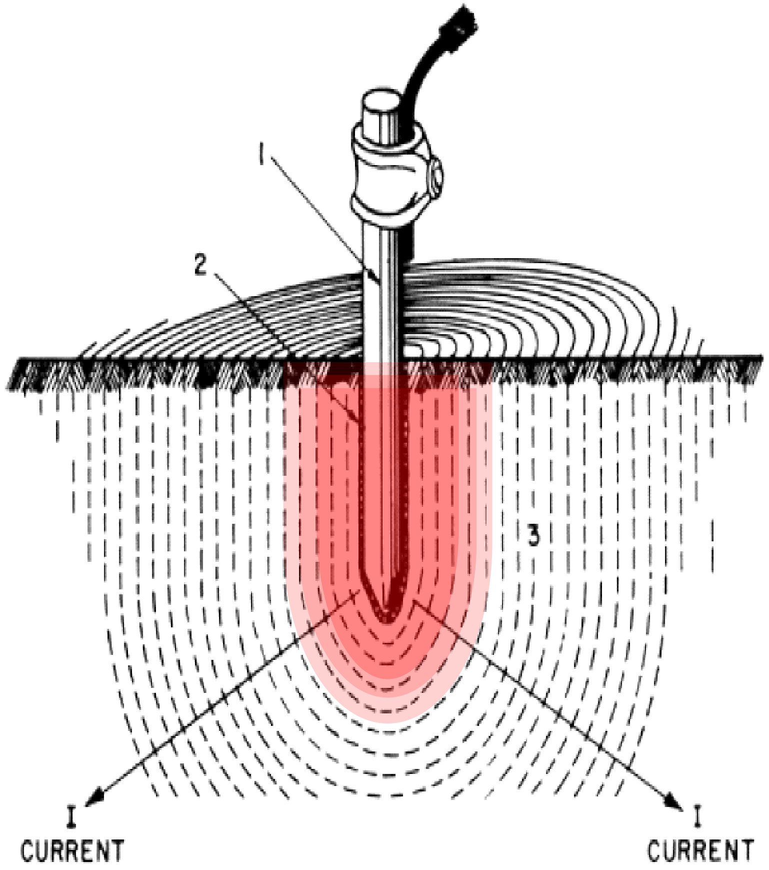
Rohit Narayan

Training Outline

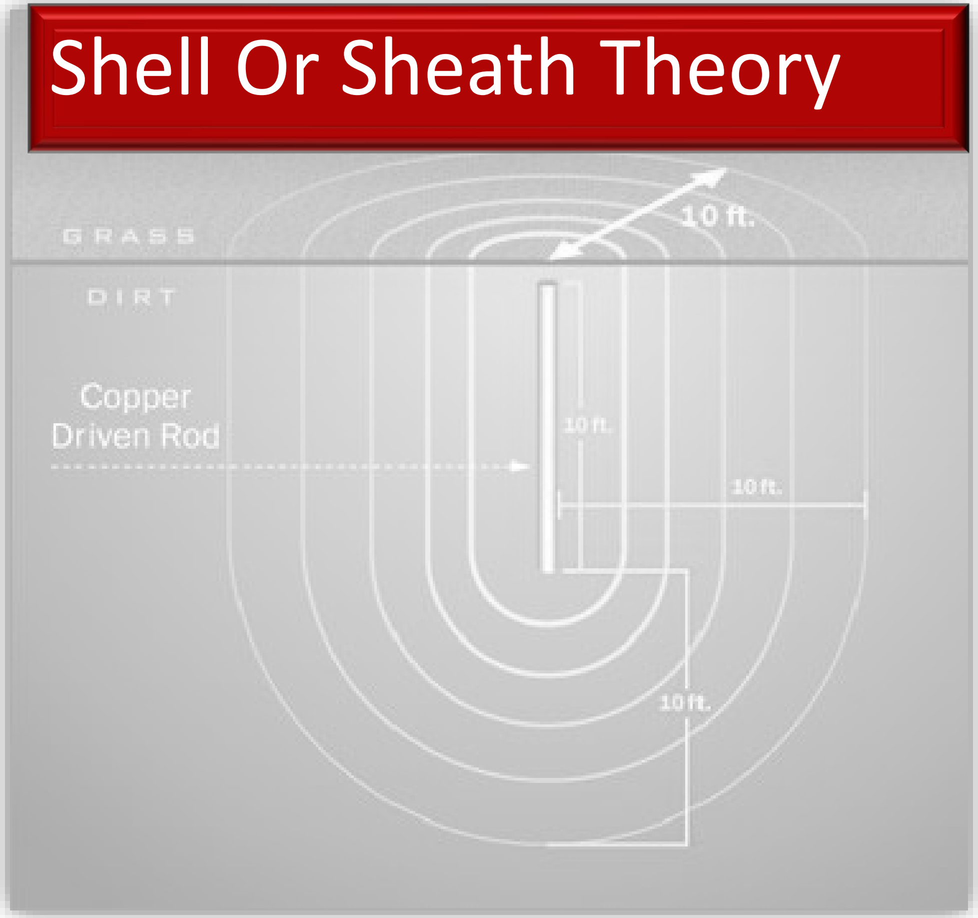
- Explanation of ground sheath theory
- Explanation of what soil resistivity and earth resistance is
- Effect of soil resistivity and electrode dimension on the earth resistance
- Calculation of earth resistance from known dimensions and soil resistivity measurements
- Discussion on parallel earth electrodes and calculation of resistance for parallel ground rods
- Methods of testing soil resistivity and earth resistance
- Grounding at Difficult Sites

Voltage Around A Ground Rod - Shell Or Sheath Theory





Voltage Around A Ground Rod



R α 1/A

R α ρ

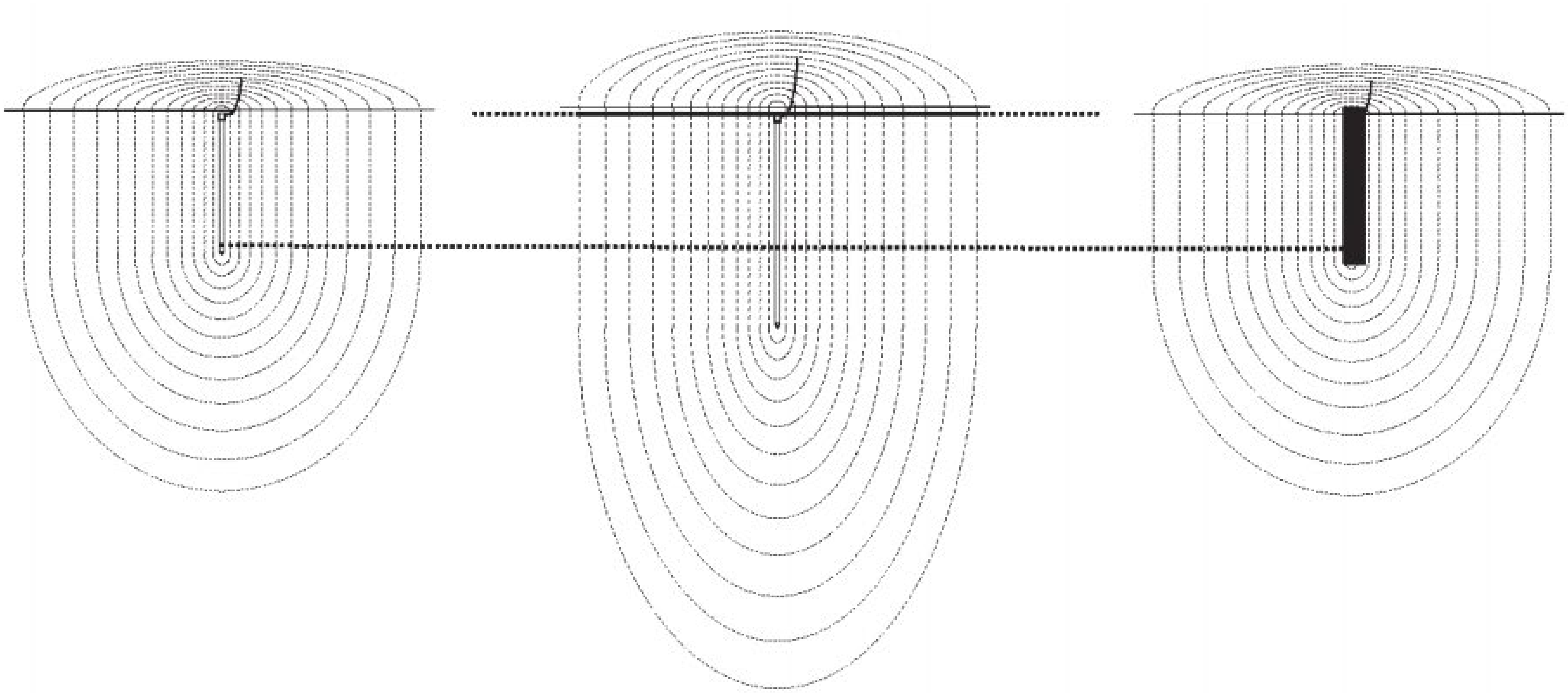
Where:

R = Resistance

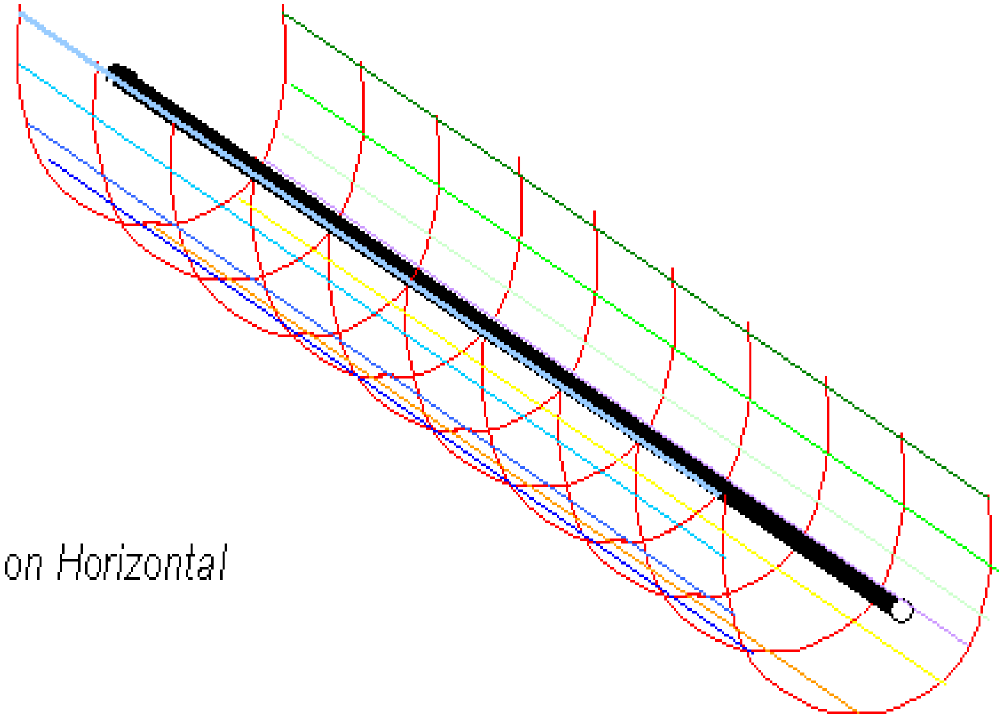
A = Surface Area

ρ = Resistivity

Electrode Dimension -Vertical

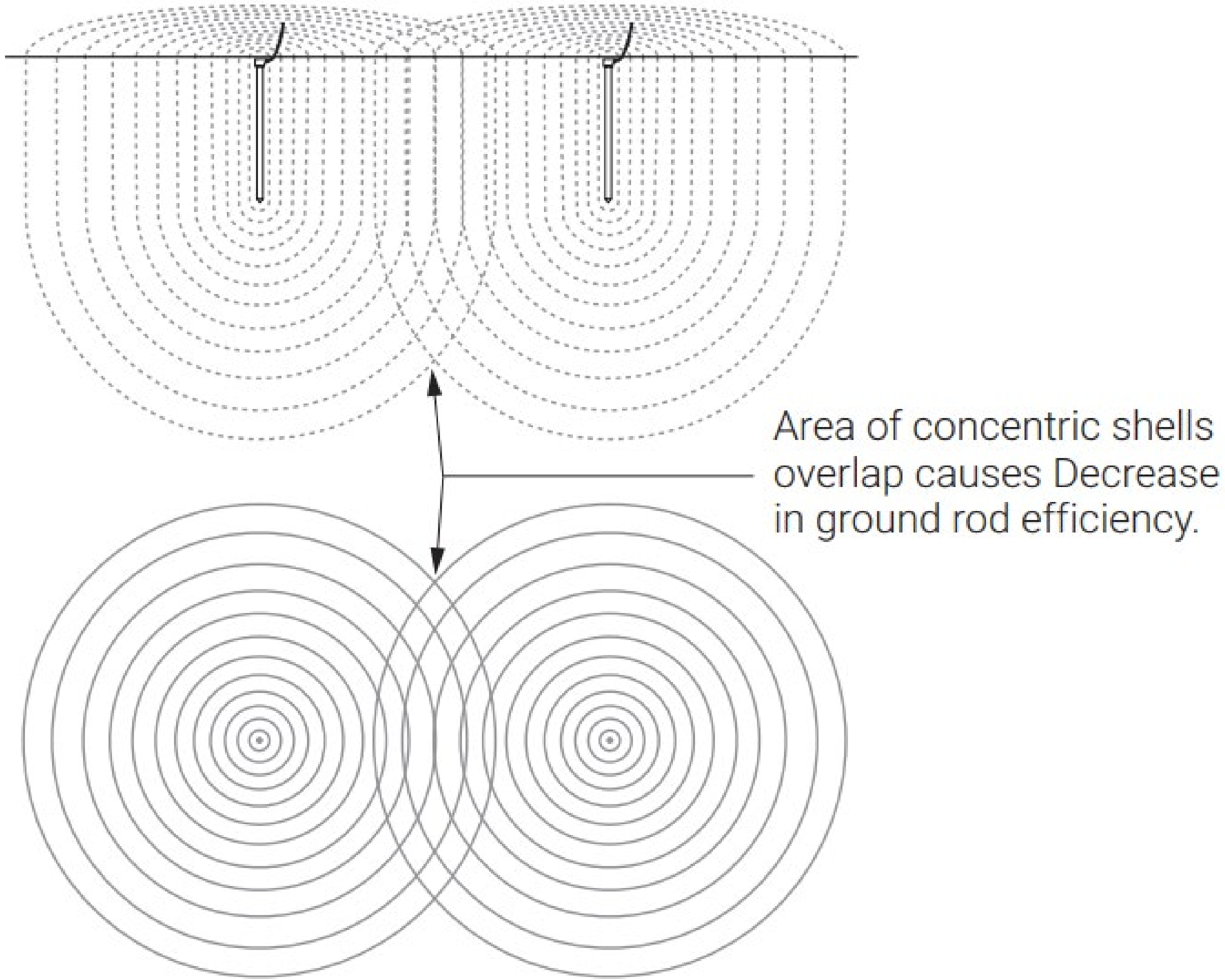


Electrode Dimension - Horizontal



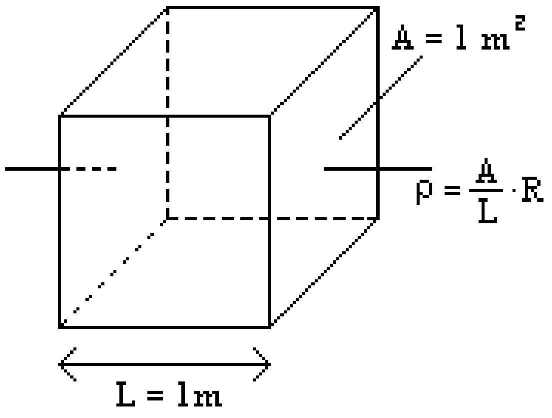
Sheath Theory on Horizontal Electrodes

Effect of Multiple Rods – Sheath Theory



Soil Resistivity

- Soil resistivity is another name for specific resistance of the soil.
- Unit of measure ohm-metre.
- An ohm-meter represents resistance of 1 ohm, between opposite faces of 1 m^3 cube.



$$\rho = \frac{A}{L} R$$

Soil Resistivity

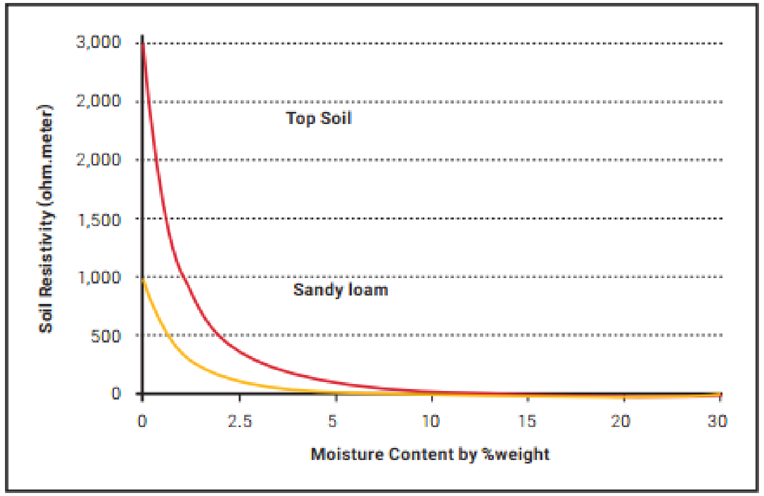
Soil resistivity is another name for the specific resistance of the soil. It is measured in ohm-meters or ohm-centimeters. An ohm-meter is that resistivity of the soil when it has a resistance of 1 ohm between opposite faces of a cube with one meter sides.

Resistance is directly proportional to soil resistivity. This relationship is not as easy to compute in real life as it may sound, because soil resistivity will inevitably vary with depth. The second difficulty in dealing with different locations is that the resistivity varies greatly with sites.

The tables below give an idea of the resistivity of several mediums that are of interest for the design of grounding system.

Material	Typical Resitivity
Copper	1.72 x 10-8 ohm.m
GEM, Material	0.12 ohm.m
Bentonite	2.5 ohm.m
Concrete	30 to 90 ohm.m

Factors that will affect the resistivity of the soil are the soil type, compactness, chemical composition, temperature and water content. Figure 4 shows the effect of moisture content and temperature on soil resistivity.



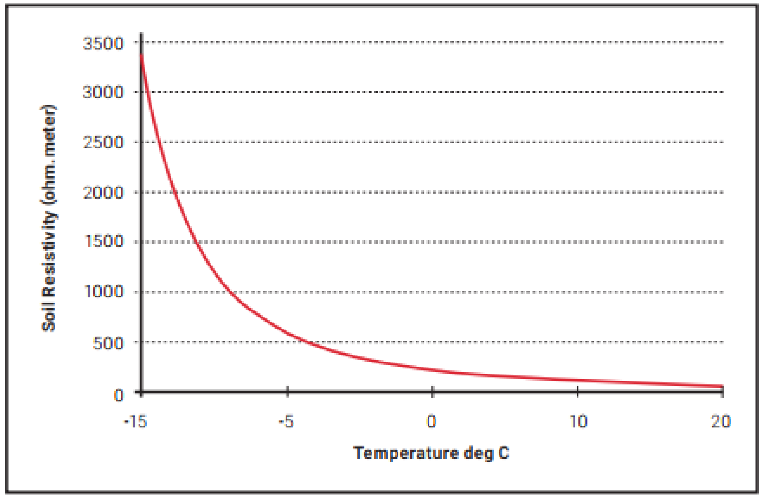


Figure 4: Effect of moisture content and temperature on the soil resistivity

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Soil Resistivity Testing

Soil resistivity test methods
- Wenner Array 4-Point Method
- Schlumberger Array
- Driven Rod Method

The Wenner Array method the most common method of measuring soil resistivity.

Then the Resistivity, ρ, is given by:

$$\rho = 2\,\pi\,a\,Re$$

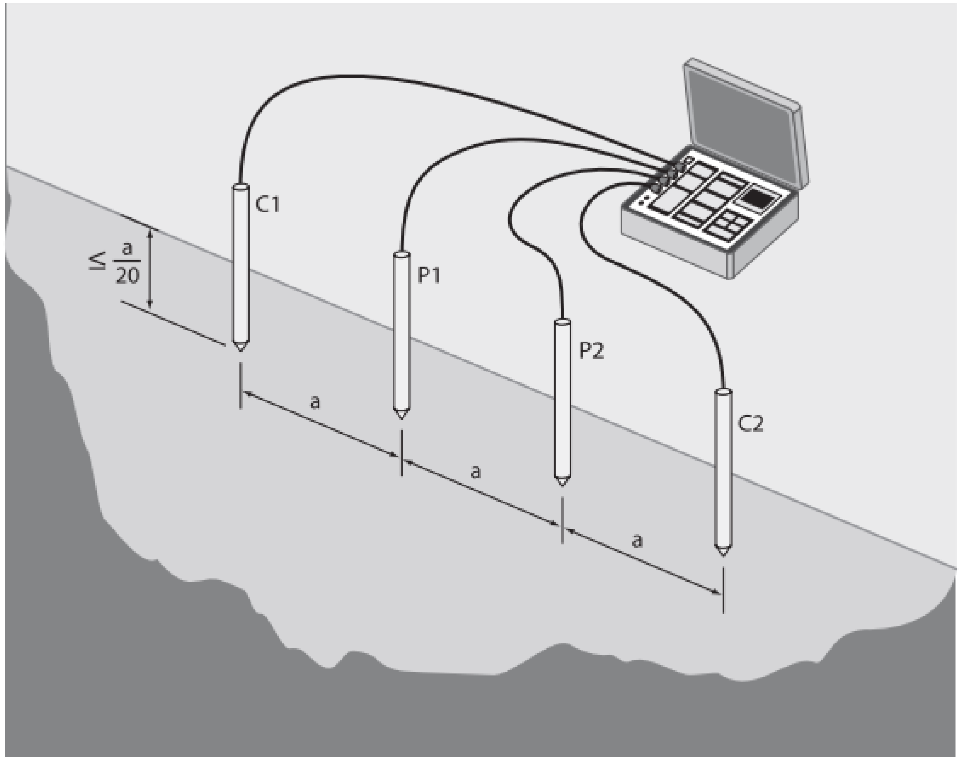
where

ρ = Resistivity of the local soil (Ω-m)

a = distance between probes (m)

b = depth of probes into the ground (m)

Re = resistance value measured by the testing device (Ω)



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Typical Recording of Data

Experience has shown that many testers of the soil resistivity often do not have a full appreciation of thee xtent to which the test needs to be carried out.

It is often noted that only a single or a handful of values are measured. It is recommended that for the design of ground electrode, a comprehensive set of results be gathered in the range of 2–40 meters

SPACING a	Measured Value of Re	Resistivity $\rho = 2 \Pi a Re$
2		
4		
6		
8		
10		
12		
14		
16		
18		
20		
22		
24		
26		

Difficulties in Soil Resistivity Measurement

Three common difficulties in obtaining soil resistivity results include:

1. Poor electrical connection between the test probes and the soil. Most modern earth test equipment will pick this condition up as an error and results obtained while the test equipment is showing error are not valid.

Remedy: If this occurs, the test probes should be driven in a bit deeper. If that does not yield a result without error, then a bottle of water shall be used to wet around each of test probes. If this still does not yield an error free result, salt mixed with a bottle of water may be used to wet the area around the test probes.

2. Test Equipment Limitation The test equipment produces a certain current to enable the tests. In sites with extremely high soil resistivity and especially at large probe spacing a, the equipment may not have adequate current source to obtain a measurement.

Remedy: Abort Test and note down reasons or use a specialist high current equipment to carry out the test. If this is feasible

3. Presence of other buried objects and fence line close to testing direction. If there is metallic objects buried under the test location or if there is fence line close by, then these are likely to interfere with the test results

Remedy: Test will be done at each site at least in two directions. If the two sets of results vary significantly, this could be the reason. A sketch of site showing buried objects, fence line and direction of testing should be made.

Aim: To test the soil resistivity in an allocated area near the training venue . (Later we will use this data to calculate ground resistance)

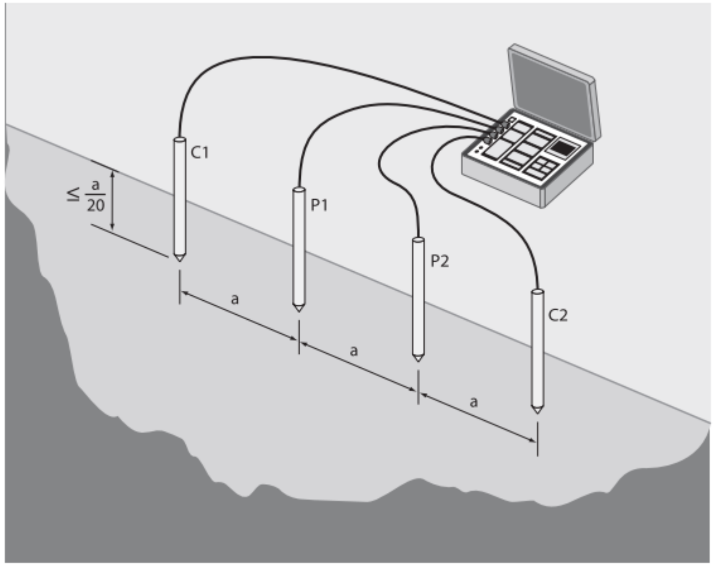
Equipment Needed:

4 Pole Ground Resistance Testers

Hammer

Measuring tape

Notepad to record results



Test procedure:

The Wenner method, for soil resistivity testing shall be used. All four electrodes are moved for each test with the spacing, a between each adjacent pair remaining exactly the same. In each method the depth penetration of the electrodes is less than 5% of the separation to ensure that the approximation of point sources, required by the simplified formulae, remains valid.

For complete procedure, please refer to equipment manual being used.

Two sets of tests shall carry out with a ranging from 1.8 metres up to 9 metres. The results shall be recorded in the result sheet similar below. The test is generally done in 2 perpendicular directions, but this is optional for this experiment.

Earth Test Equipment

Equipment

- Earth tester are available as 3 pole and 4 pole instruments
- 3 Pole instruments can only measure earth resistance
- 4 Pole instruments can measure earth resistance and soil resistivity
- Earth testers with very small power will have limitations in measuring accurately in high s resistivity areas

Resistance Calculation Formula

a) Single vertical rod length L and diameter d meters, top of rod level with surface:

$$R = \frac{\rho}{2\pi L}\left[\ln\left(\frac{8L}{d}\right) - 1\right] \qquad \text{... C3(1)}$$

Where

R = resistance, ohms

ρ = soil resistivity, in ohm meters

L = buried length of grounding electrode, in meters

d = diameter of grounding electrode, in meters

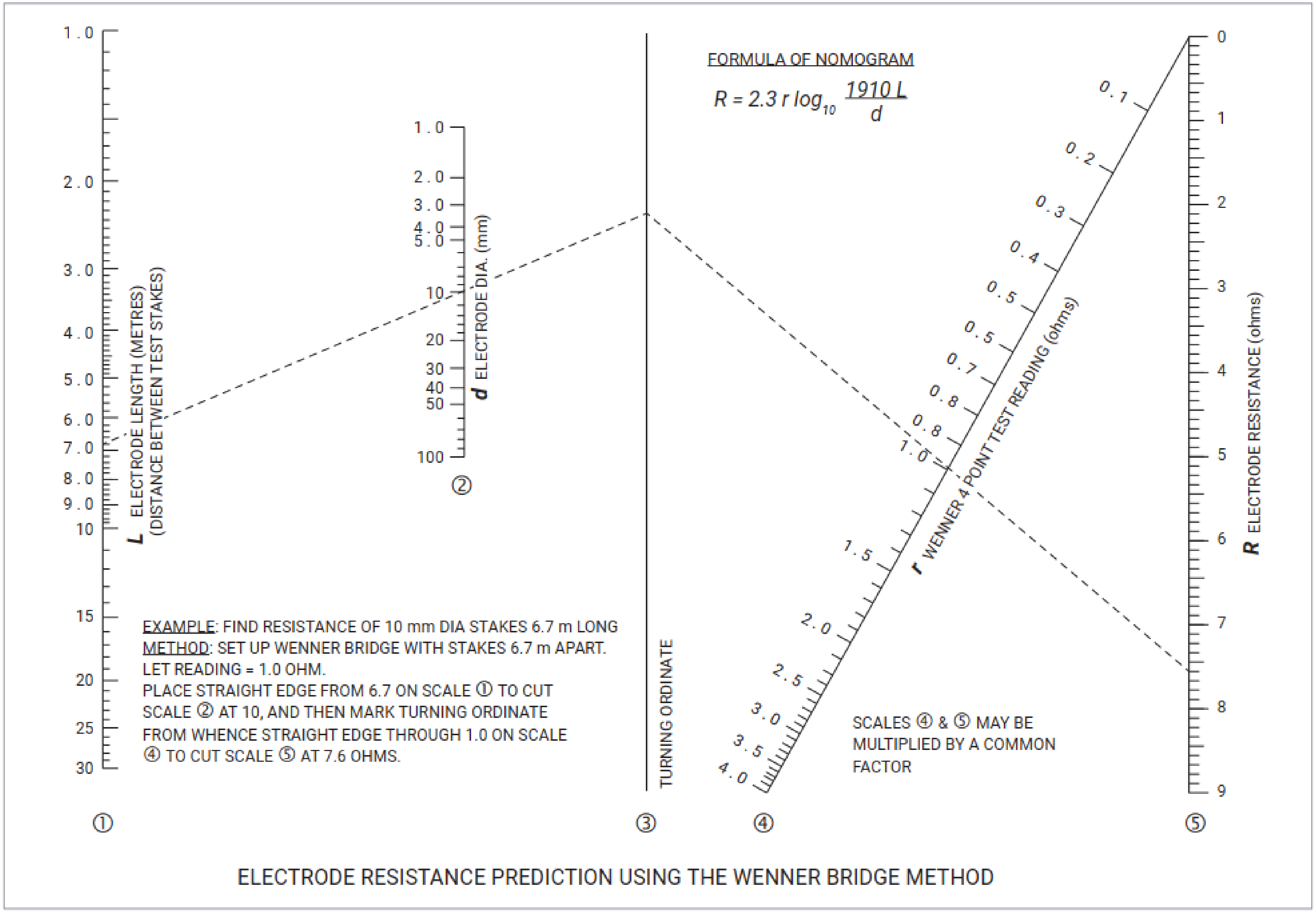
Note: Equation C3(1) is commonly referred to as the 'modified Dwight formula'.

b) Straight horizontal wire of length L and diameter d meters, on surface:

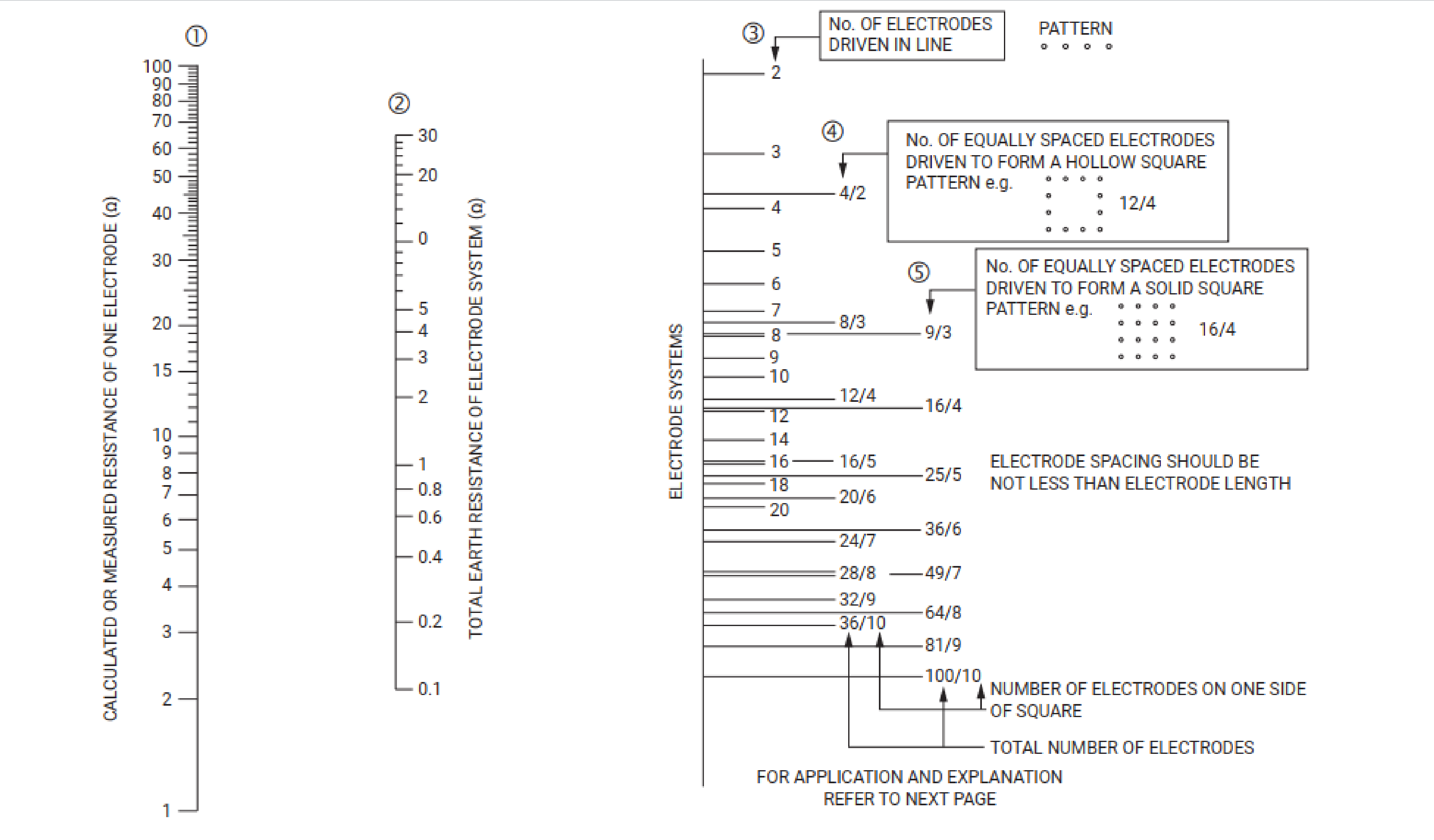
$$R = \frac{\rho}{\pi L}\left[\ln\left(\frac{4L}{d}\right) - 1\right] \qquad \text{... C3(5)}$$

For a thin strip grounding electrode, the diameter can be replaced with a half-width of the strip.

Nomogram Method to Calculate Single Electrode Resistance



Nomogram Method to Calculate Multiple Electrode Resistance



GROUND RESISTANCE OF MULTIPLE ELECTRODE SYSTEMS

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Formula For Multiple Electrodes

$$R_g = \frac{\rho}{\pi L}\left[\ln\left(\frac{2L}{a'}\right) - 1\right]$$

where:	ρ	Soil Resistivity in Ωm
	L	Buried Length of the electrode in m
	a'	Equivalent radius off the electrode at the surface in m

$$a' = \left[(dh)^{0.5}(ss')^{0.5}\right]^{0.5}$$

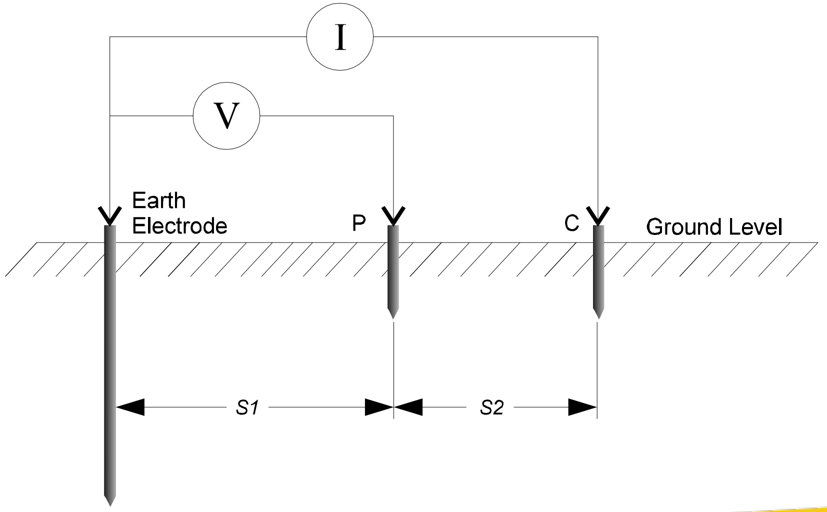
$$a' = \left[dhss'\right]^{0.25}$$

$$s' = \left(4h^2 + s^2\right)^{0.5}$$

where:	d	Diameter of the electrode in m
	h	Buried depth of the electrode in m
	s	Distance between two parallel electrodes in m
	s'	Distance from one electrode to the image of the other, in m

Ground Electrode Resistance Measurement

When an electrode system has been designed and installed, it is usually necessary to measure and confirm the earth resistance between the electrode and “true Earth”. The most commonly used method of measuring the earth resistance of an earth electrode is the 3-point measuring technique shown in Figure below. This method is derived from the 4-point method, which is used for soil resistivity measurements.



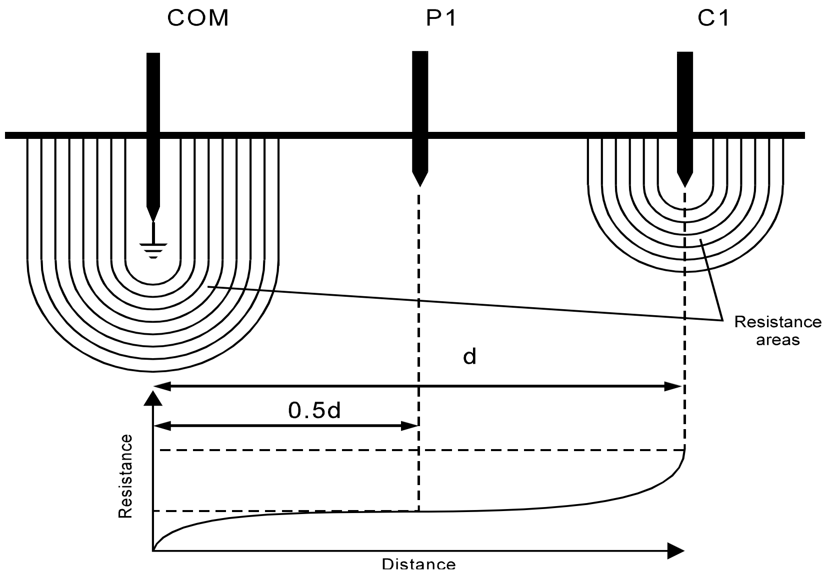
The 3-point Method of Earth Resistance Measurement

Ground Electrode Resistance Measurement

When performing a measurement, the aim is to position the auxiliary test electrode C far enough away from the earth electrode under test so that the auxiliary test electrode P will lay outside the effective resistance areas of both the earth system and the other test electrode (see Figure 11).

If the current test electrode, C, is too close, the resistance areas will overlap and there will be a steep variation in the measured resistance as the voltage test electrode is moved.

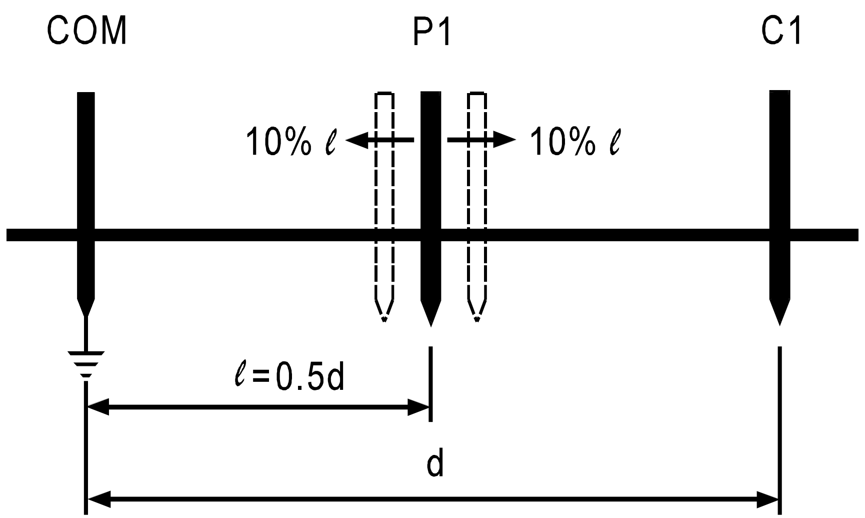
If the current test electrode is correctly positioned, there will be a 'flat' (or very nearly so) resistance area somewhere in between it and the earth system, and variations in the position of the voltage test electrode should only produce very minor changes in the resistance figure.



Checking The Validity Of A Resistance Measurement

The Fall of Potential method incorporates a check to ensure that the test electrodes are indeed positioned far enough away for a correct reading to be obtained. It is advisable that this check be carried, as it is really the only way of ensuring a correct result.

To perform a check on the resistance figure, two additional measurements should be made; the first with the voltage test electrode (P) moved 10% of the original voltage electrode-to-earth system separation away from its initial position, and the second with it moved a distance of 10% closer than its original position, as shown in Figure



Checking the validity of a resistance measurement

Maximum Theoretical Accuracy

LEAD LENGTH	MAXIMUM THEORETICAL ACCURACY
2L	50%
4L	75%
8L	87.5%
16L	93.7%
32L	96.8%

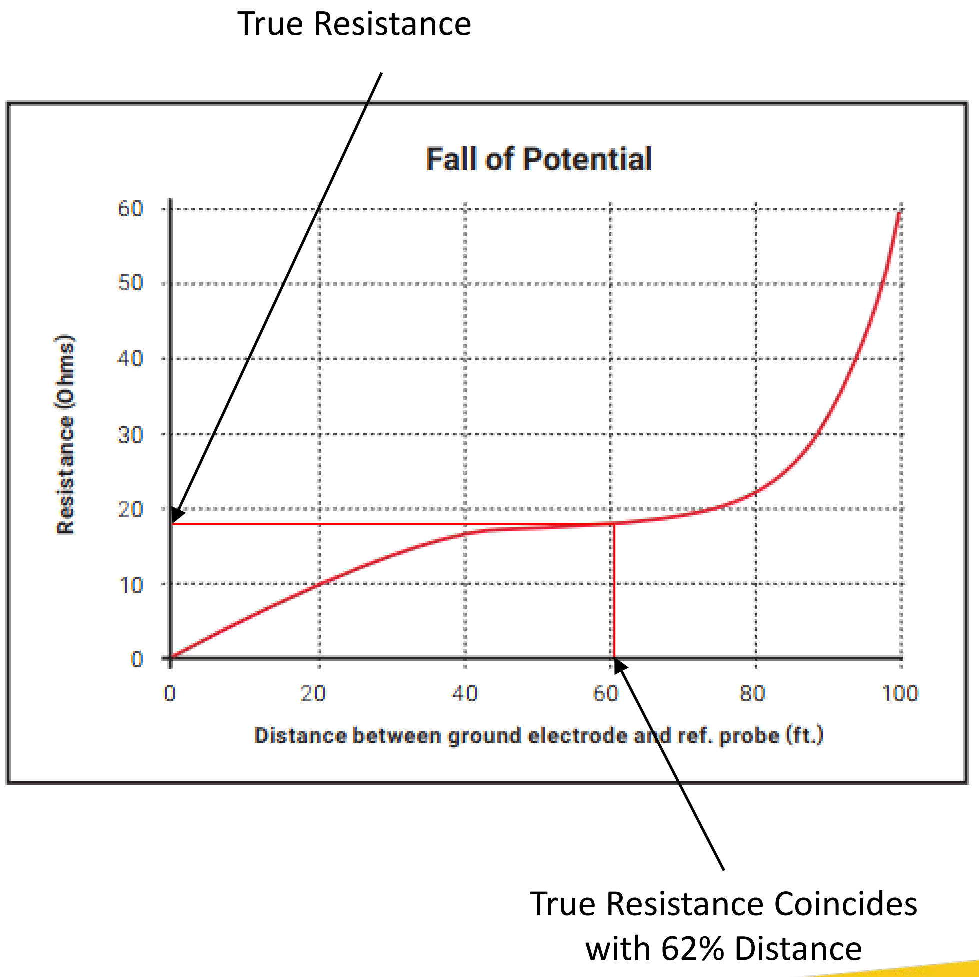
L= Radial Ground Mat Dimension

Slope Method

- This method is suitable for use with large grounding systems, such as substation or central office ground.

- It involves taking a number of resistance measurements at various ground electrode to voltage electrode separations and then plotting a curve of the resistance variation between the ground and the current.

- From this graph, and from data obtained from the tables, it is
possible to calculate the theoretical optimum location for the
voltage electrode and thus, from the resistance curve, calculate
the true resistance



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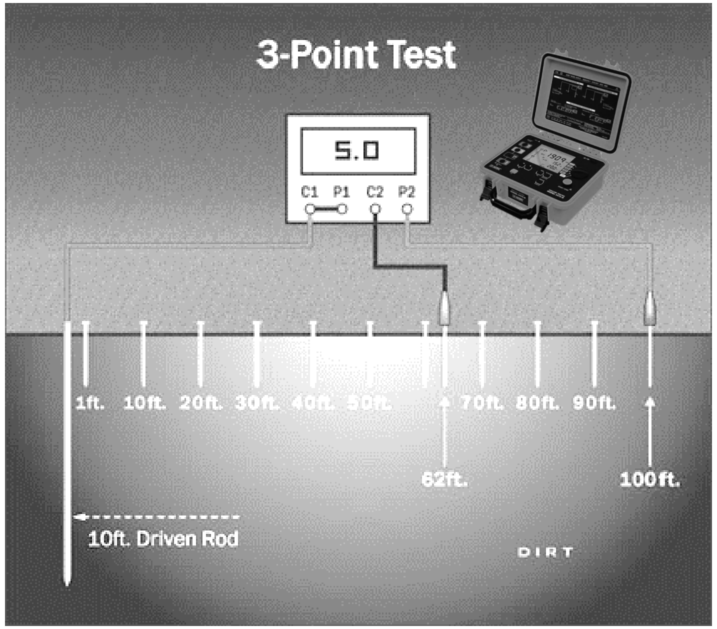
Earth Test Equipment

3 Point Tests
Resistance of ground electrode

4 Point Tests
Resistivity of Soil



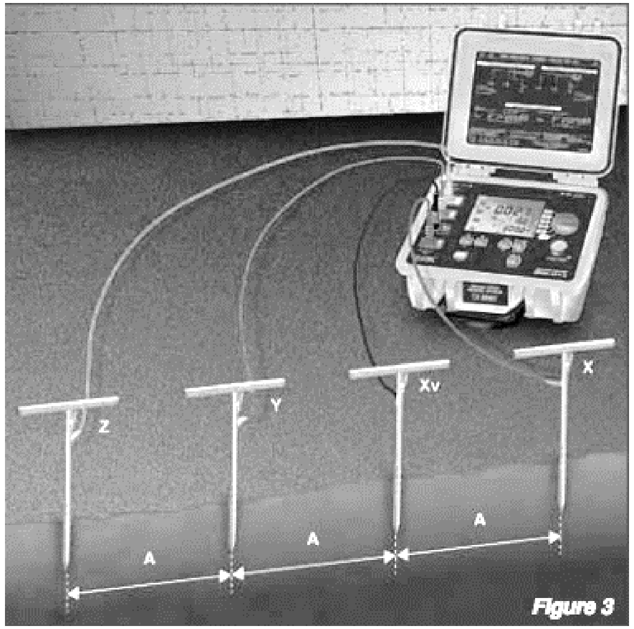


Figure 3