

Appendix 12

Earth Electrodes And Earth Electrode Testing

12.1 Introduction

This appendix provides guidance and background information on earth electrode testing and some limited information on earth electrode design and improvement.

It is not intended to cover the design of large complex earth systems, soil resistivity tests or test methods such as the clamp-voltage earth testers (e.g. the 'attached rod' and similar methods). More information on these subjects can be found in BS 7430 (for electrode design, earth design, soil resistivity testing) and various manufacturers for various testing instruments using clamps.

This appendix has been based on information kindly provided by Megger.

12.2 Earth resistance

Broadly speaking, 'earth resistance' is the resistance of soil to the passage of electric current. Actually, the earth is a relatively poor conductor of electricity compared to normal conductors like copper wire. But, if the area of a path for current is large enough, resistance can be quite low and the earth can be a good conductor. It is the earth's abundance and availability that make it an indispensable component of a properly functioning electrical system.

Earth resistance is measured in two ways for two important fields of use:

1. Determining effectiveness of 'ground' grids and connections that are used with electrical systems to protect personnel and equipment.
2. Prospecting for good (low resistance) 'ground' locations, or obtaining measured resistance values that can give specific information about what lies some distance below the earth's surface (such as depth to bed rock).

12.3 Nature of an earth electrode

Resistance to current through an earth electrode actually has three components:

- Resistance of the electrode itself and connections to it.
- Contact resistance between the electrode and the soil adjacent to it.
- Resistance of the surrounding earth.

Electrode Resistance

Rods, pipes, masses of metal, structures, and other devices are commonly used for earth connections. These are usually of sufficient size or cross section that their resistance is a negligible part of the total resistance.

Electrode-earth contact resistance

This is much less than you might think. If the electrode is free from paint or grease, and the earth is packed firmly, contact resistance is negligible. Rust on an iron electrode has little or no effect; the iron oxide is readily soaked with water and has less resistance than most soils. But if an iron pipe has rusted through, the part below the break is not effective as a part of the earth electrode.

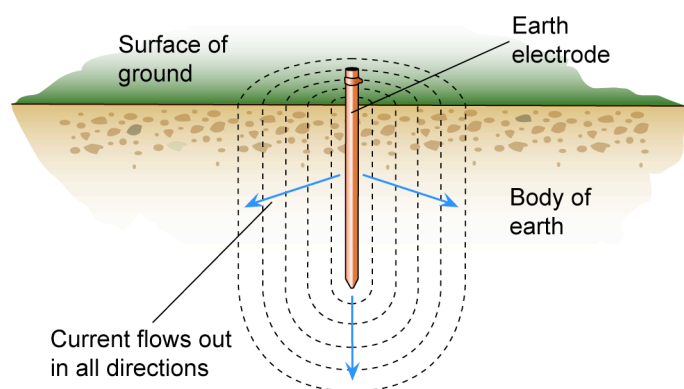


Figure 12.1 Interface of earth and electrode

Resistance of surrounding earth

An electrode driven into earth of uniform resistivity radiates current in all directions. Think of the electrode as being surrounded by shells of earth, all of equal thickness (see Figure 12.1). The earth shell nearest the electrode naturally has the smallest surface area and so offers the greatest resistance. The next earth shell is somewhat larger in area and offers less resistance. Finally, a distance from the electrode will be reached where inclusion of additional earth shells does not add significantly to the resistance of the earth surrounding the electrode.

12.4 Basic test method for earth resistance

The resistance to earth of any system of electrodes theoretically can be calculated from formulas based upon the general resistance formula:

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

where

- ρ is the resistivity of the earth in ohm-cm
- L is the length of the conducting path
- A is the cross-sectional area of the path

The theory behind resistance measurement gets quite involved but is simplified by assuming that the earth's resistivity is uniform throughout the entire soil volume under consideration.

The earth tester generates an ac signal, which is fed into the system under test. The instrument then checks the status of the circuits for good connection and noise. If either of these variables is out of specification then the operator is informed. Having checked that the conditions for test are met, the instrument automatically steps through its measurement ranges to find the optimum signal to apply. Measuring the current flowing and the voltage generated the instrument calculates and displays the system or electrode resistance.

There are three basic test methods as noted below. The first two are shown schematically in Figs. 12.2 and 12.3.

1. Fall of potential method, or three-terminal test.
2. Dead earth method (two-point test).

12.5 Fall of potential method

12.5.1 Introduction and method

This three-terminal test is the method that can be carried out with three or four terminal earth testers. Although four terminals are necessary for resistivity measurements, the use of either three or four terminals is largely optional for testing the resistance of an installed electrode. The use of three terminals is more convenient because it requires only one lead to be connected.

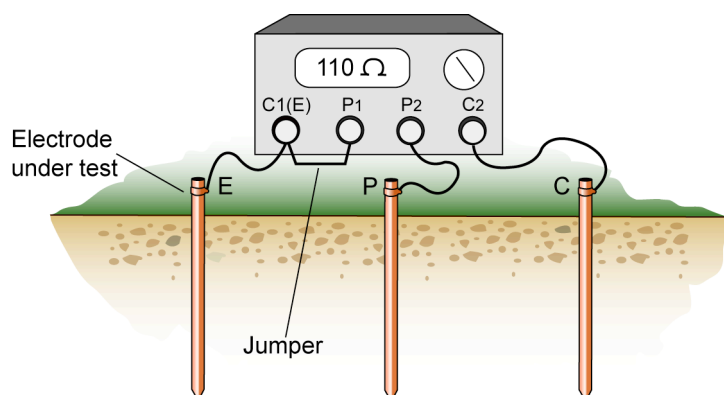


Figure 12.2 Fall of potential method

With a three-terminal instrument, connect X to the earth electrode. With a four-terminal tester, P1 and C1 terminals on the instrument are ‘jumped’ and connected to the earth electrode under test.

The driven reference rod C should be placed as far from the earth electrode as practical; this distance may be limited by the length of extension wire available, or the geography of the surroundings. Leads should be separated and ‘snaked’, not run close and parallel to each other, to eliminate mutual inductance. Potential-reference rod P is then driven in at a number of points roughly on a straight line between the earth electrode and C.

12.5.2 Simplified analysis for fall-of-potential test

This reading with P at 50 percent of the distance from the earth electrode to C is noted as R1. Reference probe P is then moved to a location 40 % of the distance to C. The reading at this point is noted as R2. A third reading, R3, is made with P at a 60 % distance. The average of R1, R2 and R3 is calculated as RA. You determine the maximum deviation from the average by finding the greatest difference between individual readings and the average. If 1.2 times this percentage is less than your desired test accuracy, RA can be used as the test result. An example of this technique is as follows:

$$R1 = 58 \, \Omega, \, R2 = 55 \, \Omega, \, R3 = 59 \, \Omega$$

$$RA = 58 + 55 + 59 = 57.3 \, \Omega$$

$$RA - R2 = 57.3 - 55 = 4.0\%$$

$$4.0\% \times 1.2 = 4.8\%$$

If your desired accuracy was 5 %, 57.3 Ω (RA) could be used as the result. This is usually more than accurate for most applications. If the result is not within the required accuracy, probe C has to be placed farther away and the tests repeated.

There are many variations on the fall of potential method. For example, resistance readings are logged for each of the points. A curve of resistance vs. distance is then drawn. Correct earth resistance is read from the curve for the distance that is about 62 percent of the total distance from the earth electrode to C.

The detail of further analysis of these methods is outside the scope of this book.

12.5.3 Lazy spikes

The problem with three or four electrode methods is often the ability to drive test electrodes. The latest designs of digital earth testers can operate with very high temporary spike resistances and still give reliable and accurate results. Because the current and voltage are measured separately, it enables electrode measurements to be carried out with test spike resistances up to 400 k Ω .

However, in urban situations, tests can be carried out using street furniture such as sign posts, metal fences and bollards. Where this is not possible, results have been obtained by laying the temporary electrodes on a wet patch of concrete. Coiled metal chains or metallized ground mats, with water poured over them, make an even better electrode because they conform more intimately to the earth’s surface than does a rigid spike.

This technique has led to measured values of “spike” of less than 10 k Ω , well inside the

maximum value that will cause an error to the reading. With modern instruments, any problem with the temporary spikes will usually be indicated on the display to show that a reading may not be valid. A more suitable position for the spike may have to be used such as along the gap between paving stones, a crack in concrete, or in a nearby puddle. As long as warning indicators do not appear, sufficient contact has been made and a reliable test may be performed.

12.6 Dead earth method

When using a four-terminal instrument, P1 and C1 terminals connect to the earth electrode under test; P2 and C2 terminals connect to an all-metallic metal system (e.g. a water pipe system). The water system could be any suitable metal structure or similar. With a three-terminal instrument, connect X to the earth electrode, P and C to the pipe system, see Figure 12.3. If the water system is extensive (covering a large area), its resistance should be low and is usually much less than one ohm. You can then take the instrument reading as being the resistance of the electrode under test.

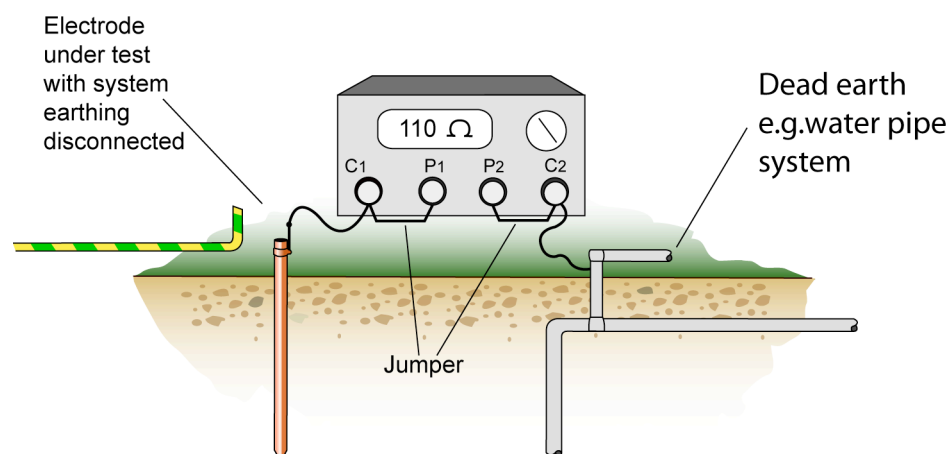


Figure 12.3 Dead earth (two-electrode) method

The dead earth method is the simplest way to make an earth resistance test. With this method, resistance of two electrodes in series is measured (the driven rod and the water system). It is, however important to note the limitations to this test method as follows:

- The dead earth metal (e.g. water pipe) system must be extensive enough to have a negligible resistance
- The dead earth metal (e.g. water pipe) system must be metallic throughout
- The earth electrode under test must be far enough away from the dead earth (e.g. water pipe) system to be outside its sphere of influence.

In some locations, your earth electrode may be so close to the dead earth system (e.g. water pipe system) that you cannot separate the two by the required distance for measurement by the two-terminal method. Under these circumstances, you can connect to the water pipe system and obtain a suitable earth electrode.

12.7 How to improve earth resistance

When you find that your earth electrode resistance is not low enough, there are several ways you can improve it as follows

- Lengthen the earth electrode in the earth.
- Use multiple rods.
- Treat the soil.

12.7.1 Effect of rod depth

As you might suspect, driving a longer rod deeper into the earth, materially decreases its resistance. In general, doubling the rod length reduces resistance by about 40 %. The curve of Figure 12.4 shows this effect.

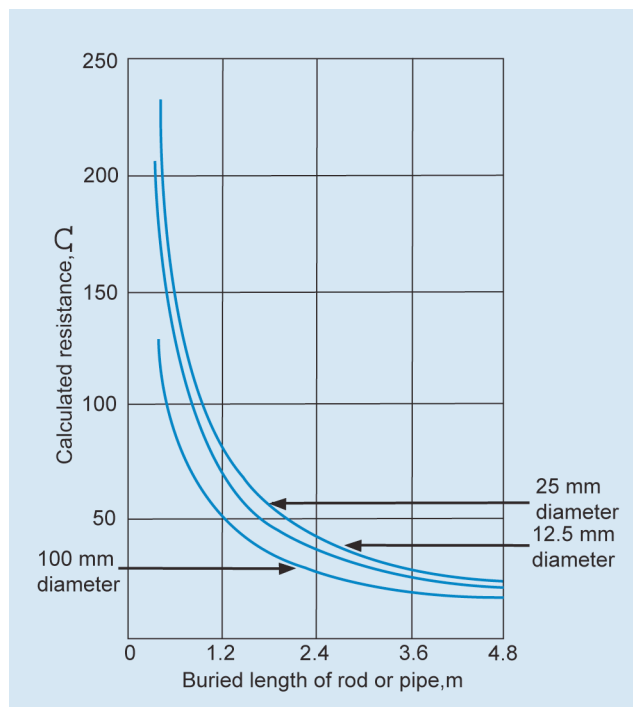


Figure 12.4 Effect of vertical depth on resistance to earth

The subject of stability of single, vertical earth electrodes often causes confusion. The depth of a vertical rod is the decisive factor for stability as the effects of drying out or freezing effect the upper part of the rod most significantly. Therefore a 3 m rod with installed resistance of say 300 ohms will be more stable than a 1.2 m rod with resistance of say 100 ohms.

12.7.2 Use of multiple rods

Two well-spaced rods driven into the earth provide parallel paths. They are, in effect, two resistances in parallel. The rule for two resistances in parallel does not apply exactly; that is, the resultant resistance is not one-half the individual rod resistances (assuming they are of the same size and depth). Actually, the reduction for two equal resistance rods is about 40 %. If three rods are used, the reduction is 60 %; if four, 66 % as shown in Figure 12.5.

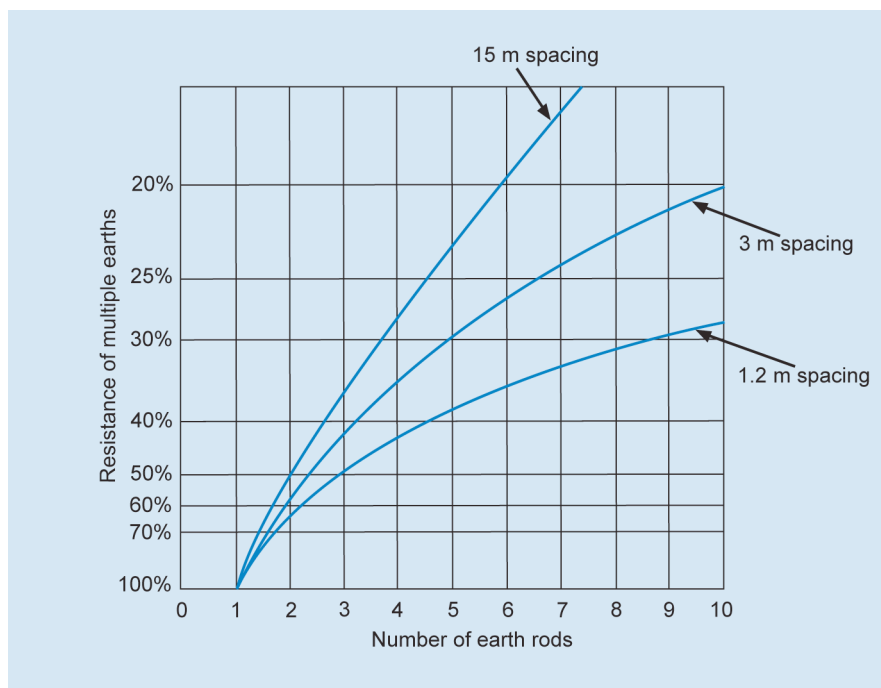


Figure 12.5 Effect of rod spacing on overall resistance

When you use multiple rods, they must be spaced apart further than the length of their immersion.

12.7.3 Treatment of the soil

Chemical treatment of soil is a good way to improve earth electrode resistance when you cannot drive deeper ground rods because of hard underlying rock, for example. It is beyond the scope of this book to recommend the best treatment chemicals for all situations.

One popular approach is to backfill around the electrode with a specialized conductive concrete. A number of these products, like bentonite, are available on the market. This subject does become specialist and it is worth discussing treatment with a specialist earthing design or installation organisation.