GROUNDING ELECTRODES EXPLAINED

In the last few decades, much has been ascertained about the interaction between the grounding electrode and the earth, which is a three-dimensional electrical circuit. Ultimately, it is the soil resistivity (and spatial variations thereof) that determines system design and performance. New technology has significantly reduced the resistance between grounding electrodes and the surrounding soil, which is a determining factor in the performance of small electrodes.

There are a number of different grounding electrodes in use today. They are the:
- Standard driven rod
- Advanced driven rod
- Grounding plate
- Ufer (concrete encased electrode)
- Water pipes
- Electrolytic electrode.

Zone (or Sphere) of Influence

An important concept as to how efficiently grounding electrodes discharge electrons into the earth is called “the zone of influence”, which is sometimes referred to as the “sphere of influence”. The zone of influence is the volume of soil throughout which the electrical potential rises to more than a small percentage of the potential rise of the ground electrode, when that electrode discharges current into the soil. The greater the volume, compared with the volume of the electrode, the more efficient the electrode. Elongated electrodes, such as ground rods, are the most efficient. The surface area of the electrode determines the ampacity of the device, but does not affect “the zone of influence”. The greater the surface area, the greater the contact with the soil and the more electrical energy that can be discharged per unit of time.

The formula for calculating the volume of soil is shown. A simpler version is used when the above formula is modified by rounding $\pi$ (pi) down to 3 and cross canceling to get the formula:

$$V = \frac{5\pi L^3}{3}$$

Thus, a single 10-foot driven rod will utilize 5,000 cubic feet of soil, whereas a single 8-foot rod will utilize about half the soil at 2,560 cubic feet.
**AN OVERVIEW OF COMMON GROUNDING ELECTRODES**

Grounding is the process of electrically connecting any metallic object to the earth by the way of an earth electrode system. The National Electric Code requires that the grounding electrodes be tested to ensure that they are under 25-ohms resistance-to-ground (Earth). It is important to know that aluminum electrodes are not allowed for use in grounding.

**Standard Driven Rod**

The standard driven rod or copper-clad rod consists of an 8 to 10 foot length of steel with a 5 to 10-mil coating of copper. This is by far the most common grounding device used in the field today. The driven rod has been in use since the earliest days of electricity with a history dating as far back as Benjamin Franklin.

Driven rods are relatively inexpensive to purchase, however ease of installation is dependent upon the type of soil and terrain where the rod is to be installed. The steel used in the manufacture of a standard driven rod tends to be relatively soft. Mushrooming can occur on both the tip of the rod, as it encounters rocks on its way down, and the end where force is being applied to drive the rod through the earth. Driving these rods can be extremely labor-intensive when rocky terrain creates problems as the tips of the rods continue to mushroom. Often, these rods will hit a rock and actually turn back around on themselves and pop back up a few feet away from the installation point. Because driven rods range in length from 8 to 10 feet, a ladder is often required to reach the top of the rod, which can become a safety issue. Many falls have resulted from personnel trying to literally ‘whack’ these rods into the earth, while hanging from a ladder, many feet in the air.

The National Electric Code requires that driven rods be a minimum of 8 feet in length and that 8 feet of length must be in direct contact with the soil. Typically, a shovel is used to dig down into the ground 18 inches before a driven rod is installed. The most common rods used by commercial and industrial contractors are 10 ft in length. Many industrial specifications require this length as a minimum.

A common misconception is that the copper coating on a standard driven rod has been applied for electrical reasons. While copper is certainly a conductive material, its real purpose on the rod is to provide corrosion protection for the steel underneath. Many corrosion problems can occur because copper is not always the best choice in corrosion protection. It should be noted that galvanized driven rods have been developed to address the corrosion concerns that copper presents, and in many cases are a better choice for prolonging the life of the grounding rod and grounding systems. Generally speaking, galvanized rods are a better choice in all but high salt environments.

An additional drawback of the copper-clad driven rod is that copper and steel are two dissimilar metals. When an electrical current is imposed, electrolysis will occur. Additionally, the act of driving the rod into the soil can damage the copper cladding, allowing corrosive elements in the soil to attack the bared steel and further decrease the life expectancy of the rod. Environment, aging, temperature and moisture also easily affect driven rods, giving them a typical life expectancy of five to 15 years in good soil conditions. Driven rods also have a very small surface area, which is not always conducive to good contact with the soil. This is especially true in rocky soils, in which the rod will only make contact on the edges of the surrounding rock.

A good example of this is to imagine a driven rod surrounded by large marbles. Actual contact between the marbles and the driven rod will be very small. Because of this small surface contact with the surrounding soil, the rod will increase in resistance-to-ground, lowering the conductance, and limiting its ability to handle high-current faults.
Advanced Driven Rods

Advanced Driven Rods are specially engineered variations of the standard driven rod, with several key improvements. Because they present lower physical resistance, advanced rods can now go into terrain where only large drill-rigs could install before and can quickly be installed in less demanding environments. The modular design of these rods can reduce safety-related accidents during installation. Larger surface areas can improve electrical conductance between the soil and the electrode.

Of particular interest is that Advanced Driven Rods can easily be installed to depths of 20 ft or more, depending upon soil conditions.

Advanced Driven Rods are typically driven into the ground with a standard drill hammer. This automation dramatically reduces the time required for installation. The tip of an Advanced Driven Rod is typically made of carbide and works in a similar manner to a masonry drill bit, allowing the rod to bore through rock with relative ease. Advanced Driven Rods are modular in nature and are designed in five foot lengths. They have permanent and irreversible connections that enable an operator to install them safely, while standing on the ground. Typically, a shovel is used to dig down into the ground 18 inches before the Advanced Driven Rod is installed. The Advanced Driven Rod falls into the same category as a driven rod and satisfies the same codes and regulations.

In the extreme northern and southern climates of the planet, frost-heave is a major concern. As frost sets in every winter, unsecured objects buried in the earth tend to be pushed up and out of the ground. Driven grounding rods are particularly susceptible. Anchor plates are sometimes welded to the bottom of the rods to prevent them from being pushed up and out of the earth by frost-heave. This however requires that a hole be augured into the earth in order to get the anchor plate into the ground, which can dramatically increase installation costs. Advanced Driven Rods do not suffer from frost-heave issues and can be installed easily in extreme climes.

Grounding Plates

Grounding plates are typically thin copper plates buried in direct contact with the earth. The National Electric Code requires that ground plates have at least 2 ft2 of surface area exposed to the surrounding soil. Ferrous materials must be at least .20 inches thick, while non-ferrous materials (copper) need only be .060 inches thick. Grounding plates are typically placed under poles or supplementing counterpoises.

As shown, grounding plates should be buried at least 30 inches below grade level. While the surface area of grounding plates is greatly increased over that of a driven rod, the zone of influence is relatively small as shown in “B”. The zone of influence of a grounding plate can be as small as 17 inches. This ultra-small zone of influence typically causes grounding plates to have a higher resistance reading than other electrodes of similar mass. Similar environmental conditions that lead to the failure of the driven rod also plague the grounding plate, such as corrosion, aging, temperature, and moisture.
**Ufer Ground or Concrete Encased Electrodes**

Originally, Ufer grounds were copper electrodes encased in the concrete surrounding ammunition bunkers. In today’s terminology, Ufer grounds consist of any concrete-encased electrode, such as the rebar in a building foundation, when used for grounding, or a wire or wire mesh in concrete.

**Concrete Encased Electrode**

The National Electric Code requires that Concrete Encased Electrodes use a minimum No. 4 AWG copper wire at least 20 feet in length and encased in at least 2 inches of concrete. The advantages of concrete encased electrodes are that they dramatically increase the surface area and degree of contact with the surrounding soil. However, the zone of influence is not increased, therefore the resistance to ground is typically only slightly lower than the wire would be without the concrete.

Concrete encased electrodes also have some significant disadvantages. When an electrical fault occurs, the electric current must flow through the concrete into the earth. Concrete, by nature retains a lot of water, which rises in temperature as the electricity flows through the concrete. If the extent of the electrode is not sufficiently great for the total current flowing, the boiling point of the water may be reached, resulting in an explosive conversion of water into steam. Many concrete encased electrodes have been destroyed after receiving relatively small electrical faults. Once the concrete cracks apart and falls away from the conductor, the concrete pieces act as a shield preventing the copper wire from contacting the surrounding soil, resulting in a dramatic increase in the resistance-to-ground of the electrode.

There are many new products available on the market designed to improve concrete encased electrodes. The most common are modified concrete products that incorporate conductive materials into the cement mix, usually carbon. The advantage of these products is that they are fairly effective in reducing the resistivity of the concrete, thus lowering the resistance-to-ground of the electrode encased. The most significant improvement of these new products is in reducing heat buildup in the concrete during fault conditions, which can lower the chances that steam will destroy the concrete encased electrode. However some disadvantages are still evident. Again, these products do not increase the zone-of-influence and as such the resistance-to-ground of the concrete encased electrode is only slightly better than what a bare copper wire or driven rod would be in the ground. Also a primary concern regarding enhanced grounding concretes is the use of carbon in the mix. Carbon and copper are of different nobilities and will sacrificially corrode each other over time. Many of these products claim to have buffer materials designed to reduce the accelerated corrosion of the copper caused by the addition of carbon into the mix. However, few independent long-term studies are being conducted to test these claims.

**Ufer Ground or Building Foundations**

Ufer Grounds or building foundations may be used provided that the concrete is in direct contact with the earth (no plastic moisture barriers), that rebar is at least 0.500 inches in diameter and that there is a direct metallic connection from the service ground to the rebar buried inside the concrete.

This concept is based on the conductivity of the concrete and the large surface area, which will usually provide a grounding system that can handle very high current loads. The primary drawback occurs during fault conditions, if the fault current is too great compared with the area of the rebar system, when moisture in the concrete superheats and rapidly expands, cracking the surrounding concrete and the threatening the integrity of the building foundation. Another drawback to the Ufer ground is they are not testable under normal circumstances as isolating the concrete slab in order to properly perform resistance-to-ground testing is nearly impossible.
The metal frame of a building may also be used as a grounding point, provided that the building foundation meets the above requirements, and is commonly used in high-rise buildings. It should be noted that many owners of these high-rise buildings are banning this practice and insisting that tenants run ground wires all the way back to the secondary service locations on each floor. The owners will have already run ground wires from the secondary services back to the primary service locations and installed dedicated grounding systems at these service locations. The goal is to avoid the flow of stray currents, which can interfere with the operation of sensitive electronic equipment.

**Water Pipes**
Water pipes have been used extensively over time as a grounding electrode. Water pipe connections are not testable and are unreliable due to the use of tar coatings and plastic fittings. City water departments have begun to specifically install plastic insulators in the pipelines to prevent the flow of current and reduce the corrosive effects of electrolysis. The National Electric Code requires that at least one additional electrode be installed when using water pipes as an electrode. There are several additional requirements including:

- 10 feet of the water pipe is in direct contact with the earth,
- Joints must be electrically continuous,
- Water meters may not be relied upon for the grounding path,
- Bonding jumpers must be used around any insulating joints, pipe or meters,
- Primary connection to the water pipe must be on the street side of the water meter,
- Primary connection to the water pipe shall be within five feet of the point of entrance to the building.

The National Electric Code requires that water pipes be bonded to ground, even if water pipes are not used as part of the grounding system.

**Electrolytic Electrode**
The electrolytic electrode was specifically engineered to eliminate the drawbacks of other grounding electrodes. This active grounding electrode consists of a hollow copper shaft filled with natural earth salts and desiccants whose hygroscopic nature draws moisture from the air. The moisture mixes with the salts to form an electrolytic solution that continuously seeps into the surrounding backfill material, keeping it moist and high in ionic content. The electrolytic electrode is installed into an augured hole and backfilled with a special highly conductive product. This specialty product should protect the electrode from corrosion and improve its conductivity. The electrolytic solution and the special backfill material work together to provide a solid connection between the electrode and the surrounding soil that is free from the effects of temperature, environment, and corrosion. This active electrode is the only grounding electrode that improves with age. All other electrode types will have a rapidly increasing resistance-to-ground as the season’s change and the years pass. The drawbacks to these electrodes are the cost of installation and the cost of the electrode itself.
GROUNDING SYSTEM DESIGN & PLANNING

A grounding design starts with a site analysis, collection of geological data, and soil resistivity of the area. Typically, the site engineer or equipment manufacturers specify a resistance-to-ground number. The NEC states that the resistance-to-ground shall not exceed 25 ohms for a single electrode. However, high technology manufacturers will often specify 3 or 5 ohms, depending upon the requirements of their equipment. For sensitive equipment and under extreme circumstances, a one (1) ohm specification may sometimes be required. When designing a ground system, the difficulty and costs increase exponentially as the target resistance-to-ground approaches the unobtainable goal of zero ohms.

Data Collection
Once a need is established, data collection begins. Soil resistivity testing, geological surveys, and test borings provide the basis for all grounding design. Proper soil resistivity testing using the Wenner 4-point method is recommended because of its accuracy. This method will be discussed later in this chapter. Additional data is always helpful and can be collected from existing ground systems located at the site. For example, driven rods at the location can be tested using the 3-point fall-of-potential method or an induced frequency test using a clamp-on ground resistance meter.

Data Analysis
With all the available data, sophisticated computer programs can begin to provide a soil model showing the resistivity in ohm-meters and at various layer depths. Knowing at what depth the most conductive soil is located for the site allows the design engineer to model a system to meet the needs of the application.

Grounding Design
Soil resistivity is the key factor that determines the resistance or performance of a grounding system. It is the starting point of any grounding design. As you can see in Tables 2 and 3 below, soil resistivity varies dramatically throughout the world and is heavily influenced by electrolyte content, moisture, minerals, compactness and temperature.

SOIL RESISTIVITY TESTING

Soil resistivity testing is the process of measuring a volume of soil to determine the conductivity of the soil. The resulting soil resistivity is expressed in ohm-meter or ohm-centimeter.

Soil resistivity testing is the single most critical factor in electrical grounding design. This is true when discussing simple electrical design, to dedicated low-resistance grounding systems, or to the far more complex issues involved in Ground Potential Rise (GPR) studies. Good soil models are the basis of all grounding designs and they are developed from accurate soil resistivity testing.

Wenner Soil Resistivity Test and Other 4-Point Tests

The Wenner 4-point Method is by far the most used test method to measure the resistivity of soil. Other methods do exist, such as the General and Schlumberger methods, however they are infrequently used for grounding design applications and vary only slightly in how the probes are spaced when compared to the Wenner Method.

Electrical resistivity is the measurement of the specific resistance of a given material. It is expressed in ohm-meters and represents the resistance measured between two plates covering opposite sides of a 1 m cube. This test is commonly performed at raw land sites, during the design and planning of grounding systems specific to the tested site. The test spaces four (4) probes out at equal distances to approximate the depth of the soil to be tested. Typical spacings will be 1', 1.5', 2', 3', 4.5', 7', 10', etc., with each spacing...
increasing from the preceding one by a factor of approximately 1.5, up to a maximum spacing that is com-
mensurate with the 1 to 3 times the maximum diagonal dimension of the grounding system being designed,
resulting in a maximum distance between the outer current electrodes of 3 to 9 times the maximum diagonal
dimension of the future grounding system. This is one “traverse” or set of measurements, and is typically
repeated, albeit with shorter maximum spacings, several times around the location at right angles and diag-
ionally to each other to ensure accurate readings.

The basic premise of the test is that probes spaced at 5’ distance across the earth, will read 5’ in depth. The
same is true if you space the probes 40’ across the earth, you get a weighted average soil resistance from 0’
down to 40’ in depth, and all points in between. This raw data is usually processed with computer software
to determine the actual resistivity of the soil as a function of depth.

Conducting a Wenner 4-point (or four-pin) Test
The following describes how to take one “traverse” or set of measurements. As the “4-point” indicates, the
test consists of 4 pins that must be inserted into the earth. The outer two pins are called the Current probes,
C1 and C2. These are the probes that inject current into the earth. The inner two probes are the Potential
probes, P1 and P2. These are the probes that take the actual soil resistance measurement.

In the test shown in Fig.10, a probe C1 is driven into the earth
at the corner of the area to be measured. Probes P1, P2, & C2
are driven at 5’, 10’ & 15’ respectively from rod C1 in a
straight line to measure the soil resistivity from 0’ to 5’ in
depth. C1 & C2 are the outer probes and P1 & P2 are the
inner probes. At this point, a known current is applied across
probes C1 & C2, while the resulting voltage is measured
across P1 & P2. Ohm’s law can then be applied to calculate
the measured apparent resistance.

Probes C2, P1 & P2 can then be moved out to 10’, 20’ & 30’
spaceing to measure the resistance of the earth from 0’ to 10’
in depth. Continue moving the three probes (C2, P1 & P2)
away from C1 at equal intervals to approximate the depth of
the soil to be measured. Note that the performance of the
electrode can be influenced by soil resistivities at depths that are considerably deeper than the depth of
the electrode, particularly for extensive horizontal electrodes, such as water pipes, building foundations or
grounding grids.

Soil Resistance Meters
There are basically two types of soil resistance meters: Low-Frequency and High-Frequency models. Both
meter types can be used for 4-point & 3-point testing, and can even be used as standard (2-point) volt meter
for measuring common resistances.

Care should always be given when selecting a meter, as the electronics involved in signal filtering are highly
specialized. Electrically speaking, the earth can be a noisy place. Overhead power lines, electric substations,
railroad tracks, various signal transmitters and many other sources contribute to signal noise found in any
given location. Harmonics, 60 Hz background noise, and magnetic field coupling can distort the measure-
ment signal, resulting in apparent soil resistivity readings that are larger by an order of magnitude, particu-
larly with large spacings. Selecting equipment with electronic packages capable of discriminating between
these signals is critical.

High-Frequency meters typically use a pulses operating at 128 pulses per second, or other pulse rates except
60. These High-Frequency meters typically suffer from the inability to generate sufficient voltage to handle
long traverses and generally should not be used for probe spacings greater than 100 feet. Furthermore, the
High-Frequency signal flowing in the current lead induces a noise voltage in the potential leads, which cannot be completely filtered out: this noise becomes greater than the measured signal as the soil resistivity decreases and the pin spacing increases. High-Frequency meters are less expensive than their Low-Frequency counterparts, and are by far the most common meter used in soil resistivity testing.

Low-Frequency meters, which actually generate low frequency pulses (on the order of 0.5 to 2.0 seconds per pulse), are the preferred equipment for soil resistivity testing, as they do away with the induction problem from which the High-Frequency meters suffer. However they can be very expensive to purchase. Depending upon the equipment’s maximum voltage, Low-Frequency meters can take readings with extremely large probe spacings and often many thousands of feet in distance. Typically, the electronics filtering packages offered in Low-Frequency meters are superior to those found in High-Frequency meters. Caution should be taken to select a reputable manufacturer.

Data Analysis

Once all the resistance data is collected, the following formula can be applied to calculate the apparent soil resistivity in ohm-meters:

\[
p = \frac{4\pi AR}{2A} - \sqrt{A^2 + B^2}
\]

\( p = \text{Resistivity} \quad A = \text{Spacing of Probes} \quad B = \text{Depth of Probes} \quad R = \text{Resistance (reading from meter)} \)

If \( A = 20 \), then \( p = 2 \cdot A \cdot R = 1.915 \cdot A \cdot R \)

Shallow Depth Readings

Shallow depth readings, as little as 6" in depth, are exceedingly important for most, if not all, grounding designs. As described above, the deeper soil resistivity readings are actually weighted averages of the soil resistivity from the earth surface down to depth, and include all the shallow resistance readings above it. The trick in developing the final soil model is to pull out the actual resistance of the soil at depth, and that requires “subtracting” the top layers from the deep readings. The following figure demonstrates how the shallowest readings impact deeper ones below it.

As you can see, if you have a 5’ reading of 50 ohm-meters and a 10’ reading of 75-ohmmeter soil, the actual soil resistance from 5’ to 10’ might be 100 ohm-meters (the point here is to illustrate a concept: pre-computed curves or computer software are needed to properly interpret the data). The same follows true for larger pin spacings. The shallowest readings are used over and over again in determining the actual resistivity at depth.

Shallow depth readings of 6-inches, 1-foot, 1.5-feet, 2-feet and 2.5-feet are important for grounding design, because grounding conductors are typically buried at 1.5 to 2.5-feet below the surface of the earth. To accurately calculate how those conductors will perform at these depths shallow soil readings must be taken. These shallow readings become even more important when engineers calculate Ground Potential Rise, Touch Voltages and Step Voltages.
It is critical that the measurement probes and current probes be inserted into the earth to the proper depth for shallow soil resistivity readings. If the probes are driven too deep, then it can be difficult to resolve the resistivity of the shallow soil. A rule of thumb is that the penetration depth of the potential probes should be no more than 10% of the pin spacing, whereas the current probes must not be driven more than 30% of the pin spacing.

**Deep Readings**

Often, the type of meter used determines the maximum depth or spacing that can be read. A general guideline is that High-Frequency soil resistivity meters are good for no more than 100-feet pin spacings, particularly in low resistivity soils. For greater pin spacings, Low-Frequency soil resistivity meters are required. They can generate the required voltage needed to push the signal through the soil at deep distances and detect a weak signal, free of induced voltage from the current injection leads.

**Test Location**

Soil resistivity testing should be conducted as close to the proposed grounding system as possible, taking into consideration the physical items that may cause erroneous readings. There are two (2) issues that may cause poor quality readings:

- Electrical interference causing unwanted signal noise to enter the meter.
- Metallic objects ‘short-cutting’ the electrical path from probe to probe. The rule of thumb here is that a clearance equal to the pin spacing should be maintained between the measurement traverse and any parallel buried metallic structures.

Testing in the vicinity of the site in question is obviously important; however, it is not always practical. Many electric utility companies have rules regarding how close the soil resistivity test must be in order to be valid. The geology of the area also plays into the equation as dramatically different soil conditions may exist only a short distance away.

When left will little room or poor conditions in which to conduct a proper soil resistivity test, one should use the closest available open field with as similar geological soil conditions as possible.

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E&S Grounding Solutions are the experts in electrical grounding design and work closely with our client’s project engineers, providing them the safest and most cost effective electrical grounding and earthing solutions available. We believe that this close working relationship enables our clients to have the most comprehensive electrical grounding design team in the market place today.

Thank you for your interest in E&S Grounding Solutions. We look forward to working with you.