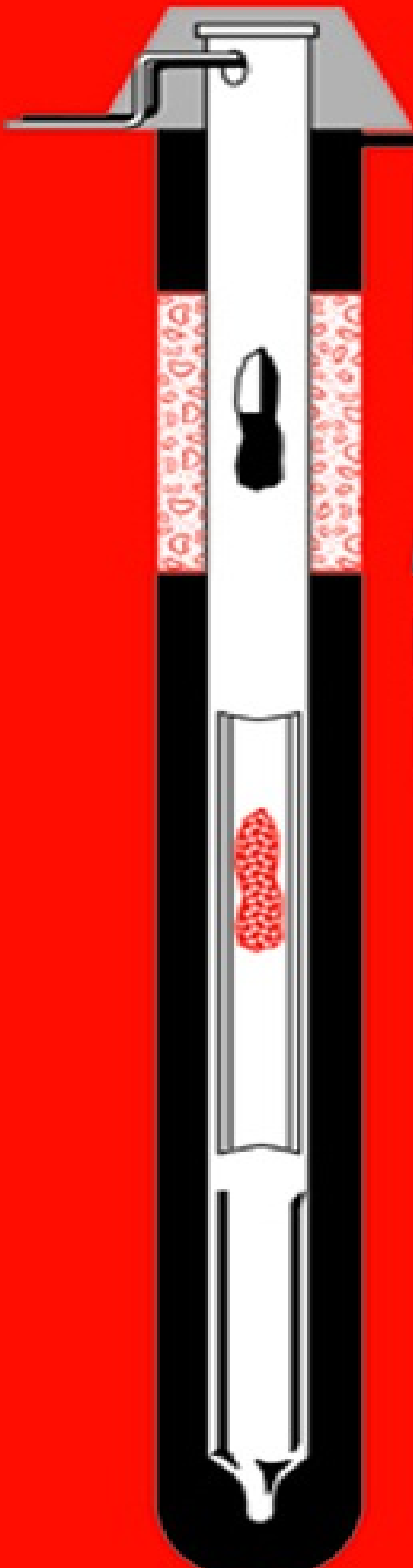

DEEP ANODE SYSTEMS

Design, Installation, and Operation

T.H. Lewis, Jr.
P.E., C.S., C.P.S.

NACE PRESS

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Published by

NACE INTERNATIONAL

NACE INTERNATIONAL

P.O. Box 218340
Houston, TX 77218-8340
www.nace.org

ISBN 978-1-57590-111-4

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Chapter 1

Introduction

1.1 PURPOSE

The purpose of this manual is to provide the design engineer with a single-source guide for designing, installing, and operating deep anode systems. The design and installation process for a successful deep anode system involves a combination of gathering data, preforming design calculations, selecting specific materials and techniques, and planning the installation method. Besides the mathematical calculations necessary to complete a specific design, many design decisions require the exercise of good engineering judgment. Decisions such as equipment requirements, hole completion techniques, site problems, materials selection, and safety procedures often require a combination of experience, knowledge, forethought, and judgment. This design manual will discuss many engineering judgment decisions and provide some possible options available with an indication of the factors that influence the particular choice for a specific design.

1.2 DEEP GROUNDBED DEFINED

The definition of a deep groundbed or deep anode system that is most often quoted is the definition endorsed by NACE International in RP0572:[1]

> One or more anodes installed vertically at a nominal depth of 15 m (50 ft) or more below the earth's surface in a drilled hole for the purpose of supplying cathodic protection for an underground or submerged metallic structure.

1.3 ADVANTAGES

Although a complete list of the advantages in using a deep anode system can be found in RP0572, it is worthwhile to elaborate on several of the most important points. Since the current discharge occurs deep in the body of the earth rather than near the surface, the anodic potential gradient is not as extensive in the near-surface soils where most utility structures are found. This means that the potential for anodic interference is greatly reduced. Therefore, deep anode systems can represent a significant advantage in areas with many foreign metallic surface structures such as municipalities and large industrial facilities.

Another significant advantage often possible using a deep anode design is the limited surface land area necessary for the installation. Since all of the anodes are stacked vertically in a single drilled hole, the installation can be completed with very limited surface land required. Not only is this an advantage in congested areas where surface land may be very limited, but also the cost of additional right-of-way can often be avoided in less congested areas. It is often even possible to install the deep anode system within the existing right-of-way for facilities such as transmission pipelines. This is possible because the anodes can be made remote from the structure by placing the discharge zone deeper in the body of the earth.

The primary operating cost of an impressed current cathodic protection system is the cost of the commercial AC power required. The electric utility bill represents a charge for the energy consumed by the cathodic protection system. Energy is the power delivered over a certain time interval. Power is determined by the current input squared times the load resistance. Since the current input is predetermined by the current required to achieve a specific level of cathodic protection, it cannot be reduced without losing some degree of protection. However, if the input resistance can be reduced, then the power delivered to obtain cathodic protection is also reduced. With high surface soil resistivities, it is possible to significantly reduce the system input resistance by placing the anodes deeper in the body of the earth where low resistivity strata can often be found. Further, the resistance remains more stable over time because the factors that control the resistance (moisture content and temperature) are more constant in deep strata.

1.4 DISADVANTAGES

Again, a complete list of the disadvantages in using a deep anode system can be found in RP0572. Although most of the disadvantages can be overcome or minimized with proper consideration and design, the most serious disadvantage is usually the additional installation cost per ampere of cathodic protection required when compared to surface groundbed designs. However, this cost is sometimes overshadowed by the savings that can be realized by reduced power, right-of-way, or interference solution costs.

1.5 DISCLAIMER

Although every effort has been made to ensure the accuracy and completeness of the information contained in this manual, neither Loresco International nor any of the specific contributors to this manual warrant or accept any liability for use of the manual or the information contained in the manual. Further, it is recognized that many specific site conditions and variables can exist which require careful consideration and application of engineering judgment by individuals with knowledge and experience in a specific area. Therefore, individuals using this manual are cautioned to seek competent scientific or engineering advice and assistance in those areas.

REFERENCES

1. NACE Standard RP0572, "Design, Installation, Operation, and Maintenance of Impressed Current Deep Groundbeds" (Houston, TX: NACE, 1995). Approved June 1972, Revised 1995.

Chapter 2

Gathering Design Information

2.1 DETERMINING DESIGN CURRENT

The deep anode system design current should be decided by first determining the current required for cathodic protection of the structure. A safety factor should be added to the cathodic protection current requirement to handle anticipated system growth and coating deterioration. If no information is available regarding anticipated system expansion and no history is available on coating deterioration, a 25-percent additional current capacity is suggested.

Depending upon the total design current, the anticipated attenuation along the structure to be protected, and the geometry of the structure to be protected, one or more deep anode systems may be necessary to provide the protective current. The maximum recommended design current for a single deep anode system depends on the geology (stratigraphy and lithology) and maximum hole diameter desired. However, design of a single deep anode groundbed with a current output rating more than 50 amps should be attempted only after all other alternatives have been considered. This 50-amp limit is suggested due to the amount of the discharge surface area required to generate this level of current output without depleting moisture levels or generating gases too rapidly to adequately dissipate.

2.2 DETERMINING GEOLOGY AND HYDROLOGY

For successful deep anode groundbed installation and operation, adequate information about the geology and hydrology at the proposed site is necessary during the design stage. It is desirable to know the exact stratification, moisture content, resistivity, and specific classification of the soils and rock layers at the proposed site along with the pore water chemistry. If only limited information can be obtained, the minimum information necessary is the anticipated depth and thickness of a low resistivity stratum adequate for current discharge and the depth to the top of the water table (phreatic surface). Of course, the more detailed the available information becomes, the better the design will be.

What constitutes a low-resistivity stratum adequate for current discharge is relative. It depends entirely upon the types of soil layers and their relative resistivities in a given area. Except for certain electronically conductive minerals, such as magnetite (Fe_30_4), specular hematite (Fe_20_3), carbon, graphite, pyrite (FeS_2), galena (PbS), chalcopyrite ($CuFeS_2$), bornite (Cu_5FeS4), covellite (CuS), copper, and pyrrhotite (FeS), most minerals which make up soil and rock layers are electrical insulators. Therefore, the conduction method in most soils and rocks is electrolytic in nature taking place through the moisture contained within the pores and channels of the layer. Consequently, the moisture content and chemistry are very important determinants of the conductivity.[1-3]

Some of the most commonly sought sediments due to their relatively low resistivities are: clay, shale, marl, chalk, and sands or porous formations containing conductive waters. The suitability of any one of these formations is dependent upon its depth and relative resistivity.

2.2.1 RESEARCHING EXISTING DATA BASES

There are several possible sources of geological information that may be helpful in the early design stages. The following is a list of potential information sources including contact information and data available.

2.2.1.1

United States Geological Survey (USGS) - Considerable surface and subsurface geological information is available either through the library reference desk at (703) 648-4302 or the Earth Science Information Center at (800) 872-6277. USGS information is available on the internet at http://www.usgs.gov/

2.2.1.2

State District Office of USGS - Each state has a district office of the USGS that maintains geologic profile information for the state. These offices are usually located in the state capital and may be contacted by telephone using the federal government information section of the telephone directory. Information may be obtained by telephone or fax request to the District Office with location descriptions providing the county, section, township, and range or longitude and latitude for the point of interest.

2.2.1.3

American Geological Institute (AGI) - This office is located in Alexandria, Virginia, at (703) 379-2480. The AGI can also be contacted on the InterNet at http://www.agiweb.org/. The AGI maintains a geological database of records for North America since 1785 and other areas of the world since 1933. The AGI provides a geoscience database on CD-ROM known as GEOREF. This information is commercially available via annual subscription, and is usually available at university or research libraries.

2.2.1.4

State Geological Surveys or Department of Natural Resources - Many states provide helpful geological information from reported drillers' logs. These offices are generally located in the state capital and may be contacted by telephone using the state government information section of the telephone directory.

2.2.1.5

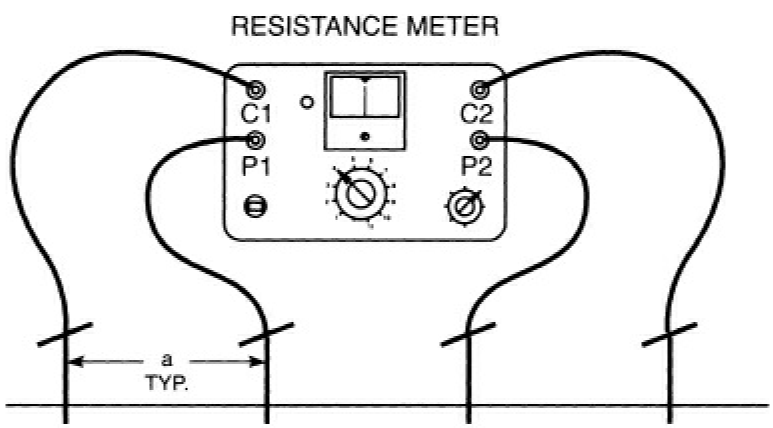
Local Water Well Drillers - Often, helpful information can be obtained from local water well drillers. Not only can they usually provide information about the stratification of soils, but also they can provide information about drilling conditions and anticipated installation problems based on previous drilling experience in the area. Local water well drillers can be located in the Yellow Pages section of the telephone directory.

2.2.2 SURFACE TESTING

Depending upon the surface topology, location of underground metallic structures, and available open testing area, it is possible to estimate subsoil resistivities using data obtained from surface testing techniques. The Four- Point test method is the most accurate method of measuring the average resistivity of large volumes of earth, in-situ.[4] Two of the four test electrodes are current injection points, and two are potential measurement points. Resistance is determined by dividing the magnitude of the test current flowing between the current electrodes into the voltage drop measured between the potential electrodes. There are several commercially available instruments that perform this calculation internally and provide the resistance directly.

Although there are a number of electrode arrangements possible, the most commonly used technique is based on the Wenner arrangement. This electrode arrangement, as shown in Figure 2-1, involves equally spacing the four electrodes distance *a* apart and along a straight line with the current electrodes on the outside and the potential electrodes on the inside.[5-6] If the depth of the electrodes does not exceed 0.1 *a*, then the apparent resistivity to depth *a* is given by the formula:

Figure 2-1: Wenner Electrode Arrangement



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

Equation (2-1)
Wenner Arrangement Equation

where ρ = resistivity (ohm-cm)
R = measured resistance (ohms)
a = electrode spacing (cm)

If ρ is desired in ohm-cm and ***a*** is measured in feet, the formula becomes:

$$\rho = 191.5\ a\ R$$

Equation (2-2)

A baseline for the electrode array should first be established, which is three times the depth of soil to be investigated. The baseline should be straight and cross relatively level terrain. The center of the baseline should be established and used as the center of the electrode array. As resistance measurements are recorded for various electrode spacings, the array should be expanded about the established center point. Incremental electrode spacings from 10 to 50 feet are suggested depending upon the detail desired.