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Standard
Recommended Practice

Design, Installation, Operation, and Maintenance of Impressed Current Deep Groundbeds

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Foreword

The purpose of this NACE International standard recommended practice is to present procedures and practices for the design, installation, operation, and maintenance of deep groundbeds used for the control of external corrosion of underground or submerged metallic structures by impressed current cathodic protection. It is intended to be used in conjunction with NACE standards RP0169[1] and RP0177.[2] This standard is intended to be used by corrosion engineers, corrosion consultants, representatives from manufacturers, and others concerned with corrosion control of underground structures.

This standard was originally prepared in 1972 by NACE Task Group T-10A-7, a component of Unit Committee T-10A on Cathodic Protection and was revised in 1985, 1995, and 2001. This 2001 revision was prepared by NACE Task Group 021 on Installation Methods for Deep Anodes. This Task Group is administered by Specific Technology Group (STG) 05 on Cathodic/Anodic Protection and sponsored by STG 35 on Pipelines, Tanks, and Well Casings. Task Group 021 is composed of corrosion engineers from oil and gas transmission companies, gas distribution companies, power companies, and communications companies as well as corrosion consultants, representatives from manufacturers, and others concerned with corrosion control of underground structures. This standard is issued by NACE under the auspices of STG 05.

In NACE standards, the terms *shall, must, should,* and *may* are used in accordance with the definitions of these terms in the *NACE Publications Style Manual*, 4th ed., Paragraph 7.4.1.9. *Shall* and *must* are used to state mandatory requirements. *Should* is used to state something considered good and is recommended but is not mandatory. *May* is used to state something considered optional.

NACE International Standard Recommended Practice

Design, Installation, Operation, and Maintenance of Impressed Current Deep Groundbeds

Contents

Section 1: General

1.1 This standard presents acceptable methods for the design, installation, operation, and maintenance of deep groundbeds that discharge impressed current for cathodic protection of underground or submerged metallic structures.

1.2 This standard is based on the best available technology and methods that have been used successfully by experienced corrosion engineers.

1.3 This standard does not designate methods for every specific situation because the complexity of some environmental conditions precludes standardizing all design and installation procedures.

1.4 The provisions of this standard should be applied under the direction of a competent corrosion engineer. The term *corrosion engineer*, as used in this standard, refers to a person who, by reason of knowledge of the physical sciences and the principles of engineering and mathematics acquired by education and related practical experience, is qualified to engage in the practice of corrosion control of underground or submerged structures.

1.5 Other types of groundbeds should be investigated before the decision is made to use a deep groundbed, because more economical alternatives may be available.

1.6 Codes, laws, and regulations in a local geographic area may require supplements to or deviation from this standard.

1.7 Necessary precautions must be taken to prevent damage to existing underground structures and deleterious modification of ground water quality.

1.8 Adequate records containing information showing site right-of-way, installation procedures, operation data, maintenance, repair, and test records should be maintained.

Section 2: Definitions

Abandonment: The discontinued use of a deep anode system.

Active Zone: The segment of the deep anode system that is designed to discharge current. In this standard, the active zone refers to that length of deep groundbed that is made up of carbonaceous backfill. In an open-hole installation, the active zone is the aqueous electrolyte.

Annular Space: The space between the well casing and the well bore or the space between two or more strings of well casing.

Anode: The electrode of an electrochemical cell at which oxidation occurs. In this standard, the anode is the positive terminal of the impressed electrical system from which current is discharged.

Anode Cap: An electrical insulating material placed over the end of the anode at the lead wire connection.

Anode Connection Encapsulation: An electrical insulating material placed over the end of the anode or within the interior of the anode body to maintain the electrical integrity of the anode-to-lead-wire connection. For the purposes of this standard, it is understood that some internal anode-to-lead-wire connections do not require the addition of electrical insulating encapsulation.

Aquifer: A water-bearing stratum of permeable rock, sand, or gravel.

Backfill: Material placed in a hole to fill the space around the anodes, vent pipe, and buried components of a cathodic protection system.

Blowdown: Injection of air or water under high pressure through a tube to the anode area for the purpose of purging the annular space and possibly correcting high resistance caused by gas blockage.

Bore Hole: A hole drilled into the earth for the installation of a deep groundbed system.

Cathodic Protection: A technique to reduce the corrosion of a metal surface by making that surface the cathode of an electrochemical cell.

Closed Hole: A groundbed installation in which the anodes have been surrounded by backfill. Typically, in a closed-hole installation, the backfill consists of a conducting carbonaceous backfill around the anodes, and above the active zone is native soil sealing material or other suitable material. Alternately, the top of the anode hole may be sealed with a plastic casing from the surface to the top of the anode backfill and left open.

Conductive Carbon Seal: Conductive seal (nonporous conductive material).

Continuous Anode: A single anode with no electrical discontinuities. For the purposes of this standard, the active zone of the groundbed may be considered a conducting continuous anode.

Continuous Rail Groundbed: A rail groundbed to be used as an anode and extending from the earth's surface to a depth greater than 15 m (50 ft) below the earth's surface.

Continuous Steel Pipe Groundbed: A steel pipe to be used as an anode and extending from the earth's surface to a depth greater than 15 m (50 ft) below the earth's surface.

Corrosion: The deterioration of a material, usually a metal, that results from a reaction with its environment.

Current Density: The current to or from a unit area of an electrode surface.

Deep Groundbed: 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.

Electrolysis: The process that produces a chemical change in an electrolyte resulting from the passage of electricity. In this standard, electrolysis is the dissociation of an electrolyte by passage of direct current, which causes anions to migrate to the anode and cations to the cathode. Elements released at the anode may include oxygen, chlorine, and other gases. Hydrogen is commonly released at the cathode.

Electrolyte: A chemical substance containing ions that migrate in an electric field. For the purpose of this standard, the term *electrolyte* refers to the soil or liquid, including the moisture and other chemicals dissolved therein, within which a groundbed and a metallic structure are buried or submerged.

End Effect: The more rapid loss of anode material at the end of an anode, compared with other surfaces of the anode, resulting from higher current density. The end effect does not occur on all impressed current anodes used in deep groundbeds.

Foreign Structure: Any metallic structure that is not intended as a part of a system under cathodic protection.

Gas Blockage: An envelopment of the anode by oxygen, chlorine, or other gas in sufficient volume to reduce the anode's contact with the electrolyte, thereby increasing resistance and lowering the anode's current discharge.

Ground Water: Water beneath the earth's surface between saturated soil and rock that supplies wells and springs.

Grout: A thin mortar used to fill cracks and crevices to create a permanent, impervious, watertight bond.

Hydrology: The scientific study of the properties, distribution, and effects of water on the earth's surface, in the soil and underlying rocks, and in the atmosphere.

Impressed Current: A DC electric current supplied by a device employing a power source that is external to the electrode system.

Interchange Flow: Fluid flow between two aquifers.

Lithology: The microscopic study, description, and classification of rock.

Notch Propagation: The tendency of a cut, nick, or scratch in a material to increase in depth and/or length when the material is stressed.

Open Hole: An installation in which the anodes are surrounded only by an aqueous electrolyte.

Packaged Anode: An anode that is supplied in a conductive container, typically metallic. The anode is centered in the container and surrounded with a conductive backfill. Packaged anodes in metallic containers should be in electrical contact with the container through an internal wire arrangement. The container is electrochemically consumed during current activation.

Potable Water: Nonsaline water that is considered safe for use and consumption by the general public.

Reference Electrode: An electrode whose open-circuit potential is constant under similar conditions of measurement, which is used for measuring the relative potentials of other electrodes.

Replaceable Deep Groundbed: A deep groundbed design that allows for the removal and subsequent replacement of components and/or backfill without drilling a new hole.

Resistance Profile Test: A log of resistance versus depth in the drilled hole for a deep groundbed.

Seal: The use of bentonite or grout to prevent the flow, migration, or movement of fluids into ground water.

Shallow Groundbed: One or more anodes installed either vertically or horizontally at a nominal depth of less than 15 m (50 ft) for the purpose of supplying cathodic protection.

Spoils: Waste material or fluid generated during the installation of a deep groundbed.

Stratigraphy: The study of rock strata, especially of their distribution, deposition, and age.

Surface Casing: A casing in the upper nonactive portion of the deep well that holds back unstable surface soils or functions as a portion of the fluid mitigation design.

Test Hole: Any excavation constructed for the purpose of determining the geologic, hydrologic, and water quality characteristics of underground formations.

Vent Pipe: A nonmetallic pipe installed along the length of the deep groundbed to assist in the removal of gases. The vent pipe must incorporate holes or slits in the shell that allow passage of the gases, while minimizing debris entry.

Venting: The dissipation of gases from a deep groundbed.

Voltage: An electromotive force or a difference in electrode potentials.

Wet Test: A dielectric test for the insulation of anode lead wires conducted at rated voltage for the insulation during aqueous electrolyte immersion of the wire.

Section 3: Environmental Considerations

3.1 This section recommends design, construction, installation, and abandonment techniques for deep groundbeds to address environmental considerations. To determine environmental considerations, the appropriate federal, state, or local natural resource, ground water management authority, or other governing entity should be contacted.

3.1.1 Items of possible concern are site location, surface runoff, interchange flow, material contamination, and abandonment.

3.2 Deep groundbed systems should be installed in areas not subject to surface or subsurface contamination. If deep groundbeds are to be installed in contaminated areas, techniques should be employed to prevent migration of the contaminants. Examples of areas to be given special consideration are:

- Low areas
- Areas containing hazardous material (hydrocarbons, heavy-metal salts, brines, etc.)
- Standing water
- Containment dikes

3.3 Precautions should be taken to prevent surface fluid runoff from entering the deep groundbed system.

3.3.1 Surface casings, if used, shall be externally sealed, and may be either internally sealed or extended above the high-water level. Sealing materials that may be used include concrete, grout, or bentonite-cement mixtures. Three grouts that have been used successfully include:

3.3.1.1 Neat cement grout – A mixture consisting of 43 kg (one 94-lb bag) of portland cement to 19 to 23 L (5.0 to 6.0 gal) of clean water.

3.3.1.2 Cement grout – A mixture consisting of 43 kg (one 94-lb bag) of portland cement to an equal volume of sand (diameter of sand should be no larger than 2 mm [0.08 in.]) to 19 to 23 L (5.0 to 6.0 gal) of clean water.

3.3.1.3 Bentonite clay grout – A mixture consisting of water and sodium bentonite clay containing high solids.

3.3.2 If casings are utilized in the deep groundbed system, a minimum space of 5.1 cm (2.0 in.) should be allowed on all sides for sealing.

3.3.3 The surface portion of uncased deep groundbed systems shall be sealed if required to prevent entry of fluid runoff.

3.3.4 Vents should be extended to a well-ventilated area above the high-water level and, if necessary, externally sealed in such a way as to prevent the entrance of runoff.

3.4 Intermixing of water between strata should be avoided.

3.4.1 Sealing within the deep groundbed system should be utilized to prevent intermixing of water between strata. If a casing is used, a seal around the outside of the casing shall be employed. Care should be given to vent pipe design to avoid interchange flow. Dual vent pipes may be used to prevent compromise of the internal seal.

3.5 Deep groundbed materials that do not contaminate underground water supplies shall be used. Materials should have third-party independent assessment in relation to the use of the material to promote and protect public health.

3.5.1 Accurate records of the material used and the data pertaining to its chemical analysis shall be maintained.

3.5.2 Potable water should be used in the installation process.

3.6 A deep groundbed system that has been depleted or is no longer required shall have an abandonment procedure. The following procedures should be considered minimum requirements.

3.6.1 All uncased holes, casings, and vent pipes shall be properly sealed.

3.6.2 All aboveground appurtenances shall be removed or secured to prevent tampering.

Section 4: Design

4.1 This section provides acceptable design procedures that should result in a deep groundbed capable of discharging the design current over an extended period of time when used in conjunction with a rectifier or other suitable power source.

4.2 The following advantages and disadvantages are characteristic of deep groundbeds and should be considered in the design of such a groundbed:

4.2.1 Advantages

4.2.1.1 Deep groundbeds may be located in congested areas where shallow groundbeds pose geographic, topographic, interference, or right-of-way problems.

4.2.1.2 Deep groundbeds may provide lower resistance than shallow groundbeds in areas of high-resistivity surface soils.

4.2.1.3 Deep groundbeds may result in lower anodic potential gradients to other structures than shallow groundbeds.

4.2.1.4 Deep groundbeds may provide better current distribution than shallow groundbeds.

4.2.1.5 Deep groundbeds eliminate some of the accidental damage that may occur to shallow groundbeds by excavation and land cultivation.

4.2.1.6 Deep groundbeds are less affected by seasonal moisture variations than shallow groundbeds and usually are not subject to freezing.

4.2.1.7 The use of open-hole deep groundbeds or closed-hole deep groundbeds specifically designed for anode replacement can facilitate inspection, repair, and replacement of groundbed components.

4.2.1.8 Deep groundbeds minimize surface disturbances in environmentally sensitive areas.

4.2.2 Disadvantages

4.2.2.1 Current requirement tests that accurately simulate actual deep groundbed installations are difficult to conduct.

4.2.2.2 Deep groundbeds are often more expensive to install than shallow groundbeds of similar current output.

4.2.2.3 Inspection, replacement, or repair of closed-hole deep groundbed installations may be difficult.

4.2.2.4 Closed-hole deep groundbeds require special design considerations because of their susceptibility to gas blockage. This disadvantage may not apply to continuous steel pipe or rail groundbeds.

4.2.2.5 Supplemental shallow groundbeds may be required to provide adequate protective current distribution to certain structures, or to provide adequate potential shifts for structures located in the immediate vicinity of the deep groundbed.

4.2.2.6 Compaction of backfill material around the anode in a deep groundbed may be difficult to achieve. The use of high-density backfill material can improve compaction. Poor compaction or absence of backfill can cause accelerated deterioration of the anode.

4.2.2.7 Open-hole deep groundbeds require an aqueous electrolyte.

4.2.2.8 Open-hole deep groundbeds may require nonconductive casing to prevent cave-in.

4.2.2.9 Open-hole deep groundbeds usually require additional depth below the bottom anode to form a sump for the collection of sediment.

4.2.2.10 Prediction of deep groundbed performance is more difficult and less exact than for shallow groundbeds.

4.2.2.11 Problems may exist with the bridging of subsurface aquifers that may require special design considerations to prevent intermixing of waters.

4.3 Site Selection

4.3.1 All available, pertinent information concerning subsurface stratigraphy, hydrology, and lithology should be obtained. Sources for such information include water-well drillers, oil and gas companies, the U.S. Geological Survey,[1] and other local, state, and federal agencies.

4.3.2 Geographic factors such as present and future urban congestion and terrain should also be considered.

[1] U.S. Geological Survey, 12201 Sunrise Valley Dr., Reston, VA 22092.

4.3.2.1 Terrain and geological characteristics may dictate the use of casing or other protective devices to avoid contamination or damage to the existing environment.

4.3.3 Availability of electrical power sources shall be considered.

4.3.4 Consideration shall be given to the prevention of mechanical and stray-current damage to all foreign structures such as pipelines, well casings, cables, electrical grounding systems, mines, and tunnels in the vicinity of the groundbed or the structure to be cathodically protected.

4.3.5 Soil resistivity or soil conductivity tests may provide useful design data.

4.3.6 In areas where the presence of suitable strata for groundbed installation is questionable, small-diameter test holes may provide useful design data.

4.3.6.1 Resistance profile tests may be conducted in conjunction with the test hole to complement the driller's log.

4.3.6.2 Small-diameter test holes may be useful for locating water zones.

4.4 Anode Hole

4.4.1 The anode hole diameter varies according to the groundbed design. Most diameters are 15 to 30 cm (6.0 to 12 in.).

4.4.2 The final depth of the anode hole depends on the subsurface strata and the design requirements.

4.4.3 The design of casing and wellhead-completion equipment must be in accordance with local, state, and federal regulations.

4.4.4 Final design may be completed after the anode hole is drilled, a resistance profile test is conducted, and resistivity of drilling samples is obtained and measured.

4.4.5 Low-permeability soils, such as clay, can dry out in the vicinity of an anode due to electro-osmosis or electrolysis of water at high anode current densities.

4.5 Materials Selection

4.5.1 Special consideration shall be given to the selection of materials because of the inherently high installation and maintenance costs of deep groundbeds.

4.5.2 Anodes

4.5.2.1 Materials such as graphite, high-silicon chromium iron, platinum, mixed-metal oxide, and steel may be used as anodes in deep groundbeds. All of these materials except steel are resistant to corrosion in halogen environments. Consideration shall be given to the ratio of anode surface area to both weight and current discharge.

4.5.2.1.1 Graphite anodes are available as cylindrical or square rods. Complete penetration of the anode pores with suitable material (linseed oil, wax, resin, etc.) may improve anode performance under most operating conditions.

4.5.2.1.2 High-silicon chromium iron is available in cylindrical rod or tubular form. Cylindrical rods are available with one or both ends enlarged.

4.5.2.1.3 Platinum-clad or platinized anodes with substrate materials of titanium, niobium (columbium), or tantalum are available in rod, tubular, small-diameter wire, wire mesh, and expanded metal forms.

4.5.2.1.4 Mixed-metal oxide anodes with titanium substrates are available as expanded metal and in rod or tubular forms. Mixed-metal oxide anodes with copper-cored titanium substrates are available in the form of small-diameter wires or rods.

4.5.2.1.5 Various forms of steel, such as rail (railroad rail), rod, shafting (sheetpile), and pipe are available. These are usually installed as continuous anodes. The upper portion may be coated to minimize current discharge from that area. A coated strip from top to bottom and/or lead wires connected at various points from top to bottom may be used to help preserve electrical continuity.

4.5.2.2 The number of anodes and the material used are determined by such factors as the environment; the total projected current output; size, shape, weight, and ratio of surface area to weight of the individual anodes; backfill; calculated groundbed resistance; design life; and other design factors.[3]

4.5.2.2.1 To minimize gas blockage, it may be desirable to operate most deep groundbed anodes at a lower current density than shallow groundbed anodes.

4.5.3 Anode Lead Wire

4.5.3.1 Each anode or anode string shall be provided with an insulated lead wire.

4.5.3.2 The size of the lead wire shall be determined by the anode's physical properties and electrical requirements.

4.5.3.3 Anode lead wire splices should be avoided.

4.5.3.4 Anodes may require additional support for lowering or hanging in the anode hole.

4.5.4 Lead Wire Insulation

4.5.4.1 The selection of insulation should be based on the expected environmental conditions.

4.5.4.2 The insulation must provide continuous coverage and adequate dielectric properties, have a high resistance to abrasion, stress cracking, notch propagation, and notch sensitivity, and provide good chemical resistance.

4.5.4.3 For installation in areas in which the electrolyte is not expected to contain chloride or other halogen ions, the following insulation material may be used: high-molecular-weight polyethylene (HMWPE) conforming to ASTM(2) D 1248[4] Type 1, Class C-5, Grade J-3, having an average insulation thickness of 2.8 mm (110 mils) with a 10% tolerance.

4.5.4.4 If any halogen or other corrosive gases or ions are expected to exist in the electrolyte, a specialized, chemical-resistant insulation material such as polyvinylidene fluoride (PVDF), radiation cross-linked polyvinylidene fluoride (XLPVDF), ethylene chlorotrifluoroethylene (ECTFE), cross-linked ethylene chlorotrifluoroethylene (XLECTFE), or other inert fluorocarbon or halogenated material shall be used.

4.5.4.4.1 Outer insulation jackets should be used for mechanical protection on thin-wall insulations subject to abrasion or notch propagation. The jacket should be of chemical- and abrasion-resistant material such as HMWPE.

4.5.5 Lead-Wire-to-Anode Connection

4.5.5.1 The lead wire-to-anode connection must be of low resistance, provide a positive moisture seal, and have sufficient mechanical strength to support the anode (see Paragraph 4.5.3).

4.5.5.2 Surface treatment and cleaning of the lead-wire insulation in accordance with the manufacturer's recommendations shall be accomplished before the anode connection is made.

4.5.5.3 The internal moisture seal must withstand the hydrostatic pressure and resist degradation from oxidizing gases released at the anode.

4.5.5.4 Center-connected anodes prevent lead-wire-to-anode connection failure caused by end effect on some types of anodes.

4.5.6 Backfill

4.5.6.1 In closed holes, conductive backfill should be used to lower the total resistance of the groundbed, to improve current distribution, to prolong anode life, to retard caving, and to provide a permeable medium for migration of gases.

4.5.6.1.1 Metallurgical coke breeze, calcined delayed petroleum coke, and calcined fluid petroleum coke may be used as conductive carbonaceous backfill around impressed current anodes.

4.5.6.1.2 Factors to be considered in the selection of backfill include resistivity, particle size, specific weight, density, and chemical analysis.

4.5.6.1.3 Backfills specially formulated to facilitate pumping, settling, and compaction can be used to improve groundbed performance and life. Desirable properties of these backfills are:

- Minimum specific gravity of 1.90
- Minimum bulk density of 1,040 kg/m^3 (65 lb/ft^3)
- Small-diameter spherical shape with approximately 98% passing a 20-mesh screen and more than 80% retained on a 100-mesh screen
- Fixed carbon content in excess of 98%
- Volatile content less than 0.3%

4.5.7 Casing

4.5.7.1 Casing may be required to control caving, to seal off and prevent undesirable transfer between water-bearing formations, and to comply with local, state, and federal codes and regulations.

(2) American Society for Testing and Materials (ASTM), 100 Barr Harbor Dr., West Conshohocken, PA 19428-2959.

4.5.7.2 Metallic casing (such as steel, iron, or aluminum) may be used if the casing does not result in undesirable current discharge at or near ground level. However, metallic casing should not be used opposite anodes in open-hole deep groundbeds.

4.5.7.3 Nonmetallic casing (such as cement, thermoplastics, or reinforced thermosetting materials) may be used to prevent current discharge at or near ground level.

4.5.7.3.1 Nonmetallic casing in open- or closed-hole deep groundbeds must be perforated in the active zone to permit current discharge. In closed-hole deep groundbed systems approximately 0.1 m^2 (1 ft^2) of perforation should be allowed per 1,200 mA of current discharge. Perforation width or diameter should be a minimum of two times the nonmetallic casing thickness in closed-hole deep groundbed systems to maximize electric current flow.

4.5.8 Venting Facilities

4.5.8.1 Gases in deep groundbeds may occur naturally or may be produced by electrolysis. Most deep groundbeds should be provided with an adequate vent pipe to prevent gas blockage. This vent pipe should be carried to a sufficient height to prevent damage to surrounding equipment and intrusion of surface water.

4.5.8.1.1 All deep groundbed installations (rectifier, hole, and venting location) shall be marked with adequate signs advising personnel to vent the installation properly before commencing work and to keep fire or sparks away from the installation.

4.5.8.2 Open-hole groundbeds and continuous steel anode groundbeds do not require vent pipes to prevent gas blockage but may need aboveground venting.

4.5.8.3 Nonmetallic, perforated vent pipes such as thermoplastics and reinforced thermosets may be used. The perforation should be throughout the active zone. The perforations should be sufficiently large (150 µm [0.006 in.]) up (minimum) to allow gas to pass and small enough (230 µm [0.009 in.]) (maximum) to minimize debris intrusion.

4.5.8.3.1 Materials selection shall be based on expected environmental conditions, as well as mechanical, fire, safety, and other regulatory requirements.

4.5.9 Junction Box

4.5.9.1 An adequately sized weatherproof junction box may be provided to terminate the anode lead wires and rectifier positive lead. A nonconductive panel equipped with individual shunts, lead wire terminal connections, provision for resistors, and a common bus bar facilitates testing. The junction box shall be designed to dissipate heat generated by resistors.

4.5.9.1.1 Junction box selection should be in compliance with fire and safety code requirements.

4.6 Typical deep groundbed designs are shown in Appendix A.

Section 5: Installation

5.1 This section recommends installation techniques for deep groundbeds that should result in cathodic protection of the structure of interest when design considerations recommended in Section 4 have been followed.

5.1.1 When casing is required, it is usually set prior to installation of the anodes. If the casing is pulled after completion of the deep groundbed, care must be taken to protect the anode lead wires from damage.

5.2 Downhole Tests

5.2.1 A resistance profile test may be made to determine the best positioning of anodes for optimum current output consistent with uniform anode life. However, this test may not be applicable for continuous steel groundbed systems.

5.2.1.1 One method of conducting a resistance profile test is to measure the resistance between an anode in the water-filled hole and the structure to be protected. Continuous measurements or measurements at anode-length intervals should be taken throughout the portion of the hole considered for possible anode placement.

5.3 Anode Assembly

5.3.1 Downhole components should not be bundled or fastened with materials that can cause gas blockage or backfill bridging.

5.3.2 The free end of each anode lead wire should be permanently identified as to depth.

5.3.2.1 The lead-wire-to-anode connection resistance shall be checked before installation by using a suitable instrument, such as a wheatstone bridge resistance instrument.

5.3.3 The lead wire insulation must be protected from abrasion and sharp objects. Minimum bending radius of lead wires must conform to the manufacturer's recommendations.

5.3.3.1 Prior to installation, lead-wire insulation shall be visually inspected for flaws or damage.

5.3.3.2 Further assurance of lead-wire insulation integrity may be achieved by conducting suitable wet tests (refer to ASTM D 3032), using proper safety precautions.

5.4 Anode Placement Methods

5.4.1 Closed Hole: Individual anodes should be centered in the hole with a suitable device that allows passage of backfill material, does not entrap gases, and does not damage lead wire insulation or preclude proper placement of anodes.

5.4.1.1 If the pumping method of backfilling is used, all anodes should be placed at the predetermined depth prior to pumping backfill. If venting facilities are needed, the vent pipe should be placed from the bottom anode to the top of the hole prior to filling (see Paragraph 5.6).

5.4.1.2 If the pouring or shoveling method of backfilling is used, the drilling mud should be displaced with clear water, and the vent pipe and the two deepest anodes should be placed at their predetermined depth. Backfill material should be poured into the hole to cover the first anode, then the third anode should be placed. This procedure should be repeated for each additional anode (see Paragraph 5.6).

5.4.1.2.1 The backfill material should be mixed with water to form a slurry to avoid bridging of the backfill as the hole is filled.

5.4.1.3 If packaged anodes are used, additional backfill material should be installed if possible (see Paragraph 5.6.1).

5.4.1.4 Vertical shifting of anodes may be necessary if strata resistivities permit.

5.4.1.5 Continuous anodes may be installed with or without the addition of recommended backfill materials (see Paragraph 4.5.6.1).

5.4.2 Open Hole: The anodes may be installed in an open hole if caving is not considered a factor or is controlled by suitable casing. The anodes should be centered in the open hole within the aqueous electrolyte.

5.4.2.1 The suspended anodes may be raised, lowered, or removed for inspection by individual lead wires.

5.4.2.2 Some lead-wire-to-anode connections may not sustain the anode weight, and additional means of support must be used (see Paragraphs 4.5.3.4 and 4.5.5.1).

5.4.2.3 Continuous anodes do not usually require individual suspension.

5.5 Venting Facilities – Closed Hole

5.5.1 A suitable permeable backfill material facilitates venting of gases.

5.5.2 The use of one or more plastic vent pipes aids in the dissipation of gases.

5.5.2.1 Plastic vent pipes normally have a series of small holes or slits in the immediate vicinity of the anodes. These openings should be small enough to prevent entry of the backfill material (see Paragraph 4.5.8.3).

5.5.2.2 The vent pipes should be capped at both ends during the backfilling operation to minimize filling with backfill material or mud.

5.5.2.3 A threaded fitting installed at the surface end of the vent pipes facilitates water or air injections, which may be required to eliminate gas blockage. The use of a screened bushing in the threaded fitting prevents entry of insects and foreign objects. The connection of a hose to the vent pipe, with the end inserted in an open water container, provides a visible test of gas venting.

5.5.2.4 Vent pipes shall be located so as to preclude the entry of corrosive gases into the junction box and rectifier. All lead-wire conduits should be sealed (see Paragraph 4.5.8.1).

5.5.2.5 The end of the vent pipe shall be located at a height that precludes any possible entry of contaminants into the deep groundbed.

5.6 Carbon Backfill – Closed Hole

5.6.1 A uniformly low-resistivity carbon backfill should be installed in the hole until the top anode is adequately covered (see Paragraph 4.5.6.1). The remainder of the hole may be left open or filled (see Section 3).

5.6.2 Backfilling can be accomplished by pumping, shoveling, or pouring. The methods to be used are usually determined by the characteristics of the strata and the backfill material selected.

5.6.2.1 Carbon backfill specifically designed for deep groundbed installation (refer to Paragragh 4.5.6.1.3) should be used. Backfill with a high surface tension that tends to float should be avoided. Wetting agents used properly can assist in settling and pumping of backfill.

5.6.2.2 Pre-soaking of packaged anodes with potable water is recommended to minimize the absorption of mud.

5.6.2.3 Backfilling of holes containing drilling mud and water may be accomplished by pumping the backfill material in slurry form to the bottom of the hole and allowing the hole to fill from the bottom up to displace the drilling mud and water.

5.6.2.3.1 The fill pipe diameter shall be sufficiently large to permit pumping the backfill material. To avoid clogging the fill pipe, backfill pumping should be continuous.

5.6.3 Depending on design, observations of the change in anode resistance to earth may be used to determine whether the backfill material has been placed around the anode.

5.7 Sealing Addressment

5.7.1 Closed Hole: Sealing should be installed during the appropriate sequence of the installation. Holes with no casings should be sealed after anodes and backfill have stabilized. Surface casing should have seals installed after insertion. Holes with casings extending from bottom to the earth surface should be sealed after stabilization of the anodes and backfill.

5.7.1.1 Surface casings and vents should be sealed or designed to prevent entry of surface fluid.

5.7.1.2 Seals addressing interchange flow may be installed during or after anode and backfill installation depending on design of the seal.

5.7.2 Open Hole: The surface casing of an open hole should be sealed upon installation. The casing should be designed to prevent entry of surface fluid. Interchange flow in the active zone of an open hole should be avoided.

5.8 Junction Box

5.8.1 A suitably sized weatherproof junction box may be installed for individual termination of anode and rectifier positive lead wires.

5.8.2 A shunt can be installed in each anode circuit to monitor the current output.

5.8.3 Resistors may be installed in individual anode circuits to balance anode outputs.

5.8.4 Sealing the cable entry may be necessary to prevent entry of gases.

5.8.5 Sealing the anode wires to prevent capillary action between insulation layers may be necessary to prevent corrosive elements from entering the junction box.

5.9 Covering the Hole

5.9.1 A means of capping or covering the anode hole shall be used to protect the installation.

5.9.1.1 Deep groundbeds, with casings above grade, should be equipped with a cap or cover that is secured to prevent unauthorized entry.

5.9.1.2 If a casing is not used or is terminated below grade, a properly supported cover shall be installed.

5.9.1.3 Venting must be provided to prevent accumulation of gases.

Section 6: Operation, Maintenance, and Replacement

6.1 This section recommends operating, maintenance, and replacement procedures for deep groundbed systems. This section also identifies the most frequently encountered problems and suggests corrective measures.

6.2 Recommended Operating Procedures

6.2.1 The groundbed installation should be energized and adjusted to conform to the required output.

6.2.2 Initially, individual anode outputs should be measured, recorded, and adjusted as required until relatively stable conditions are achieved. These data may be useful for the evaluation of groundbed performance.

6.2.2.1 If resistance is added to adjust anode output, it may be necessary to adjust the rectifier to restore the required output.

6.2.3 Periodically, the resistance of the groundbed to earth should be calculated, and if it has significantly changed, the individual anode outputs should be adjusted for optimum groundbed performance. This information should be recorded, because it may indicate deterioration of the groundbed.

6.2.4 The operation of the power source shall be inspected periodically to meet company and regulatory requirements.

6.3 Common Operating Problems

6.3.1 In closed holes, gas blockage may be a major problem and usually results from inadequate venting.

6.3.1.1 Gas is generated when electrical energy is dissipated from deep groundbeds.

6.3.1.2 Gas blockage may occur at the deepest anode first, and progress upward in the hole. This may result from gradual settling of backfill particles, silt, and other foreign materials, or from plugging of the vent pipe.

6.3.1.3 Effects of gas blockage are similar to those resulting from inadequate moisture (see Paragraph 6.3.2).

6.3.2 Increased groundbed resistance resulting from inadequate moisture usually occurs at the shallowest anode and progresses downward in the groundbed.

6.3.3 The failure of the anode, lead wire, insulation, or anode connection results in diminished or complete loss of anode output (see Section 4 for further information).

6.3.3.1 Some causes of anode failures are:

6.3.3.1.1 Severe environmental conditions (including lightning)

6.3.3.1.2 Mechanical damage to anode during handling or installation

6.3.3.1.3 Anode end effect

6.3.3.1.4 Manufacturing defects

6.3.3.1.5 Improper material selection

6.3.3.1.6 Damage by outside parties

6.3.3.2 Some causes of lead-wire failures are:

6.3.3.2.1 Severe environmental conditions

6.3.3.2.2 Mechanical damage to insulation during handling or installation

6.3.3.2.3 Manufacturing defects

6.3.3.2.4 Improper material selection

6.3.3.2.5 Inadequate moisture seal on electrical connections

6.3.3.2.6 Damage by outside parties

6.4 Corrective Action

6.4.1 Gas blockage may sometimes be cleared by injecting water or air through the existing vent pipe or by clearing the vent pipe with a smaller-diameter tube or rod.

6.4.1.1 Installations without vent pipes may sometimes be cleared of gas blockage by jetting a pipe or tube down the hole to the affected area. Caution shall be exercised to avoid damaging the anode lead wire or the anodes.

6.4.1.2 Short-term de-energizing of all or the affected anodes may temporarily lower groundbed resistance and improve current output.

6.4.1.3 Reduction or redistribution of anode current density may reduce the effects of gas blockage.

6.4.2 Under dry conditions, potable water may be added through the vent pipe or other design method to lower groundbed resistance.

6.4.3 It may be necessary to repair the casing cover, anode junction box, vent pipe, or cables due to damage done by outside parties.

6.5 Recommended Replacement Procedures for Replaceable Deep Groundbed Systems

6.5.1 In closed holes designed to be replaceable, anodes may be replaced once the carbon backfill has been removed.

6.5.1.1 Backfill may be removed by flowing water down a pipe or hose as the pipe or hose is lowered into the deep groundbed system.

6.5.1.2 The flowing water should be circulated using open tanks to allow for a method of collecting the carbon backfill being removed.

6.5.1.3 After the carbon backfill has been removed, the expended anodes and other items within the system may be removed.

6.5.1.4 Once the expended anode material has been removed, new anodes, wire, and vent may be reinstalled. After the new materials have been placed, the carbon backfill may be reinstalled and the system finished.

References

1. NACE Standard RP0169 (latest revision), "Control of External Corrosion on Underground or Submerged Metallic Piping Systems" (Houston, TX: NACE).

2. NACE Standard RP0177 (latest revision), "Mitigation of Alternating Current and Lightning Effects on Metallic Structures and Corrosion Control Systems" (Houston, TX: NACE).

3. T.H. Lewis Jr., Deep Anode Systems (Houston, TX: NACE, 2000).

4. ASTM D 1248 (latest revision), "Standard Practice for Polyethylene Plastics Molding and Extrusion Materials" (West Conshohocken, PA: ASTM).

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NACE Publication 10A196 (latest revision). "Impressed Current Anodes for Underground Cathodic Protection Systems." Houston, TX: NACE.

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Appendix A: Typical Deep Anode Designs

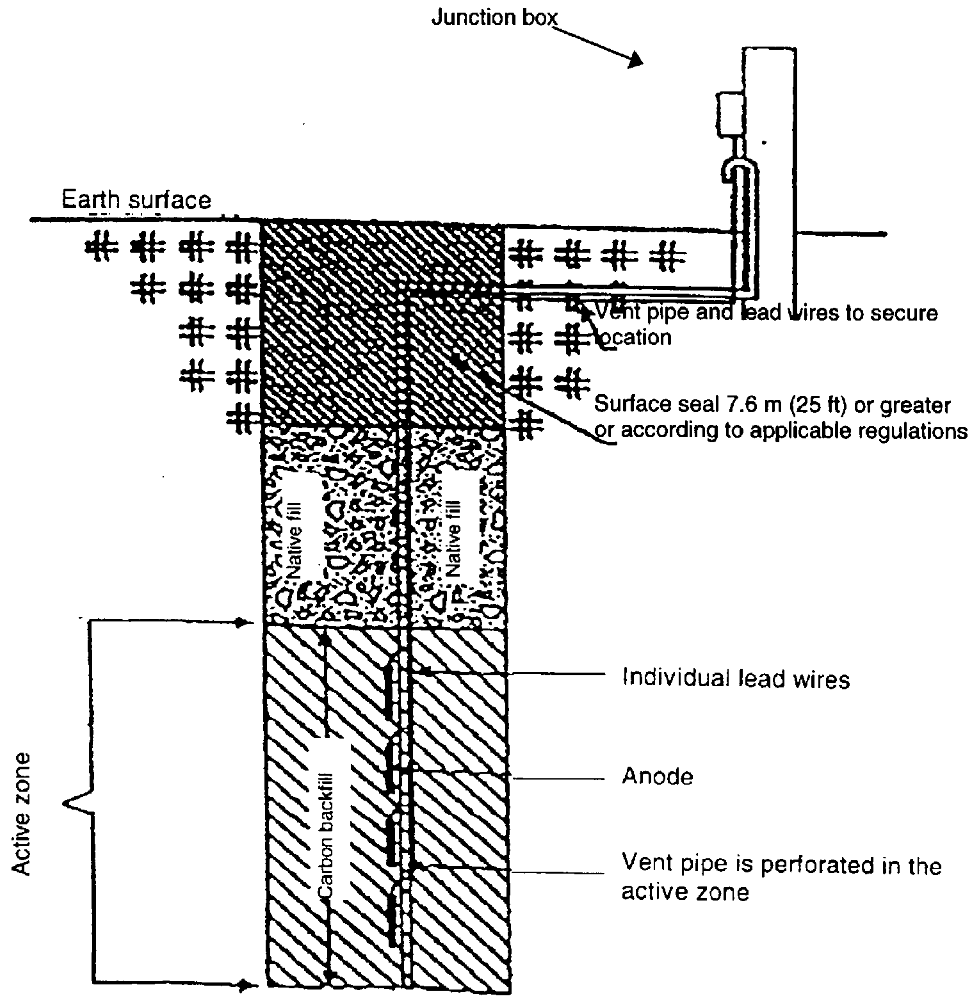

Figure A1: Closed Hole

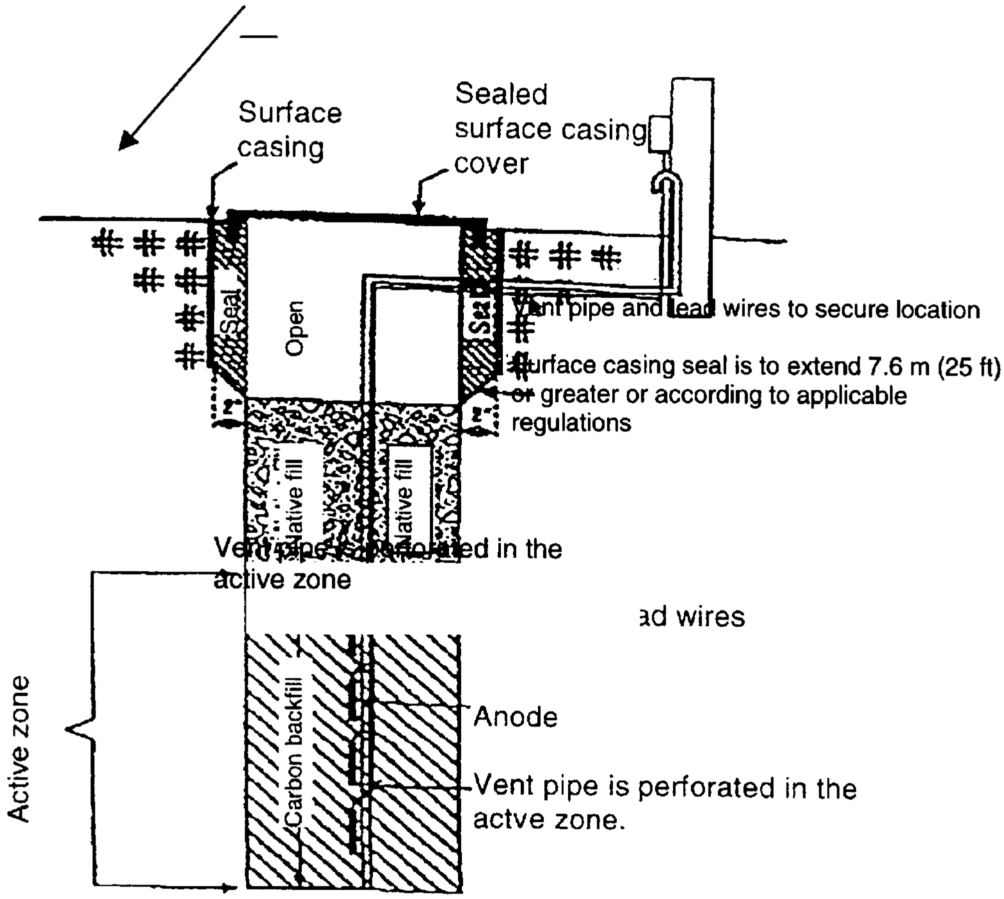

Figure A2: Closed Hole with Surface Casing

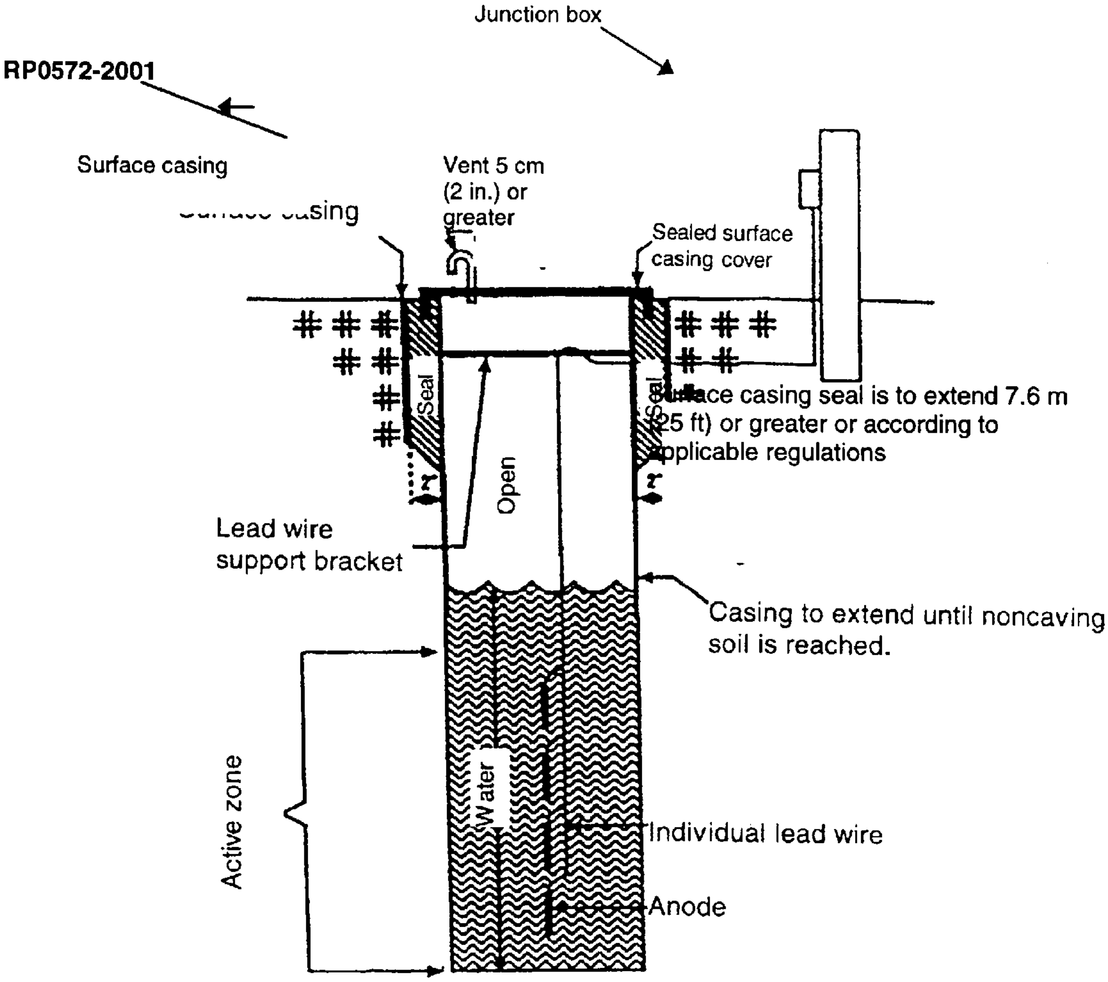

Figure A3: Open Hole with Surface Casing

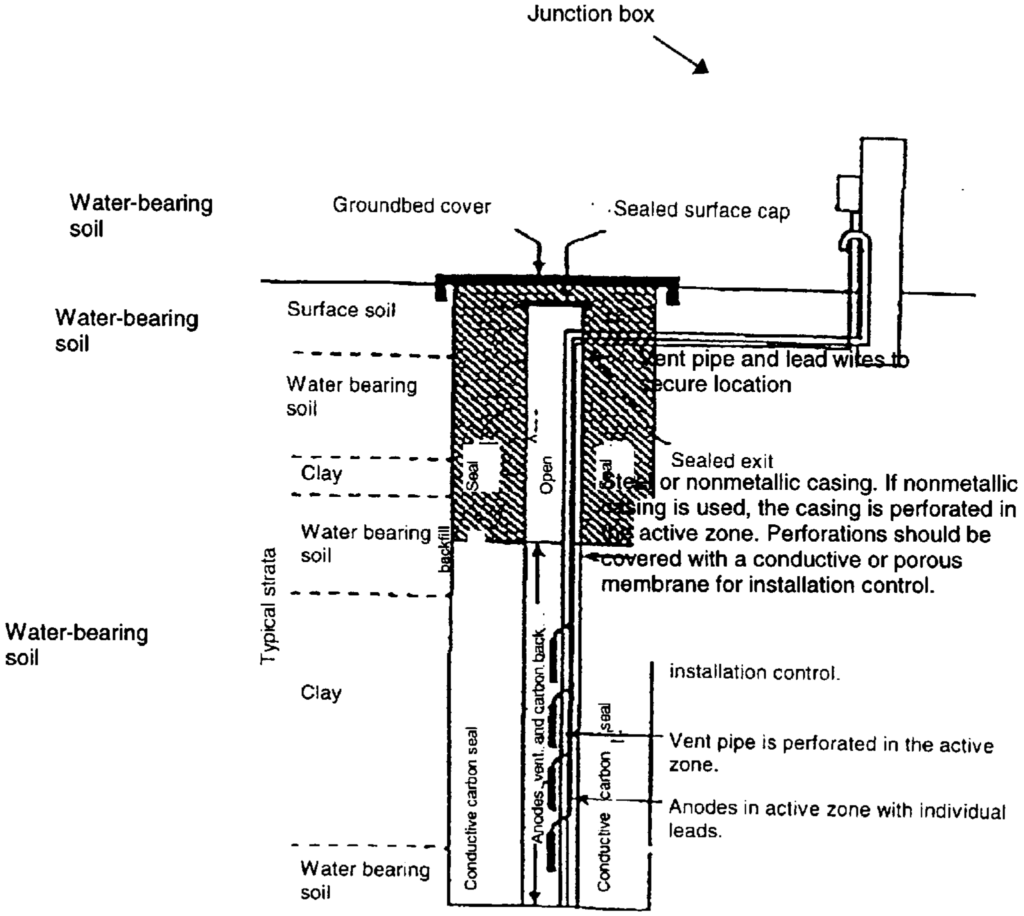

Figure A4: Environmentally Addressed System

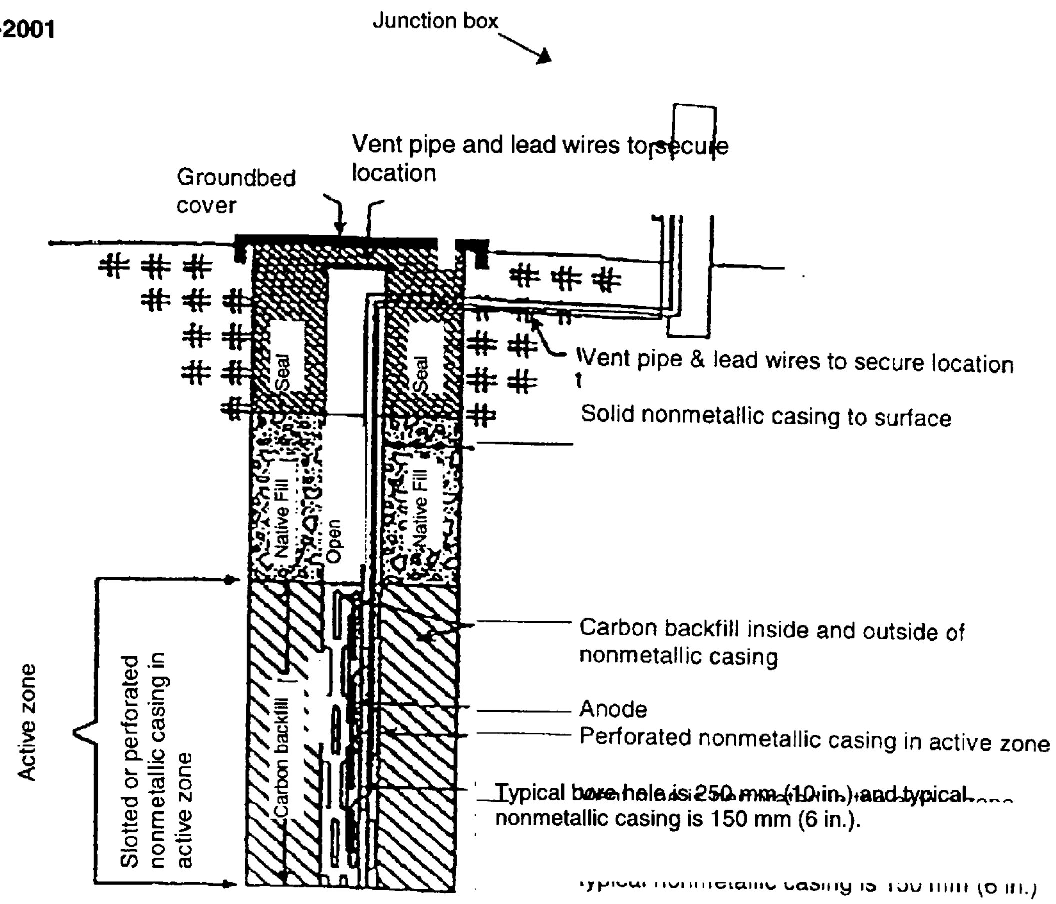

Figure A5: Typical Replaceable Closed Hole

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