
An Introduction to Constructing and Maintaining Cathodic Protection Systems

Course No: T02-009

Credit: 2 PDH

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An Introduction to Constructing and Maintaining Cathodic Protection Systems



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CONTENTS

- 1. INSTALLATION AND CONSTRUCTION PRACTICES**
- 2. SYSTEM CHECKOUT AND INITIAL ADJUSTMENTS**
- 3. MAINTAINING CATHODIC PROTECTION SYSTEMS**

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1. INSTALLATION AND CONSTRUCTION PRACTICES

1.1 FACTORS TO CONSIDER. Cathodic protection systems, and the structure to be protected, must be properly installed in order for effective protection to be achieved. NACE Standards RP-02 and RP-01 include guidelines for installation of such systems. Particular attention should be paid to maintaining the condition of the coating on the structure and maintaining the structural continuity and isolation required for proper cathodic protection system operation. If the coating on a structure is damaged (or absent), cathodic protection requirements will increase dramatically. A well-coated structure will often require only 1 percent or less of the current required to protect the same structure if bare. Sacrificial anode systems, which cannot be easily adjusted to provide increased current output, are the most susceptible to poor performance if the coating system does not meet original specifications. Open bonds and shorts to other structures are common causes of inadequate protection and the resulting interference can cause accelerated corrosion damage. Careful inspection during the entire construction process, both of the cathodic protection system and of the structures to be protected are vital to the successful application of cathodic protection.

1.2 PLANNING OF CONSTRUCTION. The most important factor in the planning of construction of facilities that include cathodic protection is the planning of inspections to insure that coatings are properly applied and not damaged during construction, and that proper isolation and bonding are achieved. For buried structures, these inspections must be performed before backfilling. Once the structure or other system components are buried, identification and correction of any discrepancies is difficult.

1.3 PIPELINE COATING. Interference problems are severe for long structures such as pipelines. It is highly desirable to reduce the amount of current required to protect pipelines to the lowest levels possible. High quality coatings, properly selected and applied, and installation of the line without damaging the coating is vital to achieving protection at the low current levels desired. Often, coating application and prevention of damage during installation are more important than the materials used.

1.3.1 OVER-THE-DITCH COATING. Over-the-ditch coating systems have the advantage of reducing handling of the coated pipe before installation. Over-the-ditch coating is best used when long sections of pipeline are to be installed in open areas under mild weather conditions. Depending on curing time for the coating, the pipe may either be lowered directly into the ditch after coating or may be held on skids until the coating is properly cured before lowering it into the ditch. If the pipe is lowered into the ditch directly after coating, the inspector should electrically inspect each section using a holiday detector or "jeep" immediately before backfilling. If the pipeline is held on skids, the skids should be padded to prevent coating damage. Damage caused by skids must be patched before inspection of the coating, lowering of pipeline into the ditch, and backfilling.

1.3.2 YARD APPLIED COATING. The use of yard or mill applied coatings is preferred over field applied coatings since better surface preparation and application are normally achieved under the more controlled conditions at a stationary plant. The coating should be inspected upon receipt at the construction site when unloading. Inspections should be performed immediately prior to placing the pipe in the ditch after all joint and field patches have been made.

1.3.3 JOINT AND DAMAGE REPAIR. Joints and field repairs should be made with coatings compatible with the primary coating system used. Joints and field patches should be carefully inspected before placing the pipe in the ditch.

1.3.4 INSPECTION. Electric Holiday Detectors should be used for all coating inspections. If properly used they can detect flaws in the coating which may not be visible. In addition to the use of the Holiday Detector, the inspector should also make detailed visual inspection of the coatings and occasional measurements of the bond strength. Visual inspection should also include observation of the following:

- a) surface preparation and coating - if practical
- b) handling of the pipe
- c) lowering of the pipe into the ditch

d) backfilling operations

Any material, even the highest quality, when applied and handled carelessly will perform poorly, but a marginal quality material will perform well when carefully applied and installed.

1.4 COATINGS FOR OTHER STRUCTURES. Coatings on other structures are equally critical when the cathodic protection system relies on the quality of the coating to achieve protective potentials with the available system current. Inspections during surface preparation, coating, handling, placement, and backfilling are vital to the performance of the overall system.

1.5 PIPELINE INSTALLATION. The use of casings to give mechanical protection to the pipeline at grade crossings, etc., is sometimes required by law, code, or physical condition. The use of casings should be avoided wherever possible due to the difficulty of protecting the pipeline within the casing and difficulties in maintaining isolation between the casing and the pipeline. The use of proper techniques when foreign pipeline crossings are made is necessary to minimize interference. Insulating joints should be properly installed. Effectiveness is achieved using adequate test and bonding stations.

1.5.1 CASINGS. Casings should be uncoated. The casing should be isolated from the pipeline with insulators and cradles which must be properly installed. The annular space at the ends of the casing should be sealed to prevent the entry of moisture between the casing and pipe. Extra thickness of coating on the pipeline for the section to be placed inside the casing may be required in order to prevent damage to the coating when the pipe is pulled into the casing. The annular space between the casing and the pipe must be kept dry until it is sealed. Casing-to-pipe resistance should be measured. A test station should be installed at the casing for future measurements. Figure 1 shows a test station for casing isolation testing.

1.5.2 FOREIGN PIPELINE CROSSINGS. Newly installed pipelines are common installed under existing lines. The owner of the foreign line should be contacted to obtain

permission to install test leads and possibly to coat short section of the foreign line. Since solutions to problems at foreign crossings require cooperative efforts, effective coordination is essential. Clearance of 2 feet between all lines at crossings is recommended. If 1-foot clearance cannot be obtained, the use of an insulating mat as is required. Direct contact between lines should be avoided at almost any cost. Installation of insulating mat crossings is recommended if substantial earth currents are detected in the area or if a new coated line is crossing a poorly coated or uncoated line. Installation of test stations with provisions for bonding at all crossings is essential.

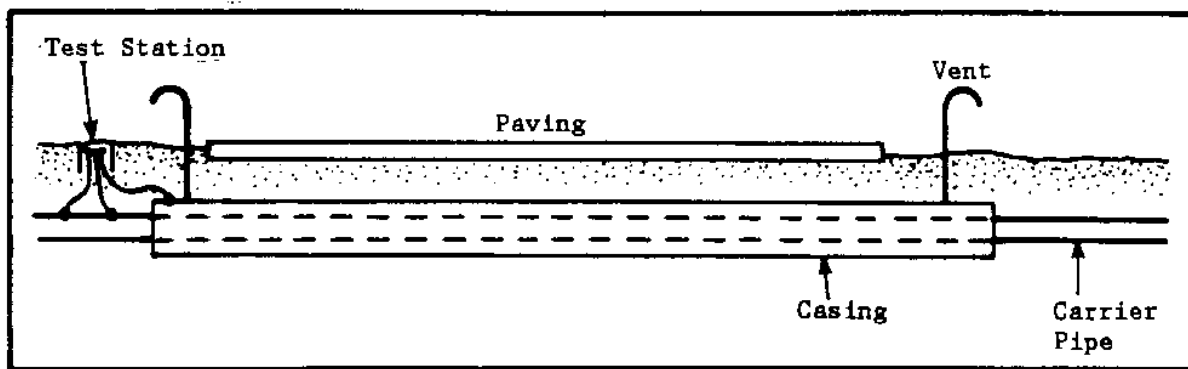


Figure 1

Test station for under-road casing isolation

1.5.3 INSULATING JOINTS. Insulating, or isolating joints must be selected so that the materials are compatible with the service environment. Isolation of steam conduits is especially troublesome. Isolating couplings must be properly assembled and tested to insure that they will be effective. When used on welded pipelines, short "spools" of pipe should be welded to each flange. The flange should then be assembled and the section welded into the pipeline. This will prevent mechanical damage to the insulating joint associated with misalignment. Flanges should be tested with a radio frequency type insulation checker after assembly to insure that they have been properly assembled. Effectiveness of buried flanges must be verified by impressing a potential on one side of the flange and measuring the change in potential on the other side of the flange. If little

or no potential change is noted, the isolating flange is effective. Test stations with provisions for future bonding should be installed at each buried insulating flange.

1.5.4 BONDS. Bonds between structure sections and to foreign structures should be made with No. 4 AWG, 7-strand insulated cable unless larger cable is required. Each bond should be brought into a test station to determine bond effectiveness and to install resistive bonds if required.

1.6 ELECTRICAL CONNECTIONS. Electrical connections to the structure are commonly made using thermo-weld techniques. The connections should be inspected visually before and after insulation is applied. If safety or other conditions preclude the use of the thermo-weld process on site, the leads should be attached to metal tabs by thermo-welding and the tabs either soldered or mechanically attached to the structure. All electrical connections should be insulated. Other electrical connections should be thermo-welded where practical as this method of connection is extremely reliable. Mechanical connections should be of the proper type for the intended use and should be properly assembled. All connections should be inspected before and after insulation.

1.7 TEST STATIONS. Test stations are required for initial test and adjustment of the cathodic protection systems, and for future inspection and maintenance. Attachment of "spare" test leads to buried structures is recommended as excavation to reconnect test leads is expensive. All test station leads should be either color coded or labeled with a metal or plastic tag. The connections to the structure should be inspected prior to burial of the structure. Whenever the structure will be located under a paved area, or whenever paving is installed over a protected structure, soil contact test stations as shown in should be installed.

1.8 SACRIFICIAL ANODE INSTALLATION. Sacrificial anodes should always be installed at least 3 feet below grade whenever possible. The top of the anode should be at least as deep as the structure to be protected. Horizontal sacrificial anode installations should be used only if obstructions such as rock outcrops preclude vertical installations.

Anodes suspended in water should be installed according to the system design and a cable connection between the structure and the suspension link is normally required. Anode lead wires should never be used to suspend, carry, or install the anode.

1.8.1 VERTICAL. Sacrificial anodes are commonly installed vertically in augered holes. If caving or unstable soil conditions are encountered, a thin metal (stovepipe) casing may be used. Anodes should be located on alternating sides of the pipe when possible to reduce interference and allow for more even current distribution. Any impermeable wrapping should be removed from packaged anodes prior to placing them in the holes. The cloth bag used with packaged anodes should be carefully handled as loss of backfill will result in reduced anode output. The anodes should be lowered into the holes either by hand, or by the use of a line attached to either the anode, if bare, or the top of the bag of backfill. The anode lead cable should not be used to lower the anode into the hole as the anode-to-cable connection is easily damaged. Sufficient slack should be left in the anode cable to prevent strain on the cable. All connections should be properly made and inspected before the installation is buried. If packaged anodes are not used and special backfill is required, it should be poured into the holes as the anodes are installed. Anode holes should be backfilled with fine soil free of stones or other debris. Sand should not be used. The backfill should be placed in 6-inch lifts and each lift tamped into place to eliminate voids.

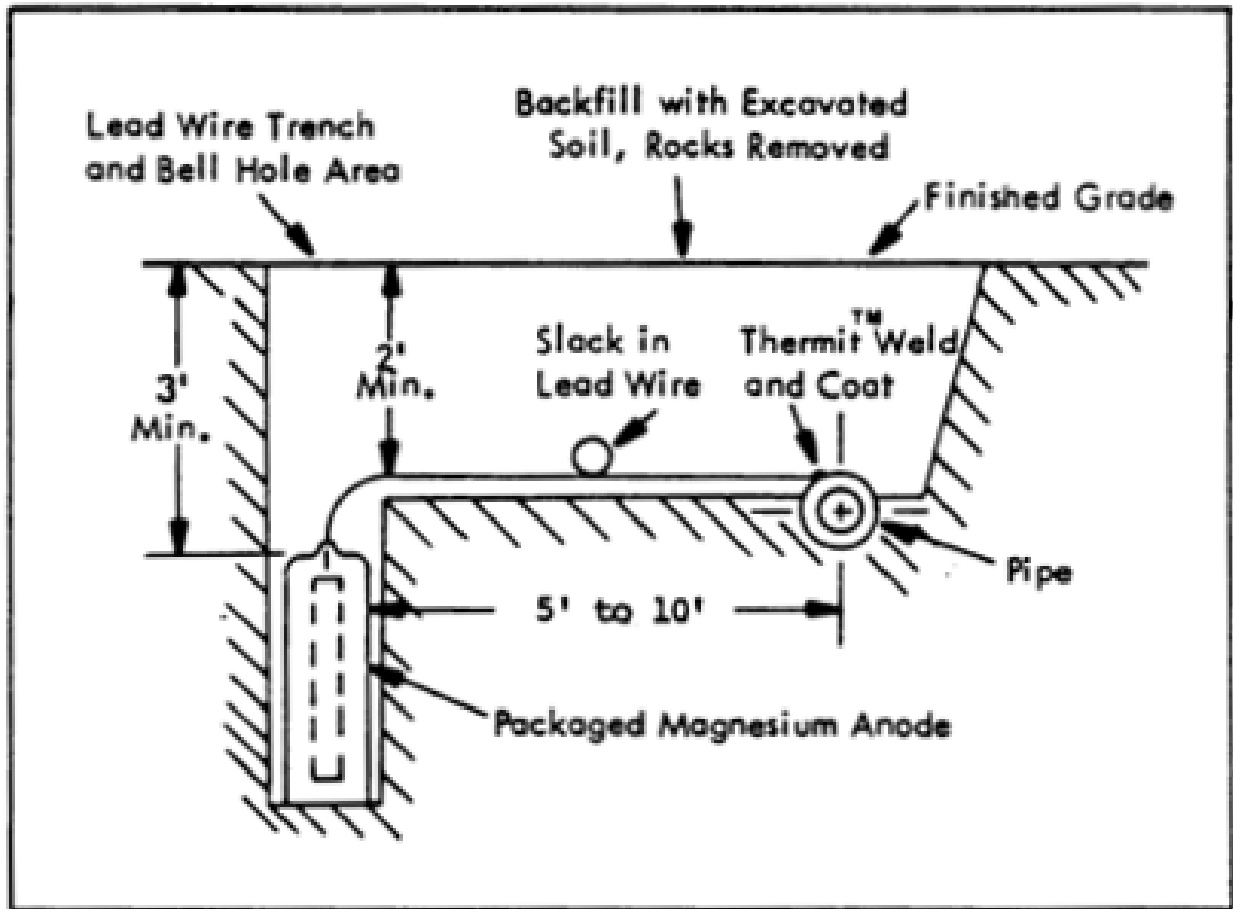


Figure 2
Vertical sacrificial anode installation

1.8.2 HORIZONTAL. Horizontal installation of sacrificial anodes is sometimes required due to obstructions or to limitations in right of way. Where obstructions are encountered, the anode may be installed as shown in Figure 3. Where right of way problems are encountered the anode may be installed vertically below the pipe or obstruction as shown in Figure 4.

1.9 IMPRESSED CURRENT ANODE INSTALLATION. Selection of sites for the rectifiers, anode beds, test stations, and other components of an impressed current cathodic protection system should be made during the system design. As in the case of sacrificial anode systems, impressed current systems must be carefully installed in order to operate properly and reliably. The most common type of impressed current anode installation is vertical. Horizontal installations are sometimes used if obstructions are encountered or if near surface soil resistivities are sufficiently low. Deep well anode installations are used to reduce interference effects or to reach low resistivity soil. Anode lead wires should never be used to suspend, carry, or install anode.

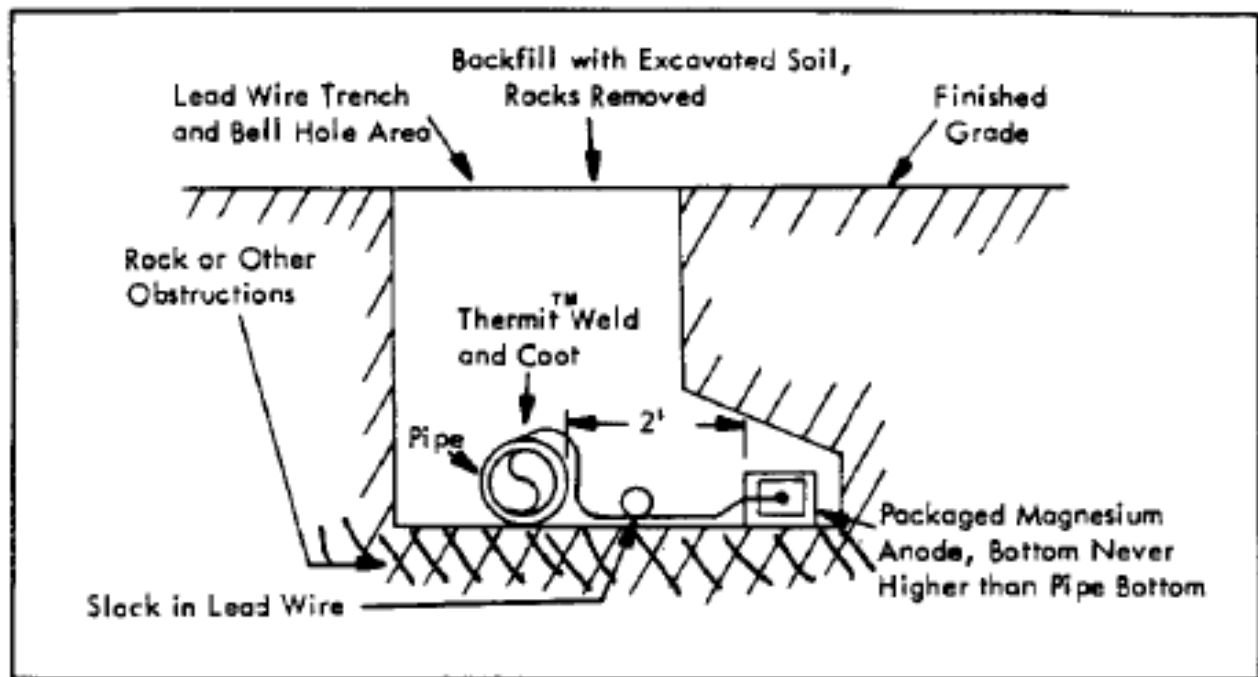


Figure 3

Horizontal sacrificial anode installation when obstruction is encountered

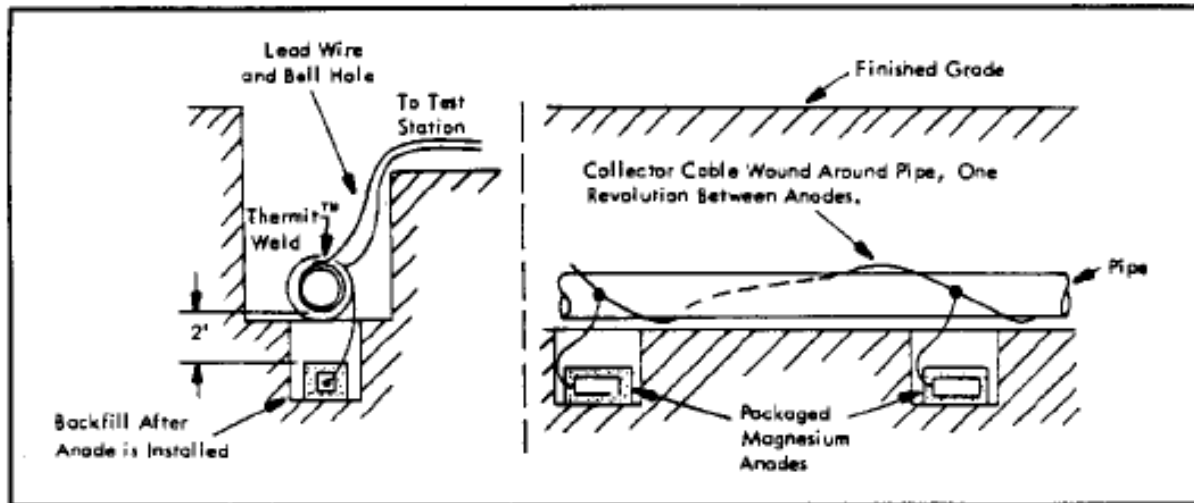


Figure 4

Horizontal sacrificial anode installation – limited right-of-way

1.9.1 VERTICAL. This is the most common type of impressed current anode installation. Both graphite and HSCBCI anodes are brittle and must be carefully handled to prevent breakage. The anode cable is particularly prone to failure if the insulation is damaged in any way and particular care must be exercised in handling the anode leads. As impressed current cathodic protection anodes are generally longer than sacrificial anodes, excavation of holes for them is often more difficult. "Jetting" of bare anodes is sometimes possible in sandy soils using equipment specially designed for this purpose.. If caving of the hole is encountered, either the use of a packaged "canned" anode complete with backfill, or a thin metal "stovepipe" casing may be necessary. If bare anodes are used, the backfill should be added as soon as the anodes are placed. The backfill should be well tamped to insure good contact with the anode. The backfill should be used to fill the hole to within a few inches of grade unless coarse gravel is available for this purpose. This is to allow the gasses generated during system operation to be properly vented. A typical vertical anode installation using a bare HSCBCI anode with backfill is shown in Figure 5. A typical vertical installation of a "canned" HSCBCI anode is shown in Figure 6.

1.9.2 HORIZONTAL. Horizontal installations of impressed current anodes are less expensive than vertical anodes. Horizontal installations may be necessary when

obstructions or other soil conditions make augering of deep holes difficult. Horizontal installations are also used where soil resistivities are very low and the increased resistance of the horizontal installation is not significant. A typical horizontal installation of a HSCBCI anode is shown in Figure 7. A minimum of 2 feet of burial for all cables and 3 feet of burial for the anode is recommended. The excavation should be partially filled with backfill before the anode is placed. After the anode is placed, the remainder of the backfill should be added and tamped into place. If backfill is not required, soil free from stones or debris should be used to fill the excavation. Again, it must be remembered that impressed current anodes, and particularly the anode leads, are susceptible to damage and must be handled carefully.

1.9.3 DEEP ANODE BEDS. In some installations where interference problems are severe, anode beds are sometimes installed deep below the surface. This causes the current flow to become more vertical and reduces interference between horizontally displaced structures. Deep anodes are also used where the resistivity of the soil near the surface is high. Anodes installed deeper than 50 feet are called "deep" anodes. Specialized equipment and skill is required for the installation of such an anode array. Installation of deep anode systems is described in NACE Standard RP-50-72. Type TAD HSCBCI or center tapped 3- by 60-inch graphite are suitable for such installations. Newly developed deep anode systems using platinized anodes show considerable promise for such applications. A typical deep anode system using HSCBCI anodes is shown in Figures 8 and 9.

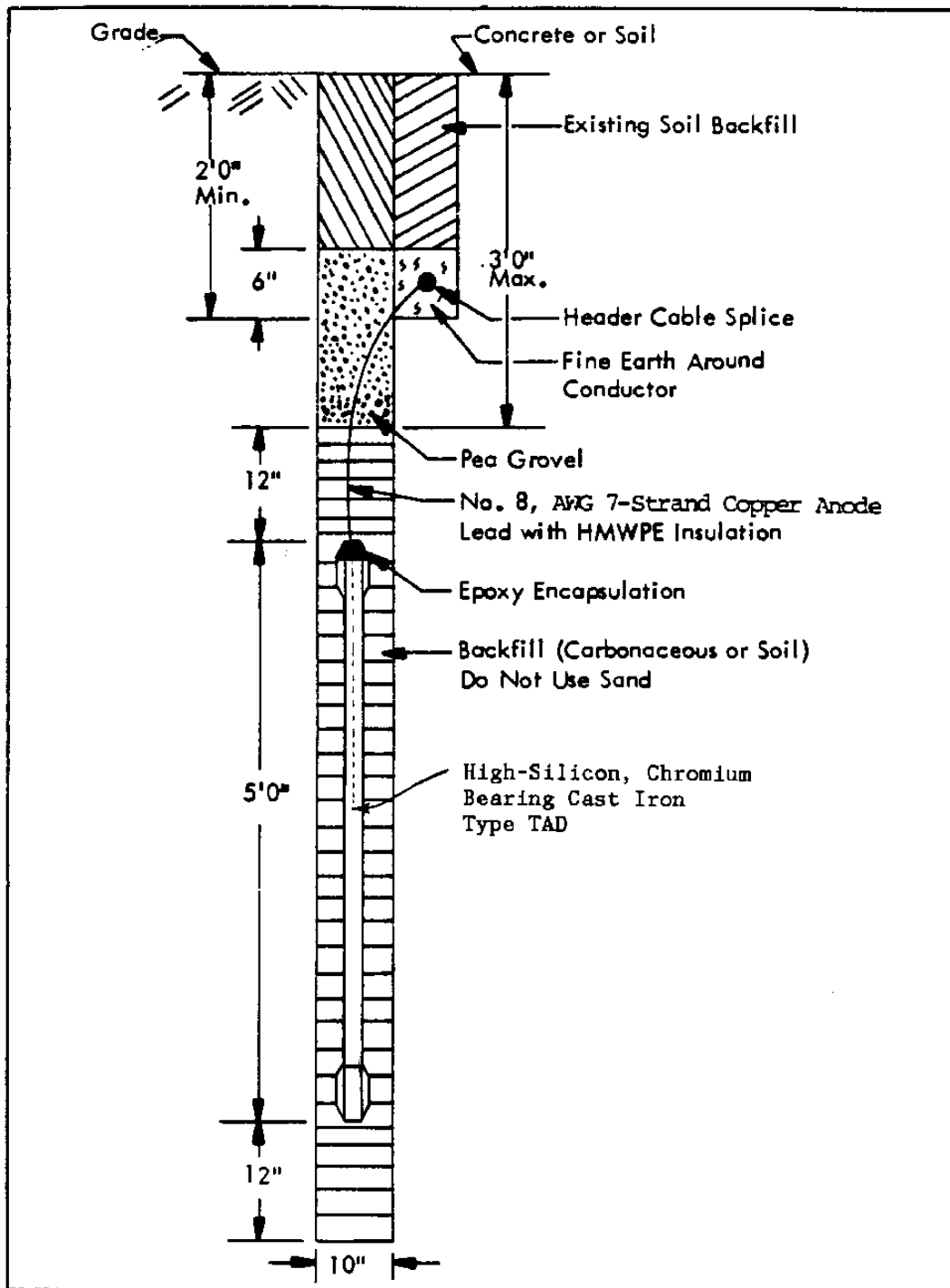


Figure 5
Vertical HSCBCI anode installation

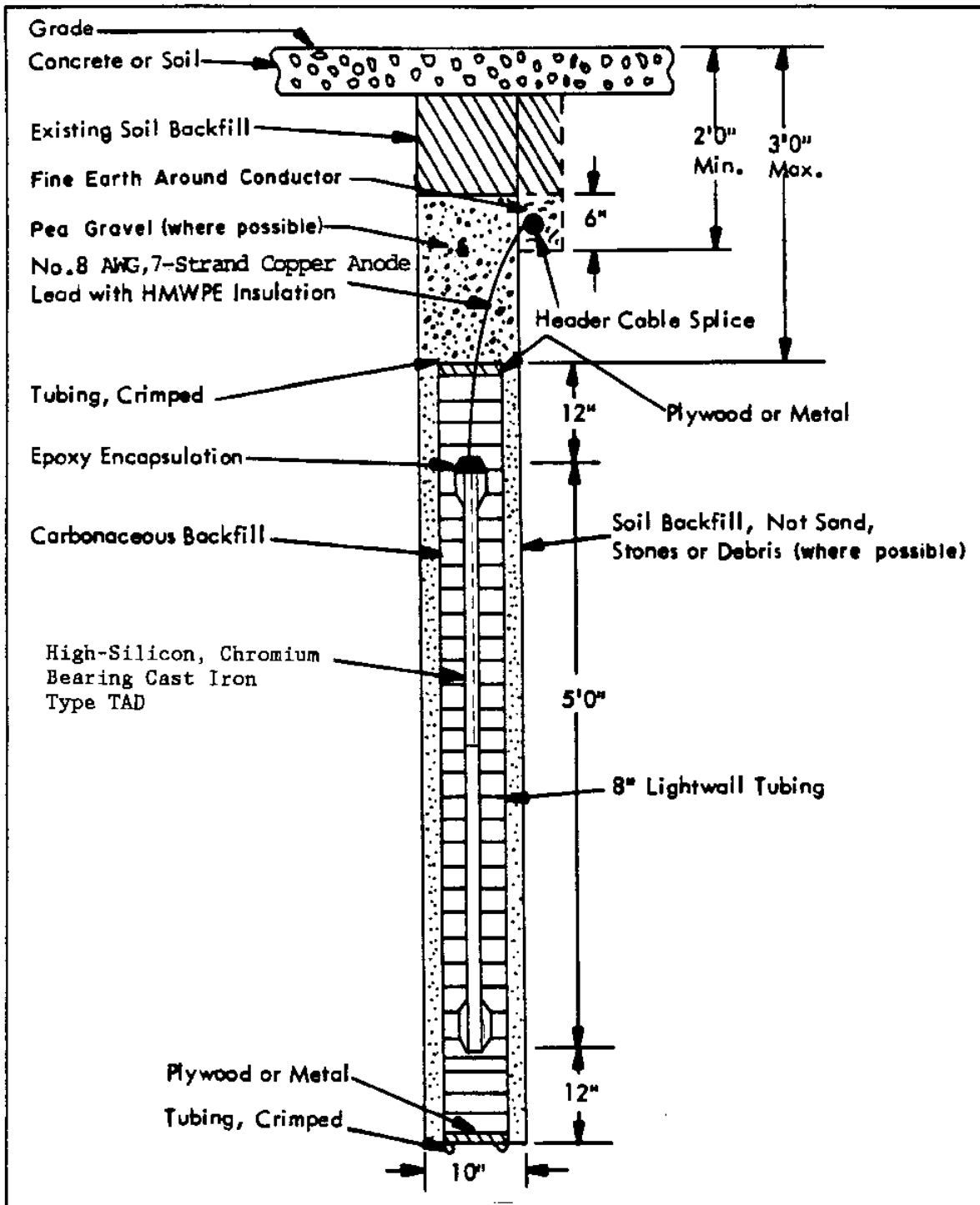


Figure 6

Vertical HSCBCI anode installation with packaged backfill

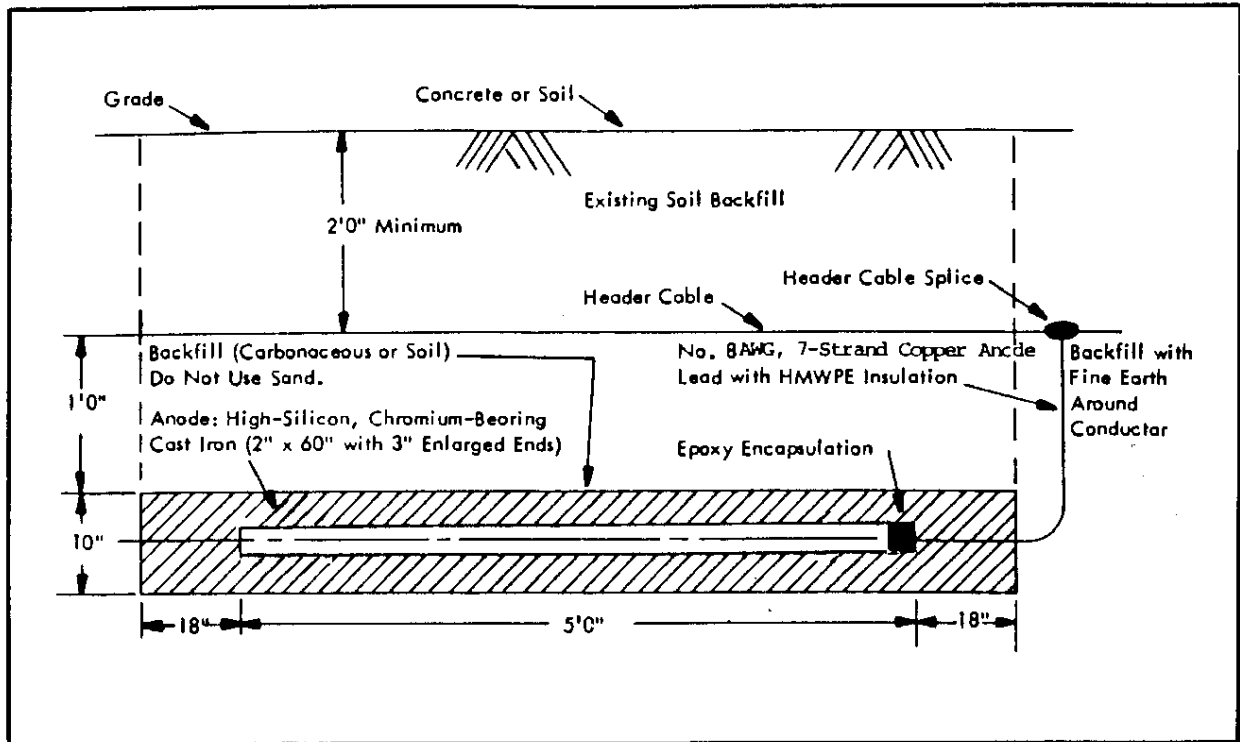


Figure 7
Horizontal HSCBCI anode installation

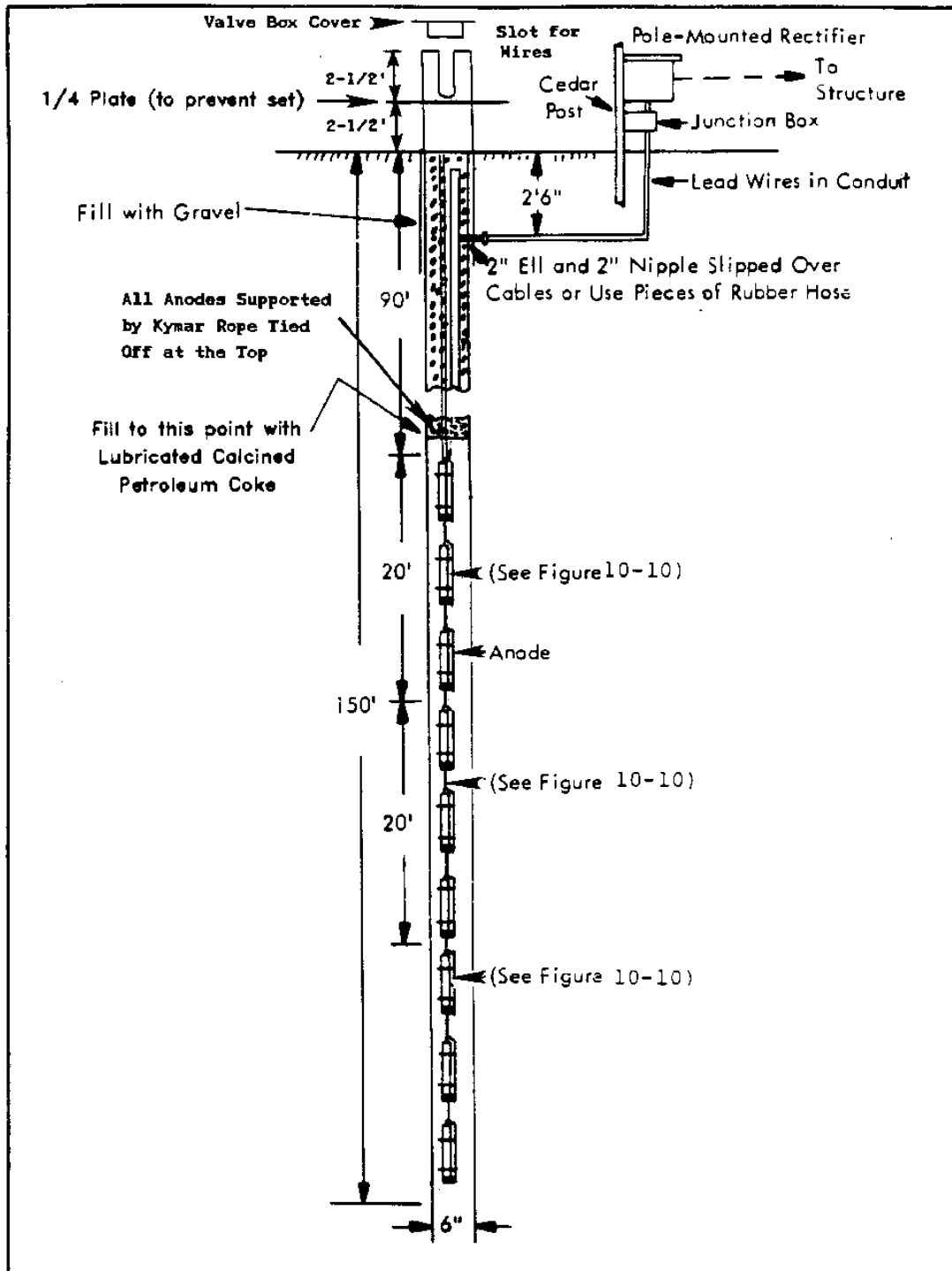


Figure 8

Typical deep well anode cathodic protection installation

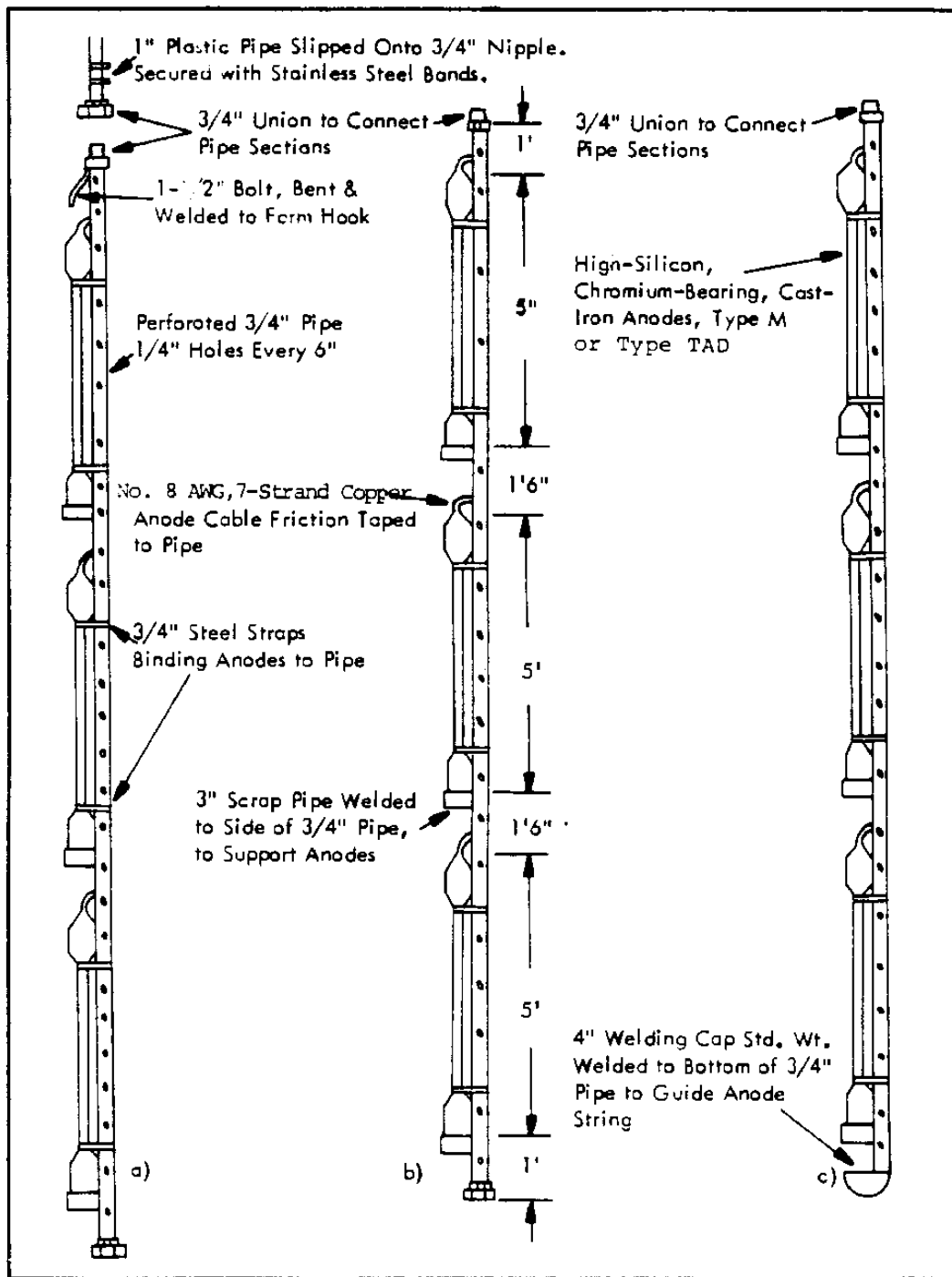


Figure 9
Deep anode installation details

1.9.4 OTHER ANODE TYPES. Button anodes and platinized anodes are commonly mounted directly on the structure. Their installation requires that the anode element be electrically isolated from the structure so that the protective current will flow through the electrolyte. Maintaining this isolation requires that the anodes be mounted in accordance with the manufacturer's instructions for the specific type and size of anode being used. In addition, a high quality protection coating or plastic shield is often required in the vicinity of a flush-mounted anode in order to insure proper current distribution. Anodes suspended in water should never be suspended using the cable leads but should be suspended using either chemical resistant lines or net bags. Nylon and polypropylene are commonly used for such applications.

1.9.5 CONNECTIONS. All connections between the anodes and rectifier in impressed current cathodic protection systems are extremely critical. The number and location of all connections and splices should be kept to a minimum and should be installed according to the design and not left to the discretion of the installer. Thermo-weld connections are preferred, although mechanical connections may be used. All of the connections in contact with the electrolyte should be encapsulated using epoxy material.

1.10 IMPRESSED CURRENT RECTIFIER INSTALLATION. Rectifiers are usually either pole-mounted or pad-mounted units. They should be installed according to applicable codes and guidance applicable to all electrical. Even though exposed wiring may be permissible, wiring in conduit is preferred to reduce vandalism and deterioration. All rectifier installations should be equipped with a fused switch to allow disconnection of power to the rectifier. Typical pole mounted and pad mounted rectifier installations are shown in Figures 10 and 11.

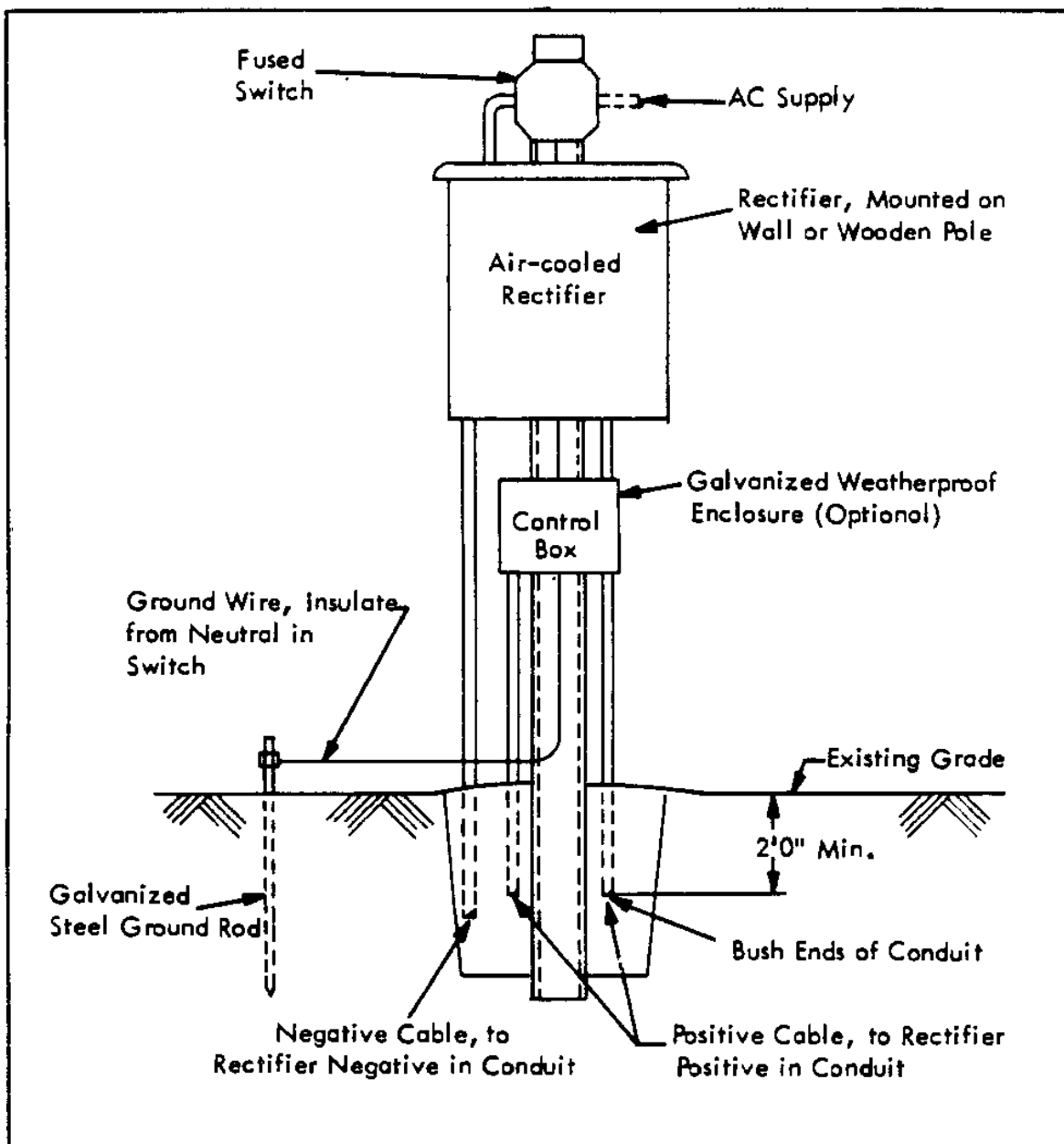


Figure 10
Typical pole mounted cathodic protection rectifier installation

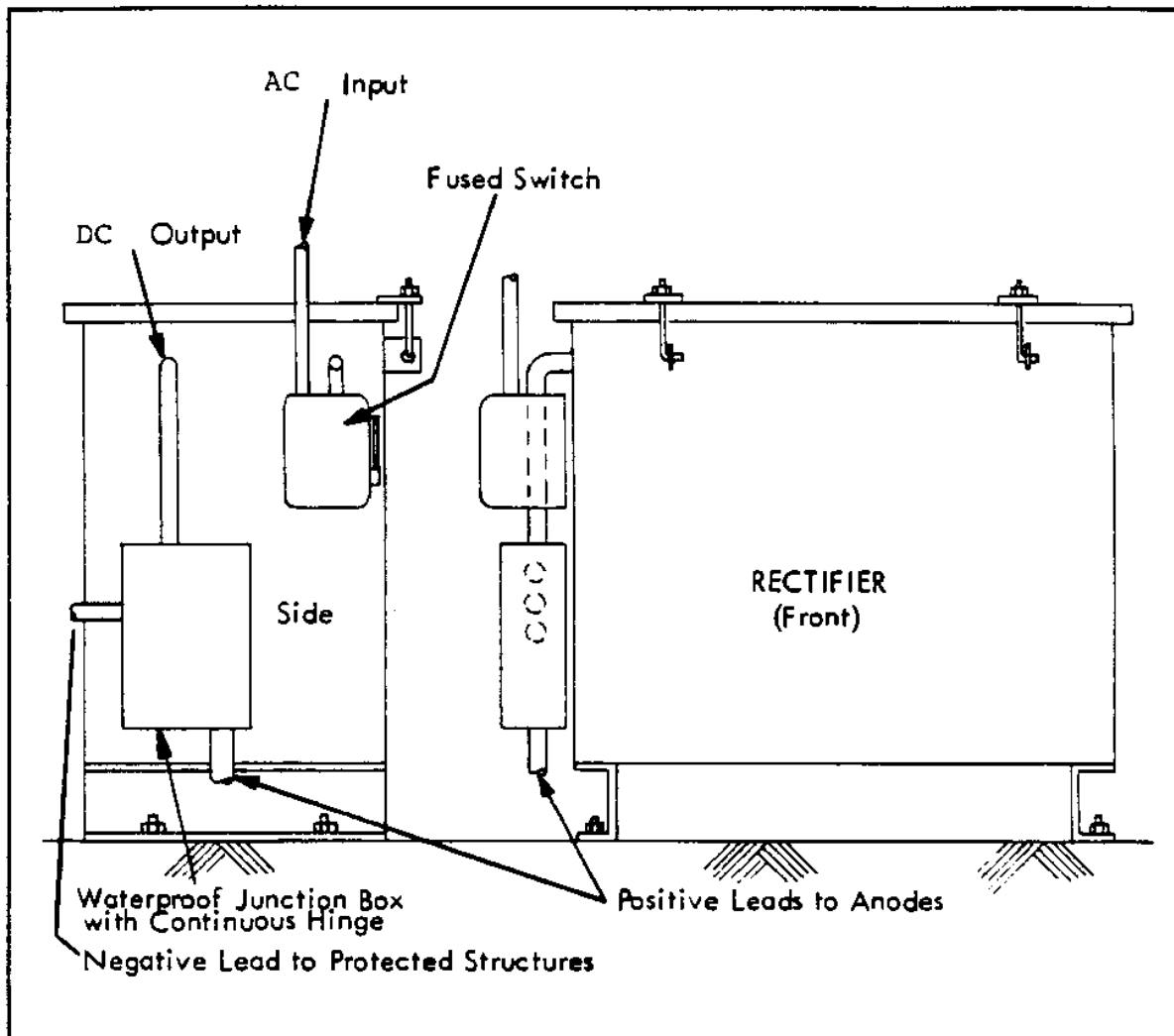


Figure 11

Typical pad-mounted cathodic protection rectifier installation

2. SYSTEM CHECKOUT AND INITIAL ADJUSTMENTS

2.1 INTRODUCTION. After a cathodic protection system is installed, it must be checked out to determine if protective potentials have been achieved without interference to other structures in the vicinity. Initial testing should be considered to be part of the system design and installation and should be the responsibility of the designer of the system. The structure-to-electrolyte potential measurement is the basic measurement that is used to determine if proper levels of protection have been achieved. The -850 mV or 100 mV negative polarization shift criteria are recommended for evaluation of the effectiveness of cathodic protection systems on steel structures. Problems with interference can be identified during the initial system checkout and should be corrected as soon as possible to prevent premature failure.

2.2 INITIAL POTENTIAL SURVEY. Structure-to-electrolyte potentials should be measured at each test station or test point. Due to polarization effects, these potentials may change substantially within the first year of installation, and should be checked monthly for the first 3 months, then quarterly for the remainder of the first year. Low potential readings may be due to inadequate protective current flow, coating damage, or interference. Sacrificial anode output currents should be measured at each potential current test station since anode current measurements can be used to determine the cause of low potential readings and to better estimate sacrificial anode consumption rates. Anode currents should also be read monthly for the first 3 months and then quarterly for the duration of the first year.

2.3 DETECTION AND CORRECTION OF INTERFERENCE. Interference is normally detected by analysis of structure-to-electrolyte potentials made during initial system checkout. Unusually high or low potential readings are found over points where current is either entering or leaving the structure.

2.4 ADJUSTMENT OF IMPRESSED CURRENT SYSTEMS. Adjustment of rectifier output is the most common adjustment made in impressed current cathodic protection

systems. Underprotection or overprotection can be corrected by adjusting rectifier output if the structure-to-electrolyte potentials are fairly uniform over the structure and the required output is within the capacity of the rectifier. Rectifier output should not require frequent adjustment as system changes that can be corrected by rectifier adjustment occur slowly. Improper system potentials may also be the result of unusual seasonal conditions and may be self-correcting.

2.4.1 UNEVEN STRUCTURE-TO-ELECTROLYTE POTENTIALS. If the structure-to-electrolyte potentials are vastly uneven, overprotection or underprotection in some areas in order to achieve proper potentials in other areas may result. In this case, if interference is not present, output of anodes at the areas of underprotection will have to be increased or anodes added. The output of anodes in the areas of over protection will have to be reduced. If the anodes are connected through resistors, resistor adjustment may be adequate. If the structure is protected by impressed systems with point ground beds, underprotected areas may have to be improved by the addition of impressed current anode beds in appropriate locations. If the anodes are not connected through resistors, resistors may be added. Protective output can be increased or decreased locally by installing additional anodes or disconnecting anodes as necessary.

2.4.2 RECTIFIER VOLTAGE AND CURRENT CAPACITY. If the voltage capacity of the rectifier is inadequate to provide sufficient current to achieve protection, reduction of system resistance by the installation of additional anodes may be appropriate. If the current capacity of the rectifier proves inadequate, and correction of any interference or shorts does not result in adequate protection over a period of 1 year, then additional current must be supplied either by installing an additional rectifier in parallel with the existing rectifier, or installing a larger capacity rectifier in place of the existing rectifier.

2.5 ADJUSTMENT OF SACRIFICIAL ANODE SYSTEMS. Overprotection in sacrificial anode cathodic protection systems is rare as the open circuit (maximum) potential of most anode materials is normally less than that potential considered to be excessive. Potentials more negative than those required for protection are, however, wasteful and will result in

premature anode consumption. Potentials in sacrificial anode cathodic protection systems can be easily adjusted by inserting an adjustable resistor in the anode lead and adjusting it to give the current required for adequate protection.

2.5.1 LOW ANODE CURRENT LEVELS. Low anode current output resulting in inadequate protection is common in sacrificial anode cathodic protection systems. Low anode current output can be the result of high soil resistivity or high circuit resistance. If high soil resistivity is suspected, wet down the soil over the anodes and remeasure the current output after a few days. If the current increases to give adequate protection, then high soil resistivity problems have been confirmed. If lowering the soil resistivity in the vicinity of the anodes does not result in increased anode output, then high circuit resistance may be the problem and all leads and connections should be checked. If all leads and connections are all right and the output is still too low, then more anodes are required to provide additional current. In the case of an impressed system, the rectifier voltage may be increased.

2.5.2 INADEQUATE PROTECTION AT DESIGNED CURRENT LEVELS. If a situation is encountered where anode current output is within design limits and adequate protection is not obtained, the current required for protection may be more than originally anticipated. This may be due to interference, unusually corrosive soil conditions, a poorly performing coating on the structure, or a shorted dielectric fitting. If any interference has been corrected and inadequate protection is still encountered, either more anodes will have to be installed, or the rectifier current output will have to be increased, or both.

3. MAINTAINING CATHODIC PROTECTION SYSTEMS

3.1 INTRODUCTION. In order to provide the increased structural lifetime and reliability intended, cathodic protection systems must be monitored and maintained. Economic analysis, made at the time when cathodic protection was selected as a means of corrosion control, should have included the cost of periodic monitoring and maintenance.

3.2 REQUIRED PERIODIC MONITORING AND MAINTENANCE. The effectiveness of cathodic protection systems usually changes with time. The consumption of both sacrificial and impressed current anodes can result in decreased anode output which results in inadequate protection. Deterioration of cable insulation or connections can result in increased circuit resistance with similar effects. Rectifier output may be reduced by aging of the stacks, or may be completely interrupted by electrical failure. The corrosion environment may change if there is a change in drainage patterns or the area around an anode is paved reducing local soil moisture content. Construction of additional structures or modification to existing structures in the area may result in interference.

3.3 DESIGN DATA REQUIRED FOR SYSTEM MAINTENANCE. In order for a cathodic protection system to be effectively monitored and maintained, the parameters used in the design of the system and the "as built" configuration of the system must be known.

3.3.1 DRAWINGS. "As built" drawings of the cathodic protection system and the structure being protected should be available as well as drawings of other structures in the area which might cause interference problems. The cathodic protection system drawings should include, as a minimum, the location and configuration of all test stations, the location and type of all anodes and rectifiers, and the location of all connections and insulating joints. These drawings should be periodically updated to show any changes made to the cathodic protection system, the structure being protected, or nearby structures.

3.3.2 SYSTEM DATA. The following system design parameters should be recorded and kept with the system drawings in order to properly monitor and maintain the cathodic protection system.

3.3.2.1 DESIGN POTENTIALS. The desired potentials used in the design of the cathodic protection system should be indicated. In some cases, different criteria may be used to establish minimum protective potentials at different locations of the same structure.

3.3.2.2 CURRENT OUTPUT. The design current outputs of the rectifiers or sacrificial anodes in the system should be recorded. This data is most important in the initial system checkout but may also be used to evaluate discrepancies in structure-to-electrolyte potential readings.

3.3.2.3 SYSTEM SETTINGS AND POTENTIAL READINGS. The initial system settings and potential readings should be recorded. Changes to the system, such as rectifier adjustment, should be periodically recorded as described in paras. 3.4 and 3.5. Potential readings taken both at the time of initial system adjustment and during periodic monitoring should be recorded as described in paras. 3.4 and 3.5 in order to detect trends in the readings. Changes in potential readings are often more important than the actual values themselves in determining the cause of improper system operation.

3.3.2.4 RECTIFIER INSTRUCTIONS. In order that all rectifiers in the system can be properly maintained, adjusted, and repaired, instructions for the rectifiers must be retained. An original copy should be retained in the maintenance files and a copy should be kept within the rectifier enclosure for field reference.

3.4 BASIC MAINTENANCE REQUIREMENTS. Basic maintenance requirements are as follows:

- a) Monthly. Take rectifier panel meter and tap setting readings. Record readings (see sample form). Check rectifier connections.

- b) Quarterly. Take structure-to-electrolyte potential readings at selected locations (not less than four points per system). The test points should include:
- (1) the point of least negative potential,
 - (2) the point of highest negative potential, and
 - (3) two points of least negative potential not the same as (1). Record readings (see sample form). Inspect anode-to-structure connections in galvanic anode systems quarterly.
- c) Annually. Inspect submerged sacrificial and impressed current anodes for consumption. Inspect test stations for broken wires, loose connections or other damage. Make structure-to-electrolyte potential readings at all test points and submit data in accordance with Owner instructions. In addition to the basic requirements listed above, opportunities to inspect buried or otherwise inaccessible structure surfaces should be used to inspect the surfaces for evidences of corrosion or coating deterioration. Such opportunities may be presented by construction or maintenance in the vicinity of the protected structure.