

WATER AGENCIES' STANDARDS

Design Guidelines for Water, and Sewer Facilities

SECTION 11.1 CORROSION CONTROL

11.1.1 PURPOSE

This section provides guidelines for in-house staff and design consultants in designing structures to be buried underground related to water and sewer facilities.

11.1.2 GENERAL

It is the responsibility of the user of these documents to make reference to and/or utilize industry standards not otherwise directly referenced within this document. The Engineer of Work may not deviate from the criteria presented in this section without prior written approval of the Agency's Engineer.

11.1.3 INTRODUCTION

Corrosion is a serious problem that must be given consideration when designing structures to be buried underground. The waterworks industry, one of the major installers of underground pipelines, loses in the billions of dollars annually to corrosion related failures. This chapter will discuss one of the primary corrosion prevention methods used in the industry.

The principle of cathodic protection is to make the entire surface of the structure a cathode, thus directing corrosion to a sacrificial material (an anode). Cathodic protection is accomplished by discharging a DC electrical current from an expendable material (anode) through an electrolyte (soil, water, wastewater) in a manner that ensures DC current is collected on all parts of the structure's metallic surface (e.g., pipe, tank, etc.) making the entire surface a cathode.

If required by a project and required in the contracted scope of the work, the Design Consultant retains a NACE-certified cathodic protection specialist to design corrosion mitigating systems. In addition, it may be necessary to coordinate corrosion control systems with adjacent projects in various stages of design and/or construction. The Design Consultant should contact the Agency's Engineer for additional information concerning the status and details of adjacent projects.

11.1.4 EVALUATION OF CATHODIC PROTECTION NEEDS

The need for cathodic protection is determined through field and laboratory tests and other investigations to assess the corrosion potential of the environment toward proposed facility materials. Field and Laboratory investigations are conducted for all proposed facility sites or alignments. The Design Consultant also retains the services of a corrosion engineer to evaluate soil and water corrosivity at the site and along pipeline alignments through field and laboratory tests. The corrosion engineer provides preliminary data on corrosion control methods, including protective coatings, materials of construction and cathodic protection.

- A. Field and Laboratory Investigation: Field investigations, by the qualified geotechnical engineer, include onsite measurements of soil resistivity and the collection of soil and water samples for laboratory analysis. Testing procedures are performed in accordance with the Predesign Surveys described later in this section.

1. Soil/Water Tests: Tests are made to characterize the corrosivity of electrolytes (existing soils and water) in which the structures are to be located. The required testing is described in the following paragraphs.
2. Field Resistivity Survey: Soil resistivity primarily depends on the chemical and moisture content of the soil. The higher the level of chemical constituents, the lower the soil resistivity. Moisture generally decreases soil resistivity until the maximum solubility of the chemicals is achieved. Beyond this point, an increase in moisture generally increases resistivity as the chemicals become more diluted. As Table 11-1 shows, the corrosion of metals in soil and water normally increases as electrical resistivity decreases.

Table 11-1
Resistivity Values vs. Corrosivity

Soil Resistivity, ohm-cm	Degree of Corrosivity
0-1,000	Very Corrosive
1,000-3,000	Corrosive
3,000-5,000	Fairly Corrosive
5,000-12,000	Mildly Corrosive
Above 12,000	Negligible

Measurements of the electrical resistivity of in-situ soils are made using the Wenner 4-pin method in accordance with ASTM G57 or other ASTM approved methods. Tests are made at intervals not exceeding 1,000 feet along the pipeline alignment or on a 300-foot-square grid at any facility site. Typically in-situ soil resistivity is measured in ohm-cm from ground level to depths of 2.5, 5, 7.5, 10, and 15 feet. For deeper structures test depths are increased to meet specific project requirements.

3. Laboratory Analysis: Soil and water samples are collected in the field for laboratory analysis to determine their corrosive properties. Tests are conducted for the following parameters:
 - Electrical resistivity using the soil box method defined in ASTM G187 for samples with moisture contents “as-received” and saturated with deionized water
 - Analyze soil/water samples for major soluble salts commonly found, such as chloride and sulfate, per ASTM D4327 and D513
 - pH per CTM 643

Any samples with a pH of less than 6.5 is tested to determine total acidity in addition to the other required tests. Additional tests may also be warranted depending on the results of the field resistivity survey.

Laboratory procedures for chemical analysis must be provided.

4. Coordination with Geotechnical Studies: Planning, collection, and investigation of soil samples is coordinated by both the corrosion and geotechnical engineers for efficiency in retrieving samples. Soil samples collected by augers, split-spoon samples or other methods are acceptable. However, samples should not be taken from holes where a drilling machine is used, as drilling mud may contain salts that could affect the test results.

5. Stray Current Evaluation: The evaluation of stray current requires the use of a specialty expert in this area. The Design Consultant provides the expertise necessary to meet these requirements through the use of a cathodic protection specialist.

Field investigations include interviews with knowledgeable sources and measurements to determine the potential for stray current from DC sources. Possible sources of DC current include cathodic protection systems in operation on other utilities or agencies, electric transit systems, if any, and industrial sources such as metal processors and welding machines.

Evaluations must also consider the possible effects of cathodic protection systems for pipelines or facilities under consideration towards other buried utilities in the vicinity.

6. Coordination with Other Utilities: Other utilities or companies with underground metallic piping or tank systems that lie in or near the pipeline alignment must be contacted to determine the extent of potential interference.
7. Earth Potential Gradient Tests: In conjunction with personnel interviews to determine probable locations of DC current sources, field measurements of earth potential gradient are made to detect the presence of current in the earth at locations along the pipeline alignment. Tests are made by measuring the potential between two identical portable reference electrodes placed a suitable distance apart and in contact with the soil. Where appropriate, the cathodic protection or other electrical system is interrupted to observe the change in earth potential gradient associated with the system.
8. Induced Voltage: The potential for induced voltage from high voltage electrical power transmission lines is evaluated if a facility site or alignment is situated near power lines. Field measurements of the electromagnetic field may not be sufficient to assess the potential for induced voltage. A specialist in AC-induced voltage mitigation must evaluate the need for induced voltage suppression and design the facility accordingly unless the contracted scope of work specifically excludes this requirement. In any case, the DESIGN CONSULTANT ensures that induced voltage mitigating devices, if required, do not interfere with the installed or to be installed cathodic protection systems.

11.1.5 INTERPRETATION OF RESULTS

The cathodic protection specialist interprets and evaluates results of field and laboratory investigations and interviews to determine the needs for cathodic protection. The evaluation includes consideration of the information about protective coatings and linings and materials of construction.

The results of this evaluation are included in a Corrosion Control Field Report. This report includes preliminary studies of corrosion potential and related subjects covered in this chapter.

11.1.6 STANDARDS AND REFERENCE

The practices and recommendations of accepted references are used during the course of work. The following references should be considered primary sources if information:

- A. NACE International: Methods for performing field and laboratory testing, data collection, and evaluation of results should follow the recommended practices of NACE International. NACE International is located in Houston, Texas. Particular attention should be given to the following standard practices and test methods:
- SP0169 Control of External Corrosion on Underground or Submerged Metallic Piping Systems.
 - SP0177 Mitigation of Alternating Current and Lightning Effects on Metallic Structures and Corrosion Control Systems.
 - RP0187 Design Considerations for Corrosion Control of Reinforcing Steel in Concrete.
 - RP0196 Galvanic Anode Cathodic Protection of Internal Submerged Surfaces of Steel Water Storage Tanks.
 - RP0285 Corrosion Control of Underground Storage Tank Systems by Cathodic Protection.
 - SP0286 The Electrical Isolation of Cathodically Protected Pipelines.
 - SP0388 Impressed Current Cathodic Protection of Internal Submerged Surfaces.
 - SP0572 Design, Installation, Operation, and Maintenance of Impressed Current Deep Anode Beds.
 - TM0497 Measurement Techniques Related to Criteria for Cathodic Protection on Underground or Submerged Metallic Piping Systems.
- B. American Water Works Association Standards and Publications: Information on pipe materials, coatings and corrosion control practices used in the water industry can be obtained from AWWA in Denver, Colorado.
- C. Manufacturers' Associations: Trade associations may provide supplemental sources of information about details and common practices for specific materials of construction. Caution should be used when strictly following their recommendations because their recommendations may be structured to benefit their particular product.

11.1.7 CORROSION CONTROL REPORT – CONCLUSIONS AND RECOMMENDATIONS

Ductile Iron pipe has different requirements for corrosion control and soil corrosivity thresholds. This is also true for concrete or cement-mortar coated steel. In general, cathodic protection in conjunction with highly effective dielectric coatings should be provided for buried or submerged metallic structures if any of the following conditions exist:

- Soil resistivity is 12,000 ohm-cm or less (measured in the field only) or 5,000 ohm-cm or less (measured in a laboratory in saturated condition), or when a wide range of soil resistivities exists regardless of their absolute values.
- Soil with high chloride or sulfate concentrations.
- Waters with high chloride concentrations, high TDS, or high dissolved oxygen concentration (cathodic protection is not effective in waters with high velocity).
- Areas subject to stray electrical currents.
- Support facility steel or ductile iron piping and steel storage tanks.

The evaluation reaches one of two possible conclusions:

- A. First possible conclusion: When the study is conducted, cathodic protection is determined necessary. This conclusion results in the design, installation and commissioning of cathodic protection systems concurrent with construction of the facility. The cathodic protection system is designed for a minimum service life of 20 to 30 years, after which it requires replacement or upgrading for continued service. Cathodic protection systems are normally the impressed current type, unless the current requirements are low and the current density requirement can be reduced by providing a highly effective dielectric coating on the facility. When current

requirements are 1 to 2 amps or less, the use of cast or ribbon galvanic anodes (magnesium or zinc) should be considered.

A major consideration for the cathodic protection alternative is that stray current from the cathodic protection system must be controlled to prevent damage to other facilities. If not controlled, the cost savings resulting from leak prevention on the protected facility could be surpassed by the costs of damage to other facilities.

- B. Second possible conclusion: When the study is conducted and cathodic protection is deemed unnecessary at the time of construction, all facilities are then provided with the test stations. Electrical continuity of the structure is necessary for future needs of a cathodic protection system. Corrosion monitoring results are used to determine when, or if, cathodic protection is required. The major consideration with this conclusion is the requirement for a correct future assessment of the need for cathodic protection.

Therefore, the competent evaluation of the need for cathodic protection can be difficult. Unless test data demonstrates actual corrosive failure of a facility, consultants and vendors will offer a wide range of opinions on whether cathodic protection is required. Future cathodic protection installations will most likely be the impressed current type because the galvanic anode installations for existing large facilities are usually prohibitive as adequate amounts of current is limited.

The conclusions and recommendations of the cathodic protection specialist's and corrosion engineer's evaluation for corrosion control on the project are submitted as the Corrosion Control Report.

11.1.8 CORROSION CONTROL DESIGN

The design of cathodic protection or corrosion monitoring systems for projects must be in accordance with the following:

- A. Coordination with Structure Design: Coordination with structure design is required to ensure that the cathodic protection system is fully compatible with the design of the structure to be protected or monitored. The materials and protective coating considerations for a particular structure require coordination between the corrosion engineer and the "specifiers" of the materials of construction and coatings. It is also necessary to identify locations and configurations of appurtenant facilities such as valve vaults, service connections, instrumentation, and connections to other structures.

The approximate locations of cathodic protection or corrosion monitoring equipment, devices, outlets, and appurtenances are shown on the approved drawings. Exact locations are determined by the Construction Contractor subject to approval by the District Engineer.

The District Engineer verifies all data and final locations of work done under other sections of the specifications required for placing the electrical work.

The cathodic protection engineer coordinates with the Design Engineer's electrical discipline staff to be sure that the electrical grounding methods do not accelerate corrosion of pipes, tanks, and other structures and equipment in the area by creating corrosion cells or draining protective current from the intended structures to be protected.

1. Pipe and Equipment Materials: Some pipelines may be constructed from metallic materials other than steel such as ductile iron, copper, or galvanized iron. All candidate pipe materials are considered for corrosion mitigation needs.

Underground steel tanks, water immersed gates, valves, steel parts of other structures, and equipment exposed to corrosive environments may also receive cathodic protection or may require protection from the adverse effects of impressed current cathodic protection applied to other structures.

2. Optimization of Coating and Cathodic Protection: Cathodic protection systems are designed to provide adequate current to polarize the structures to be protected to levels generally accepted for complete protection.

A key consideration for designing cathodic protection systems is minimizing the cathodic protection current requirement. This is necessary to minimize the total current output from cathodic protection facilities reducing the consumption of anodes and the cost of power supply. The larger the current output, the greater the chance of stray current interference. Such interference increases the resultant costs for mitigation.

The current requirement for cathodic protection is a function of several variables, including the facility surface area to be protected and soil conditions. The quality and condition of the structure's protective coating(s) will determine the current requirement of the structure. The major determinant in current requirement for a given facility size is its effective coverage of the protective coating on the facility. A coating with a high degree of coverage, i.e. few coating holidays, of the pipe surface requires less current since less of its bare surface is in contact with the soil.

To achieve the most cost-effective corrosion protection system, the combined facility coating and cathodic protection must be optimized. The coating must protect most of the facility surface and be complemented by an appropriate cathodic protection system to protect the uncoated areas or coating holidays of the pipe surface. The coating is selected for the appropriate environment and the greatest effective coverage without excessive cost. The cathodic protection system is selected to deliver sufficient cathodic protection current areas with coating holidays without causing stray current interference on other facilities.

3. Stray Current Control: Stray current from a cathodic protection system must be controlled to prevent damage to other facilities. The cost savings resulting from corrosion prevention on the protected facility could be surpassed by the cost of damage to other facilities. The cathodic protection design should provide a means for testing for and mitigating potential stray currents produced by the system.
4. Grounding Needs: The cathodic protection system is coordinated and consistent with electrical grounding needs of the facilities to mitigate induced voltage from high voltage power transmission lines.

Facilities with cathodic protection systems are insulated from electric utility grounding systems to prevent excessive current requirements and therefore the waste of energy. This means that facilities such as pumps, electrically operated equipment, instruments and controls and similar connections should be electrically insulated from the protected facility to conserve energy.

Facilities equipped with only corrosion monitoring systems are also electrically isolated from utility grounding systems. This condition lends itself to the future application of cathodic protection if warranted and prevents to potential corrosion cells that would otherwise not be present.

5. Interfaces between Contracts: Facilities and other structures are designed and constructed so that the finished system is compatible with existing structures and facilities, and that corrosion protection is not compromised for both new and existing structures. Where insulating joints are required, the Construction Contractor provides and installs the connecting insulating joint assembly.

B. Cathodic Protection System Types: The type of cathodic protection system selected by the cathodic protection specialist must provide an acceptable minimal service life of 20 to 30 years. Factors to be considered during selection are:

1. Galvanic or Sacrificial Anodes: Galvanic anodes use the natural potential difference (voltage) between two different metal alloys to generate direct electrical current (DC). These anodes consist of magnesium or zinc castings or ribbons directly connected to the pipe. With magnesium and zinc being anodic to steel, ductile and cast-iron, stainless steel, lead and copper, the anodic material will sacrifice itself to protect the structure they are attached to.

Zinc anodes should be considered in low resistivity environments (less than approximately 1,500 ohm-cm) or in brackish or saline water and soil conditions. In these low resistivity conditions, zinc anodes have a longer operating life than magnesium anodes because of their lower driving voltage, hence lower current output, and higher current efficiency. In soil conditions having higher soil resistivities and where galvanic anodes are required, magnesium anodes should be used.

The number of anodes depends on the electrolyte conditions and the current requirement. Anodes are sized to provide a minimum service life of 20 to 30 years. Galvanic anode systems are best suited to applications where current requirements are low (less than 2 amps), where structures are well-coated, and in areas of low electrolyte resistivity. Galvanic anode systems are frequently used where the following items are important:

- No external power supply is available or allowed (classified areas).
- Low maintenance effort needed.
- Minimal interference with other structures is mandatory.
- Low installation cost is mandatory (needs economical comparison).
- Minimal easement or right-of-way needed.

Considerations that discourage the use of galvanic anode systems are:

- Limited driving potential and current output.
- High electrolyte resistivity.
- High cost of retrofit or upgrade.
- Adjustment of output is required.

Where conditions are unfavorable for galvanic anode or sacrificial anode protection, impressed current systems should be considered.

2. Impressed Current: Impressed current cathodic protection systems are used when the current requirement is more than can be generated by a galvanic system. An outside source of power is necessary to operate this type of system.

Rectifiers should be used to convert alternating current (AC) to direct current. The DC current goes from the positive DC terminal of the rectifier to the groundbed (anodes) where it is discharged into the electrolyte. This current is collected on the structure to be protected. The electrical circuit is completed as the DC current returns via the protected structure to the DC

negative terminal of the rectifier. Typical impressed current anodes are made of graphite, high-silicon cast iron, mixed-metal oxide coated titanium and plantinized titanium or niobium.

Impressed current systems are best suited to applications where current requirements are high, and in areas of high electrolyte resistivity.

Impressed current systems are frequently used where:

- Large current is required.
- High-resistivity soil or water conditions exist.
- Current must be adjustable.
- Contamination of the product is prohibited.

The following considerations may discourage the use of impressed current systems:

- Slightly higher initial installation cost.
- Skilled maintenance effort.
- Continuous cost for AC power.
- Interference with other structures.
- Congested areas.
- No available power source.

Where conditions are unfavorable for impressed current protection systems, galvanic or sacrificial anode protection, or a combination of the two methods should be used.

3. Selection of Protection System: The type of cathodic protection system, design configuration, and component specifications should be selected to deliver the required current with due consideration of the control of stray currents.

The replaceable parts of cathodic protection systems are designed to provide a service life of 20 to 30 years. This includes items such as rectifiers, anodes, and wiring. A longer design life is not recommended and is not economical as the durability of construction materials for continuous use becomes marginal and the risk of equipment failure increases substantially.

The actual service life and performance of a cathodic protection system may fluctuate depending on the following:

- The average current output.
- Soil or water conditions.
- Actual anode consumption efficiency.
- The rate of material deterioration.
- The addition of facilities.

The design should incorporate sufficient safety and redundancy factors to achieve the design life under a reasonable range of conditions.

Features necessary for the operation of the cathodic protection system must be designed to last for the life of the structure or facility.

- C. Consistency Among Contracts: Cathodic protection systems are designed for consistency among adjacent projects. All system components and configurations are as required by these standards and guidelines. In the absence of pertinent standards, the specifications and details of a previously designed facility for previous projects are used as a reference for consistency.

- D. Design Criteria for Cathodic Protection: Pumping station, storage facility, pipeline, and pressure control station project design criteria are as described in these Guidelines.
- E. Construction Phase Considerations: Successful installation and operation of cathodic protection systems requires special attention to certain details. Examples are provided in the following paragraphs.

Inspection during the construction of test stations and cathodic protection facilities is important only for certain parts of the job. Cathodic protection systems are relatively fragile, so there is considerable potential for mechanical damage. Also, the systems rely on low voltage and current, therefore, any unplanned resistance in wires and wire connections could reduce the system effectiveness.

Some important items to be addressed by the Construction Manager during detailed inspection are as follows:

- Thermite weld wire connections to structures must be sound and properly insulated from contact with the electrolyte.
- Splices are not allowed in impressed current anode wires or headers. However, if a splice must be made, it should be in an aboveground splice box. Splices between galvanic anode lead wires and anode header wires must be thoroughly insulated from contact with the electrolyte.
- Anodes must be properly positioned and installed without stressing the lead wire. Wires must be correctly color coded and marked as to function and the structure to which they are connected. This is especially important for rectifier output leads and pipeline crossings.
- The power supply to the rectifier must be the correct voltage and phase.
- Electrical continuity of the structure must be tested to ensure that electrical continuity required by cathodic protection exists. All insulators must be tested to ensure they are functioning. The loss of an insulator can cause loss of protection for part or all of the structure.

- F. Operation and Maintenance Considerations

Items, which are accessible from the ground, must be checked periodically during the life of the structures.

Cathodic protection system rectifiers should be monitored quarterly.

The Design Engineer designs facilities for corrosion monitoring and cathodic protection for periodic access and measurement. Test boxes, rectifiers and other facilities are placed in accessible locations and away from hazards such as traffic and areas prone to flooding. Signage is provided for corrosion protection facilities if streets and walks are not fully developed.

Agency staff must use technical specialists to conduct the appropriate measurements, maintain records, recommend modifications to the system, and determine replacement requirements.

11.1.9 STANDARD CORROSION TESTING PROCEDURES

- A. Predesign Surveys:

1. Soil Resistivity Testing (Field): In-situ soil resistivity testing is typically conducted by the Wenner 4-Pin Method. This test procedure requires the use of an AC resistance meter, such as a Soil Resistance Meter, Model 400, manufactured by Nilsson Electrical Laboratory, Inc. The Wenner method requires that 4 electrodes, or pins, be driven into the ground along a straight line, equidistant from each other, as shown in Figure 11.1.1. An alternating

current from the meter flows through the outside probes, C1 and C2. Due to the resistance of the soil, a voltage drop is created across the inner pins, P1 and P2. This voltage gradient is proportional to the average resistance of the soil mass to a depth equal to the pin spacing. The resistivity of the soil is then computed from the meter reading according to the instructions found in the meters operating manual.

Resistance measurements should be made at 1000-foot intervals, as a minimum, along the proposed alignment or on 300-foot-square grid at any facility site. As mentioned, the Wenner 4-Pin method measures average soil resistivity to a depth equal to the pin spacing. Since it is desirable to obtain information about the soil conditions at the depth of the structure, pin spacings should be selected to contain the soil strata in which the structure is to be located.

2. **Soil Resistivity Testing (Laboratory):** Soil samples should be extracted from specific locations and depths. The samples should be packaged appropriately and tested as soon as practical upon removal to reduce the effect of changes of in-situ moisture content. Representative samples should be placed in a soil box, as shown in Figure 11.1.2. The sample resistivity is determined from the resistance meter reading and the geometry or constant for the soil box. The testing should be repeated after successive increases in moisture content with the deionized water. The sample should be retested after each addition of water, until a minimum value has been reached. This value should then be recorded as the "minimum" saturated resistivity.
3. **Chemical Analyses:** Soil samples should be forwarded to a qualified laboratory specializing in soil corrosivity analysis, for the testing of pH, and chloride, sulfate, bicarbonate, and other soluble ion concentrations normally found in soil or water.

Once again, the samples should be analyzed as soon as possible upon arrival, so as not to cause significant variation in the "as-found" condition of the sample. Chemical testing is performed in accordance with recognized standard procedures and reported in (ppm), parts per million. Minimum standard test procedures include ASTM D513, ASTM D4327, ASTM G187, and CTM 643.

When collecting soil samples representative of the structure's environment, samples should also be taken above the structure to account for changes due to moist conditions or leaching of material or chemicals from upper soil strata.

4. **Structure-to-Electrolyte Potential Surveys:** Half cell potential surveys should be incorporated in a predesign survey where a structure is located. Ideally, the testing is performed at test station locations. Where test stations have not yet been installed, electrical connection must be made to the structure at appurtenances. The voltmeter to be used in the testing must have an input impedance of at least 10 meg-ohms. The testing must also be performed with a calibrated copper/copper sulfate reference electrode (CSE), which is known to be functioning properly.

If an analog voltmeter is used, the positive test lead is connected to the copper copper/sulfate reference electrode and the negative test lead is connected to the structure. If a digital voltmeter is used, the positive test lead is connected to the structure and the negative test lead is connected to the reference electrode. The reference electrode is placed as close to the structure as possible, as shown in Figure 11-1-2. The use of water at the CSE location may be advisable to reduce contact resistance between the CSE and the soil. The potential is recorded in millivolts,(mV) and a notation

is made indicating the test station number and any other relevant information such as pipeline station number.

Where structure-to-electrolyte potential measurements are to be performed on a structure under galvanic cathodic protection, the potential of the structure should be recorded with the anode both connected and disconnected from the structure. The open circuit potential of the anode must also be recorded. Where the cathodic protection system is an impressed current type, the potential of the structure is recorded prior to and during temporary interruption of cathodic protection current, or "instant off" using a current interrupter.

5. **Current Requirement Testing:** Current requirement testing is generally performed to determine how much current is needed to protect a structure, regardless of the type of system planned for design. Testing requires the use of a portable DC power supply, voltmeter with shunt or an ammeter, reference electrode, test leads, temporary anodes, and means for making an electrical connection to the structure. The temporary anodes may be an existing structure (for example a chain link fence) or an anode system installed for the purpose of testing. The power supply may be a portable rectifier or power supply or a battery. The positive lead from the power supply should be connected to the temporary anodes and the negative lead to the structure, as shown in Figure 11-1-3. Pipe-to-soil potential measurements should be made at multiple locations prior to energization of the structure. These locations should be selected to facilitate testing both close to and far away from the temporary anode location so that attenuation characteristics, as defined in "Corrosion Control Testing" can be estimated, in addition to the levels of polarization achieved during testing. The potentials should be recorded both with the DC power "on" and "off." The voltage and current outputs should all be recorded for each test setup. Multiple measurements may be required for incremental increases in current and polarization potentials to calculate or project the final anticipated current required for the purpose of design of the cathodic protection system.

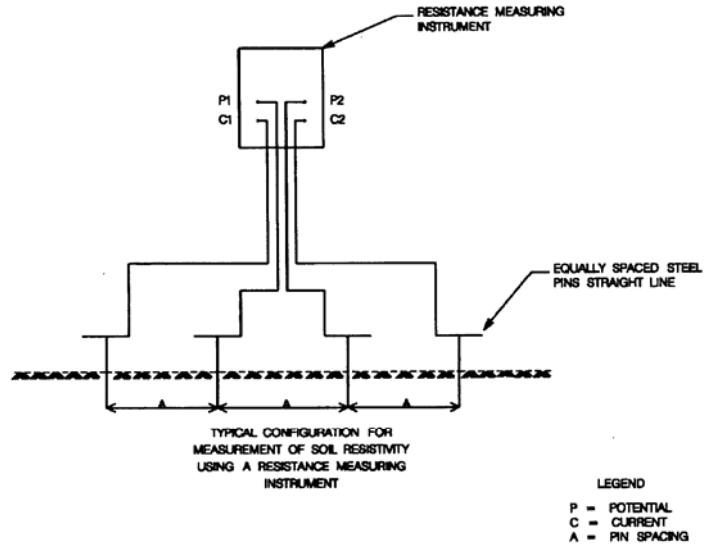
B. **Electrical Continuity Testing:**

1. **Testing for Pipelines:** Electrical continuity testing for bonded pipe joints is performed after backfilling of the pipe. Testing requires the use of a power supply, volt and ammeter or multimeter, test leads, and means of making two electrical connections to the pipe. The positive and negative terminals of the power supply should be connected to the pipeline at a known distance along the pipeline to be tested. The length of pipe and number of joints must be recorded, as well as the voltage and current output of the power supply. The resulting voltage drop from the application of current on the pipe span being tested should be measured and recorded. This testing may be done along the length of pipe or across individual pipe joints, as required and shown in Figure 11-1-4. From the power supply outputs and the voltage drops measured, the resistance of the test pipeline span can be calculated. This value should be compared to the theoretical resistance of the pipe and joint bonds for the span being tested. These calculations are based upon pipe material, size, wall thickness, and joint bond wire gage and length. Field test results of no more than 120% of the theoretical resistance value indicate the pipe is continuous.
2. **Isolation Testing:** Insulating flange kits and dielectric unions are tested using a Gastronics Model 601 Insulation Checker, or with other proven test methods. The meter is placed across the flange or other insulating device being tested. Electrical isolation is sufficient when the meter reading is 100%. Care must be taken when using the insulation checker, especially when pipe larger than twenty four inches (24") in diameter are involved. Two

(2) test methods for electrical isolation should be performed and be in agreement.

- C. Post Installation Testing: Post installation testing is performed as required in the plans and specifications for the project and as directed by the Construction Manager. Testing requires the performance of the standard test methods presented in this attachment. The minimum requirements are as listed in the test method or as required by the Construction Manager and shown on the drawings and specifications.

Figure 11.1.1
Wenner 4 Pin Method for Measurement of Soil Resistivity



NOTE:

RESISTIVITY MEASUREMENTS DIRECTLY OVER BURIED METALLIC STRUCTURES WILL YIELD INACCURATE RESULTS

Figure 11.1.2
Soil Box Method

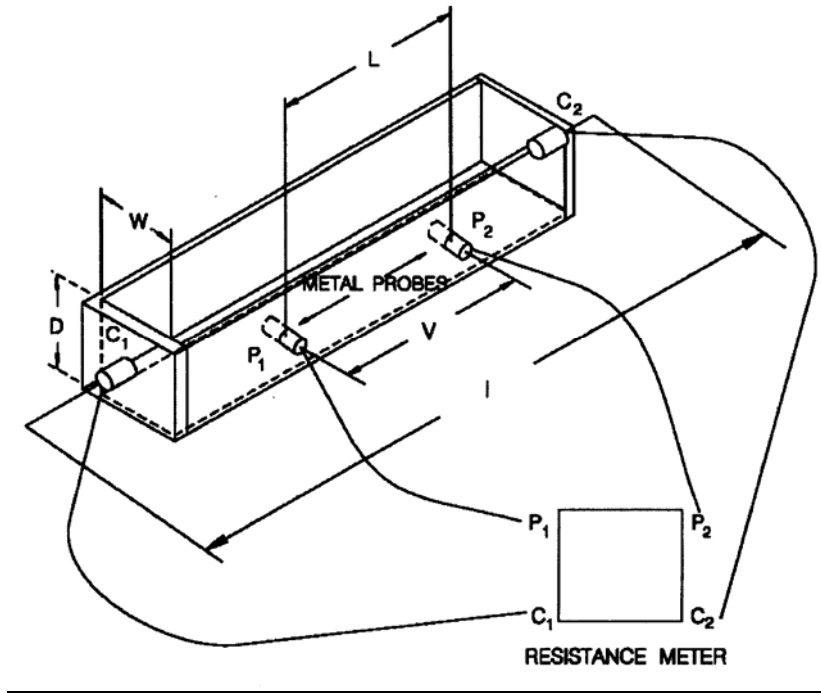


Figure 11.1.3
Pipe-to-Soil Potential Measurements

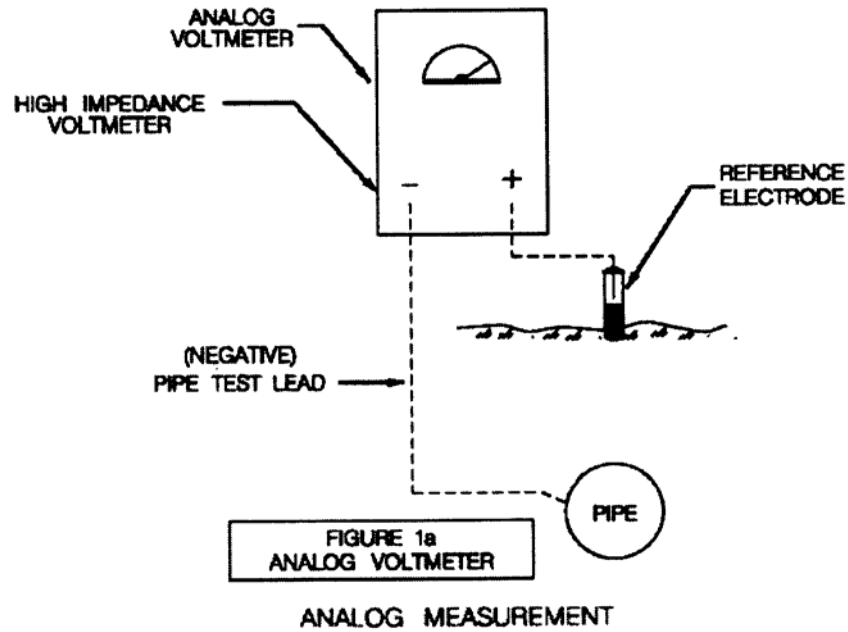


Figure 11.1.3 (continued)
Pipe-to-Soil Potential Measurements

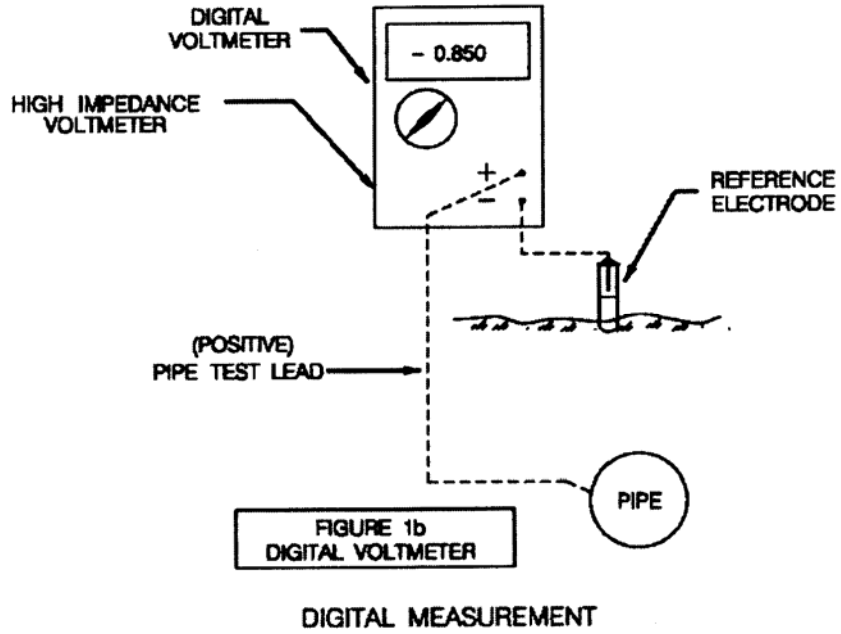


Figure 11.1.4
Current Requirement Test

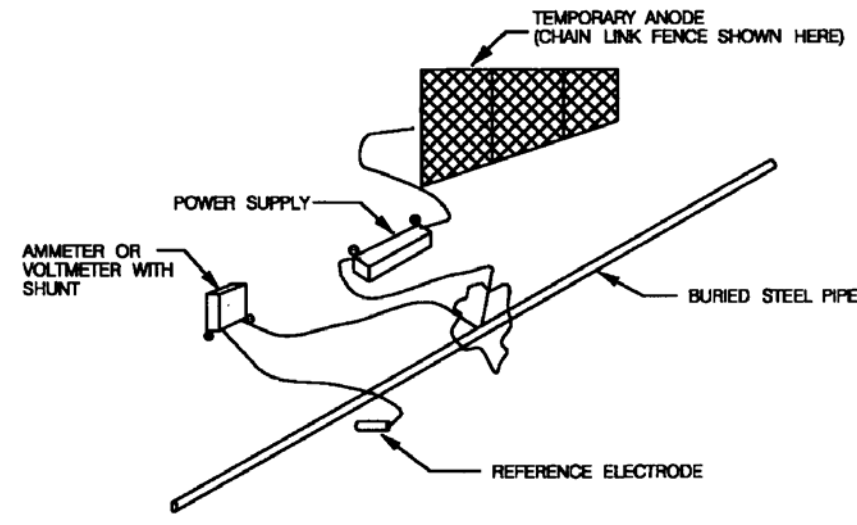
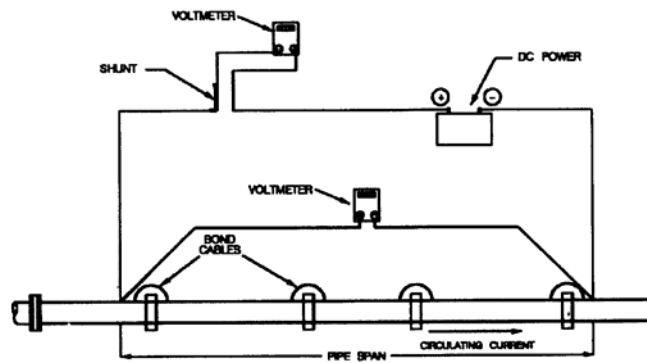


Figure 11.1.5
Continuity Bond Testing



NOTE:

THE FOLLOWING MUST BE KNOWN:

- PIPE DIAMETER
- PIPE WALL THICKNESS
- PIPE SPAN
- NUMBER OF BOND CABLES
- NUMBER OF PIPE JOINTS
- BOND RESISTANCE
- PIPE MATERIAL RESISTANCE

11.1.10 REFERENCE

- A. Should the reader have any suggestions or questions concerning the material in this section, contact one of the member agencies listed.
- B. The publications listed below form a part of this section to the extent referenced and are referred to in the text by the basic designation only. Reference shall be made to the latest edition of said publications unless otherwise called for. The following list of publications, as directly referenced within the body of this document, has been provided for the users convenience. It is the responsibility of the user of these documents to make reference to and/or utilize industry standards not otherwise directly referenced within this document.
 1. Water Agencies' Standards (WAS):
 - a. Design Guidelines:
 1. Section 11.2, Corrosion Control Design
 - b. Standard Specifications:
 1. Section 13110, Cathodic Protection and Joint Bonding
 - c. Standard Drawings:
 1. WC – Series Cathodic Protection Details
 2. Others:
 - a. NACE International:
 1. SP0169, Control of External Corrosion on Underground or Submerged Metallic Piping Systems.

2. SP0177, Mitigation of Alternating Current and Lightning Effects on Metallic Structures and Corrosion Control Systems.
 3. RP0187, Design Considerations for Corrosion Control of Reinforcing Steel in Concrete.
 4. RP0196, Galvanic Anode Cathodic Protection of Internal Submerged Surfaces of Steel Water Storage Tanks.
 5. RP0285, Corrosion Control of Underground Storage Tank Systems by Cathodic Protection.
 6. SP0286, The Electrical Isolation of Cathodically Protected Pipelines.
 7. SP0388, Impressed Current Cathodic Protection of Internal Submerged Surfaces.
 8. SP0572, Design, Installation, Operation, and Maintenance of Impressed Current Deep Anode Beds.
 9. TM0497, Measurement Techniques Related to Criteria for Cathodic Protection on Underground or Submerged Metallic Piping Systems.
- b. American Water Works Association Standards (AWWA) Standards and Publications

END OF SECTION