CATHODIC PROTECTION REQUIREMENTS FOR MILITARY PROJECTS

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1. Abstract

This paper discusses the problem of corrosion relating to buried and submerged metallic structures and presents cathodic protection as one effective method for mitigation of corrosion. Safety, economics, and applicable regulatory and legal requirements pertaining to corrosion control on military structures are important aspects for consideration by the cathodic protection designer. Military regulations and federal law also provide restrictions on not only how cathodic protection designs are to be accomplished and what structures it is required to protect, but also on the persons that are considered qualified to perform those designs. The responsible Corps' designers must become more aware of these various aspects of corrosion control as they are related to military projects. Various criteria, including DoD regulations, federal law, technical manuals, etc., require cathodic protection on certain structures, regardless of the specific soil or electrolyte corrosivity. The types of structures requiring both coatings and cathodic protection are summarized herein and explanations for the mandatory requirements are offered.

2. Impact of Corrosion

Corrosion is a major economic, environmental, and safety problem adversely affecting our nation, as well as many of our military facilities.

According to government and industry statistics, over $220 billion dollars are lost to corrosion in the United States alone each year. This is equivalent to approximately 3 or 4% of the Gross National Product (GNP). A large portion of this loss could be prevented if adequate corrosion control methods are utilized.

The military has many facilities in existence today, and many more being constructed every year, that either are required by law, military regulations, or good engineering economics to be controlled against the adverse impact of corrosion. According to data published by the U.S. Army Construction Engineering Laboratories (CERL), the Army alone currently owns and maintains approximately 20,000 underground fuel storage tanks (USTs); 4,000 miles of buried gas pipes; and 300 elevated water storage tanks. Since many of these structures can and are being damaged by corrosion due to inadequate corrosion control, millions of dollars are spent annually for repairs resulting from corrosion. If leaks of fuel or gas occur, in addition to excessive repair and loss of product costs, the ramifications could be damage to our environment and/or injury or death to human life due to the resulting unsafe conditions.

3. Corrosion Defined

The general definition of corrosion among practicing corrosion control personnel is the deterioration of a material, usually a metal, or its properties because of a reaction with its environment.

The corrosion process occurs as a result of many different corrosion mechanisms. Corrosion of metals mainly occurs through an electrochemical process.

4. The Corrosion Cell

In order for the electrochemical corrosion process to occur, a complete electrical circuit consisting of an anode, cathode, electrolyte, and metallic path must exist. Additionally, there must be an electrical potential difference between the anode and cathode; the anode and cathode must both be immersed in an electrically conductive electrolyte which is ionized; and the metallic path must connect the anode and cathode (which is usually the metallic structure itself). Once these conditions are met, an electrical current will flow and corrosion will occur. Ionic current flows from the corroding area of the structure (anodic area), into the electrolyte, and returns to the structure at some other area (cathodic area.) The ionic (or galvanic) current, flowing from the structure, carries metallic ions with it. These metallic ions are changed by chemical reaction into oxides and are deposited, in the form of rust, on the structure at the anodic areas. Simultaneously, electrons flow from the anodic areas to the cathodic areas through the metal structure. In localized attack, all or most of the metal loss occurs at discrete areas. Pitting is one common form of localized corrosion that occurs on many buried and submerged metallic facilities. Pitting may occur on a freely exposed surface of a metal or alloy where the surface is non-homogeneous under deposits of foreign matter or at imperfections in a film or coating.

The potential difference required to produce the corrosion current can be generated by many different types of corrosion cells, or a combination of more than one of those cells.

5. Types of Corrosion Cells

The following is a list of some of the possible corrosion cells that may exist on buried or submerged metallic structures: dissimilar metal cell; concentration cell; differential aeration cell; stray current cell; stress cell; new pipe and old pipe cell; motion cell; combination cell; and temperature cell.

The most common cells occurring are discussed in subsequent paragraphs. Additionally, it should be noted that, normally, on any one particular buried or submerged metallic structure, it would not be unlikely to observe a combination of several of these corrosion cells.

5.1 Dissimilar Metal Corrosion Cell

A dissimilar metal or galvanic corrosion cell is a very common form of corrosion that results from contact between dissimilar metals. A difference in the electrode potential of the two metals and the difference in the size of the dissimilar metals drive the process. The Galvanic Series is a list of metals arranged according to their corrosion potentials in a given environment. One extreme of the Galvanic Series is referred to as the most "active" metals while the other extreme is referred to as the most "noble" metals. The more "active" metal will be the anode and the more "noble" metal will be the cathode.

5.2 Concentration Corrosion Cell

One type of concentration corrosion cell is caused when different portions of a metallic structure come in contact with different environments. One example of the occurrence of this type of cell would be a metallic underground storage tank (UST) located in an area with a high water table. If the soil surrounding the lower portion of the tank is saturated with groundwater while the soil surrounding the upper portion of the tank is not, then a concentration corrosion cell could be created. This cell forms due to the fact that the structure is lying in an electrolyte that contains different substances or the same substance in different amounts. In the UST example referred to above, different amounts of moisture in the various soils surrounding the tank creates different conductivities and, subsequently, produces the potential difference necessary for electrochemical corrosion to occur. The anode would be the bottom of the tank (more conductive soil) and the cathode is the upper portion of the tank (less conductive soil) in this case.

Another very common example of this type of corrosion is metallic piping passing through concrete thrust blocks, concrete floors, or other concrete structures. The part of the metal exposed to the soil will be the anode and the part exposed to the concrete will be the cathode. This is a common occurrence for fire protection piping. Concentration cells can also be formed when structures are exposed to various types of soils with different chemical concentrations, different resistivity values, different oxygen concentrations, etc.

5.3 Differential Aeration Corrosion Cell

The differential aeration cell is really just another type of concentration cell and is also referred to as an "Oxygen Concentration Cell." In this type of corrosion cell, the electromotive force is due to a difference in air (oxygen) concentration at one electrode as compared with that at another electrode of the same material. Most pipeline construction consists of pipe installed in excavations and buried with backfill. The backfill used to bury the structure can be a jumble of various soils and debris that require extended periods of time to settle. Even after many years, the soil above the pipe remains more permeable, more biologically active and more heterogeneous than adjacent soil at the same depth. At and below pipe depth, moisture content in the backfilled trench exceeds that of adjacent soils. This could make measurement of bulk soil properties deceptive in terms of predicting the chemistry occurring at the steel surface. Subsequently, even if bulk soil resistivity measurements indicate high resistivity, the measurements may not be representative of the resistivity or corrosivity of the soil surrounding the pipeline. Therefore, the Army and Air Force requires both CP and coatings on some buried metallic pipelines regardless of soil corrosivity. Additionally corrosion variables other than resistivity, such as dissimilar metals, salt contamination, bacteria, and various other variables contributing to the corrosion process in addition to resistivity values, may be present which could cause the structure to corrode.

5.4 Stray Current Corrosion Cell

DC currents produced by sources other than the specific structure and its surrounding environment can also create a corrosion cell due to its stray currents intercepting the structure. One example would be a direct current (DC) operated streetcar system located in the vicinity of a metallic underground storage tank (UST). The streetcar system would serve as a DC current source providing stray currents to the soil surrounding the UST. Current flowing from the streetcar system is collected on the UST at the cathodic areas and is discharged in the anodic areas in its return to the streetcar rail system in order to complete the electrical circuit. The tank provides a more conductive path than the surrounding soil and, subsequently, easily becomes a component of the stray current circuit. Without proper corrosion control, the UST would severely corrode in the anodic areas under the influence of the stray current source. The DC source can be other sources as well, such as impressed current cathodic protection rectifiers, generators, direct current transmission lines, etc.

5.5 New Pipe and Old Pipe Corrosion Cell

This condition is similar to the dissimilar metal corrosion cell. However, even when the metals have the same alloying composition, this type of corrosion can occur. Some reference books refer to this type of cell as a surface film cell. Some chemical or electrochemical reactions can take place on a metal surface, making it behave quite differently from a piece of clean metal. “Old” steel is cathodic with respect to “new” steel, which is noted in the Galvanic Series where the potential of bright (new) steel is markedly different from that of old, rusted steel. This type of corrosion cell can be observed when old steel is scraped or marred during excavation; the new exposed steel becomes anodic to the surrounding old steel and corrodes at a faster rate. It is strictly a surface phenomenon.

New construction or maintenance repair work occurring on military bases routinely requires the connection of new pipe to old pipe. Subsequently, we must properly mitigate this type of corrosion cell by protective coatings, installation of isolation flanges, and/or application of cathodic protection. Otherwise, the new pipe might deteriorate and leak at a faster rate than the old pipe to which it is connected.

6. Corrosion Can Be Controlled

Corrosion control must be properly addressed during the design, installation, and subsequent operation of systems adversely affected by the corrosion process.

Much corrosion can be properly controlled or entirely eliminated from occurring on our military facilities. There are various methods to accomplish corrosion control. Some of these methods will be discussed.

7. Corrosion Control Methods

The five most common methods available today are: protective coatings; design; environmental control; material selection; and cathodic protection.

It is not uncommon for more than one of these methods to be used in conjunction with each other in order to provide a corrosion control system. Protective coatings include organic and inorganic materials, which form a barrier film between the substrate and its environment. Design considerations include items such as inclusion of corrosion allowances for anticipated general or uniform attack during a finite structure life, physical layout and orientation of components (including inclusion of isolation joints at specific locations), and control of such influencing factors as velocity, temperature, vibration, residual stress, etc. Environmental control includes items such as removal from contact with an electrolyte altogether or modifying the electrolyte by controlling the pH, use of additives or inhibitors, deaeration, or substitution of the existing environment with another environment. Material selection includes selection of less corrosive materials for construction of structure, such as non-metallic materials, wherever possible. Cathodic Protection is an electrochemical technique, which may be used in certain applications and is also required in many other applications.

Protective coatings, when used in combination with a well-designed cathodic protection system, provide the most cost-effective corrosion control measure for the protection of buried and/or submerged metallic structures, including ductile iron pipes in corrosive soils. The relationship between protective coatings and cathodic protection is important and, subsequently, must be discussed.

7.1 Protective Coatings

Normally the first line of defense against corrosion is protective coatings. Protective coatings provide a barrier between a corrosive environment and the structure. However, no coating is perfect and consists of holidays, or voids in the coating system, often resulting from improper application and/or damage.

Cathodic Protection is often used in conjunction with protective coatings, and is used to protect areas of exposed metal due to coating damage or application imperfections. Subsequently, the size of the cathodic protection system (rectifiers, anodes, etc.) can be greatly reduced when used in conjunction with coatings because it only has to provide protective currents to a very small percent of the total buried surface area of the structure. The success of the cathodic protection system depends upon maintaining a good coating system. Conversely, the life of the structure and its coating system is extended by maintaining a good cathodic protection system. Coatings and cathodic protection work together in order to provide the best method of corrosion control.

7.2 Cathodic Protection

Cathodic protection can be defined as an electrical method of mitigating corrosion on metallic structures that are exposed to electrolytes such as soils and waters.

In order to prevent the flow of current from the structure, and the concurrence of corrosion, a system of cathodic protection can be applied to the structures. Since most corrosion is due to electrochemical process involving the flow of electric current, cathodic protection is the only method of corrosion control that can effectively halt or stop corrosion. It effectively reverses the electrochemical process. In some cases, field experience has shown that cathodic protection is such an effective means of providing the required levels of safety and environmental protection that both protective coatings and cathodic protection are required by Federal law and DoD regulations. Army ETL 1110-3-474, paragraph 5.a states that CP is a functional requirement for virtually all projects involving new aboveground water tanks, direct buried or submerged metallic structures, or the repair or replacement of similar existing structures. These laws and regulations are referenced in this paper.

Two types of cathodic protection systems may be utilized, sacrificial (galvanic) systems and impressed current systems.

7.2.1 Sacrifical Cathodic Protection

A sacrificial cathodic protection system reduces corrosion of a metal in an electrolyte by galvanically coupling it to a more anodic metal. By putting an anode in the electrolyte near the structure and connecting it electrically to the structure, all points on the structure become cathodic with respect to the anode. In essence, such a system prevents the exit of metallic ions by causing an external flow of current onto the structure. Hence the structure is protected and the anode corrodes rather than the structure.

7.2.2 Impressed Current CP

An impressed current cathodic protection system accomplishes the same function as the sacrificial cathodic protection system with the following exception. Impressed current type cathodic protection systems provide cathodic current from an external power source. A direct current (DC) power source (rectifier) forces current to discharge from expendable anodes (but consisting of very durable materials) through the electrolyte and onto the structure to be protected.

8. Standards and Laws

Various standards produced by organizations and laws (Code of Federal Regulations) exist pertaining to corrosion control of buried or submerged metallic facilities. Some of these are as follows:

NACE International Standards (formerly National Association of Corrosion Engineers)

40 CFR Part 280 - Underground Storage Tanks (UST)49 CFR Part 192 - Transportation of Natural Gas and other Gas by Pipeline

49 CFR Part 195 - Transportation of Hazardous Liquids by Pipeline

Individual State Environmental and Safety Laws

Many state environmental and safety laws are more restrictive than the federal laws and national standards. Our cathodic protection designs must also adhere to these state laws.

External corrosion related pipeline failures are less frequent today because of pipeline safety regulations requiring the design, installation, and subsequent monitoring of cathodic protection systems. Potential problems are identified and remedial actions can be taken to prevent metal loss, which could eventually result in pipeline failure.

9. Military Criteria

In addition to federal laws, Corps of Engineers cathodic protection designers must be aware of and adhere to Army technical guidance and regulations, such as:

ETL 1110-3-474, Cathodic Protection

TM 5-811-7, Cathodic Protection

MIL-HDBK-1004/10, Electrical Engineering, Cathodic Protection

MIL-HDBK-1136, Maintenance and Operation of Cathodic Protection Systems (Draft)

Guide Specifications (Army)
- UFGS 13110A Cathodic Protection System (Sacrificial Anode)
- UFGS 13111A Cathodic Protection System (Steel Water Tanks)
- UFGS 13112A Cathodic Protection System (Impressed Current)

Air Force specific criteria, such as AFI 32-1054, Corrosion Control, is not listed here, but one should be aware that there are other criteria existing for Air Force projects. This is not an all-inclusive list of applicable military guidance.

Some of the structures requiring cathodic protection, as well as the designer qualifications, as required by Army ETL 1110-3-474, are provided in the subsequent paragraphs.

9.1 ETL 1110-3-474 Requirements

ETL 1110-3-474 requires cathodic protection and coatings regardless of soil or water resistivity for: natural gas and propane piping; liquid fuel piping; oxygen piping; underground storage tanks (UST) systems; fire protection piping; steel water tank interiors; ductile or cast iron pressurized piping under floor slab; underground heat distribution and chilled water piping in metallic conduit; and other structures with hazardous products.

These requirements are the same for both Air Force and Army projects. All buried metallic components of these facilities listed shall be coated and cathodically protected even if they are metallic fittings or other metallic components of a non-metallic pipeline or structure.

One facility not specifically listed is Above Grade Tank Bottoms. However, if the above grade tank contains hazardous products and its bottom is in contact with the earth, then it would be included in the last item listed. Additionally, along with environmental requirements such as secondary containment, leak monitoring, etc., cathodic protection is mandatory for protection of the bottoms of on-grade fuel tanks in some states such as Florida. MIL-HDBK-1136 requires that all ferrous tanks in contact with earth to be cathodically protected. Lastly, MIL-HDBK-1022A, Petroleum Fuel Facilities, paragraph 2.12.1, requires cathodic protection be installed between the liner and the tank bottom to protect the bottoms of above grade fuel storage tanks.

There is much ductile iron fire protection piping and/or non-metallic fire protection piping with ductile iron components already in existence and, also, are being installed routinely on military bases. Since pressurized ductile iron piping installed under floor slabs is specifically noted in this list, surveys and findings on the corrosion activity of ductile iron is noteworthy. Pitting corrosion has been reported to be the primary mode of failure for ductile iron pipes. Many surveys have been conducted in Canada, as well as other places to substantiate this fact. One survey conducted in the United Kingdom Water Industry in 1984 consisted of a study of 359 corrosion failures on 118 ductile iron mains. The survey results suggested that pitting corrosion was a primary mode of failure and the average maximum pitting corrosion rate for unprotected ductile iron was typically in the range of 0.50 to 1.5 mm/year (20-60 mils/year), with values of up to 4.0 mm/year (160 mils/year) in some instances. Similar studies conducted in Calgary, Canada have resulted in the mandatory requirement of cathodic protection on all new metallic pipes to be installed in that city. More recent articles in NACE International’s magazine, *Materials Performance*, have discussed corrosion studies performed on ductile iron piping systems which substantiates other independent studies.

9.2 Designer Qualifications

Qualified personnel must accomplish cathodic protection design. ETL 1110-3-474 requires the following:

- All pre-design surveys, designs, and acceptance surveys must be by a “Corrosion Expert.”
- “Corrosion Expert” is a NACE Certified Corrosion Specialist, CP Specialist, or registered Professional Corrosion Engineer.
- “Corrosion Expert” must have a minimum of 5 years experience in CP design and experience must be type specific.

The above are the basic CP designer qualification requirements for Army projects. The requirements are the same for Air Force projects, as well as for cathodic protection design protecting certain facilities in private industry. The designation “Corrosion Expert” is the same term as is used by the Environmental Protection Agency’s (EPA) Office of Underground Storage Tanks (OUST) in the applicable portion of the Code of Federal Regulations. NACE International requested the EPA to clarify the term “Corrosion Expert.” They clarified the term to mean the same as is indicated in the referenced Army regulation. The environmental laws for the state of Florida also require essentially the same credentials for a cathodic protection designer.

The design of the entire CP system must also be completed prior to construction contract advertisement except for Design-Construct and pre-approved underground heat distribution systems as required by this same ETL.

The CP designer must be knowledgeable of other engineering disciplines as they pertain to the application of cathodic protection and he/she must coordinate his/her efforts with those disciplines.

10. Design Coordination

The CP designer must be aware of and properly coordinate the requirements of various other specification sections, some of which are:

- UFGS 02510A Water Distribution System
- UFGS 02552A Pre-Engineered Underground Heat Distribution System
- UFGS 02556A Gas Distribution System
- UFGS 13202A Fuel Storage Systems
- UFGS 13210A Elevated Steel Water Tank
- UFGS 13930A Wet Pipe Sprinkler System
- UFGS 15200A Pipelines, Liquid Process Piping

This coordination effort would include reviewing these various other specification sections which specify buried or submerged metallic components that require cathodic protection by law or regulation. Specifications for protective coatings for those metallic components must also be reviewed for compatibility with cathodic protection since all coatings are not compatible. The various specification sections should be in technical agreement, not only with each other, but also with applicable laws and regulations. Some possible design conflicts are already existing in the various guide specifications of which the CP designer should be aware. For example, specification section 02510A, paragraph 2.1.5 allows polyethylene encasement of ductile iron pipe in accordance with AWWA C105. There is much controversy over the validity of this particular corrosion control method. Although not normally used for the protection of other pipe materials, this corrosion control method is pushed by the ductile iron industry for protection of ductile iron; however, case studies have proven that ductile iron can severely corrode while utilizing this method. Even if non-metallic water piping is utilized for the majority of fire protection piping on a particular project, ductile iron will be utilized on fire hydrants, post indicator valves, and piping under slab (required by paragraph specification section 13930A for wet pipe sprinkler systems). Subsequently, adequate corrosion control must be implemented. Since both fire protection piping and pressurized ductile iron piping under floor slab requires cathodic protection, they must also have bonded coatings in accordance with the applicable cathodic protection guide specifications. Additionally, Air Force guidance does not allow the use of non-bonded coatings, such as polyethylene encasement, for corrosion control and NACE International does not recommend the use of non-bonded coatings with cathodic protection. CP requires bonded coatings, and when it is required, other sections must properly address it.

11. Advantages of Adequate Corrosion Control

Extended coating and structure life yielding cost savings; protection of the environment; improved public and employee safety; and avoidance of costly litigation resulting from non-adherence to applicable laws and regulations are just a few of the advantages afforded with an adequate corrosion control system. How cathodic protection can extend structure life, protect the environment, and improve safety has been explained. Cathodic protection’s ability to extend coating life of structures is an important cost savings that many times may not be realized or understood by the user of the facility. This benefit is supported by the following:

> Naval Civil Engineering Laboratory Technical Report - R765 - “Cathodic protection of a water tank can double or triple the time between coatings”
>
> American Water Works Association Standard ANSI/AWWA D104 - “For submerged areas of a tank, cathodic protection systems can reduce the frequency of coating maintenance”
>
> National Association of Corrosion Engineers Recommended Practice - RP0388 -“Properly designed and maintained cathodic protection systems can extend the useful life of the coating.”

What can happen if we do not properly design, construct, operate, and maintain corrosion control systems as required by regulations as well as federal and state laws? The following paragraphs illustrate examples of costly damage, some of which resulted in deadly accidents and subsequent litigation.

12. Carlsbad, NM Explosion

At 5:26 a.m. on August 19, 2000 an explosion occurred on one of three adjacent large natural gas pipelines near Carlsbad, New Mexico. El Paso Natural Gas Company operates the pipeline system. The pipelines supply consumers and electric utilities in Arizona and Southern California. Twelve people, including five children, died as a result of the explosion. The explosion left an 86 feet long crater.

The National Transportation Safety Board (NTSB) and the Office of Pipeline Safety (OPS) investigators at the accident site observed internal corrosion in the section of the pipe that failed. The ruptured section of pipe was taken to a NTSB metallurgy lab for examination. The NTSB was responsible for determining the cause of the failure.

A wide variety of methods can be used to monitor and protect pipelines from the most likely causes of failure; the combination of methods chosen by an operator must factor in known risks that a particular pipeline faces (e.g., corrosion, excavation-related, material defects, etc.). Some of the more common methods are: cathodic protection systems that control for external corrosion, close interval surveys that use electrical readings to look for external corrosion, leak detection systems that detect releases of product, pipeline right-of-way monitoring (via foot, vehicle, or from a plane), inspection and testing of valves and overpressure devices, etc.

13. Lively, TX Explosion

In August 1996, a high-pressure gas line exploded approximately 200 yards from a house in Lively, Texas, near Dallas. A large US oil company owned and operated the gas line. As a result of the explosion, two teenagers were killed.

The family of the teenagers subsequently filed suit against the oil company. As per the plaintiff's attorney, on the day of the explosion, the gas line was like Swiss cheese with evidence of severe corrosion. The law requires that the oil company protect its lines against corrosion with both protective coatings and cathodic protection. In this case, the cathodic protection rectifier was not in service and had not been for some time. Records were changed to indicate that the system was operable when in fact it was not. This was proven in court and the company was found to be guilty of negligence and malice. The family was awarded over 300 million dollars in the wrongful-death lawsuit.

14. Corroding of Steel Embedded in Concrete

Steel embedded in concrete exposed to salt water is especially vulnerable to corrosion in the splash zone areas. Salt eventually works its way to the metal structure beneath the concrete and begins to corrode the embedded metal. The corrosion by product exerts pressure on the concrete and causes it to crack. The concrete is eventually spalled away, exposing the metal beneath.

Cathodic protection is one recognized method to protect against this type of corrosion damage. Cathodic protection and coatings are utilized on bridge supports, bridge beds, buildings, and other steel reinforced concrete structures exposed to salt water, or corrosive environments.

15. Summary

If corrosion of metallic structures exposed to electrolytes is not controlled or eliminated, it can result in very costly consequences. The effects of damage resulting from corrosion can cause harm to our environment, as well as to human life.

Cathodic protection, in combination with protective coatings, has proven to be the most effective method to control corrosion of metals exposed to electrolytes, such as soils and waters.

Since this method of corrosion prevention is so effective, many laws and regulations require it. The laws and regulations were created in order to gain the resulting economic, environmental, and safety benefits. However, in order for cathodic protection to provide the proper protection it must be designed, installed, operated, and maintained by qualified personnel.