STRAY CURRENT CORROSION DUE TO UTILITY CATHODIC PROTECTION

By

Richard W. Shipley

David Darwin

Carl E. Locke, Jr.

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ABSTRACT

The conditions in which stray currents contribute to the corrosion damage of highway structures, the tests to determine if these conditions exist, and the methods recommended to alleviate either the conditions or the damage caused by stray current corrosion are investigated. An extensive review of the literature concerning the fundamentals of stray current corrosion and the practices of utility cathodic protection is presented, including a comprehensive study of the history of stray current corrosion, from its conception with the direct current trolley systems of the late 1880's to its present day problems in the cathodic protection industry. Federal, state, and Kansas Department of Transportation rules and policy are reviewed as they pertain to utility cathodic protection and the damage it may cause to adjacent underground highway structures. Based on the research covered within this report, procedural changes for the prevention of stray current corrosion damage to highway structures and additions to the KDOT Utility Accommodation Policy (1994) are recommended.

The research herein concludes that: (1) that all construction close to cathodically protected utilities should be reported to the utility owners so that stray current interference can be assessed, (2) any utility pipeline found uncovered should be reported to its owner so that it can be inspected for corrosion damage, and (3) no underground highway structure should be located within the area of influence of a cathodic protection groundbed. Additionally, its recommended that the KDOT Utility Accommodation Policy (1994) be modified to: (1) directly state the policy on stray current interference from utility cathodic protection systems, (2) require utilities installing cathodic protection systems to submit the design plans as part of the process necessary to obtain a permit agreement for operating in a highway right-of-way, and (3) state that KDOT may require additional inspections along pipelines where interference could jeopardize the structural integrity of an underground highway structure.

Keywords:

bridges, cathodic protection, highway structures, stray currents, stray current corrosion, stray current interference

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TABLE OF CONTENTS

LIST OF FIGURES

CHAPTER 1: INTRODUCTION

1.1 General

In the United States, billions of dollars are spent each year on the prevention of corrosion and on the maintenance and rehabilitation of metallic structures subject to corrosion. One method of prevention is cathodic protection, a procedure that has been used successfully for many years by utility companies on underground pipelines. During the development of the techniques that are now in use for cathodic protection, damage to adjacent underground structures was observed. The cause of the damage was the presence of current passing between the protected and unprotected structures, which is known as "stray current." Experience gained in the use of cathodic protection has led to the development of standards to predict, avoid, and/or mitigate the damaging effects of stray currents. With pipeline and highway right-of-ways growing smaller and more costly, highway structures are found increasingly in proximity to cathodically protected lines. It is clear that a better understanding of the impact of utility cathodic protection on adjacent underground metallic structures will put state departments of transportation in a stronger position to prevent potential damage due to stray current corrosion.

Stray current corrosion occurs when wayward direct current enters an underground metallic object at one point only to return to the soil at another point. Corrosion occurs at the point where the current returns to the soil. Sources of stray direct current can include railway systems, mining operations, high voltage dc transmission lines, and cathodically protected utility pipelines. Although each of these sources poses a potential danger to any underground metallic structure located nearby, proper design can prevent damage before it occurs.

1.2 Background

A corrosion cell may be generated under many conditions. To understand stray current corrosion and the conditions under which it occurs, it is important to demonstrate how the electrochemistry of the corrosion cell works and its relationship to utility cathodic protection.

1.2.1 Basic Corrosion Cell

Several conditions must be met for corrosion to occur: regions with different electrical potentials must form an anode and a cathode, a metallic pathway must join the anode and cathode, and a conductive electrolyte must be in contact with the metallic object.

The first condition requires a difference in potential between one point on the metal and another, forming the anode and the cathode. Differences in potential commonly occur because of conditions within the electrolyte, the structural material, or both. The properties of soil, a heterogeneous material, can vary greatly along the dimensions of an underground structure. These variations can include changes in moisture content, oxygen level, and chloride concentration, as well as changes in the base soil material. The structure itself can produce changes in potential when dissimilar metals are in contact. Contact between metals of different electromotive activity, known as "galvanic coupling," may produce the difference in potential necessary to drive a corrosion cell. This effect can occur due to the presence of welding material, bolt connectors, valve fittings, or even new structures joined to existing structures that are coated with corrosion by-products.

Differences in the soil or the structure can be localized, resulting in the formation of microcells, or cover relatively large areas of the structure, resulting in the formation of macrocells. Microcells occur when the anode and cathode are located adjacent to one another, such as along the surface of a metal object subject to uniform corrosion. Macrocells occur when the anode and cathode are found at distinct locations within the overall structure. As an example, a macrocell might form on a buried steel pile with one end encased in concrete and the other end imbedded in soil. The concrete provides a highly alkaline environment, while the soil provides more neutral surroundings, creating a potential difference between the sections of the pile in the two materials.

Another condition required for the formation of a corrosion cell is the existence of a metallic pathway between the anode and cathode. In most cases, this pathway results from the conductive nature of the structure itself.

Lastly, the corrosion cell needs an electrically conductive medium or electrolyte that is in

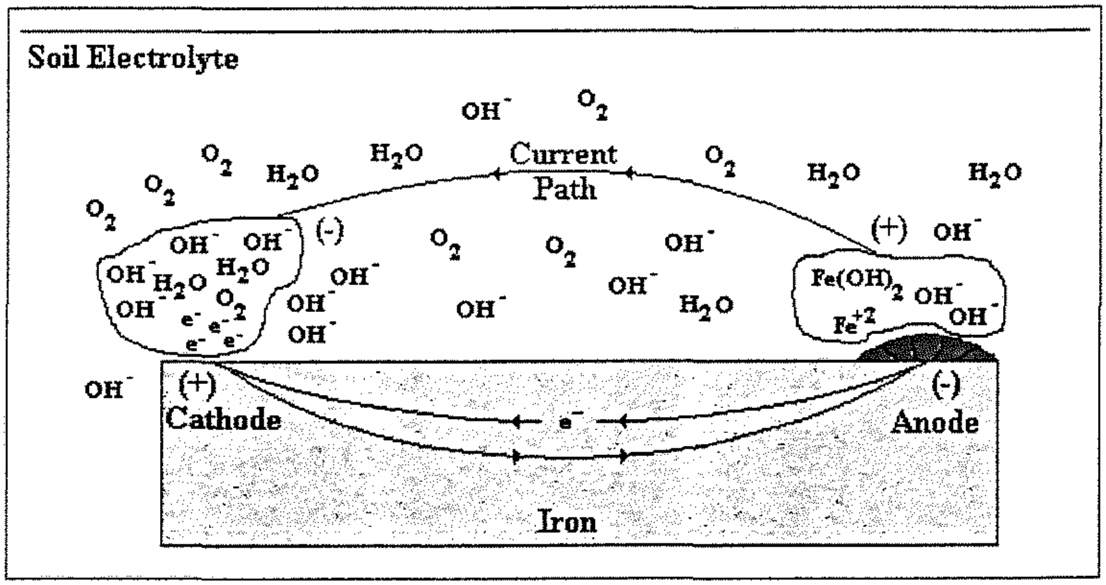

Figure 1.1 Basic Corrosion Cell.

contact with the anode and cathode. Water, the most common electrolyte, contains hydroxyl (OH^-) and hydrogen (H^+) ions. Soil types can vary from acidic to alkaline, depending on regions in which they are found. Highly alkaline pore water can serve as an electrolyte in reinforced concrete.

Once all of the conditions, i.e. the existence of a potential difference, a metallic pathway, and a surrounding electrolyte, are met, corrosion will occur. With reference to Fig. 1.1, the following reactions will occur for a steel or iron object buried underground, undergoing corrosion.

$$Fe \rightarrow Fe^{+2} + 2e^- \qquad \text{anodic (oxidation) reaction} \quad (1.1)$$

$$1/2O_2 + H_2O + 2e^- \rightarrow 2OH^- \qquad \text{cathodic (reduction) reaction, alkaline} \quad (1.2)$$

At the anode, iron is oxidized in reaction (1.1), releasing ferrous ions, Fe^{+2}, into the electrolyte while discharging electrons along the metallic pathway to the cathode. This excess of electrons gives the anode a negative potential. The positively charged ferrous ions react with negatively charged hydroxyl ions, OH^-, found in the electrolyte to form ferrous hydroxide ($Fe(OH)_2$). This may react, yet again, to form ferric hydroxide ($Fe_2(OH)_3$), which is commonly known as rust (Peabody 1967).

The cathodic reaction varies with the type of electrolyte. In a neutral or alkaline electrolyte, reaction (1.2) occurs at the cathode as the electrons provided by reaction (1.1) arrive via the metallic path. This need for electrons to reduce the oxygen gives the cathode a positive charge. The rate of the reaction at the cathode is greatly influenced by the availability of oxygen in the electrolyte and governs the rate of corrosion in the cell when in short supply.

Similarly, in an acidic electrolyte, reaction (1.3) occurs at the cathode with the reduction of hydrogen and is likewise governed by the hydrogens availability.

$$2H^+ + 2e^- \rightarrow H_2 \qquad \text{cathodic [reduction] reaction, acidic} \quad (1.3)$$

Reactions (1.1) and (1.2), or (1.3), take place at a finite and equal rate. The quantity of electrons produced in reaction (1.1) is governed by the availability of oxygen or hydrogen to be reduced respectively at reactions (1.2) or (1.3). An excess of electrons at the cathode awaiting reaction is known as cathodic polarization. Likewise, reaction (1.1) becomes anodically polarized as it becomes more positive and the rate of corrosion is reduced. Without polarization, corrosion rates would proceed unchecked with any change in potential within the cell.

It is important to note that current flows from the cathode to the anode within the metallic pathway, which is consistent with the conventional idea of current passing from positive to negative. Current flowing within the electrolyte travels from the anode to the cathode. Although less obvious, this current path follows the same convention. Positive ferrous ions are released into the electrolyte at the anode, while negative hydroxyl ions are formed within the electrolyte at the cathode. Current then flows from the positive electrolyte at the anode to the negative electrolyte at the cathode. It is the current flow leaving the metal, through the electrolyte, that creates the corrosion damage (see Fig. 1.1).

The quantity of metal removed is directly proportional to the current flowing in the corrosion

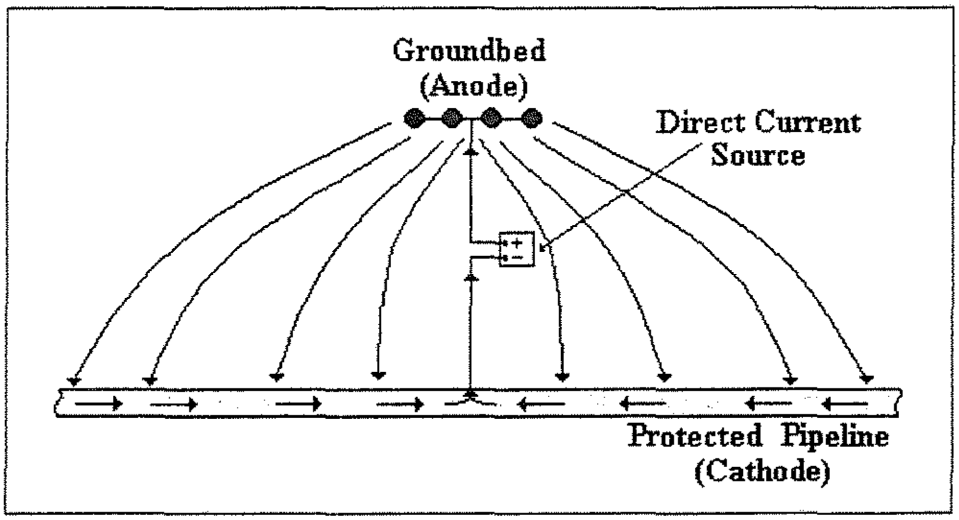

Figure 1.2 Basic Cathodic Protection of an Underground Pipeline. Arrows indicate direction of current path.

cell. For steel or iron in a typical soil, a current of one ampere will remove about 20 lbs of the metal in one year. Although current is often measured in milliamperes for most corrosion cells, severe damage may occur if the anodes are highly localized. For example, when the anodic areas are limited to very small regions, such as the small holidays in protective coatings, total corrosion will be low, but corrosion at the holidays may be severe.

Another factor affecting the rate of corrosion is the resistance of the cell. Cell potentials can vary from a fraction of a volt in a microcell to several volts in a macrocell. According to Ohm's Law, Voltage = (Amperage) x (Resistance). Therefore, for a given potential, the lower the resistance of the corrosion cell, the greater the current flow and, proportionally, the greater the rate of corrosion. The resistance of buried metallic objects, such as piles and large diameter pipes, is often negligible, and therefore, the majority of the resistance for the corrosion cell is determined by the surrounding soil resistivity and the protective coating, if any, on the metallic structure.

1.2.2 Utility Cathodic Protection

Cathodic protection has been used to protect underground utilities since 1930. Cathodic protection is obtained by impressing a negative shift in potential upon the metal structure to be

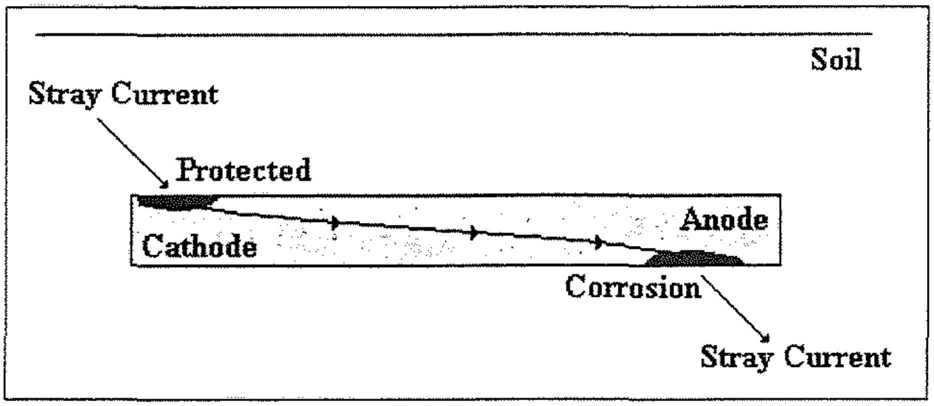

Figure 1.3 Stray Current Corrosion.

protected. This is done by either impressing current upon the structure or by galvanically coupling the structure to a more active metal. In either case, electrons are provided at the cathode to prevent the oxidation of the metal, reaction (1.1). Cathodic protection does not eliminate corrosion but causes the metallic structure to become the cathode in a macrocell, while corrosion is localized (under ideal conditions) at a designated anode location or "groundbed" buried within the ground (see Fig. 1.2).

An impressed cathodic protection system, as shown in Fig. 1.2, is commonly used to protect underground utilities. A direct current source is used to drive the electrons and protect the pipeline. Impressed current cathodic protection systems can be used to protect stretches of pipeline up to 80 km (50 miles) in length between groundbed locations. Another form of cathodic protection uses sacrificial anodes to provide protection. The sacrificial anodes are made of a more active metal than the protected structure. This creates a macrocell from the dissimilar metals, with the more active, corroding anode connected metallically by an insulated lead wire to the protected cathode. Sacrificial anodes have a limited area of protection and are generally used, with respect to utilities, for short pipes [less then 300 m (1000 ft)] or at points were localized corrosion areas ("hot spots") are found. They have been widely used for the protection of ship hulls and tanks found in sea water environments. Sacrificial anodes have also been used to prevent damage in areas under the influence of stray currents (see Chapter 4).

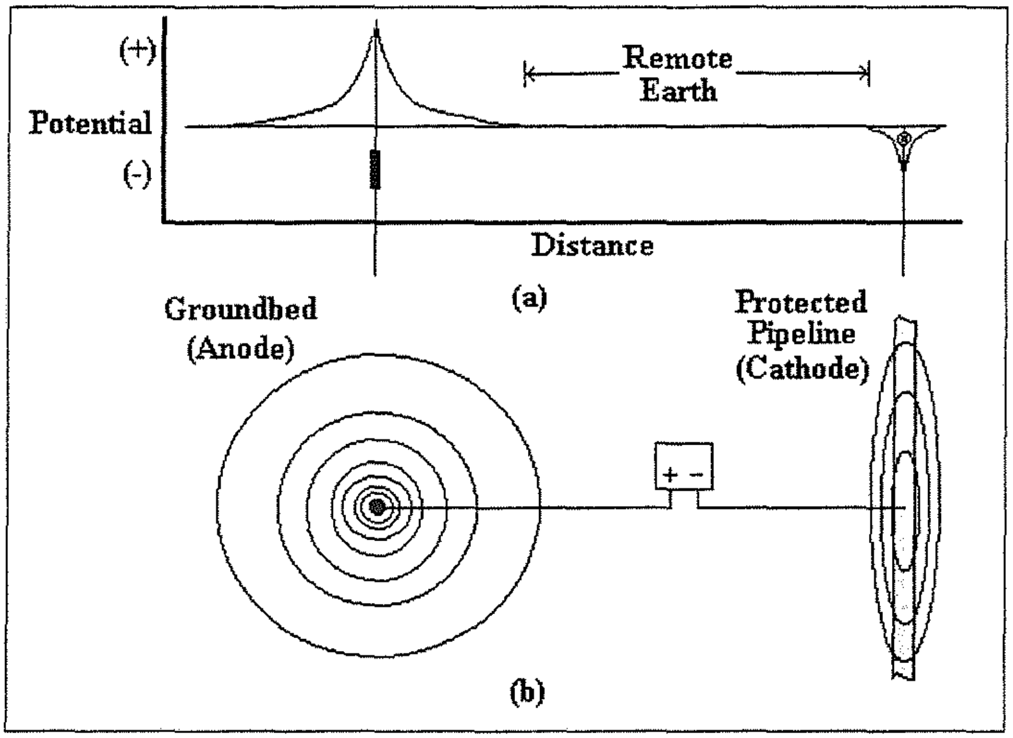

Figure 1.4 Impressed Current Influence Areas, (a) Potential Profile, (b) Equal Potential Lines.

1.2.3 Stray Current Corrosion

Stray current corrosion (see Fig. 1.3) is a specialized form of corrosion caused when direct current enters an underground metallic object at one point (the cathode) only to return to the soil at another point (the anode). Although the cathodic portion of the buried metallic object exhibits a certain amount of protection due to the stray current, damage occurs at the anode as the current returns to the electrolyte in proportion to the rate of current discharge.

Impressed current cathodic protection systems, due to their large area of protection, are more likely to influence other buried metallic structures than are sacrificial anode systems. Consider Fig.1.4. When current flows from an anode into the earth, the potential of the anode is raised with respect to the surrounding earth, with the potential decreasing in all directions away from the anode. Conversely, at the cathode, the protected metallic structure is negative with respect to the surrounding earth, with the potential increasing in all directions away from the cathode (Smith 1943). These changes in potential can be thought of as equal potential circles radiating from the anode or equal potential ellipses radiating from the cathode (pipeline), centered on the lead cable connecting the groundbed to the pipeline. Regions in the soil where the gradient in potential is non-zero are known as "areas of influence" for the respective anode and cathode. Regions where the potential gradient becomes zero are referred to as "remote earth."

Cathodic protection interference occurs when another underground metallic structure is within one or both of the areas of influence. As the unprotected, or "foreign," metallic structure crosses equal potential lines, the change in potential along the structure creates the conditions necessary to form a corrosion macrocell. The greater the difference in potential, the greater the current flow. If combined with low electrical soil resistance, high currents can be produced, with proportionally high rates of corrosion. Methods of predicting and testing for the existence of cathodic protection interference, as well as the mitigation of any damaging effects, will be discussed in Chapter 4.

1.3 Object and Scope

The object of this report is to summarize the conditions under which stray current corrosion occurs and explain how adjacent highway structures may be affected. This report describes how to avoid stray current conditions, as well as how to monitor and mitigate problems. The history of stray current corrosion in the United States is examined, including a discussion of the experiences that led to the development of current standard practices. Standard practices, governing regulations, and procedures in surrounding states are covered as they pertain to utility cathodic protection and nearby foreign structures. Lastly, recommendations are made on how to deal with stray current corrosion problems as they affect highway structures.

The work presented in this report includes the results of a comprehensive literature search, with sources dating back to 1885. Several literature search indexes were used, as well as cross references from bibliographies found to hold useful information. Much of the information gathered for this report pertains to cathodic protection interference as it relates to foreign pipelines. This information, together with the limited research pertaining to nonpipeline structure interference, has been examined and interpreted with highway structures in mind. Regulating legislation and standard cathodic protection practices have been examined, and surrounding state DOTs have been contacted, as were industry experts in the field of cathodic protection.

CHAPTER 2: HISTORY OF STRAY CURRENT CORROSION IN THE UNITED STATES

Stray current corrosion has been a part of modern life since the late 1800's. First with its connection to dc railways and then to utility cathodic protection, stray current corrosion represents an invisible and often unpredictable problem for engineers. Traveling beneath the earth's surface and often laying undetected until failure occurs, stray currents can greatly reduce the life expectancy and cost effectiveness of underground metallic structures. If the presence of stray currents is not recognized beforehand and properly taken into account in the design of buried metallic structures, severe property damage and safety issues may soon follow. The proper recognition of a possible "danger area" and the proven remedies to eliminate it, or its influence, can be found by examining problems and successful solutions from the past.

2.1 Direct Current Street Railways

Starting in the early 1800's, prior to the introduction of dc powered street railways, many cities used horse drawn streetcars for urban transportation. Steel wheels and small steel rails imbedded in the street surface were used to limit the frictional resistance of the cars. With the invention of the first electric powered street railway, or trolley, in 1887, many of these horse drawn rail systems were converted by adding overhead lines and powerhouses. Direct current was fed from the positive bus at the powerhouse into the overhead line, through the streetcar's motor, into the rails, and back to the negative bus of the powerhouse (See Fig. 2.1). From the beginning, street railway companies were aware that portions of the current would travel through the earth rather than the rails, but they did not anticipate the damaging effects this would have on the telephone, gas, and water utilities found in the streets below.

Stray current corrosion of pipelines was first identified in Boston in 1891. Lead, which is removed at a rate of approximately 60 lbs per ampere per year, was first to be attacked on covered telephone lines. Damage to cast-iron utility pipelines was later discovered to be occurring at a rate of 20 lbs per ampere per year. Laboratory tests were conducted by Charles A. Stone and Howard

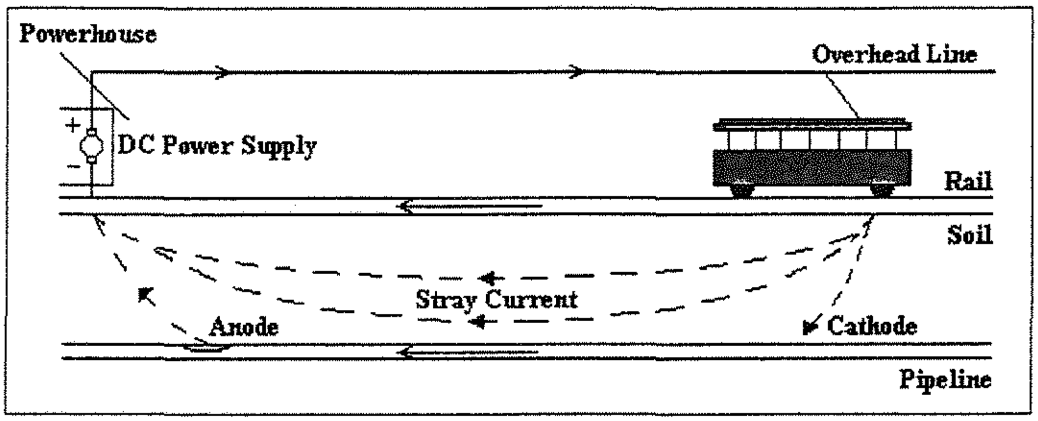

Figure 2.1 Stray Current Corrosion due to Single Return Direct Current Railway.

C. Forbes using soil samples from the damage areas (The Destructive Effects 1894). Reproducing the conditions at the damage sites in the laboratory, Stone and Forbes reported similar corrosive effects for commercial pipes subjected to stray currents. Surveys by the team in Boston, and later Peoria, Illinois, determined the nature of the distribution of electrical current in the two cities (Maury 1900). Where current left buried cables and pipes, destruction occurred. The most concentrated damage to the pipelines was often located beneath the powerhouses where the stray current left the preferential path of the pipeline to return to the negative bus of the direct current source. More wide spread destruction of the pipelines often occurred at piping joints. Pipes being joined were often first coated with two insulating layers of coal tar before being fitted together and sealed with lead (Maury, 1900). This often produced electrical resistance between the two pipes which, when strong enough, forced the stray currents traveling along the pipe to "leap frog" over the joint (see Fig. 2.2). Damage occurred where the current exited one pipe to return to the other pipe. Stray current corrosion was soon discovered in every city employing a single overhead return electric railway system.

In the late 1800's, Brooklyn, New York utility services reported extensive damage due to stray currents. In 1894, the same year street railways were installed, 300 miles of lead covered telephone lines where found destroyed. The Brooklyn Union Gas Company claimed a sharp increase in the number of leaks in their lines beginning with the 1894 introduction of street railways. In one

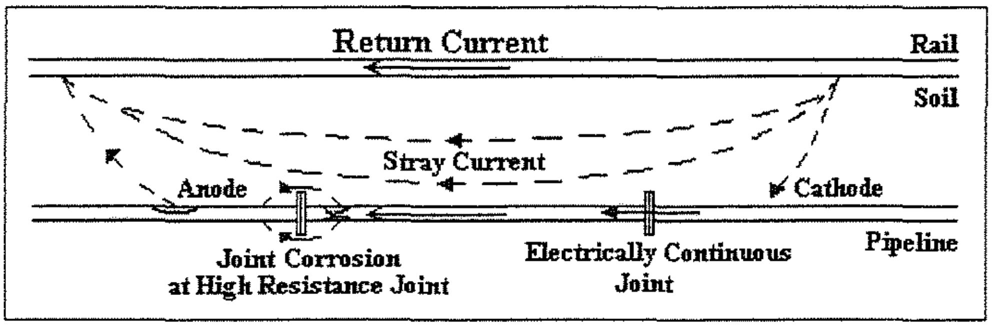

Figure 2.2 Joint Corrosion due to Stray Direct Current Single Return Railway.

"danger area," 38 service pipes were completely destroyed in a three year period. In 1899, the gas company blamed the loss of 13% of its total production on leakage due to stray current corrosion (Sheldon 1900).

Brooklyn's problems were not limited to telephone cables and pipes. There were also serious worries over possible damage to the Brooklyn bridge. Concerns were raised when damage due to stray currents was found at the base of columns supporting elevated rails in the vicinity of the bridge. Steel anchors weighing 23 tons incased in concrete were at both ends of the bridge and deterioration of these anchors would endanger its stability. Although found by an electrical expert at the time to be suffering no immediate damage, it was recommended that no point on the bridge structure should be more positive than one volt with respect to the ground (Stray Currents 1899).

In Kansas City, Kansas, Professor Lucien I. Blake of the University of Kansas was asked to investigate stray current problems in that city. Prof. Blake performed a detailed survey for the Metropolitan Water Company, mapping out the "danger areas" associated with stray currents. In an area where the water company had been forced to replace its service pipes every six months, Prof. Blake reported that, "there was sufficient voltage between pipe and rail here to run small incandescent lamps and sufficient current to burn out the largest wire at hand, a No. 12." (Electrolysis 1899).

To completely eliminate the problem of stray currents, short of discontinuing railway services altogether, three methods were often recommended. First, the use of double return overhead trolleys was suggested and successfully used in both Cincinnati and Washington, D.C., passing no return current through the rails. Unfortunately, railways complained of difficulty in converting to a double overhead system due to its complicated intersections and crossings. Next, the use of an insulated conduit, or "plow," in the street surface was suggested for conducting current. This method was used successfully in New York and Washington state. However, it was difficult to convert railways already in place to this method, and the modified systems were troubled by short-circuits in winter, when salts were used as deicers. Lastly, the use of alternating current was suggested as a method to completely eliminating stray current problems. Unfortunately, the technology to do this did not exist at the time. Thus, rather than change the electrical distribution/return system, it proved to be more practical for the electric railways to minimize the damaging effects of stray current.

As the problem of stray current corrosion reached epidemic proportions by the early 1900's, utilities began to seek damages against the electric railways, finding the courts to be, generally, in their favor (A Court Decision 1901, Report 1901). This led to a study and a series of papers by the National Bureau of Standards (Digest 1918). This work was continued by the American Committee of Electrolysis, which consisted of members of organizations representing both electric railways and utilities. A report by the committee (Report 1921) laid the foundation for the design and maintenance of electric railways that is still used today. Their recommendations included: increasing the conductivity of the return rails, increasing the resistance of the leakage path to the earth, increasing the resistance between the earth and underground metallic structures, and increasing the resistance of the underground metallic structures (Szeliga 1993).

One method to increase rail conductivity was to use very heavy return rails with good bonds between the rails. Many electric railways had used pre-existing rails from the days of horse drawn streetcars. For economic reasons, these rails were often small and of very high electrical resistance, promoting unnecessarily large stray currents. Compounding the problem were gaps between the rails. By using large, lower resistance rails with proper electrical bonds connecting adjacent rails, many of the wayward current problems were reduced. The most commonly used solution was to connect the pipes that were nearest to the powerhouse to the negative bus of the power supply, providing the current with a metallic return path to its source. This "electrical bonding" or "forced drainage" was considered by most experts to be a "temporary" solution and tended to increase the area of influence of the stray current problem. Although eliminating the damage caused by stray current leaving the pipes nearest the powerhouse, this solution insured that the pipelines would provide the preferential path for stray currents. If pipe joints were not properly electrically connected to one another, localized joint corrosion would occur with greater frequency and intensity than had the pipeline remained metallically disconnected from the powerhouse.

The resistance of the leakage path could be increased by isolating the rails from the earth. Originally, this was done by using creosote treated wooden ties to increase the isolation of the rails from the street. Later, concrete ties with electrically insulated fasteners were employed with improved performance. Recently, a plastic membrane material imbedded beneath the rails has been used to provide even greater resistance.

Increasing the resistance between the earth and underground metallic structures is achieved by isolating the structures from damaging currents. In the American Committee of Electrolysis report (Report 1921), the use of coatings to isolate underground metallic structures was not recommended due to the possibility of creating small anodic regions at coating imperfections. Today, the use of electrical shielding and isolating coatings (in conjunction with cathodic protection) is considered to be an effective way of increasing the resistance between the earth and metallic structures.

Lastly, increasing the resistance of underground metallic pipelines, which can greatly reduce the effects of stray current, is accomplished by using short segments of pipe with insulated fittings. The resistance can be significantly increased making it difficult to travel along the structure.

Although the recommendations provided by American Committee of Electrolysis (Report 1921) were made in 1921, they are still the basis of the methods used today. Additional advancements in materials over the last several decades have continued to improve direct current electric railway isolation but have not eliminated stray currents altogether.

2.2 Utility Cathodic Protection

While electric railways caused much destruction to utilities throughout the United States, once discovered and corrected, often by bonding the negative bus to the pipeline, utilities found that their pipelines, made negative to the earth, were experiencing a limited amount of protection. However, only as electric railways began to be replaced by automobiles and buses in the 1920's and 30's were the true benefits of marrying pipelines to rails recognized. Some cities developed plans to set up earth current generators to continue the positive corrosion benefits provided by the discontinued railway services. In one case, a defunct railway was forced to continue direct current generation without compensation (Pope 1954). Thus, it was only a matter of time before the use of impressed electrical current was taken to its next logical step.

In 1930, Robert J. Kuhn, an electrolysis engineer for the New Orleans Public Service, recognized the opportunity to incorporate a new idea in pipeline corrosion prevention, cathodic protection (Kuhn 1935). Kuhn was familiar with both the positive and negative characteristics of stray currents from his work with utilities and New Orleans' own trolley system. He presented a paper entitled "Galvanic Currents on Cast-Iron Pipes" (Kuhn 1928) to the first National Bureau of Standards Underground Corrosion Conference in 1928. In the paper, Kuhn suggested that it might be possible to protect cast-iron or other metallic underground pipes from the corrosive effects of soil by impressing upon them a negative electrical charge. After receiving little encouragement from his peers, Kuhn remained confident that he could apply an impressed negative charge to protect the newly proposed high pressure natural gas service coming to New Orleans.

Given the highly corrosive nature of the soil in New Orleans, an economical and practical method of protection was needed. The welded steel mains were coated with asphalt priming paint and covered with two layers of asphalt-impregnated asbestos felt, wrapped in a spiral around the pipeline. Not only did Kuhn have the corrosive nature of the soil to deal with, there were also five electric railway substations creating stray current problems. Kuhn turned this problem into an advantage by bonding the new pipeline to the rails, making both structures negative to the earth. Kuhn also knew that the electrical drainage would not be sufficient to prevent natural soil corrosion at points remote from the bonds. Therefore, at these locations he placed battery charging rectifiers with the negative poles of the rectifiers connected to the pipeline and the positive poles bonded to scrap cast-iron pipes designed and placed to prevent stray current corrosion to other nearby structures. Only about 0.3 volts dc were used, creating the first cathodically protected pipeline.

Elsewhere, the extensive networks of oil and gas pipelines constructed in the 1920s were becoming corrosion problems in the 1930s. The sharp increase in leaks and the successes of New Orleans and others cities attempting to use cathodic protection moved the new method of corrosion prevention of underground pipelines into accepted practice. In 1936, the Mid-Continent Cathodic Protection Association, later to become the National Association of Corrosion Engineers (NACE), formed to exchange ideas and information on the use of cathodic protection (Morgan 1987). NACE has since become the leader in bringing together experts in research and development to further the understanding of corrosion and cathodic protection. NACE has developed recommended practices for cathodic protection based on the experience of experts in the field.

Many of the problems that once plagued electric railways confronting unprotected utilities now posed very similar problems between cathodically protected pipelines and their unprotected neighbors. Fortunately, most cathodic protection designers were familiar with the earlier problems and took these lessons into consideration. Still, unfamiliarity with the new technology and/or the services in and around cathodically protected structures led to the premature destruction of many buried metallic services. As Robert Kuhn (1935) wrote,

> Since there is an element of possible danger to other structures and even to the line thought to be protected by this process, the work of applying this method of protection should be handled only by an expert along these lines. However, just as dynamite is a very dangerous article in the hands of the uninitiated, still it finds world-wide use in many fields. Cathodic protection likewise can be used to advantage to prevent uneconomic depreciation on many valuable underground structures and submerged structures of both the gas and other fields.

2.3 Today

Today, both cathodic protection and electric railways are used extensively, and successfully, throughout the world. Cathodic protection has gone far beyond its use for just pipelines and is now used to protect storage tanks, reinforced concrete bridge decks, oil wells, steel ship hulls, water towers, hot water heaters, and virtually any metallic object that involves an anode, a cathode, a metallic current pathway, and an electrolyte. Each of these protected structures brings with it the possibility of causing stray current damage. Only the use of proper design techniques can prevent this from occurring.

The National Association of Corrosion Engineers has been a leader in the organization of cathodic protection ideas and standards. Its Group Committee T-10: Underground Corrosion Control is responsible for bringing together experts in the field of cathodic protection. This committee has established the recommended practices for cathodic protection and the prevention of electrical interference with other underground metallic structures. NACE has also developed standards for the formation of Underground Corrosion Control Coordinating Committees (UCCCC). These committees bring cathodic protection companies and utilities together to promote corporation and awareness. UCCCC's have been formed in many major cities throughout the United States.

Lastly, the pipeline and cathodic protection industries represent a "tight knit" community of professionals eager to work together and share in the development of designs that provide the best service and most economical results. Construction of underground metallic structures in the vicinity of a cathodically protected service should be reported to those involved to avoid or mitigate stray current problems.

CHAPTER 3: A REVIEW OF RECOMMENDED PRACTICES AND GOVERNMENT REGULATIONS

3.1 General

Highway right-of-ways are often shared by natural gas and hazardous liquid pipelines, as well as water, waste, and communication pipelines and conduits. While many of the utilities found crossing or running along highway right-of-ways pose little danger to the public, natural gas and hazardous liquid pipelines can pose a threat if they deteriorate due to corrosion. Cathodic protection, in conjunction with protective coatings, has been found to be the most effective method of preventing corrosion in underground environments, and is, with very few exceptions, required by state and federal law.

The minimum safety standards set forth by the federal government for the transportation of natural gas and hazardous liquids are found in the Code of Federal Regulation (CFR), Title 49 (1995). Parts 191 and 192 of CFR 49 cover the transportation of natural and other gases by interstate pipeline, while Part 195 of CFR 49 covers the transportation of hazardous liquids by interstate pipeline. With CFR 49 as a guideline, the Kansas Corporation Commission (1989) has developed Pipeline Safety Regulations for intrastate pipelines carrying natural gas and hazardous liquids. These state regulations closely follow the minimum standards set forth by the federal government with a few increased restrictions. The Kansas Department of Transportation has added further restrictions for pipelines considered hazardous to public safety within highway right-of-ways in the KDOT Utility Accommodation Policy (1994).

3.2 Requirements for External Corrosion Control of Underground or Hazardous Liquid Pipelines

Due to the similarity between the requirements in the Kansas Corporation Commission Office of Pipeline Safety Regulations and CFR 49, the discussion of natural gas and hazardous liquid pipelines will be presented as they are found in CFR 49, Parts 191, 192 and 195 with any modification found in the Kansas Pipeline Safety Regulations noted, as applicable.

3.2.1 Natural and Other Gas Pipelines, CFR 49, Part 192 (1995)

3.2.1.1 Construction Requirements

The placement of underground pipelines and their relationship to other underground metallic structures is of great importance when the pipelines are subjected to cathodic protection. Although clearance, cover, and casing considerations appear to be made with the physical well-being of the underground pipeline in mind, each affects the cathodic protection of the pipeline and the possible effects of stray currents on nearby underground metallic structures.

Underground pipelines are required to maintain at least a 300 mm (1 ft) clearance from all underground structures not associated with the pipeline. If this clearance is unattainable, then measures must be taken to provide protection to the pipeline to prevent possible physical damage from surrounding structures. For well coated pipelines, the current requirements for impressed cathodic protection are so small that potential gradients in the earth around the pipeline are negligible (Peabody 1967), and therefore, only minimal clearance is needed to avoid stray current corrosion. However, if the coating is damaged or deteriorated near the vicinity of a nearby underground metallic structure, the potential gradients may be high enough to cause stray current corrosion to that nearby structure. If a sacrificial anode cathodic protection system is being used to protect the pipeline, sufficient distance is needed between the anode location and the nearby underground metallic structure to place the structure outside of the anode's area of influence. The area of influence of a damaged pipeline coating or sacrificial anode require field testing to accurately determine and will be discussed further in Chapter 4.

Cover requirements vary, but generally for normal soil conditions a 1 m (3 ft) minimum cover depth is needed. For cover that consists of consolidated rock a minimum depth of 600 mm (2 ft) is required. Cover can be less than 600 mm (2 ft), if allowed by state or municipal law, or if the pipeline is installed in a common trench with other utilities, as long as measures are taken to prevent physical damage to the pipeline by external forces. Cover, as it relates to cathodic protection, provides a barrier to external damage to the protective coatings. CFR 49 requires that all possible measures be taken to prevent the damage of protective coatings when placing and backfilling pipelines.

If casings, metal sleeves surrounding a section of pipeline to protect it from traffic loads, are used in conjunction with pipelines that cross under railroads or highways, they must be designed to withstand superimposed loads, sealed at the ends if there is a possibility that may water enter, and, if vented, protected from the weather to prevent the entrance of water into the casing. CFR 49 also requires that casings be electrically isolated from the protected pipeline. When isolation is impractical, other measures must be taken to minimize the corrosion of the protected pipeline.

Care must be taken to prevent short circuits between a cathodically protected pipeline and its casing. These can occur in many ways, from the failure of end insulators or insulated spacers to the formation of welding icicles within the casing during construction. Short circuiting a pipeline to the surrounding casing effectively shields the section of pipe within the casing from the protection current. Defects in the pipeline's protective coating within the casing cause the pipe to be subjected to whatever corrosive environment might be found within the casing interior. This corrosive environment often consists of water, which has inevitably entered the casing through either the failure of an end seal or as water vapor that has entered through the casing vents. Fortunately, the reduced oxygen content of the casing interior reduces the rate of corrosion at pipeline coating defects.

Care must also be taken to prevent damage to the protective coating of the pipeline within the interior of the casing. When the casing is properly installed and no short circuit exists with the pipeline, the casing becomes part of the conductive environment surrounding the pipeline. If an electrolyte (e.g. water) is present between the casing and the pipeline, protective current will flow from the surrounding soil into the casing and then through the electrolyte to the pipeline. Where the current leaves the casing to enter the electrolyte, the casing interior is subjected to corrosion. The greater the area of defective coating on the pipeline, the greater the demand for protective current and the greater the damage to the casing interior.

Corrosion failures within casings are rare, but do occur (Peabody 1967). Failure of a cased pipeline requires more involved repairs and expense than failure of a pipeline without a casing. Fortunately, the increased current demand resulting from a short circuited casing, which is usually either uncoated or poorly coated, can be easily detected during inspection and remedied before corrosion failure of the pipeline or its casing occurs.

3.2.1.2 External Corrosion

CFR 49, Part 192 divides external corrosion protection requirements into two categories based on when the pipeline was constructed. Gas utilities installed before August 1, 1971 must be cathodically protected along the entire length of the pipeline if the pipeline has an effective external coating. A pipeline is considered not to have an effective coating if its current requirements for cathodic protection are substantially the same as if it were bare. Bare or ineffectively coated pipelines, as well as compressor, regulator, and measuring stations must be cathodically protected in areas determined to be undergoing active corrosion. Active corrosion areas can be determined using electrical surveys or, where surveys are impractical, using leak history records. Under the requirements for corrosion control by the Kansas Corporation Commission on Pipeline Safety, surveys must have been conducted on all unprotected bare steel service lines by May 1, 1991.

Gas utilities installed after July 31, 1971 must have an external protective coating suitable for cathodic protection and be must cathodically protected. Exceptions are allowed if a pipeline operator can prove via tests, investigation, and experience in an area that the underground environment is noncorrosive. To do this, the pipeline operator must complete a pipe-to-soil survey six months after installation of the pipeline at intervals not to exceed 6 m (20 ft) along the entire length of the pipeline. If a corrosive environment is found to exist, the pipeline must be cathodically protected. Another exception is allowed for temporary service pipes, not to exceed five years, whose corrosion during the temporary service will not be detrimental to public safety. Regardless of the corrosive environment or time in service, all externally coated pipelines must be cathodically protected, and the design, installation, operation, and maintenance of cathodically protected pipelines must be carried out by, or under the direction of, a person qualified in pipeline corrosion control methods.

External protective coatings must be applied properly and must be compatible with cathodic protection systems. The surface of the pipeline must be properly prepared, and the coating must have sufficient adhesion to the pipeline surface to resist underfilm migration of moisture. The external coating material must be ductile enough to resist cracking and have sufficient strength to resist damage due to handling and soil stresses. External coatings must be inspected just prior to lowering the pipe into the ground and just before backfilling, and any damage detrimental to the coating must be repaired. All possible precautions must be taken throughout the pipeline installation process to prevent damage to external coatings. As mentioned previously, damage to protective coatings can increase the current demands on the cathodic protection system and increase the potential gradient found in the soil near the defect leading to possible stray current corrosion in nearby structures.

Cathodic protection criteria are listed in Appendix D of CFR 49, Part 192 for different metals and testing techniques. The criterion most commonly used for steel pipelines is a negative pipeline voltage of at least 0.85 volts with respect to a saturated copper-copper sulfate when the protective current is applied. This potential difference is measured by connecting the copper-copper sulfate electrode to the positive terminal of a voltmeter and the pipeline to the negative terminal of the voltmeter via a test station terminal attached to the pipeline. The copper-copper sulfate electrode is placed in the soil above the pipeline. This pipe-to-soil reading must be less than or equal to -0.85 volts to insure adequate cathodic protection. On the other hand, care must be taken not to lower the pipelines potential too far into the negative range, since hydrogen gas may be formed from the direct reduction of water at the pipeline surface. Excessive hydrogen production may result in damage to protective coatings and create protection problems. Potentials resulting in hydrogen production vary with environmental conditions, but a minimum potential of -1.2 volts is used as a general guideline to insure no damage may occur (Peabody 1967). Field tests of individual sites may find that environmental conditions support potentials acceptable at values ranging from -1.5 to -3.0 volts.

Cathodically protected pipelines and their components must be monitored periodically. The pipelines must be tested at least once per calendar year, but at intervals not to exceed 15 months, to determine whether the criteria for cathodic protection are being met. If tests are found to be impractical at these intervals for short segmented pipelines, not in excess of 30 m (100 ft), the pipelines may be surveyed on a sampling basis. At least 10 percent of the entire structure must be tested each calendar year, distributed over the entire system, with a different 10 percent being tested each subsequent year until the entire system has been tested over a 10 year period. Each cathodic protection rectifier must be tested six times per calendar year at intervals not to exceed 2 ½ months. Reverse current switches, diodes, and interference bonds (all of which mitigate interference current), whose failure would jeopardize structural protection must be inspected six times a year at intervals not to exceed 2 ½ months. All other interference bonds must be checked at least once per calendar year, but at intervals not to exceed 15 months. Pipelines that have previously been deemed not to require cathodic protection must be inspected at intervals not exceeding three years after the initial evaluation. If a corrosive environment is found at the time of inspection, cathodic protection must be applied. Any time that a utility operator discovers or is made aware that a portion of a buried pipeline is exposed, that pipeline must be examined for evidence of external corrosion damage. Prompt remedial action is required to correct any deficiencies or external corrosion found during any inspection.

Buried pipelines must be electrically isolated from other underground metallic structures, unless the pipeline and other structure are interconnected and cathodically protected as a single unit. Inspections and electrical tests must be made to assure proper electrical isolation. Cathodic protection systems must be designed and installed to minimize the adverse effects of stray currents. Operators of pipelines that are subjected to stray currents must implement programs designed to minimize damage due to cathodic protection systems.

3.2.2 Hazardous Liquid Pipelines, CFR 49, Part 195 (1995)

The requirements for hazardous liquid pipelines under CFR 49, Part 195 are nearly identical to those of natural gas pipelines already reviewed. The explanations for these regulations are also identical and therefore only a brief discussion of the rules effecting and governing hazardous liquid pipeline cathodic protection is provided.

3.2.2.1 Construction Requirements

Cover and clearance requirements under Part 195 are nearly the same as those in Part 192. Cover is generally 1 meter (3 ft) above hazardous liquid pipelines and 300 mm (1 ft) of clearance is required unless impracticable. Where impracticable, clearance may be reduced as long as adequate provisions are made for corrosion control. No provisions are made in Part 195 for casings, but each pipeline is required to be adequately designed to withstand the dynamic forces exerted by traffic loads when crossing under railroads and highways.

3.2.2.2 External Corrosion

All new hazardous liquid pipelines constructed under the provisions of Part 195 must be cathodically protected and have effective external protective coatings. Hazardous liquid interstate pipelines constructed prior to March 31, 1973, hazardous liquid intrastate pipelines constructed prior to October 19, 1988, and carbon dioxide pipelines constructed prior to July 12, 1993 that have effective external coatings must also be cathodically protected. Bare or ineffectively coated pipelines must be electrically tested, and cathodic protection must be provided to those areas along its length exhibiting active corrosion. A pipeline is considered have an ineffective coating if its cathodic protection current requirements are substantially the same as a bare pipeline. Bare or ineffectively coated pipelines must be electrically surveyed to determine areas of active corrosion. Points along the pipeline found to be actively corroding must be cathodically protected.

As in Part 192, external protective coatings must be applied properly and must be compatible with cathodic protection systems. The surface of the pipeline must be properly prepared, and the coating must have sufficient adhesion to the pipeline surface to resist underfilm migration of moisture. The external coating material must be ductile enough to resist cracking and have sufficient strength to resist damage due to handling and soil stresses. All pipeline coatings must be inspected just prior to backfilling.

Cathodic protection systems must be installed on all buried hazardous liquid facilities to mitigate corrosion that might result in structural failure. A test procedure must be developed to insure proper cathodic protection. Part 195 does not provide criteria or test procedure for cathodic protection, but does require the installation of a cathodic protection system no later then one year after completing pipeline construction.

Like natural gas pipelines under Part 192, cathodically protected hazardous liquid pipelines and their components must be monitored periodically. Pipelines under cathodic protection must be tested at least once per calendar year, at intervals not to exceed 15 months, to determine whether the cathodic protection is adequate. Operators must maintain test leads that allow electrical measurement of the adequacy of cathodic protection over the entire pipeline. Cathodic protection rectifiers must be tested for proper operation six times per calendar year at intervals not to exceed 2 ½ months. Bare pipelines and those pipelines that are not cathodically protected must be electrically inspected every five years to determine if additional protection is needed. Any time that a utility operator finds that a portion of a buried pipeline is exposed, the pipeline must be examined for evidence of external corrosion damage.

Electrical isolation of hazardous liquid pipelines and the mitigation of interference currents are not addressed in Part 195.

3.3 KDOT Utility Accommodation Policy (1994)

The KDOT Utility Accommodation Policy (1994) lists the rules that all public, private, or cooperatively owned utility operators must follow when operating or requesting to operate within the right-of-way of the Kansas State Highway System. Authorization to operate within a right-of way is provided through the issuance of Highway Permit Agreements or, in the case of longitudinal installation along Fully Controlled Access Highways, Utility Permit Agreements.

KDOT policies on the removal, remodeling, maintenance, or relocation of any utility is governed by two cases. If the utility is permitted to operate within the Kansas highway system right-of-way, that permit does not constitute permission for permanent use of the right-of-way. KDOT can require the removal, remodeling, maintenance, or relocation of any utility within its right-of-way permit at no cost to the state under its Highway and Utility Permit Agreements. If the utility is operating in a private right-of-way, the costs for removal, remodeling, maintenance, or relocation are reimbursed by KDOT.

These policies are in keeping with the general attitude of the cathodic protection industry. In general, cathodic protection operators follow a "first come, first served" policy where the new underground operator in an area is responsible to insure there are no interference problems with existing, buried metallic structures. Organizations such as the local chapters of the NACE and Underground Corrosion Control Coordinating Committees (UCCCC) bring cathodic protection industry professionals together to discuss operational problems and form relationships that insure the amicable resolution of interference problems. Where mitigation of interference is required, often all operators work together to insure the safe operation of effected cathodically protected systems. Modification costs are often low and operators may not deem reimbursement to be necessary. However, when costs are found to be high, the new operator in an area is usually responsible for reimbursement of the other utilities involved.

According to the KDOT Utility Accommodation Policy, natural gas and hazardous liquid pipelines are not allowed to run longitudinally along Fully Controlled Access Highways right-of-ways. These same pipelines are allowed to run longitudinally along Primary, Secondary, and Urban Highway right-or-ways. According to the policy, "Longitudinal installations must be located on a uniform alignment on top of the back slope, preferably within 2.1 m (7 ft) or less of the right-of-way line." This insures a safe environment for traffic and reserves space for future highway expansions and other utility installations. Pipelines must be installed at a minimum depth of 0.9 m (3 ft). If a shallower depth is needed, the pipeline must be rerouted or protected with a casing, concrete slab, or other suitable means.

Natural gas and hazardous liquid utilities are subjected to similar restrictions when crossing right-of-ways. Utilities crossing under roadways and ditches must have a minimum cover of 1.5 m (5 ft) below the crown grade or 1 m (3 ft) below the ditch grade, whichever governs. If a shallower depth is needed, the pipeline must be rerouted or protected with a casing, concrete slab, or other suitable means. Crossings should be normal to the roadway, and unsuitable or undesirable crossing locations, such as near bridge footings, should be avoided.

According to the KDOT Utility Accommodation Policy, a casing is required when utilities cross under the right-of-way or under side roads and major entrances. Pipelines carrying high pressure natural gas, liquid petroleum products, ammonia, chlorine, or other hazardous or corrosive products need not be cased if they consist of cathodically protected, welded steel pipe that is coated according to industry standards, meet CFR 49 Parts 191, 192, and 195 with respect to wall thickness, and are designed to operate at stress levels in accordance with Federal Pipeline Safety Regulations.

Utilities that are attached to bridges must meet strict guidelines set forth by the KDOT Utility Accommodation Policy. Attachments are not permitted to bridges on Fully Controlled Access Highways unless they are serving a highway facility or would result in an adverse economic impact that can be documented. Furthermore, pipelines transmitting natural gas or hazardous liquids may not be attached to any bridge structure except in extreme cases. Attachments to pre-existing bridge structures may not involve drilling, cutting, or welding of any structural steel. Special clamps and fittings may be used on steel and concrete members instead of drilling or cutting. Newly planned bridge structures deemed necessary to carry pipeline attachments may include in the design those attachments, and the cost of their construction and installation may be passed on to the utility requiring them. All natural gas and hazardous liquid pipelines must be encased along the length of the bridge and beyond the back of the bridge abutments. Under any circumstances, utility lines are not permitted to pass through bridge abutments.

It is important to electrically isolate any cathodically protected utility from the bridge structure. Cathodically protected pipelines can cause accelerated corrosion of bridge foundation steel when mounted on bridges located in a wet environment (James 1994). Casings required by the KDOT Utility Accommodation Policy must provide insulation between the cathodically protected pipeline and the bridge on which it is mounted. An electrical short circuit in the casing could result in accelerated corrosion damage to the bridge. However, if inspection is undertaken by the utility operator and remedial action is taken to correct any deficiency, damage to the bridge can be avoided.

3.4 Overall Policy

The KDOT Utility Accommodation Policy seems to effectively take into account, either directly or indirectly, many of the factors that contribute to stray current corrosion. It relies heavily on federal regulations, CFR Title 49, Parts 191, 192, and 195, which require utility operators to effectively design, install, and monitor cathodic protection systems. CFR 49, Part 190 reports that "officers, employees, and agents authorized by the Office of Pipeline Safety may inspect, at reasonable times and in a reasonable manner, the records and properties relevant to determining the compliance with pipeline safety regulations." Part 190 also includes civil and criminal penalties that might be suffered if compliance is not achieved. CFR 49, Part 191 gives procedures for reporting incidents, safety related conditions, and annual pipeline summary data by operators of gas pipeline facilities.

The adaptation of federal regulations by the KDOT Utility Accommodation Policy places the responsibility for preventing electrical interference on the owners and operators of cathodically protected utilities. Notification about new underground metallic structures and concerns about old structures that may be affected by stray currents should be directed to the utility companies involved. Cathodic protection professionals working for utility owners are willing to address and rectify any problems brought to their attention.

Other guidelines for the design, installation, and monitoring of cathodic protection systems and the prevention of interference on foreign metallic structures are offered by the NACE. NACE Standard RP0169-92 (1992) "Control of External Corrosion on Underground or Submerged Metallic Piping Systems," gives guidelines for designing, installing, and operating cathodic protection systems, and for the control of interference currents. This standard presents the guidelines upon which the cathodic protection procedures used by the cathodic protection industry are based and is the indirect source of the CFR 49 corrosion control regulations concerning cathodic protection.

A telephone survey of the bridge departments of the states surrounding Kansas (Missouri, Colorado, Oklahoma, Nebraska, and Iowa) indicates that KDOT is the only department of transportation examining the possibility of stray current corrosion due to utility cathodic protection.

The purpose of the survey was to determine the level of awareness of stray current corrosion in surrounding departments of transportation. In 4 of 5 cases (Iowa being the exception), the individuals polled were unaware of the phenomenon of stray current corrosion or its relationship to utility cathodic protection. None of the individuals contacted were aware of any damage to highway structures caused by stray currents, and no investigation into the possibility of stray current corrosion damage has been conducted. By examining the circumstances and effects surrounding stray current corrosion due to utility cathodic protection, KDOT is in a much stronger position than the other DOTs to predict and prevent damage to highway structures.

CHAPTER 4: PREDICTION, DETECTION, AND MITIGATION OF STRAY CURRENTS DUE TO UTILITY CATHODIC PROTECTION

4.1 General

The prevention of stray current corrosion of underground metallic structures due to utility cathodic protection requires the ability to (1) predict the circumstances under which it might occur, (2) detect its presence, and (3), if unavoidable, mitigate the effects of the stray current in a manner that reduces the possible damage to a minimum. Predicting areas that pose a hazard to underground metallic structures and determining the best course of action to combat these hazards can prevent future concerns and limit repair costs. A simple structure-to-soil test can provide the information necessary to determine the areas of influence surrounding anode groundbeds and pipelines. If stray current corrosion is found, standard methods have been established to successfully mitigate the damaging effects. The knowledge necessary to predict, detect, and mitigate the effects of stray current corrosion makes it possible to place underground metallic structures near utilities protected by cathodic protection systems with the certainty that no harm will occur.

4.2 Predicting Potential Stray Current Corrosion

The area of influence of a pipeline cathodic protection system and its potential to damage underground metallic structures rely on several factors. The position of the groundbed and the cathodically protected pipeline with respect to the underground metallic structure in question, together with the soil's electrical resistivity, make it possible to determine if the cathodic protection system is in a position to influence the structure. If the buried metallic structure lies in the area of influence of a cathodic protection system, the effect of any protective coating surrounding the buried structure must be examined to predict its influence on the path of the stray current.

4.2.1 Area of Influence

As mentioned in Chapter 1, the area of influence of an anode (groundbed) or a cathode (pipeline) can be described by a series of concentric circles or ellipses of decreasing or increasing potential emanating from the respective source. The change in potential with distance eventually becomes immeasurable at "remote earth." Many variables can effect the area of influence of a cathodic protection component, including the soil resistivity, soil structure, pipeline coating, and system current.

The soil resistivity affects the size of the area of influence of cathodic protection components. The greater the soil's resistivity, the wider the diameter of the influence area (Peabody 1967). Soil resistivity varies with depth, moisture content, and material make-up, all of which can vary along the pipeline. The lowest resistivity soil (100 to 10,000 ohm-cm) is preferred when placing a groundbed to reduce the distance to remote earth, as well as to reduce the number of anodes needed at each groundbed site and the current requirements of the system (Stephens 1985).

The soil's structure has possibly the greatest effect of extending the groundbed area of influence (Peabody 1967). In places where the surface layer of soil is relatively shallow with higher resistivity material beneath, such as rock, the current will find it preferable to remain in the lower resistivity soil, extending its area of influence rather then entering the higher resistivity material (see Fig. 4.1).

Pipeline coatings effect the area of influence surrounding the pipelines themselves. Bare cathodically protected pipelines can have an area of influence of 20 to 30 m (70 to 100 ft). Bare cathodically protected pipelines of any great length are rare today because of the high power requirements and resulting costs. For the well coated pipelines used in cathodically protected systems today, the area of influence surrounding the pipeline is negligible. However, where severe damage to exterior pipeline coatings has occurred, increased potential gradients in the vicinity of the defect will occur. These defects should be detectable during routine annual inspections.

Obviously, those cathodic protection systems requiring greater currents to provide protection will produce greater areas of influence. Current requirements can be affected by the overall size of the pipeline system to be protected and the resistance of the pipeline itself, as well as design considerations already mentioned with soil resistivity, soil structure, and pipeline coatings.

The portion of the cathodic protection system most likely to cause stray current corrosion is

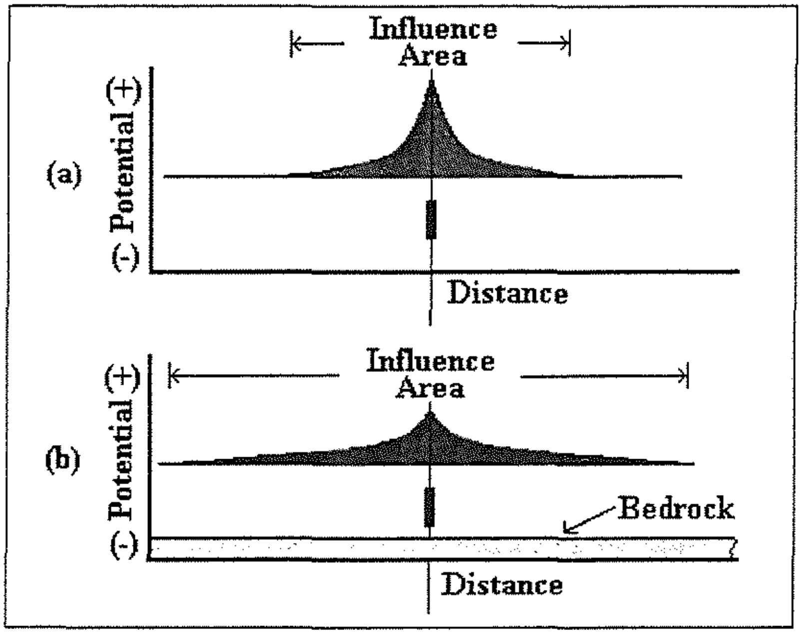

Figure 4.1 Anode Area of Influence (a) under normal conditions, (b) with high resistivity material (bedrock) creating a shallow soil depth.

the anode groundbed. Damage due to an adjacent groundbed, however, is unlikely to occur to highway structures sharing the right-of-way with utilities which are cathodically protected, since impressed cathodic protection systems do not allow the intersection of the anode area of influence with the pipeline (cathode) area of influence. In most cases, impressed current cathodic protection systems will be effective only if sufficient distance is maintained between the groundbed and the pipeline so that an area of "remote earth" exists between the two system components. It is true that impressed cathodic protection systems can be applied with the groundbed "close" (meaning the pipeline intersects the groundbed area of influence), as is the case with sacrificial anode systems. These "close" groundbed systems, however, have a limited range and are too costly for the protection of large utility systems. Typically, the distance between groundbed and pipeline for an impressed current cathodic protection system is 120 to 150 m (400 to 500 ft) (Stephens 1985).

Any groundbed located within 100 m (300 ft) of a buried metallic structure is reason for concern for the safety of that structure from stray current corrosion, and indicates the need to contact the utility to determine if there is sufficient distance between the groundbed and the structure.

4.2.2 Coated Underground Metallic Structures

The current flow within a cathodic protection system must complete the circuit of the system. In an impressed current system, as shown in Fig. 1.2, the current must travel from the direct current power source to the groundbed, where it is then distributed through the soil and finds its way to the pipeline at imperfections in the coating. Once the current enters the pipeline, it travels along the pipeline length back to the direct current power source. Even stray currents must complete the circuit created by the cathodically protected system. Since current travels along "the path of least resistance," coatings found on buried metallic structures can have a major effect on whether a structure is affected by changes in potential within the environment surrounding that structure. These coatings can include epoxies and concrete cover.

Epoxy-coated pilings have been used to reduce corrosion damage. Like coated pipelines, coated piles reduce the surface area exposed to the corrosive environment. Damage to the coatings due to driving into the soil and holidays created by coating flaws can produce small anodic areas. If exposed to a potential gradient and a preferential current path exists through the pipe due to the small anodic sites, severe accelerated corrosion will occur due to stray currents.

Concrete provides a high level of resistance when used as a coating for underground metallic structures, as well as an electrically inert layer of ferric oxide on the embedded steel. The resistivity of dried concrete has been found to be $1\text{x}10^9$ ohm-cm, while saturated concrete has been found to have a resistivity of $1\text{x}10^4$ ohm-cm (Locke 1986). Fresh concrete is alkaline and oxidizes the surface of steel to form an electrically inert layer of ferric oxide (Hertlein 1992). Dry concrete does not provide the electrolyte necessary to conduct current, while saturated concrete, where the ferric oxide coating is maintained, electrically isolates the steel from corrosive currents (Hertlein 1992).

A study by the Florida Department of Transportation seems to prove the protective effect of concrete for reinforcing steel (Miller, Hartt, and Brown 1976). A steel reinforced bridge model exposed to running fresh sea water and stray currents was used in the study. The model was designed to simulate conditions found in bridge structures of the Florida Keys and, in addition to standing in sea water, was kept moist with a continuous salt spray. Even under these electrically conductive conditions, only 0.01% of the current applied entered through the sea water into the reinforcing steel and contributed to corrosion of the steel. The authors were quick to point out, however, that even 0.01% of the 20 amperes typically used to protect pipelines could cause a significant increase in corrosion at relatively small anodic sites. Fortunately, the State of Kansas does not have the extremely rich chloride environment of sea water that is both capable of damaging the ferric oxide protective layer found on reinforcing steel and more electrically conductive than fresh water. Therefore, it can be concluded that an even smaller percentage of the applied current will enter reinforcing steel in concrete found in soil or fresh water.

As mentioned in Chapter 2, several studies were conducted by the National Bureau of Standards in the early 1900's. One of these studies concluded with the 1919 edition of National Bureau of Standards Technologic Report No. 18, "Electrolysis in Concrete" (Rosa, McCullom, and Peters 1919). This report concluded that stray currents alone could cause major corrosion damage to underground metallic structures imbedded in concrete. Unfortunately, these studies did not take into account the high levels of calcium chloride used as an admixture to accelerate the setting and hardening of the concrete. It is now known that calcium chloride can break down the protective ferric oxide layer around reinforcing steel and promote corrosion. In some of the studies conducted by the NBS, the calcium chloride levels were 10 times today's recommended corrosion threshold (Hime 1994). For this reason, the 1919 report is not used as a source of information on the performance of reinforced concrete exposed to stray currents.

Concrete can provide a significant barrier against stray currents, as long as cover is maintained and the ferric oxide layer is undisturbed. Cracking and insufficient cover can allow moisture to come into contact with reinforcing steel, promoting corrosion. The penetration of chlorides, sulfates, and carbonation beneath the surface of concrete can reduce the alkaline environment surrounding reinforcing steel and destroy the protective ferric oxide layer. With the destruction of the ferric oxide layer and the penetration of moisture from the environment, stray currents can accelerate the corrosion process.

4.3 Detection of Stray Currents

The cathodic protection industry has produced several tests which can be used to detect stray currents. By far the most widely used test for electronically surveying pipelines and other underground structures is the "structure-to-soil" test. The test uses a copper-copper sulfate electrode and a multi-range voltmeter. With the negative terminal of the voltmeter connected to the buried metallic structure and the positive terminal of the voltmeter connected to the copper-copper sulfate electrode placed in contact with the soil, the potential difference between the metallic structure and the soil can be determined. By plotting the potential readings as they fall along or away from the structure being tested, a profile of the structure-to-soil potentials can be created, giving information on potential levels and areas of influence. With the use of this simple equipment and a knowledge of the cathodic protection system and nearby underground metallic structures, an electronic survey can be conducted to determine the presence of potential gradients and fluctuations that indicate the presence of stray currents.

Structure-to-soil measurements are most often used in "over-the-line" potential surveys. These surveys are used by utilities to determine if cathodic protection potential criteria are being met and can locate any hot spots which may have formed due to protective coating damage or deterioration. The negative terminal of the voltmeter is connected to the pipeline, either through a permanent terminal connection or a metallic probe, and the positive terminal of the voltmeter is connected to the copper-copper sulfate electrode. The electrode is then placed in contact with the soil directly over the pipeline and the potential is read from the voltmeter. These measurements are taken at increments ranging from a few meters to several kilometers depending on whether the utility can substantiate, when plotted, that protection potential criteria are being met along the length of the pipeline. This "over-the-line" test cannot alone determine whether a "hot spot" (a point of active corrosion along the pipeline) will interfere with a nearby underground metallic structure.

Structure-to-soil surveys can also be conducted on pipelines, conduits, or corrugated steel pipes crossing cathodically protected pipelines or entering groundbed areas of influence to determine if interference exists. By plotting the structure-to-soil potential of an unprotected, horizontal structure at the point it crosses a cathodically protected pipeline or along portions of the structure entering a groundbed area of influence, the current being discharged or received by the structure from the cathodic protection system may be determined. If a structure foreign to the cathodic protection system is discharging current (say at a point crossing the protected pipeline), the structure will show a much more positive structure-to-soil potential at the point of discharge than on other portions of the structure. Likewise, if a structure foreign to the cathodic protection system is receiving current (say along the length of the structure passing through the area of influence of a groundbed), it will show a much more negative structure-to-soil potential at the area of reception than on other portions of the structure. Although receiving current is not in itself damaging to the structure, the eventual discharge of that current is a source of corrosion damage, if not corrected.

The method most often used to determine if a cathodic protection system is interfering with a nearby underground metallic structure is the method of "pulsing" the electrical source to the cathodic protection system at certain intervals and examining the potential shifts, if any, in the nearby structure. A device called a "current interrupter" is used to cycle the power source of the cathodic protection system at a predetermined interval. By pulsing the cathodic protection power, for example 20 seconds "on" and 10 seconds "off," the surveyor can look for swings in potential in the underground metallic structures (again with the use of the structure-to-soil test) either caused by the proximity of an anode groundbed or nearby pipeline hot spot. This is typically used in determining if interference exists between pipeline crossings and determining the effects of groundbed placement on nearby pipelines. This method of pulsing the cathodic protection power source may not be useful in determining the amount of stray current interference suffered along the length of a vertical underground metallic structure, but can indicate if interference exists. In the case of an electrically continuous bridge structure, it may be possible to detect shifts in potential from one end of the bridge to the other by pulsing the cathodic protection system and taking readings at the opposing ends. In this way, it may be determined if a nearby cathodic protection system is forcing unwanted stray currents in the bridge and, thereby, promoting increased corrosion.

Another way to determine if an underground metallic structure is suffering from interference created by a cathodic protection system is to determine if the structure is within the area of influence of the system. This is done with a copper-copper sulfate electrode and voltmeter and is performed in the same manner as the structure-to-soil survey. In this case, the negative terminal of the voltmeter is connected to the groundbed instead of the pipeline. Readings are taken at 15 to 30 m (50 to 100 ft) intervals until it is determined that there is no significant decrease in potential (Stephens 1985).

By determining whether an underground metallic structure either is in an area of influence and possibly being damaged by stray current corrosion or is actually exhibiting damage due to shifts in potential, action can be taken to mitigate the effects of the stray currents. Owners of cathodically protected utilities and nearby metallic structures affected by interference should consult with each other to determine the best and most economical solution to the interference problem.

4.4 Mitigation of Stray Current Corrosion

The cathodic protection industry has created several standard solutions to mitigate the effects of stray currents in underground metallic structures. Drainage bonds and sacrificial anodes are commonly used to shift the potential of the structure being effected, while improved coatings are used to increase the resistance to current flow to the structure. The costs of installing some of these corrective methods may be higher than moving the offending cathodic protection system and should be weighed during negotiations to correct the interference problem.

4.4.1 Drainage Bonds

When pipelines cross and one cathodically protected pipeline interferes with another pipeline foreign to its protective system, drainage bonds are commonly used to mitigate the problem. The procedure involves connecting a resistor between the two pipelines with the resistance adjusted to drain enough current from the line being affected to eliminate the damaging condition (Peabody 1967). This requires determining the undisturbed potential of the effected pipeline with the cathodic protection system "off." The bond is placed between the pipelines with a variable resistor, which is adjusted with the cathodic protection system "on" until the potential of the disturbed pipeline returns to it original value. While this is commonly used in the cathodic protection industry at points of pipeline crossing, it is not likely to be used in correcting problems with vertical metallic structures, such as driven piles and piers, since it is difficult to determine the potential shift in those members along their length.

4.4.2 Sacrificial (or Galvanic) Anodes

Another form of mitigation of electrical interference is the use of sacrificial anodes. This involves the use of the anodic gradient fields surrounding galvanic anodes to offset the cathodic potential gradient field surrounding the pipeline (Peabody 1967). The technique is applied at the point of crossing and requires a single line of anodes connected to the effected structure and located between it and the offending cathodically protected pipeline. A discharge of current still occurs at the crossing, but with the anodes in place, this discharge, and resulting corrosion, takes place at the anodes and not on the metallic structure. As the name "sacrificial" implies, replacement of these anodes is required from time to time as they corrode away over a period of several years.

4.4.3 Improved Coatings

If interference is occurring between a cathodically protected pipeline and a foreign metallic structure, it is likely due to a damaged pipeline or low quality pipeline coating. Although coatings currently used for cathodically protected pipelines are of superior quality and life expectancy, some older pipelines, placed more than twenty years ago, may exhibit signs of deterioration and produce measurable potential gradient fields near their surface. It is likely that any pipelines producing gradient fields of significance have been repaired or replaced due to high power and therefore high operating costs. Coatings that are damaged during installation will be spotted during the electrical survey of the coating before backfilling. Any damage due to backfilling or from construction of other structures near the pipeline will be detected during subsequent required testing, as discussed in Chapter 3. Damage to the coatings, once detected, can be easily repaired by excavation and patching.

4.5 Comments

The greatest concern to operators of underground metallic structures near cathodic protection systems comes from the position of the structures relative to the groundbeds of the systems. Little can be done to fully protect the foreign structure if it lies in the area of influence of the groundbed. Compounding the problem for vertical metallic structures is the difficulty in testing, monitoring, and correcting problems at depth. Although there are few cases where such interference might exist for metallic highway structures, if such a case is found, the best solution is to move the cathodic protection groundbed to insure that no interference exists. Many groundbeds are likely to be located in privately owned right-of-ways, but the Kansas Department of Transportation [through the Kansas Utility Accommodation Policy (KDOT 1994)] may be well justified in requiring the movement of such groundbeds at no expense to the state, if the pipeline is located within the highway right-of-way.

CHAPTER 5: RECOMMENDATIONS

5.1 Review

Cathodic protection interference occurs when an underground metallic structure foreign to the cathodic protection system passes through, or is found within, the area of influence of components of that protection system. These areas of influence may be found along bare cathodically protected pipelines or portions of cathodically protected pipelines with protective coatings where coating damage and/or deterioration are found. Of much greater concern are the areas of influence associated with groundbed locations which radiate up to several hundred meters around the groundbed. By entering the area of influence of a cathodic protection system component, a change in potential within the foreign underground metallic structure is produced unless the structure is shielded (via a protective coating). This change in potential creates a current flow within the foreign structure in accordance with Ohm's Law. The damage to the foreign structure is then proportional to the current flow leaving the structure to return to the electrolyte. For steel, the quantity of metal removed is 20 lbs for each one ampere of current flow per year.

5.2 Procedural Recommendations

The following guidelines are recommended to prevent interference damage caused by stray currents produced by cathodically protected utilities.

1. All construction (new or maintenance) around the area of cathodically protected utilities should be reported to the utility owner of concern so that protective coating damage, if any, can be accessed and repaired following construction.

2. If a cathodically protected pipeline is uncovered, or found uncovered, the utility owner should be contacted and is required by law to inspect the pipeline to insure the adequacy of the protective coating and to inspect for any signs of corrosion damage to the pipeline.

3. No underground highway structure should be located within the area of influence of an anode groundbed without testing for stray current interference. If the structure is within 100 m (300 ft) of a groundbed location, testing should take place to determine if the structure lies outside of the groundbed's area of influence. The test should either (1) determine the area of influence of the groundbed by applying a structure-to-soil test to the groundbed or (2) when the power source to the cathodic protection system is pulsed, determine if a change in the potential of the structure in question occurs by applying a structure-to-soil test on the underground highway structure thereby determining whether interference has occurred.

4. No underground highway structure should be located within the area of influence of a bare cathodically protected pipeline without testing for stray current interference. If the structure is within 30 m (100 ft) of a bare cathodically protected pipeline location, testing should take place to determine if the structure lies outside of the bare pipeline's area of influence. The test criteria are the same as described above for the area of influence of an anode groundbed.

5.3 Recommendations to KDOT Utility Accommodation Policy (1994)

Several changes or additions to the KDOT Utility Accommodation Policy (1994) are recommended.

1. The KDOT Utility Accommodation Policy (1994) indirectly approaches the problem of stray current interference by adopting the Code of Federal Regulations, Title 49, Parts 191, 192 (natural gas utilities), and 195 (hazardous waste utilities). These codes are, in general, more concerned with the issue of public safety due to the rupture of a utility line from corrosion than with the protection of nearby underground metallic structures from interference caused by utility cathodic protection systems. The KDOT Utility Accommodation Policy (1994) would be a much stronger document in regard to stray current interference if the requirements were stated directly. To this end, the following requirements should be added to the policy:

> Buried cathodically protected pipelines must be electrically isolated from underground metallic highway structures, unless the pipeline and highway structure are interconnected and cathodically protected as a single unit. Inspections and electrical tests must be made to assure proper electrical isolation. Cathodic protection systems on pipelines must be designed and installed to minimize the adverse effects of stray currents to adjacent structures.

2. The KDOT Utility Accommodation Policy (1994) provides the authorization to operate within a right-of way provided through the issuance of Highway Permit Agreements or, in the case of longitudinal installation along Fully Controlled Access Highways, Utility Permit Agreements. KDOT requires the submittal of construction and maintenance plans for review before issuance of a permit. These requirements should be extended to cathodic protection design and maintenance. The plans should note groundbed and pipeline crossings near underground highway structures and detail the steps proposed to insure the safety of those structures.

3. The KDOT Utility Accommodation Policy (1994) should state that,

> After careful review of the cathodic protection plans for an underground utility, KDOT may require additional inspections along the pipelines where interference would jeopardize the structural integrity of an underground highway structure.

Additional inspection requirements may be needed based on predictions made following the evaluation of a cathodic protection system (see Section 4.2). Stray currents detected in conjunction with a cathodic protection system may also prompt additional inspection requirements (Section 4.3). For pipelines where interference would jeopardize the structural integrity of an underground highway structure, it would be reasonable to require inspections six times a year, at intervals not to exceed 2 ½ months.

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