# Large Diameter Transmission Pipeline Corrosion Control State-of-the-Art: Advances in the Steel Water Pipe Industry

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## ABSTRACT

Various studies in the past fifteen years have highlighted the dire consequences of failing to proactively protect buried metallic water distribution and transmission infrastructure from the effects of corrosion. Metallic municipal pipelines are composed of cast and ductile iron, composite concrete pressure pipes and steel pipe. For more than a hundred years, the buried steel pipe industry has employed effective corrosion protection both on the inside and outside walls of pipelines; lines more than one hundred years old serve as testimony of the effectiveness of these systems. Both rigid cementitious and flexible dielectric corrosion barriers, combined with cathodic protection, when required, have ensured long service lives. By the 1940's, the American Water Works Association (AWWA) had published two standards for corrosion protection of steel pipes --- one for cementitious systems, the other for dielectric systems. With advances in technology, many other technologies have been added to the list of standards, the most recent as recently as 2008. This paper will provide an update on the state-of-the-art of lining and coating systems currently specified for steel pipe by the engineering community at large. AWWA, NACE International and other standards-writing organizations' documents will be discussed. Focus on corrosion prevention through surface preparation for lining and coating applications, quality control, handling, repair, joint completion, and installation will be highlighted.

## INTRODUCTION

The condition assessment of distribution and transmission water pipeline infrastructure in the United States has been evaluated, documented, and graded by numerous agencies over the past decades. The American Society of Civil Engineers (ASCE) gave a letter grade of *D-* to water and wastewater infrastructure in their most recent report card for America's infrastructure (ASCE 2009). More than a decade ago, the Federal Highway Administration (FHWA) funded research to quantify the cost of corrosion in various sectors of the nation's infrastructure (FHWA 2002). The study estimated that the cost of corrosion for drinking water systems was $19.25 Billion per year and $13.25 Billion for sewer systems. These high price tags included the cost of replacing aging infrastructure, the cost of unaccounted-for treated water through leaks, and the cost of linings, coatings, and cathodic protection. Available funding to upgrade this segment of the infrastructure is very limited; the needed amount is estimated to be in excess of $1 Trillion dollars. Therefore one of the best tools US Engineers and Municipal

Owners have at their disposal to reduce corrosion costs is to incorporate proven technologies to reduce and improve life cycle costs of buried metallic pipelines. Dechant and Smith (2004) provided a state-of-the-art of corrosion control for ferrous piping materials. This paper is a follow-up to that publication and provides up-to-date information on existing and newer technologies for corrosion control of steel pipe.

## CORROSION AND ITS CONTROL

Corrosion is the degradation of a material through environmental interaction. In the case of buried metallic pipelines, the electrochemical process of corrosion occurs in the near-ambient temperatures of aqueous soils. The aqueous environment is the electrolyte where the process of oxidation and consumption of electrons takes place. This process is referred to as a half-cell reaction or corrosion cell if the reactions are physically separated. There are four necessary components of a corrosion cell:

1. an anode
2. a cathode
3. a metallic path connecting the anode and cathode
4. anode and cathode must be immersed in an electrically conductive electrolyte

Removing any one of these requirements mitigates corrosion on underground metallic pipelines. The steel pipe industry has generally incorporated two methods for corrosion prevention, discussed below.

**Passivating Steel versus Dielectric Systems**: The first method is to reduce the conductivity of the electrolyte by inducing a high pH, using a rigid cementitious mix, thereby creating a *passive* environment. This is done by placing the material to be protected, in this case the walls of the metallic pipe, in intimate contact with the cement-mortar. Both cementitious linings and coatings are used for passivating the metallic walls internally and externally. Linings protect the inside of a pipe while coatings protect the outside. The second method is to form a continuous film of a flexible, electrically insulating material over the metallic surface to be protected. This system is referred to as a “dielectric” coating system, which physically separates the electrolyte from the metallic surface. Both methodologies have benefits and disadvantages, discussed later in this paper. With either method, for a comprehensive corrosion protection system, the pipeline must be made electrically continuous for proper monitoring and installation of cathodic protection, if required. This means the use of bonding wires to create electrical continuity at gasket joints; for welded joints, joint bonding is not required as electrical continuity already exists.

## HISTORY

For more than one hundred years, steel pipes have been protected from corrosion with the use of both dielectric and cementitious coatings and linings. One of the earliest recorded installations of riveted steel pipe was at Railroad Flats, CA in 1858. From that time through the early 1900’s, steel pipe was generally protected from corrosion with dielectric materials such as bitumen, asphalt, and mineral rubber (Cates 1971) as well as coal tar enamel. Regionally, cement mortar was another proven product and was effectively used for passivating steel. The true effectiveness of dielectrics such as coal tar enamel can be found in steel pipes ranging in diameters of 8.5-feet to 30-ft, installed on the Hoover Dam in the 1930's. These gigantic coal tar enamel lined and coated pipelines continue to channel water at the rate of 3,400 $ft^3$/sec today (Eilperin 2012). Similarly, some of the oldest buried steel pipes have also been protected using cementitious linings and coatings, although the use of cementitious lining is substantially higher today than coating. Adoption of versatile proven dielectric coating systems has led to a decline in the use of cement mortar coatings in the past fifteen years.

**AWWA Coating and Lining Standards:** There are currently twenty-six standards under the Steel Pipe Committee of AWWA, as well as the M11 Design Manual for Steel Water Pipe (AWWA 2004). Fifteen of these twenty six standards relate to the corrosion protection of steel pipe. Two are related to cementitious passivating systems, while the remaining thirteen are dielectric products. The first two AWWA standards for corrosion protection were published in 1940 and 1941, AWWA C203 for Coal Tar Enamel (a dielectric system), and AWWA C205 for Cement Mortar, respectively. Both systems had already proven their effectiveness by the time these standards were published. Table 1 provides a comprehensive listing of all AWWA steel pipe coating and lining standards.

**Table 1: AWWA Standards for the Coating and Lining of Steel Pipe**

| AWWA Standard Designation | Standard Title |
|---|---|
| C205 | Cement-Mortar Protective Lining and Coating for Steel Water Pipe-Shop Applied |
| C602 | Standard for Cement-Mortar Lining of Water Pipelines In Place |
| C203 | Coal-Tar Protective Linings and Coatings for Steel Water Pipelines—Enamel and Tape--- Hot Applied |
| C209 | Cold Applied Tape Coatings for the Exterior of Special Sections, Connections, and Fittings for Steel Water Pipelines |
| C210 | Liquid-Epoxy Coating Systems for the Interior and Exterior of Steel Pipelines |
| C213 | Fusion-Bonded Epoxy Coating for the Interior and Exterior of Steel Water Pipelines |
| C214 | Tape Coating Systems for the Exterior of Steel Water Pipelines |
| C215 | Extruded Polyolefin Coatings for the Exterior of Steel Water Pipelines |
| C216 | Heat-Shrinkable Cross-Linked Polyolefin Coatings for the Exterior of Special Sections, Connections, and Fittings for Steel Water Pipelines |
| C217 | Cold-Applied Petrolatum Tape and Petroleum Wax Tape Coatings for the exterior of Special Sections, Connections, and Fittings for Buried or Submerged Steel Water Pipelines |
| C218 | Coating the Exterior of Aboveground Steel Water Pipelines and Fittings |
| C222 | Polyurethane Coatings for the Interior and Exterior of Steel Water Pipelines |
| C224 | Two-Layer Nylon-11-Based Polyamide Coating System for the Interior and Exterior of Steel Water pipe, Connections, Fittings, and Special Sections |
| C225 | Fused Polyolefin Coatings for the Exterior of Steel Water Pipelines |
| C229 | Fusion-Bonded Polyethylene Coatings for Steel Exterior Water Pipelines |

The variety of materials represented in the list of standards today include Cement-mortar, polyurethane, polyethylene tape (as well as fusion-bonded polyethylene, the most recent addition to the list), liquid and fusion bonded epoxies, coal tar, extruded, cross-linked and fusion bonded polyolefin's, petrolatum and petroleum wax tape, and nylon polyamides. In addition to standards for both cementitious and dielectric coatings and linings, several of these documents specifically address in-field and above-ground applications, joint completion, as well as the protection of fittings and specials. Most of the dielectric coatings were originally used in the oil and gas industry. Many of the criteria for these coatings were established to meet the stringent requirements of those hazardous material pipelines. In the development of the dielectric coating standards for water applications, consideration is given to water absorption, permeability, dielectric strength, adhesion, cathodic disbondment, handling, holidays, field procedures and materials for repair of damage to the coatings. These parameters ensure a durable coating system that will substantially increase the longevity of a pipeline.

Similar consideration is given to the integrity of the cement mortar coatings and linings. Physical properties such as compressive strength, water soluble chloride ions, cement mixture, absorption, and water content are all part of the AWWA C205 requirements. The thickness of the cement mortar coating is ¾-inch for all steel pipe diameters. The thickness for cement mortar lining varies by diameter, as shown in Table 2. Lining thicknesses for steel pipes are always 3 to 5 times higher than those of another ferrous pipe material, ductile iron pipe, as listed in AWWA C104 (2008). Bonded joints are typically recommended for electrical continuity in gasket-joint steel pipes, Figure 1.

**Table 2: Thickness of Cement-mortar Lining per AWWA C205**

| Nominal Pipe Diameter (in) | Lining Thickness (in) |
|---|---|
| 4 – 10 | ¼ |
| 11 – 23 | 5/16 |
| 24 – 36 | 3/8 |
| > 36 | ½ |

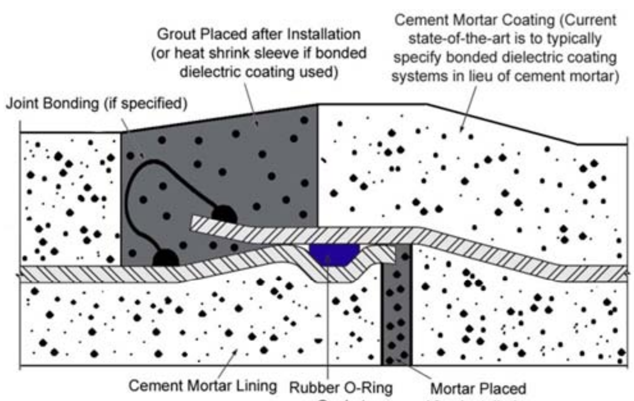


**Figure 1: O-Ring Gasket Rolled-Groove Steel Pipe Joint**

These standards were written as each technology was developed and proven. Organizations such as AWWA do not typically undertake the writing of standards for "new products" unless they have already been in use and their effectiveness proven over several years, typically five to ten years minimum. For example, while the AWWA C222 standard for polyurethanes was first published in 1999, wide use of polyurethane for the coating and lining of steel pipe can be traced back to the 1980's (Bambei et al. 2011). All coating and lining systems have specific properties as outlined in the appropriate standard that should be considered in their selection for specific site conditions. Some have better dielectric strength; others are more abrasion resistant. Some of these coatings are made specifically for fittings while others are for aboveground service. Costs differ for many of these products depending on diameter, end use, fabricator experience and availability, project magnitude, and protection needs based on soil conditions. Critical parameters for each of the 13 dielectric coating/lining standards are shown in Table 3.

**Table 3: Select QA Requirements of Dielectric Coatings and Linings**

| AWWA Standard | Thickness | Adhesion | Adsorption | Holiday Testing | Original Publication | Current Edition |
|---|---|---|---|---|---|---|
| C203 | 50 mil | Pull Test | N/A | Required | 1940 | 2009 |
| C209 | 30 mil | 20 ozf/in. width | Water Vapor Transmission | Required | 1976 | 2007 |
| C210 | 16 mil | 800 psi | Water Vapor Transmission | NACE RP0188 | 1978 | 2008 |
| C213 | 12 mil | Knife Test | N/A | NACE RP0490 | 1979 | 2008 |
| C214 | 50-80 mil | 200 oz/in. width | 0.2% max. | NACE RP0274 | 1983 | 2007 |
| C215 | 30-68 mil | 20-30 psi | 0.2% max. | NACE RP0274 | 1988 | 2010 |
| C216 | 45-60 mil | 15 lb/in. width | Water Vapor Transmission | Required | 1989 | 2007 |
| C217 | 43 mil | N/A | Water Vapor Transmission | N/A | 1991 | 2009 |
| C218 | 7-14 mil | V-Cut | N/A | NACE RP0188, if specified | 1991 | 2008 |
| C222 | 20-25 mil min. | 1500 psi | 2% max. | NACE RP1088 | 1999 | 2008 |
| C224 | 12 mil min. | Rating of 8 per ASTM D6677 | 1.9% max. | NACE SP0188 | 2001 | 2011 |
| C225 | 50-75 mil | 32 lbf/in. | Water Vapor Transmission | NACE RP0188 | 2003 | 2008 |
| C229 | 63-90 mil | 17 lbf/in. width | 0.1% max. | NACE RP0274 | 2008 | 2008 |

The diversity of materials has made coating and lining standards more complex. Each requires differing methods of application and inspection. Dielectric coatings are *bonded* to the steel substrate and require at least a SSPC SP 6/NACE No. 3 blast cleaning or higher (SSPC 2007). While values in Table 3 typically vary by product, the standard for each product was written with the intention of making all products approximately equal. Values differ because of the inherent unique physical/mechanical and chemical properties of each product.

## USE AND ADOPTION OF COATING AND LINING TECHNOLOGIES

As already mentioned, coal tar enamel and cement mortar were the earliest approved AWWA standards for the corrosion protection of steel water pipe. It wasn't until 1976 that the next coating standard for steel pipe protection was approved. In the thirty seven years since then, the remainder of the coating/lining standards were published, as shown in Table 3. In a 2-article series published in CoatingsPro magazine, Hall (2012a and 2012b) makes the assertion that 45 to 55 percent of steel water pipelines in service are cement mortar coated, while 5 to 10 percent of in-service steel pipes are coated with coal tar enamel (2012a). Similarly, she estimates that for at least the past 50 years, greater than 95% of steel water transmission pipelines incorporated cement mortar lining while less than 1% of steel pipelines in service are lined with coal tar enamel (Hall 2012b). The articles do not however present a source for this information, nor any scientific methodology by which these numbers were derived. Regarding the use of coal tar enamel, Hall states that the specification of coal tar enamel "has decreased substantially during the past two decades due to its suspected carcinogenic nature, its volatile organic compound (VOC) content, and the odor emitted during application, which caused stringent permitting requirements for its use in populated areas. These issues have forced some water agencies to curtail specifying CTE and some pipe manufacturers from applying CTE to pipe." While this is accurate, she fails to present a realistic state of the decline in the use of cement mortar coatings in light of the availability of substantially more efficient and effective dielectric coating systems for steel pipe.

Table 4 shows the results of an in-depth analysis by Northwest Pipe Company to study the adoption and uses of various AWWA-approved coating and lining systems in the past decade. Data was gathered on all projects in the US and Canada since 2000 that bid with steel alternatives using various coating systems. It included all projects, whether Northwest Pipe Company won a particular project as the low bidder or not, and is hence reflective of the total North American market for large diameter steel pipe. Comparisons are then made to the estimates provided by Hall (2012a and 2012b).

As can be seen, there were some substantial disagreements between the actual numbers derived through the Northwest Pipe Company analysis versus the estimates presented by Hall (2012a, 2012b). Most noteworthy is the fact that while 45-55% of steel pipes in service may be coated with cement mortar, only 18% of pipes installed since 2000 have had cement mortar coating. The percentage of steel pipes that have been installed with a layer of cement mortar protection on top of a dielectric coating has only been 10% since 2000. The impact of polyurethane coatings on the overall market is quite remarkable, whereby 31% of all steel pipes have been installed with this coating in lieu of either tape coating, or cement mortar coating.

**Table 4: Coating and Lining Type by Usage**

| Coating or Lining System | Northwest Pipe Analysis | | CoatingsPro Article (Hall 2012a, 2012b) | |
|---|---|---|---|---|
| | % Pipe with Exterior Coating | % Pipe with Interior Lining | % Pipe with Exterior Coating | % Pipe with Interior Lining |
| Portland Cement Mortar (CMC) | 18% | 81% | 45-55% | >95% |
| Coal Tar Enamel (CTEC) | 4% | <1% | 5-10% | <1% |
| Liquid Epoxy | 2% | 5% | <1% | <3% |
| Fusion Bonded Epoxy | <1% | <1% | <1% | <1% |
| Tape and Cement Mortar Overcoat* | 10% | NA | 35-45% | NA |
| Extruded Polyolefin (Pritec) | 1% | NA | 5-10% | NA |
| Polyurethane | 31% | 11% | <5% | <2% |
| Polyamide | <1% | <1% | <1% | <1% |
| Fused Polyolefin | <1% | NA | <1% | NA |
| Fusion-Bonded Polyethylene | <1% | NA | <1% | NA |
| Paint | 2% | 2% | - | - |
| Tape Only | 28% | NA | ** | NA |
| CTEC or Paint and Cement Mortar Overcoat* | 2% | NA | - | - |
| Other | 1% | 0% | - | - |

** Cement Mortar Overcoat (CMC) added to tape, CTEC or paint is used as a rock-shield only and not for corrosion protection*
*** Totals have been combined with Tape and Cement Mortar rock shield*

- *NWP analysis covering January 3, 2000 – August 2, 2012*
- *Coating and Lining data is from actual projects with specific coatings and linings specified*
- *Percentages are not NWP only sales but represent what was specified by the entire market across USA and Canada*
- *Municipal projects only*

## CEMENTITIOUS COATINGS

The current state-of- the-art for cement mortar coatings, “CMC,” is established in AWWA Standard C205-12. Cement mortar has been successfully used to protect steel pipe from corrosion within this standard since its first writing in the 1940’s. The technology of providing a high pH (greater than 11) environment in intimate contact with the metallic material to be protected is well known and established. Advantages of CMC versus dielectric coatings can be lower manufacturing costs and increased pipe stiffness. Disadvantages include increased weight, allowable deflection limitations, and limitations on the allowable yield strength of steel for the cylinder which can increase wall thickness and cost. Another potential disadvantage of cement mortar coated pipe is that it is not recommended in soils where a wet-dry cycle of moisture can, in time, tend to flush the required high pH environment.

A disadvantage of CMC is the potential for detrimental cracking under internal pressures or from over deflection due to external loading conditions. To safe guard from these situations the AWWA standards limit the design working stress of the steel cylinder and the allowable deflection of CMC buried pipelines. The allowable design working stress for the steel cylinders, once limited to 16,500 psi has been increased over the years and current AWWA Standards allow steel cylinder working pressure stress limits of 18,000 psi. The allowable deflection for cement mortar coated steel pipe is limited to 2%. The limitations of design working stress and deflection can place CMC pipe at a disadvantage compared to dielectrically coated pipelines – especially in higher pressure applications. Dielectrically lined and coated steel pipe such as polyurethane can have design working stress in excess of 25,000 psi and deflections of 5%.

## DIELECTRICALLY COATED PIPELINES

As already discussed, dielectric coatings are designed to isolate the electrolyte from the metallic surface. All the above mentioned coating systems satisfy this main criterion to a greater or lesser degree; the specified system must meet the full needs of the intended environment. Dielectric systems can be broken down into two categories: tape systems and thin film systems or "paints." Figures 2a and b show the application of polyurethane coating and a 3-layer tape coating system, respectively.

**Figures 2a, b: Polyurethane Coating, Tape Coating**

Tape systems meeting requirements of AWWA C214 have been the most widely used dielectric coating system for over thirty years for steel water pipe. Tape systems are very efficient to install in the factory and the typical 3-layer system has reasonable resistance to handling damage. In some regions of the country, particularly in Southern California, tape coatings are over-coated with cement mortar to protect the tape. This is done to address some extreme environments such as very high temperatures encountered in summer months during installation, or rocky backfill conditions. Over-coating tape (rock shield) with CMC should always be evaluated by the Owner and Engineer as it comes at a high manufacturing and installation price for a potentially small decrease in coating holidays which can be adequately protected from corrosion by a good cathodic protection system.

Thin film systems or paints typically come in two types which make up over 90% of the commonly used systems in today's steel water pipe industry: polyurethanes, per AWWA C222, and epoxies, per AWWA C210. Both may be used for lining and coating applications, though this paper primarily addresses the use of these systems for exterior coating applications. Surface preparation for both is a near white blast (NACE No. 2, SSPC SP10) and both can be applied as a single coat with a range of thicknesses. Both have excellent resistance to handling damage, adhesion, dielectric strength and ease of field joint completion. They are competitive from a cost of material standpoint but polyurethanes have an application advantage in the factory due to their fast set times. Polyurethanes cure and can be handled within minutes of application, where epoxies require hours of set time before they can be handled. This short set time allows applicators to move product much faster and efficiently. The set time does not however pose a disadvantage when epoxies are used as linings. Current paint systems have evolved over the past twenty years into highly durable, flexible and efficiently applied products both in the factory and for joint completion in the field, and now have a prominent position in the market place.

Dielectric systems have been designed utilizing steel cylinder working stresses in excess of 25,000 psi. When combined with a cement mortar lining system, dielectric coated steel pipes have an allowable deflection of 3% per AWWA; for both dielectrically coated and lined steel pipes, allowable deflection is 5%. Cement mortar lined and coated pipes on the other hand have a deflection limit of only 2%. The higher allowable working stress limits for all dielectric coating systems gives these systems the advantage of thinner steel cylinders for the same pressure rating as compared to cement mortar-coated pipe. Higher allowable deflections can have advantages for dielectric systems in deep fills or lower stiffness embedment soils..

## HANDLING, JOINTS, AND REPAIRS

Handling of pipe joints both in the manufacturing plant and the field is critical to maintaining the integrity of any coating system. Cementitious coatings, although very durable against impact damage, are rigid and therefore susceptible to cracking from bending moments. Dielectric systems are flexible enough to resist pipe bending moments but some may be more susceptible that others to impact damage. It is recommended that painted coatings be visually inspected or holiday tested immediately prior to being placed in the ditch, and that cement mortar pipe be visually inspected.

Joints for steel pipe are either non-restrained gasket-jointed, or restrained by welding. Typical welded joints are bell and spigot, lap-welded internally or externally, and in seismic or landslide-prone areas, double-welded. Pipelines with high internal pressures in excess of 1000 ft of head or designed to withstand high longitudinal forces may have butt welds, but for both lap-welded and butt-welded joints, the coating system is held back several inches so the weld can be performed without damage to the coating. This bare-steel area is referred to as the “hold back area” and must be “completed” by coating once the welding has been completed. Rubber gasket joints are efficient to install in the field, requiring insertion of the gasketed spigot end into the bell. However these joints are not electrically continuous and require bonding clips or straps. It is common to use heat shrink sleeves on gasketed joints since it is not common practice to coat the spigot OD as this can affect gasket sizing and seating. This is particularly true for tape coating. However, with polyurethane coated gasket-joints, properly sized rubber gasket joints with polyurethane coating may not require field joint completion with heat shrink sleeves.  Cement mortar and welded joints require the joint to be properly coated prior to final burial. Field joint completion of cement mortar coated pipe is done by placing lean concrete into a “diaper” which totally encompasses the field joint. The procedure is explained in detail in the steel pipe installation standard, AWWA C604 (2011), and also in AWWA C205 (2012).

Field joint completion for dielectric coated pipe can be accomplished by several methods, depending on the manufacturer’s recommendations. Currently, the most widely used joint completion method for steel pipe is per AWWA C216, heat shrinkable sleeves, Figure 3.

**Figures 3 a, b: Application of a Heat Shrink Sleeve, Completed Joint per AWWA C216**

There are also cold applied tape systems, paint systems, wax tape systems, and patch systems which can be used if approved by the specific coating manufacturer. Continuous coating integrity and electrical continuity are the key requirements for coating systems to perform for the design life of a pipeline. A steel pipeline with quality coatings, monitored regularly, and applied with a cathodic protection system if required, should yield the design service life of the line. Cathodic Protection systems are designed for dielectric coated pipelines using NACE Standards SP0169 (2007) and for cement mortar coated pipelines NACE SP0100 (2008). Placement of test stations at typical intervals of 1000-ft or greater enables an owner to continuously monitor for corrosion and to effectively determine whether a cathodic protection system is required at a later time.

## CONCLUSION

The high cost of corrosion in American buried water infrastructure systems can be reduced for future generations with the proper design, installation, monitoring, and maintenance of new steel water pipelines. Corrosion is mitigated by installation of coating systems which either isolate the electrolyte from the metallic surface, or passivate the metal surface through cementitious contact. No coating system is perfect. Steel pipelines must be installed with electrical continuity and monitored regularly to ensure the corrosion process is not damaging the exterior of the pipe. If corrosion is detected, a properly designed cathodic protection system should be installed and monitored. With the available technologies today, as well as the knowledge-base on corrosion, there is no reason that a steel water pipe should fail due to external corrosion.

Steel pipe designers and owners have two options when selecting coatings for steel pipe: dielectric coatings or cementitious coatings. Dielectric coatings are an offshoot of the oil and gas industry with proven life-cycle costs in very aggressive environments. Cementitious coatings have applications in the water industry with proven performance in specific environments. The trend of the industry however is toward dielectric systems, polyurethanes in particular, giving designers more options in steel strengths and deflection allowances. The overall cost of manufacturing, installing and maintaining a steel pipe coating system should be approached with a life-cycle cost mentality.

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