How to Provide Indefinite Life for Municipal Metallic Transmission Pipelines

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Abstract

Three current corrosion strategies used for Municipal Metallic Transmission Pipelines (MMTP) (defined as concrete pressure pipe, ductile iron pipe, or steel pipe 24” diameter and larger) as part of a comprehensive Asset Management Program are:

1. Run to Failure
2. Run to Failure and Repair as Required
3. Operate and Maintain to Provide an Indefinite Life (repair-free service life >100 years)

The paper will discuss the short- and long-term impacts of each strategy and detail why the strategy of “Operating and Maintaining to Indefinite Life” provides the most reliable Municipal Metallic Transmission Pipelines with the fewest repairs at the lowest total cost of operation to the owner. It will be shown that the strategies of “Run to Failure” and “Run to Failure and Repair as Required” are overall more costly since both strategies accept corrosion, unscheduled repairs, planned failure of the pipeline and the resulting high replacement costs of the MMTP. The paper will focus on methods of design, corrosion protection, maintenance and installation which allow all MMTP materials to be equally operated and maintained for an indefinite life.

Introduction

Corrosion is a significant problem for our nation. According to a 2002 Federal Highway Administration report, the annual cost of corrosion in the USA is $276 billion, with water and wastewater systems comprising $36 billion of that total. To put this close to home, consider the number of water main breaks in one’s own system or in the news last year. Corrosion is a natural process that can be controlled or even prevented in its entirety. Corrosion prevention is especially critical for our high risk buried MMTP 24” diameter and larger. While corrosion in distribution systems is also an issue, this paper will focus on transmission lines 24” and larger.

To address corrosion realities, some municipalities have initiated comprehensive Asset Management strategies (Villalobos, 2006). The Villalobos paper detailed Asset Management Strategies available including Run to Failure, Run to Failure and Repair and Operate and Maintain to Provide an Indefinite Life. Distribution systems often utilize the Run to Failure or Run to Failure and Repair strategy. These strategies may be effective as the risk to the public is generally lower and the cost and complexity of unscheduled repairs to the smaller diameter pipes is manageable. However, for high risk transmission mains corrosion protection methods should be employed to provide a pipeline that has indefinite life. It will be demonstrated that this approach provides the best long term solution, maintains the public confidence in the water systems and is more cost effective than the Run to Failure strategies.

Operation and Maintenance Strategies

RUN TO FAILURE

Simply put, this strategy entails installing a transmission pipeline for the lowest initial cost and hoping for the longest possible service life. This strategy allows corrosion of the pipeline (depletion of the asset) with the expectation that the pipeline will provide a desired service life. As the pipeline corrodes, the ability for the pipe to hold internal pressures decreases as does factors of safety. This results in increasing unscheduled repairs and the possibility of lowered pumping pressures to continue operation of the line. Oftentimes, this strategy and the Run to Failure and Repair strategy are based solely on past performance history of a material. In the case of ductile iron pipe, which has significantly thinner wall thickness than cast iron pipe (as shown in Figure 1), the assumption that ductile iron pipe will provide similar service life to cast iron pipe is not warranted without additional corrosion control or protection measures.

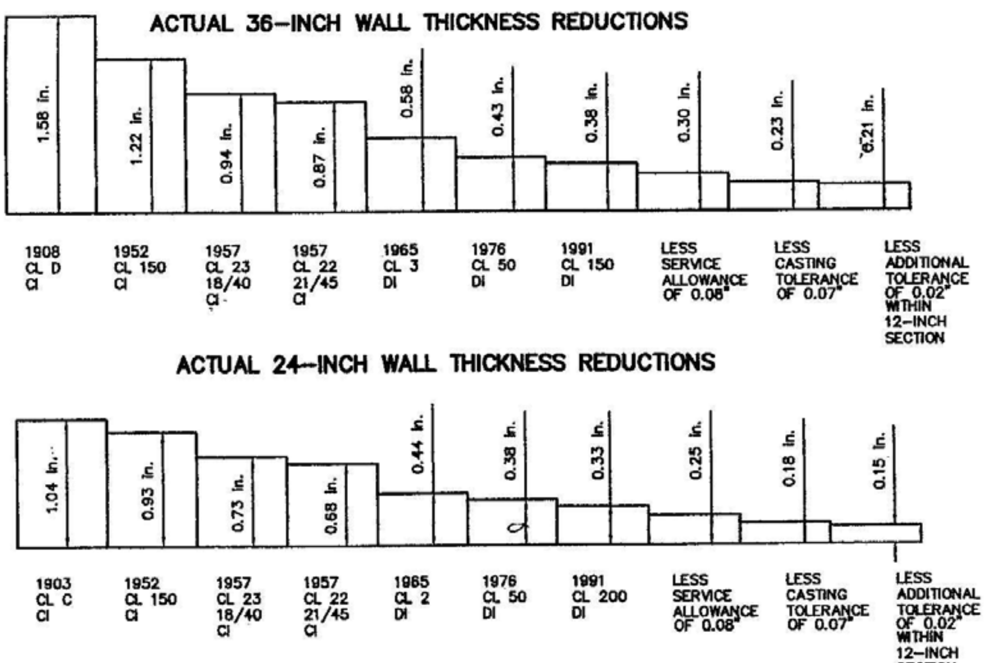

Figure 1. Actual Size of American Water Works Association (AWWA) Specification Thickness Reductions for 36- and 24-inch Diameter Cast and Ductile Iron Pipe 1908 to present (150 psi Operating Pressure) (Spickelmire, 2006)

RUN TO FAILURE AND REPAIR

Like the Run to Failure strategy, this method allows for corrosion and eventual failure of the MMTP but hopefully not before the desired design life has been achieved. At this point, another very large capital expenditure will be required to replace the original pipeline. As Villalobos and Perry report, “Run until failure and repair strategies can incorporate many of the extended life corrosion control procedures outlined in published reports and manuals… including: coatings or exterior encasements; monitoring systems; and corrosion reducing galvanic anode or impressed current systems" (Villalobos, 2006). While this method sometimes incorporates corrosion control (reducing the rate of corrosion), the MMTP will eventually fail, sometimes prior to the 50 year design life that is common in the industry. Some reports claim these corrosion control methods can extend lives to 75 years or longer but even then failure and replacement is expected. In addition, unscheduled repairs will become significant as the pipe's ability to hold internal pressure reduces due to corrosion of the MMTP.

Unscheduled Repair and Replacement Costs are significant in both of these strategies. To quantify these costs, a full life cycle cost analysis should be done for each project but as a simple example lets assume:

- Interest rate of 4.5% and Inflation rate of 3%.
- Design service life of 50 years for a 48" MMTP at initial installed cost of $5,000,000.
- Cost of repair $70,769 – Assumes two day repair, equipment, labor and significant restoration work but no claims from the public for property damage or injury (Lawrence, 2005).
- Repair costs in year 20, 30, 40 and 50 would be approximately $127,000, $171,000, $230,000 and $310,000 for each unscheduled occurrence (Lawrence, 2005).
- Replacement cost of 48" MMTP is $21,919,000 in 50 years (Lawrence, 2005).
- Villalobos and Perry state "the relative cost of the regular inspection, completion of minor repairs and cathodic protections will range between 2% and 5% of the initial capital cost of the MMTP" (Villalobos, 2006). Therefore the cost to provide a 48" MMTP with indefinite life would initially cost an additional $100,000 to $250,000, depending on the environmental conditions. There should be no significant repair costs as long as the 48" MMTP was properly designed, installed, monitored and maintained (anode replacement). It is apparent from this information that providing a MMTP with the capability of an indefinite life will be highly beneficial in both the short- and long-term. Saddling future generation with large repair and capital replacement costs of major pipelines is most likely not practicing good fiduciary responsibility. This begs the question: what must be done to have a MMTP with indefinite life in varying environments?

Operate and Maintain to Provide an Indefinite Life

This strategy is forward-looking. It looks not only at present needs and initial cost but also future needs such as inspection, redundancy or maintenance of the system. Generally more planning, field survey and design work is needed. Initial decisions are key to the effectiveness of the strategy but the decisions are based on sound engineering, national standards for construction and design such as NACE (National Association of Corrosion Engineers). "The primary benefit will be a more reliable source of delivery for water or wastewater in the case of MMTPs with fewer unplanned repairs, and, in the long term, a lower total cost of operation" (Villalobos, 2006).

Steps to be Taken for MMTP to Provide an Indefinite Life

FIELD SURVEY

In areas of known corrosive activity or high risk MMTP, field surveys should be completed and a corrosion evaluation performed by an independent corrosion engineer who have no direct or indirect association with a pipe manufacturer. Steps recommended:

- Test for stray current from DC sources such as cathodic protection currents from oil and gas lines, light rail or industrial sources. Are there plans for this type of infrastructure in the future? Such plans are often unpredictable, so it is wise to make provisions to handle DC currents on transmission lines.
- Check for AC current from overhead power lines if they exist or are anticipated.
- Perform in situ resistivity and pH measurements at anticipated buried pipe elevations. In situ testing is needed as exposure to oxygen or changes in moisture content can make lab-only readings unrepresentative of the site conditions.
- Determine groundwater elevations in borings.
- Perform lab testing for chloride, sulfide, sulfate, redox potential, pH and resistivity.
- Investigate the history of pipeline corrosion in the area.
- Analyze the corrosivity of the water or wastewater and the potential for the formation of hydrogen sulfide in forcemains.

With this information an independent corrosion engineer or corrosion professional can determine if the site is in fact "corrosive" for buried pipe. For the purpose of the paper, "corrosive" soils will be defined as soils with resistivity of 5,000 ohm-cm or less (Spickelmire, 2006) and/or pH of 5 or less (Hall, 1998). Some may argue these values are conservative but for the expectation of indefinite life MMTP these types of soils should be considered corrosive and appropriate corrosion protection methods should be utilized.

STRUCTURAL DESIGN FOR INTERNAL PRESSURES AND EXTERNAL LOADS

While structural pipe design is not the topic of the paper, it does bear mention regarding both the design of MMTP as it relates to corrosivity and indefinite pipe life. All three MMTP (concrete pressure, ductile iron and steel pipe) derive their ability to hold internal pressure from either steel or iron (ferrous materials). While unprotected ferrous components assure corrosion over time, they also assure physical properties that do not change with time (unlike plastics, which have dramatic reduction in physical properties in as little as 100,000 hours or 11.4 years). Ferrous materials will not "wear out" but do corrode, resulting in less capability to hold internal pressure (lowered factors of safety) and the resulting common "pipe break." To assure the indefinite life of the pipeline, designers should consider engineering pipelines for working and surge pressures higher than those initially expected to account for corrosion among other issues. In a previous paper it was recommended that all transmission lines be designed for no less than 150 psi working pressure with appropriate addition for surge so no "weak links" will exist and the system will have the ability to handle higher pressures for future demand (Mielke, 2004). Surge has a significant impact on MMTP longevity and especially for concrete pressure pipes where under-design or corrosion of reinforcement wire can result in cracking of the cement-mortar coating and/or over stressed reinforcing wire. The author has seen a trend toward higher calculated design surge pressures and even design of pipelines to pump shut off head to minimize risk.

CORROSION PROTECTION METHODS FOR THE INTERIOR OF MMTP

Conveyance of raw and treated water is the most common task for MMTP. Cement mortar or concrete is the most common corrosion protection measure used for lining MMTP. Upon application of the high pH cement a passivating iron oxide forms which protects the ferrous components from corrosion. The passivating film is maintained by the high pH environment and has been proven to be an excellent lining material which prevents both pipe wall corrosion and tuberculation. It is recommended that one "fill interior joint recesses with cement mortar" after joint completion to assure formation of the oxide layer at the joint (Hall, 1998). For corrosive water (pH of 5.5 or less, or containing chemicals corrosive to concrete such as sulfates or chlorides), barrier type linings such as PVC (Hall, 1998), epoxy or polyurethane should be used. In forcemains where the line runs continually full and no air or air pockets exist cement-mortar lining is commonly used.

For gravity sewers or forcemains where air can enter the line or be trapped, such as at high spots or partial flow areas, cement-mortar lining is not the best option. Air allows for the breakdown of the sewage producing hydrogen sulfide gas, which combines with humidity on the crown of the pipe wall, creating sulfuric acid. This acid will attack the cement-mortar lining and render the passivating iron oxide film useless, resulting in direct corrosion of the unprotected ferrous components. In these environments, barrier coatings such as epoxy or polyurethane are recommended for ductile iron or steel pipe and PVC liners for concrete pipe. A key element for the barrier coatings is the surface preparation (generally sand blasting or similar) required for good adhesion to the pipe wall. Without good surface preparation and the resulting adhesion creating a "tight bond," the effectiveness of these coatings is minimal.

For pipelines expected to operate well in excess of 100 years, provisions should be considered in design for future pigging or cleaning of the line. Incorporation of shop fabricated wyes will allow access in the future for cleaning. Reduced head loss from cleaning of pipelines can be cost effective, improve water quality and provide additional longevity for cement-mortar lining. Shop installed manways should always be incorporated into the design to allow internal inspection of the pipeline and access points for leak detection systems if the need arises in the future. Adding these features during design is straight forward, cost effective and eliminates the need for large field taps in the future.

Corrosion Control Methods in Non-corrosive Environment

MMTP and their ferrous components are not corrosive in all soils. In neutral, free draining soils, those described with uniform resistivity in excess of 5,000 ohm-cm, pH of greater than 5, redox >100 mv, no stray DC currents and no significant chloride, sulfates or sulfides concentrations, an indefinite life is possible. In the "right" environment, cast iron pipe in France has been shown to provide service since the 1600's (Villalobos, 2006). Figure 2 details a 1906 steel pipe line in NJ being extended by welding to new tape coated steel pipe for the next 100 years of service. The difficulty with most projects is assuring that there won't be sections or pockets of soils that are indeed "corrosive" since soils are generally not homogeneous, especially over the route of a long transmission main. Future stray currents are also hard to predict, along with the impact of road salts or heavy fertilization.

Figure 2. 1906 72" Steel Pipe connected to new Steel Pipe in NJ (National Welding Corporation, 2006)

Corrosion monitoring is an economical means of addressing the "what-if's" of MMTP in non-corrosive soils. The system consists of bonded joints (provides electrical continuity across ductile iron gasketed joints, as shown in Figure 3), insulated joints at connections to existing pipe or dissimilar pipe material, and monitoring test stations. The net result of this inexpensive corrosion monitoring system is that it allows the owner to monitor the pipeline for corrosion in the future and be proactive by taking corrective measures, such as installing buried anodes, long before a pipe break occurs.

Figure 3. Ductile Iron Pipe Bonded Joint (Southwest Pipeline, 2004)

Some discourage making a pipeline (electrically) continuous and instead prefer to deal with corrosion in isolated sections of pipe. Others would suggest that by making the pipeline continuous, corrosion will take place over a much larger surface area and as such will minimize the impact of the corrosive area. It can be argued that continuous pipe does have a positive impact as virtually all ferrous pipelines were electrically continuous prior to approximately 1960 due to the methods of jointing. Lead joints on iron pipe and riveted or welded joints for steel or concrete pipe produced continuous pipe by default. Rubber gasketed push joints for ductile iron pipe (developed in late 1950's) (Bonds, 2003) or steel or concrete pipe effectively insulate between pipe joints as long as there is no metal-to-metal contact between pipe ends. Since all MMTP materials utilize gasketed joints, joint bonding should be a standard practice.

Monitoring systems are very cost effective, even for owners that choose to practice Run to Failure or Run to Failure and Repair strategy. Monitoring systems typically cost less than 1% of the initial cost of the project. The corrosion monitoring systems will provide a "window" to determine if corrosion is present in specific areas of the pipeline and since all the "electrical" connections were completed during initial construction, the cost of corrective measures to address problem areas will be relatively small. Maintenance budget overruns and the impacts on the public can be minimized. Both the concrete pressure pipe industry (Hall, 1998), (ACPPA) (Prosser, 2003) and the steel pipe industry (Northwest Pipe, 2006) recommended bonded joints, test stations and monitoring of pipelines as good practice.

CONCRETE PRESSURE PIPE IN NON-CORROSIVE ENVIRONMENT

High pH mortar in contact with the steel cylinder and reinforcing wire or bar forms a passive iron oxide film. This oxide film is maintained by the alkalinity of the cement-mortar coating. As long as the exterior joint recess is properly filled and cured with cement mortar and movement from mechanical restraints does not result in cracking of the cement-mortar coating, indefinite life can be achieved in this environment. To accomplish this for prestressed concrete cylinder pipe, specify both "bonding plates" for joint bonding connections and "shorting straps," each of which are cast into the pipe wall. Shorting straps reduce the voltage drop in the long prestressing wires if cathodic protection is provided (Hall, 1998). Joints should be bonded to the bonding plates and monitoring systems installed and monitored periodically.

DUCTILE IRON IN NON-CORROSIVE ENVIRONMENT

Ductile iron depends primarily on wall thickness to provide desired service life. In non-corrosive environments where the corrosion rate is measured in mils/year is very low standard ductile iron pipe may be able to provide indefinite service life. It still would not be appropriate to equate the expected life of ductile iron to cast iron pipe as the thickness of ductile iron pipe "can be as much as 75% thinner for a similar pressure and diameter pipe" (Spickelmire, 2006). There is much debate on the use of polyethylene encasement to address this dramatic decrease in wall thickness. When bonded joints (Figure 3) are used and monitoring stations installed, the polyethylene encasement may actually cause problems.

At best, it is difficult to install polyethylene encasement without damage (hole, tears, joint leaks etc.). Also problematic is the fact that polyethylene encasement is loosely attached to the pipe wall and not considered a bonded coating per NACE Standard RP0169. Bonded coatings do not allow corrosion to proceed laterally past an area of damaged coating. If monitoring determines that cathodic protection is needed in an area, the polyethylene encasement can effectively "shield" the pipe wall from protective cathodic currents that are not directly in contact with the soil. Since the polyethylene encasement allows corrosion to advance laterally past the damaged area and the polyethylene encasement shields the pipe wall from protective cathodic currents, corrosion is most likely to continue under the polyethylene encasement. As evidence, the Ductile Iron Pipe Research Association recommends the use of polyethylene encasement when crossing oil or gas lines with cathodic protection to "shield" the pipe from the cathodic protection currents that would like to "consume" the ductile iron pipe to protect the oil or gas line (Bonds, 1997). Polywrap shielding in essence may not allow the ductile iron pipeline to be properly monitored or cathodically protected. The author is aware of no national standard for the design of cathodic protection on polyethylene wrapped ductile or steel pipe.

STEEL PIPE IN NON-CORROSIVE ENVIRONMENT

Steel pipe offers a number of AWWA coating systems that can provide indefinite life in most environments. The most common are three-layer tape system, polyurethane, cement mortar, extruded polyethylene and coal-tar coatings. Polywrap is not recommended for steel pipe due to previously discussed installation issues and the fact it is not tightly bonded to the pipe.

The cement-mortar coating option is similar to the coating system used on concrete pressure pipe. As previously mentioned, cement-mortar coatings can provide an indefinite life in non-corrosive soils that are free from stray currents.

The balance of the coatings is bonded dielectric coatings, which act as a barrier coating and provide excellent dielectric resistance to stray currents. Per NACE Standard RP0169 bonded coatings depend on good surface preparations and the resulting good adhesion strength to provide corrosion protection. The adhesion strength allows the coating to stay tightly bonded to the pipe wall surface during all phases of construction and not allow the migration of water or air between the coating and pipe wall to begin a corrosion cell. Dielectric coatings are tough and resist construction damage with thickness of up to 80 mils for tape systems versus 8 or 4 mils for polyethylene encasement. Still holidays may occur in the coatings that could cause pitting corrosion in pockets of corrosive soils. Monitoring systems are recommended to address this "what if." In the future, if areas of excess current flow (corrosion) are detected during periodic monitoring, cathodic protection using buried anodes could be simply installed at that time without "digging up" sections of the pipeline. With the tightly bonded coating the cathodic protection currents would be assured to protect the areas of damaged coatings. This process is very similar to that used successfully on oil and gas pipelines throughout the USA and by virtually all independent corrosion engineers using the NACE Standard RP0169. Simply put, it works. As evidence, compare the number of gas leaks in your community to the number of water leaks.

Corrosion Protection Methods in Corrosive Environment

In corrosive environments, corrosion protection methods, which stop or prevent corrosion, in conjunction with cathodic protection should be used for all MMTP to provide indefinite life. Corrosion control methods accept corrosion of the asset, unscheduled repairs and large replacement costs and are not appropriate for the "Operate and Maintain for Indefinite Life Strategy" in corrosive environments. As such, the balance of the paper will address MMTP corrosion protection options for owners and engineers.

CONCRETE PIPE IN CORROSIVE ENVIRONMENT

Cement-mortar coatings are susceptible to the loss of their corrosion protection ability in corrosive environments, both from soil and stray currents. S.C. Hall describes certain conditions and a sampling of possible solutions follows (Hall, 1998):

- Sulfate soils with more than 0.2% SO_4^{2-} or waters containing more than 2000 SO_4^{2-} may require Portland cement with 5% tricalcium aluminate.
- Acid soils with pH less than 5.0 may require the exterior to be coated with high build coal-tar epoxy.
- High chloride soils of greater than 350 ppm may require the exterior to be coated with coal-tar epoxy.
- Stray current electrolysis caused by discharge from cathodic protection system or other DC sources may also need to be coated with high build coal-tar epoxy.
- Subaqueous or high ground water installations may require high build coal-tar epoxy coating of the pipe and the joint (Carnegie) rings.
- Protection of steel joint rings requires epoxy or zinc coating in addition to filling of joint recess with cement. As commentary by the author, movement at restrained joints should not be allowed during field test pressures or surge events to limit cracking of the cement-mortar coating at he joints and possible corrosion. Typically mechanical restrained joints allow longitudinal and/or rotational movement as they take up slack or engage with thrust loads. Welded restrained joints should be considered to limit joint movement.
- Application of cathodic protection requires the use of shorting straps for PCCP, bonded joints and test station leads previously discussed to provide corrosion monitoring. The cathodic protection headers are integral with the cathodic protection system and can consist of galvanic (buried anodes bags or ribbon anodes comprised of zinc or magnesium) or impressed current system.

DUCTILE IRON PIPE IN CORROSIVE ENVIRONMENTS

In order to provide indefinite life in corrosive environments, ductile iron pipe requires corrosion protection systems and design per NACE standard RP0169. Tightly bonded dielectric coatings offer an effective solution and history, as they provide both a barrier coating that is resistant to virtually all soil corrosivity issues as well as resistance to stray currents. Possible corrosion protection options include:

- Polyurethane coating such as US Pipe Polythane™, a product that was produced and sold in USA beginning in 1988 (Horton, 1995). A. M. Horton reports that Polyurethane "cures quickly to form a hard, yet flexible film that is resistant to chipping, cracking and impact damage." Horton also reports that on one 31,000' project shipped over 2,000 miles, "the exterior coating had little or no shipping damage and had an installed coating efficiency of 99.66% when tested as part of a cathodic protection system (Madison Chemical, 1994)" (Horton, 1995).

Figure 4. Ductile Iron Pipe with polyurethane coating (Szeliga/Lieu, 2002)

- Coal-tar epoxy coating. A.M. Horton reports "coal-tar epoxy has been used to protect the interior and exterior of iron pipe in excess of 40 years. It has been proven to be an excellent protective coating if properly applied in sufficient thickness" (Horton, 1995).
- Tapewrap coating. Available in two- (50mil) or three- (80 mil) layer systems from tape manufacturers specifically for ductile iron pipe. The tape product is also available in a system that requires no sand blasting and can utilize standard factory shop-coated pipe for tapewrap.

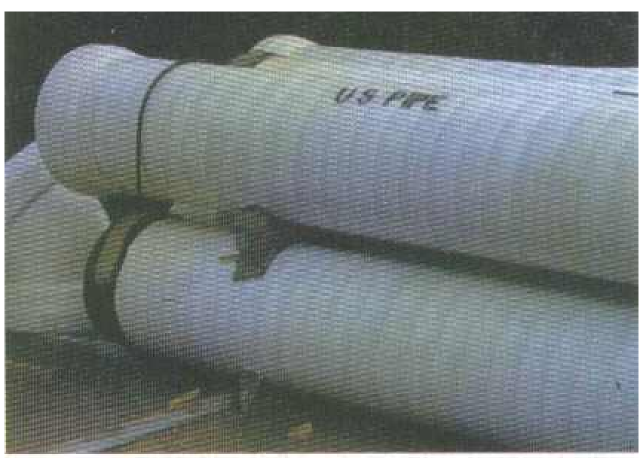

Figure 5. Tape-coated Ductile Iron Pipe (Szeliga/Lieu, 2002)

- Extruded polyethylene, such as ShawCor Pipe Protection's Pritec™ system. Similar to tape system except the coating is extruded onto the pipe to form a tough 70 mil coating.

- Surface preparation for ductile iron pipe per NAPF (National Association of Pipe Fabricators) 500-03. All of the above coatings, with the exception of one tape system option, require a prepared (generally blasted) surface for proper bonding of the coating to the surface. The NAPF-500 national standard was developed by pipe manufactures, consulting engineers, coating suppliers and fabricators for surface preparations of ductile iron pipe and fittings. Surface preparation is an ongoing essential component for pipe lining application and coating of fittings. Currently there is much controversy on the ability to properly blast and/or prepare the exterior surfaces of ductile iron pipe for coating application in the USA despite the NAPF 500 standard and the apparent successful coating history. It has been argued that the recent refusal of the USA ductile iron pipe industry to provide exterior bonded coatings is driven by the high selling price of the coated product (Spickelmire, 2006).
- Zinc-rich coating with a top coating has been used over the past 30 years in Europe per ISO Standard 8179. Some USA ductile iron pipe manufacturers have and are most likely manufacturing the zinc-coated product in the USA and shipping overseas (ACIPCO International, Feb. 7, 2007).
- Zinc-AL coating with blue epoxy finish coat produced and marketed as PAM Natural by Saint-Gobain, the largest ductile iron pipe manufacturer in the world. (Saint-Gobain, Dec. 20, 2006). Product is represented as more durable than Zinc-rich coating and manufactured per British Standard EN 545:2002.
- External coatings referenced in the British Standard EN 545:2002 include:
    1. Zinc rich paint coating having a minimum, mass of 150 g/m2, with finishing layer,
    2. Thicker zinc coating, having a minimum. mass of 200 g/m2, with finishing layer,
    3. Polyethylene sleeving (as a supplement to the zinc coating with finishing layer),
    4. Zinc-aluminum (85Zn – 15Al) coating having a minimum. mass of 400 g/m2, with finishing layer (PAM Natural),
    5. Extruded polyethylene coating,
    6. Polyurethane coating,
    7. Fiber reinforced cement mortar coating having a nominal thickness of at least 5mm, and
    8. Adhesive tape.
- Other European Coating standards for ductile iron pipe include:
    1. DIN 30 675 Part 2 "Corrosion protection systems for ductile iron pipes,"
    2. DIN 30 674-3 "Coating of ductile cast iron pipes. Part 3: Zinc coating with a protective finishing layer,"
    3. DIN 30 672 "Tape and shrinkable materials for the corrosion protection of buried and underwater pipelines without cathodic protection for use at temperatures up to 50C,
    4. DIN 30 6704 Part 2 "Cement mortar coatings for ductile iron pipe," and
    5. EN 14628 Ductile Iron pipes, fittings and accessories – External polyethylene coating for pipes – requirements and test methods. (This is not polyethylene encasement).

- Polyethylene encasement is a loose or unbonded coating and NACE RP0169 recommends against the use of loose or unbonded coatings. Much discussion and controversy regarding the use of polyethylene encasement in general but especially on transmission lines with cathodic protection. Installation damage and the fact the polywrap is not tightly bonded to the pipe is key. As Spickelmire reports, "there are no industry standards for cathodic protection of polyethylene-encased ductile iron pipe… The major problem is that no long-term non-biased scientific study shows whether polyethylene encasement with cathodic protection works or not" (Spickelmire, 2006). Szeliga also reports that based on "actual experiences of independent (owners or their consultants)" that "PE encasement is not adequate for corrosion control of DI pipe in corrosive soil if the risk of pipe failure in not acceptable" (Szeliga, 2007).
- Application of cathodic protection includes bonding of joints, heat shrink sleeves at joints, electrical isolation from other pipelines, installation of monitoring stations and either galvanic (magnesium anodes) or impressed current cathodic protection in accordance with RP0169.

STEEL PIPE IN CORROSIVE ENVIRONMENTS

Like both concrete and ductile iron, steel requires corrosion protection methods in conjunction with cathodic protection to provide indefinite service life. Steel water pipe has extensive experience in providing corrosion protection measures as the industry has used much of the knowledge, standards and practices from the oil and gas industry. The result is in general a good long-term performance history. Corrosion protection options for buried pipe include:

- Tapewrap system per AWWA C214 and C209
- Polyurethane per AWWA C222
- Epoxy per AWWA C210
- Extruded polyolefin system per AWWA C215
- Coal-tar enamel per AWWA C203
- Heat shrink sleeves per AWWA C216. Used to complete joint for all dielectric coated pipelines.
- Surface preparation specifications are included in the AWWA spec and reference SSPC standards.
- Cement mortar per AWWA C205. This is a similar standard to the cement-mortar coating in the AWWA standards for concrete pressure pipe. Environmental limitations for cement-mortar coatings are mentioned in the concrete pressure pipe section.
- Application of cathodic protection includes bonding of joints, heat shrink sleeves at joints, electrical isolation from other pipelines, installation of monitoring stations and either galvanic (magnesium anodes) or impressed current cathodic protection per NACE RP0169 standard.

Conclusions

Transmission pipelines are very expensive to build and come with high risk due to the everyday dependence by the public and the risk of injury and or property damage from failures. The cost of unscheduled repairs and enormous replacement costs of transmission pipelines can result in undo financial burdens. In the early to mid-1900's, owners were using the best pipe materials and practices available at the time and hoped for the best. Some of these pipelines have performed quite well, perhaps due to non-corrosive soils. Today owners, engineers and manufacturers have a much broader technology base but there is scattered understanding of the process of corrosion control and corrosion protection. Some of this is likely due to lack of exposure, reluctance to change and commercial issues. In any regard, it is recommended that some asset management strategies be employed when designing or building transmission pipelines. It can be concluded that Operating and Maintaining to Provide Indefinite Life is the best strategy as it assures long term service with the lowest overall cost and fewest unscheduled repairs. The knowledge, technology and products exist to provide an owner with water transmission pipelines that can be constructed, operated and maintained for indefinite life.

Recommendations

1. Conduct a field survey as detailed in the paper. If the environmental conditions are unknown, how can informed decisions be made regarding corrosion strategies?
2. Operate and Maintain to Provide Indefinite Life is the best corrosion strategy for transmission lines and provides the lowest overall cost and fewest unscheduled repairs. Use corrosion prevention practices as they stop or eliminate corrosion.
3. Utilize Equal Corrosion performance specifications for all MMTP materials. If a corrosion protection strategy is selected, then all MMTP materials should require a similar level of corrosion performance (corrosion protection).
4. Always bond joints and provide monitoring systems for all MMTP. This practice is inexpensive when done during construction and provides a "window" to monitor the pipeline. Monitoring for the first few years can be supplied by the pipe supplier if the owner is unfamiliar or lacks the personnel.
5. Specify the corrosion protection levels needed for transmission pipeline systems. Don't be satisfied with the status quo or "this is what is available" when it comes to critical corrosion decisions. Our dependents are counting on us.

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