Longest Polyurethane Lined and Coated Steel Pipeline in North America: The Provo Reservoir Canal Enclosure Project

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ABSTRACT
Polyurethanes have found extensive applications in the pipe coating industry because they exhibit excellent corrosion resistance, abrasion resistance, toughness, and chemical resistance, as well as a wide range of useful mechanical properties. Though the first AWWA standard for polyurethane lining and coating of steel pipe was published in 1999, fast-setting, high-solids polyurethane has been used to line and coat steel pipe since the 1980's. The Provo Reservoir Canal Enclosure Project (PRCEP) is a 21-mile, 126-inch diameter steel pipeline that was placed into service in early May 2012. This $150 million undertaking is saving approximately 8000 acre-ft of water annually from evaporation and seepage, and has the capacity to carry 400 MGD of raw water. Several pipe materials were considered for the construction of this line, with polyurethane lined and coated steel pipe being selected as the most economical solution for the project. The PRCEP line is one of the longest and largest-diameter polyurethane lined and coated steel water transmission pipelines in the world, and certainly the longest in North America. This paper systematically outlines the contents of the AWWA C222 standard for polyurethane coating systems and relates it to the project, in tandem with discussions on the requirements of the project specifications. In-plant coating application and quality control are discussed. Installation and constructability issues are discussed from the Contractor's perspective.

INTRODUCTION
Construction of the 21-mile, 126-inch diameter pipeline, known as the Provo Reservoir Canal Enclosure Project (PRCEP), was originally a 3-year undertaking that has resulted in the prevention of approximately 8000 acre-ft, or 2.6 billion gallons of water loss annually from evaporation and seepage. The pipe-laying was completed one year ahead of schedule in early April 2012, and the line was tested and placed into operation in May 2012. This landmark $150 million project addresses public safety concerns associated with an open canal located in an urbanized area; improves water quality by eliminating external sources of contamination; provides redundancy for drinking water supplies to the Salt Lake Valley; provides in-stream flows to help with the recovery of an endangered fish species; and, finally, allows for the development of an equestrian-pedestrian recreational trail and park along the entire length of the enclosed canal. Murdock et al. (2011) provide details of the project and discuss the selection process of polyurethane lined-and-coated steel pipe as the most economical solution amongst the three conduit materials considered: cast-in-place concrete box culvert, reinforced concrete pressure pipe (RCPP), and spirally welded steel pipe (WSP). Canal hydraulics, design considerations, pipe materials, jointing options, corrosion protection, manufacturing considerations, transportation and hauling issues, and constructability are discussed.

<u>Literature Review</u>: Steel pipes have been lined and coated with polyurethanes since the 1980's, but the first American Water Works Association (AWWA) standard for polyurethanes, AWWA C222 (2008) wasn't published until 1999 and was last updated in 2008. In recent years, the use of

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polyurethane lining and coating systems on municipal steel pipelines has grown substantially. Literature is replete with case histories of successful projects in a variety of applications. Bambei at al. (2011) reported on adhesion testing performed periodically on polyurethane lining in a 108-inch water transmission line placed into service at Denver Water in 1997. The lining was reported to be in good condition after fourteen years of service, and still meets the coating system's original performance requirements. Rivera et al. (2010) reported on a case study of a raw-sewage application in Pima County, AZ, where polyurethane was used to line and coat a 42-inch diameter WSP sanitary sewer line, buried 30-ft deep. The coating system was evaluated for acceptability under the Pima County/City of Tucson 2003 SSPI, Maricopa Association of Government (MAG) Standards, the City of Los Angeles Green Book Standard Specification, and the State of Washington Dept. of Ecology Criteria for Sewer Works Design; the Arizona Dept. of Environmental Quality (ADEQ) provided final approval of the product. The line was designed for a minimum 100-year service life. Bass et al. (2011) report on the fully structural rehabilitation by Sliplining of a 48-inch diameter PCCP water transmission main at Halifax Water, utilizing polyurethane lined-and-coated, gasket-joint, WSP. Compared to all other rehab options, the engineer determined that the polyurethane coating system would best withstand the high chloride concentrations within the surrounding backfill of the host PCCP line. The rehab solution was designed to provide a 100-year service life.

WSP CORROSION PROTECTION STATE-OF-THE-ART

As a standard practice, WSP is protected internally and externally with flexible and/or rigid, lining and coating systems. The terms rigid and flexible define their ability to be deformed without damage; flexible lining/coating materials can be deformed more so than rigid materials, without sustaining damage. They are further categorized as cementitious or dielectric. Cementitious systems, rigid in nature, primarily made of cement mortar, per AWWA C205, function by increasing alkalinity in the immediate vicinity of the pipe walls, thereby passivating the steel. The augmented alkalinity provided by the Portland cement in the cement mortar mix causes the steel to become "passive" in relation to the corroding effects of the fluid on the inside of the pipe, and the soil on the outside; a shell against long-term corrosion is thereby created.

Dielectric barriers, flexible in nature, on the other hand provide a physical "layer of obstruction" that fully separates the pipe wall from its internal and/or external environments. Examples of dielectric systems include tape coating, AWWA C214, paints such as polyurethane lining/coating, AWWA C222, and epoxy lining/coating, AWWA C210, or extruded polyolefin coatings, AWWA C215.

PROJECT CORROSION PROTECTION NEEDS

The design team of the PRCEP was required to achieve a 75-year service life of the selected conduit material. Consequently, sources that could lead to corrosion of the selected material had to be identified. These included:

1. Corrosivity of native soils
2. Winter salting and de-icing agents that could penetrate the soil
3. Electrical interference with existing pipes that paralleled the pipeline

There were 34 separate road crossings that the pipeline would traverse; salts and de-icing chemicals could percolate through soils to the pipeline at these crossings in the winter months. Impressed current systems protecting the Jordan and Alpine Aqueducts that parallel approximately 75 percent of the alignment of the PRCEP pipeline could cause electrical interference and lead to corrosion.

Murdock et al. (2011) provide details of measures incorporated into design to prevent corrosion of each of the different pipe materials chosen for the final bid. As mentioned earlier, polyurethane lined and coated steel pipe was selected as the most economical solution for the project. The project specifications provided the following lining and coating options for WSP, as well as cathodic protection to offset the effect of stray currents from other pipelines protected by impressed current systems:

Lining: ***a.*** Cement-mortar (per C205, with modifications), ***b.*** polyurethane (per C222, with modifications)
Coating: ***a.*** Tape coating with cement mortar over-coat for additional damage protection (per C214 with modifications, and C205, respectively), ***b.*** polyurethane (per C222 with modifications), and ***c.*** extruded polyolefin (per C215 with modifications)
Cathodic Protection: To offset the effects of stray currents from nearby impressed-current protected pipelines, a deep well anodic system with low voltage was specified along the length of the pipeline. Test stations were placed at ¼-mile intervals for long-term corrosion monitoring.

From a design-standpoint, selection of the polyurethane lining and coating for the WSP minimized any possibility of damage during transportation. Use of a handling ratio, D/t, of 288, again did not present any concerns about the possibility of damage to the polyurethane. The use of polyurethane also made each 40-ft section of pipe significantly lighter than would have been the case with a cementitious lining. Approximately 70 gallons of polyurethane paint was used to line and coat each piece of 126-inch diameter pipe.

MATERIAL HISTORY

A German polymer scientist, Prof. Dr. Otto Bayer[3] of I. G. Farbenindustry (today's Farbenfabriken Bayer), is given credit for his pioneering work on the chemistry of polyisocyanates (Xiao et al. 2012) and polyurethanes beginning in 1937; his findings were published ten years later in the *Angewandte Chemie* journal (Bayer 1947). Wallace Hume Carothers' ground-breaking work on the production of the world's first synthetic fibers was the starting point of Bayer's work. In his attempts to circumvent Carothers' patents on polyamides and polyesters, Bayer chose the urethane reaction, which led to the discovery of polyurethanes. Since its invention, polyurethanes have been utilized in a wide array of applications, including coatings. During WWII, a small amount of polyurethane was produced for "super-coating" of German warplanes, but large-scale production did not begin until Bayer and Monsanto formed the Mobay Corporation (Seymour et al. 1992). The diversity of polyurethane applications today include refrigerator insulation, artificial organs, automotive components including bumpers, panels and even seating, ski-boots and shoes, large satellite antennas, etc. Coatings currently represent 5% to 10% of the domestic polyurethane market, and are steadily growing. In 2002, 5.5 billion pounds of polyurethane was used for coating applications in the United States (Xiao et al. 2012).

[3] Dr. Otto Bayer is sometimes confused as the founder of the Bayer Company, makers of *Aspirin* and other pharmaceutical products. Felix Hoffman, a chemist with Friedrich Bayer and Company, invented the primary ingredient of Aspirin in 1897, which by 1899, became the Bayer Company's biggest-selling drug worldwide <http://www.wonderdrug.com/pain/asp_history.htm> (March 27, 2012). Dr. Otto Bayer, the inventor of polyurethanes, was born in 1902, worked for I. G. Farbenindustry and later Mobay Corporation, and died in 1984.

CHEMISTRY

ASTM classifies polyurethanes into six general types (ASTM 2003). The type permitted in the AWWA C222 (2008) steel pipe coatings generally consists of an "ASTM D16 Type V thermoset, aromatic polyurethane plastic polymer that is the reaction product of diphenylmethane diisocyanate (MDI) resin and polyol resin or polyamine resin or a mixture of polyol and polyamine resins" (AWWA 2008). Linking of the diisocyanate and polyol/polyamine occurs by step-growth polymerization, or *polyaddition*. Figure 1 illustrates the typical synthesis of polyurethane, where the urethane groups, — NH-(C=O)-O-, link the molecular units.

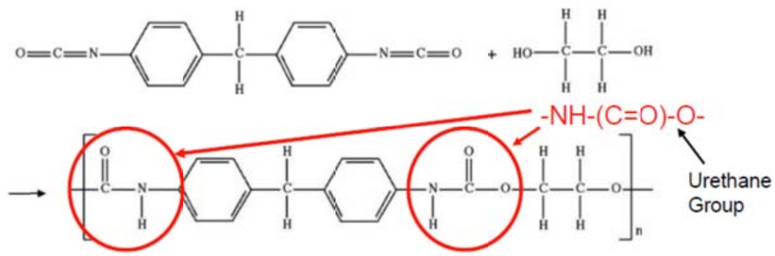

Figure 1: Linking Molecular Units by Urethane Groups (Rahman, 2011)

Referred to as a plural component (or "two package") system, the reaction between the polyol/polyamine and diisocyanate reactants occurs in situ, and is the typical commercial method used to produce polyurethane coatings (Seymour et al. 1992). When appropriately formulated, polyurethanes provide the chemical resistance and corrosion protection properties of other dielectric paint systems such as epoxies, but with added durability, flexibility, elongation, rapid cure times, and abrasion and impact resistance. Most polyurethane steel coating systems are solvent free (100% solids) and are *fast-setting*, curing in under 30 minutes. The rapid cure time of polyurethane is an advantage over paints such as epoxy when used for coating pipes.

PRCEP POLYURETHANE REQUIREMENTS

With the AWWA C222 (2008) standard as the basis, the project corrosion engineer incorporated various modifications into the final project specification for the polyurethane lining and coating. The basic polyurethane requirements were listed as follows:

Lining: For lining, the material was required to be self-priming, plural component, 100 percent solids (zero VOC), non-extended[4], and suitable for immersion. Despite being a raw water line, NSF 60 and 61 certifications were needed for the material. One coat, of 35-mil minimum dry film thickness (DFT) was specified.

Coating: For coating, the polyurethane was required to be self-priming, plural component, 100 percent solids, and non-extended, and suitable for burial or immersion. One coat, of 35-mil minimum DFT, was specified.

[4] The term "non-extended" is used to specify polyurethane coating systems that do not contain non-reactive liquid additives. These non-reactive additives, oftentimes called "plasticizers" for their ability to impart flexibility into the cured film, are used for various reasons: added flexibility, slip, hydrophobicity, etc. Plasticizers are usually of large molecular weight so they become trapped within the polyurethane matrix, making them non-migratory. If fuel oil or other chemicals are used to extend the polyurethane, this may result in a negative impact on the coating adhesion.

AWWA C222 STANDARD

Physical and Performance Requirements: The C222 standard for polyurethane coating and lining systems sets physical and performance requirements of both shop-applied and field-applied polyurethane for steel water pipe, special sections, welded joints, connections, and fittings. These requirements are for the polyurethane materials, testing, substrate surface preparation, handling, and packaging. There are currently eight pre-qualification properties of the material that must be tested, all conducted under laboratory conditions:

1. Cathodic Disbondment: Intended to evaluate a coating's ability to maintain a corrosion barrier, with a holiday, exposed to an electrolyte (wet soil) on a cathodically protected pipeline, and is performed per ASTM G95. Minimum value is 12mm in 28 days.
2. Flexibility: Performed per ASTM D522, this test determines a coating's resistance to cracking when elongated; a sample is bent 180 degrees over a 3" mandrel. No cracking or delamination is the passing criteria.
3. Impact Resistance: This test determines the energy required to rupture coatings applied to pipe from a falling weight. Performed per ASTM G14, the material is required to withstand a minimum 75 in-lb of energy.
4. Abrasion Resistance: This test determines the resistance of coatings to abrasion produced by a Taber Abraser, per ASTM D4060. 100-mg loss of material per 1000 revolutions is the maximum loss permitted.
5. Chemical Resistance: This is an evaluation of a coating's resistance to chemical reagents specified, and is performed per ASTM D543. Chemicals include 10% H_2SO_4, 30% NaCl, 30% NaOH, and #2 diesel fuel.
6. Dielectric Strength: Determination of the dielectric strength (ability of material to physically isolate lined/coated pipe surface from environment) of solid insulating materials at commercial power frequencies. ASTM D149 is utilized for this test. Minimum value in C222 is 250 V/mil.
7. Water Absorption: Determines the relative rate of absorption of water by plastics when immersed, per ASTM D570. 2% maximum absorption is permitted by C222.
8. Hardness: Determination of indention hardness of rubber, per D2240. Minimum acceptable value is 65 Shore D.

The adhesion test, performed per ASTM D4541, is listed as a requirement in C222 only for post-coating-application quality control inspection. The test is designed to evaluate the tensile (perpendicular/normal force) adhesion of coating to the substrate after application. Minimum adhesion value in C222 is 1,500 psi. The PRCEP specification, however, required that the adhesion test be performed first, as part of pre-qualification testing, under laboratory conditions, at a minimum acceptable value of 3,000 psi, followed by its use as a post-coating application quality control inspection, with a minimum acceptable value of 1,750 psi.

Additional Pre-Qualification Tests in PRCEP Specification: The project specification required three tests to be run on the material that are not currently listed in the C222 standard, discussed below. The specification did not require the chemical resistance, dielectric strength, and hardness tests (discussed in items 5, 6, and 8 above).

1. Permeance: This is a measure of water vapor transfer through the material, tested per ASTM E96, Water Method (App. XI). Project permitted 0.050 inch-pound.
2. Wet Adhesion: Performed per ASTM D870, this test evaluates the coating material's resistance to water using water immersion, and was utilized on the PRCEP to analyze loss of adhesion in

exposed areas versus non-exposed areas. Project specification allowed no greater than 10 percent loss of adhesion.

3. Tensile Strength: This test is designed to verify the ability of the material to withstand tensile forces for adequate performance based on the application. Performed per ASTM D412, with 4000 psi minimum specified for the project.

Whenever changes to the C222 standard's physical/mechanical parameters are made in a project specification, there should be sound engineering reasoning behind those changes as it can sometimes result in substantially higher costs to the Owner. On this project, the Owner felt that a higher cost was justifiable based on the desired life expectancy of the pipeline.

IN-PLANT APPLICATION PROCEDURES

<u>Surface Preparation</u>: The longevity and effectiveness of any coating system is directly related to the surface preparation that the substrate undergoes prior to application of the coating. To this end, the C222 standard requires that the pipe first be cleansed of oils, grease and soluble contaminants; this is followed by an abrasive blast cleaning with mineral or slag abrasives or steel grit with an angular profile. The near-white metal blast, performed per SSPC-SP 10/NACE No. 2 (2006), is required to have a blast anchor pattern or profile depth of 2.5 mil minimum (measured in accordance with ASTM D4417). The PRCEP specification required a white metal blast cleaning per SSPC-SP5/NACE No. 1 (2006), with a minimum 3 mil angular profile.

For quality control, C222 requires that the temperature be measured and recorded to ensure it is above the dew point at the time of abrasive blast cleaning. After the blast cleaning, the surface of the pipe is cleaned, profile depths measured and recorded, and a visual comparison of the coloration of the blasted surface is made with the SSPC cleaning method specified. The standard also requires that flash rusting of the prepared surface be prevented. Figure 2a shows a completed exterior blast surface undergoing final cleaning, figure 2b shows a completed interior blast surface, and figure 2c shows coating profiler strips that are used to measure and record blast profile depths, per ASTM D4417 (2011).

Figure 2a, b, c: Exterior, Interior Abrasive Blast Cleaning, Profiler Strip

<u>Polyurethane Application</u>: The PRCEP specification required that the Coating Applicator (pipe manufacturer in this case) and the supervisor shall have 5 years of experience with the specified coating system, personnel dealing directly with the application have 2 years of experience, and that the Applicator shall be certified by the polyurethane manufacturer within the past 1 year. While C222 is not specific on the number of years of experience, the standard does require that the Applicator undergo training by the coating manufacturer. The PRCEP specification also required a

2-year warranty on workmanship and material from the Contractor and Applicator; warranty is not addressed in the C222 standard.

The section on Coating Application in C222 pays particular attention to temperature and environmental conditions during application, and calls for "fast-setting, short pot-life coating systems" to be applied by manual spraying, automatic spraying or by centrifugal applications, using appropriate plural component equipment. Two types of coating conveyor equipment systems are briefly described; in reality, the actual equipment usually varies from one applicator to another, so detailed guidance on this topic is not provided in the standard. On the PRCEP, a stationary but rotating pipe and a traveling spray gun were utilized for the external coating, Figure 3a and b. The internal lining was applied by keeping the pipe stationary, but rotating, figure 3c, and using a polyurethane spray lance, shown in Figure 3d that gradually extended longitudinally, along the entire inside length of the pipe, as the material was sprayed.

Figure 3a, b, c, d: Coating Application Progression, Pipe Rotation System for Lining, Lining Spray Lance

Post-application quality control measures outlined in C222 includes: 1. visual inspection of the coating ("no blisters, cracks, bubbles, delamination, or any other visible defects"), 2. measurement of dry film thickness (DFT) ("if the thickness is found to be less than the amount required, all of the pipe coated since the last thickness measurement shall be checked and overcoated if necessary"), 3. holiday testing per NACE RP-0188 (NACE 1999), with a minimum voltage setting of 100 V/mil, and, 4. adhesion testing per ASTM D4541. NACE RP-0188 has been changed to NACE SP0188-2006.

DFT Quality Control: The C222 standard specifies 20 mil DFT for lining, and 25 mil minimum DFT for coating, but does not specify a maximum thickness; this is left to the manufacturer's recommendation, as long as the material passes all the prequalification tests previously discussed. The PRCEP specification required a minimum DFT for both the lining and coating of 35 mil. While C222 requires the measurement of DFT in accordance with SSPC-PA 2, the PRCEP specification excluded the use of SSPC-PA 2 and instead, required the use of a calibrated magnetic pull-off or eddy current equipment.

Electrical Continuity/Holiday Testing: The PRCEP specification required that holiday testing be conducted using the high voltage spark test per NACE RP-0274 instead of the test specified in C222. The Elcometer Model D236® or equivalent high voltage testers with 0 to 30 kV voltage capability was specified.

<u>Adhesion Testing</u>: The adhesion testing of polyurethanes using ASTM D4541 has been the subject of further research in recent years due to the variability in testing results that may be obtained. Bambei et al. (2011) and McFatridge (2012) provide discussions on the variability. Croll et al. (2012) provide results of research conducted to study causes of the variabilities. For acceptance, the C222 standard requires that 2 pipes per shift be selected at random, one at the beginning of the shift, the other half-way through the shift, which are then tested for adhesion per ASTM D4541. Acceptable adhesion per C222 is 1,500 psi. If the adhesion values are unsatisfactory, then 2 additional tests are conducted at two different locations on the same pipe. The pipe coating on this pipe is rejected if either additional test fails. All pipes coated on that shift are then systematically inspected for acceptance or rejection. The PRCEP specification required that acceptable adhesion value be 1,750 psi minimum. Two types of pneumatic equipment were cited as acceptable adhesion testers: Defelsko Positest AT®, or Elcometer® HATE Model 108. Figure 4a shows dollies glued to coating surface for testing, and figure 4b shows test performance using Defelsko Positest AT® equipment.

Figures 4a, b: Dollies Glued to Coating for Adhesion Test, Test Performance

Based on the way in which the frequency of testing was defined in the PRCEP specifications (specific surface area of pipe coated), every other piece of pipe was tested for adhesion. None of the pipe on the entire 21-mile project failed the adhesion testing.

<u>Coating Repair</u>: Pipe coating repair guidelines are provided in C222 as well as the PRCEP specifications. Emphasis is placed on holiday testing in C222 to ensure successful repair; adhesion testing of repairs is not required. The project specification differentiates between "minor repairs" (less than 6-inch in greatest dimension) and "major repairs" (exceed 6-inch in greatest dimension), and limits major repairs to no more than two per pipe section and not to exceed 50% of the pipe.

INSTALLATION & CONSTRUCTABILITY

The C222 standard provides guidance on the in-field completion of welded and gasketed joints following assembly. It also provides guidelines on handling of polyurethane coated pipe in relation to trench conditions and backfill and bedding materials. Similar guidance is also provided in the PRCEP specifications.

<u>Joint Completion</u>: For both internally and externally welded joints, C222 requires that an 18-inch wide strip of heat-resistant material be taped on each side of the joint holdback to prevent damage to the polyurethane from weld-splatter. Following completion of welding, C222 permits external and internal joint completion using a number of options, as long as the material is compatible with the originally applied lining and coating material. The PRCEP specification for polyurethane lined and coated WSP permitted only polyurethane to be used for internal joint completion, and only heat shrink sleeves, per AWWA C216, to be used for external joint completion.

For internal joint completion, C222 requires joint surface preparation to be the same as that used when shop-applying polyurethane on the pipe. Material application on a joint is also held to the same standard as shop-coated and lined pipe. Following joint completion, DFT, adhesion and holiday testing are applied to ensure quality control. The PRCEP specifications required that internal joint completion be performed by qualified applicators who had done at least 3 similar projects within the past 3 years, using the same coating system. The PRCEP also provided added guidelines on external joint completion using heat-shrink sleeves, per AWWA C216, and also to facilitate weld-after-backfill. Figure 5a shows heat-shrink sleeve application preparation, figure 5b shows heat being applied to a sleeve with a torch, and figure 5c shows pipe with completed joints being backfilled in the trench.

Figures 5 a, b, c: Heat-shrink Sleeve Application, per AWWA C216

<u>Field Handling</u>: Despite the tough nature of polyurethanes, prevention of damage to the coating system during pipe transportation and handling is emphasized in C222. The use of wide belt slings instead of chains, cables, or tongs is given emphasis, as is the importance of preventing metal tools or heavy objects from coming into direct contact with the finished coating. The dragging or skidding of coated pipe is also forbidden. Figure 6a shows pipe being hoisted using wide belt slings and placed into the trench on the PRCEP pipeline; figure 6b shows the pipe being adjusted to line and grade.

Figures 6 a, b: Pipe Hoisted and Placed into Trench, Grade Adjustment

<u>Bedding & Backfill</u>: C222 specifies that in rocky terrain trenches with hard objects that could cause damage to the coating, a 6-inch layer of soil with a maximum particle size of ¾-inch should be placed prior to pipe laying. In instances where rocks or other hard objects are in the backfill material, “screened backfill with a maximum particle size of ¾-inch shall be placed around the coated pipe to a minimum depth of 6-inch above the polyurethane coating before the remainder of the trench is backfilled. On the PRCEP, Controlled Low-Strength Material (CLSM) was specified on the bottom half of the pipe in the haunch area (Murdock, 2011). Pipe zone material above the CLSM to 1-ft above the top of the pipe was specified as well-graded, 1-inch minus, granular material compacted to 90 percent. Trench backfill from the pipe zone material to a minimum of 4-ft above the top of the pipe was specified as a 6-inch minus earthfill, compacted to 90 percent. At roadway crossings, the entire pipe zone material was CLSM, followed by a granular material compacted to 96 percent. None of these scenarios presented any threat of damaging the polyurethane coated pipe.

Contractor's Perspective: The PRCEP was the first time that the Contractor had installed polyurethane lined and coated steel pipe of such large diameter and long length. From an equipment standpoint, the light-weight of the pipe, compared to concrete pipe or even cement-mortar lined steel pipe of the same diameter, was an advantage. The pipe sections were also easier to handle. Savings were realized through the use of equipment that was more suited to handle lighter weight pipes. The coating was very durable, considering the imperfect conditions of a job-site, and performed very well. The 40-ft length of each pipe section was another advantage as it reduced the number of joints that had to be welded together. During the design phase, the engineer recognized that the 40-ft long sections of pipe would make it difficult to negotiate the numerous curves along the canal's alignment without the use of mitered sections and fittings. To maximize the use of 40-ft sections, the engineer allowed for the centerline of the pipe to be adjusted up to 4-ft on both sides (Murdock 2011). The ability to holiday test all internal joints following joint completion was another advantage that provided the Contractor peace-of-mind. For external joint completion, the Contractor built a special platform that made heat-shrink sleeve application both easier as well as safer, figures 5a and b. Overall, the use of polyurethane lined and coated steel pipe was a sound decision that contributed to the completion of the project one year ahead of schedule.

CONCLUSION

The end of pipe-laying operations on the Provo Reservoir Canal Enclosure Project pipeline in April 2012, and the testing and subsequent operation that began in May 2012, marked the completion of a landmark project one year ahead of schedule. Use of polyurethane lined and coated spirally welded steel pipe offered various advantages that contributed to the early completion of the project, with no significant incidents to hinder its rapid progress. The lighter weight and longer lengths of the pipe joints translated into costs savings for the Contractor. The design engineer was able to specify a D/t ratio of 288 despite the pipe's large diameter primarily because of the flexible nature of the polyurethane material and its high resistance to damage. Utilizing the AWWA C222 standard as the basis for the coating system will ensure that the necessary corrosion protection for the long-term performance of the pipeline is met. Whenever changes to the C222 standard's physical/mechanical parameters are made in a project specification, there should be sound engineering reasoning behind those changes as it can sometimes result in substantially higher costs to the Owner. On this project, the Owner felt that a higher cost was justifiable based on the desired life expectancy of the pipeline. The 150 psi working pressure steel pipeline, with a 225 psi transient pressure capability, will enable the Owner to change operating conditions, if needed in the future, from the current low average operating pressure of 42 psi.

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