Joint Completion Method for Welded Steel Pipe: The Success of Weld-After-Backfill on the Southern Delivery System

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ABSTRACT

The Southern Delivery System (SDS) is a regional project in Colorado currently under construction that will bring water from the Arkansas River to the City of Colorado Springs, the City of Fountain, Security Water District, and Pueblo West Metropolitan District. Colorado Springs needs SDS to help protect the community against drought, to provide water for the growing population, and to provide redundancy in Colorado Springs' water delivery system, which originates in the Colorado Rocky Mountains. A core component of SDS consists of approximately 45 miles of predominately 66-inch diameter raw water conveyance pipeline. Welded steel pipe conforming to American Water Works Association (AWWA) Standards has been specified for the pipeline.

Weld-after-backfill (WAB) is a construction sequence for steel pipe in which the bell and spigot lap joint is internally welded after the heat shrink sleeve has been applied over the external coating hold back area and the pipeline backfilled. WAB is generally desirable for larger diameter steel pipes, such as the SDS raw water conveyance pipeline, because internal welding can be undertaken independent of pipe laying, joint assembly and backfilling. Consequently, increased pipe installation rates are possible with a corresponding reduction in installation costs and public impacts when compared to non in-situ joint welding.

As with any Program the magnitude of SDS, cost-effective design is critical. To this end, the SDS Program has specified WAB for the 66-inch diameter raw water conveyance pipeline where single lap welded joints are required. To date, over 100,000 lineal feet (lf) of SDS pipe, comprising over 2,000 joints have been successfully installed using WAB. This paper will provide background on the application of WAB for SDS, projected cost savings and emerging technologies associated with WAB for pipe of variable wall thicknesses, joint welding techniques and backfill systems required for the Program.

INTRODUCTION

SDS is a regional project in Colorado that will bring water from the Arkansas River to residents and businesses in the City of Colorado Springs, the City of Fountain, Security Water District and Pueblo West Metropolitan District. Colorado Springs needs SDS to help protect the community against drought, to provide water for the growing population and to provide redundancy in Colorado Springs' water delivery system, which originates in the Colorado Rocky Mountains. Core components of SDS include:

- A reservoir connection at the existing North Outlet works of Pueblo Dam
- Approximately 45 miles of 66-inch diameter raw water pipeline
- Three pump stations with total of 26,750 horse power
- A 50 million-gallon-per-day water treatment plant and finished water pump station
- More than 4 miles of large diameter finished water distribution pipeline

In July 2009, the Colorado Springs Utilities Board (Board) authorized construction of SDS, setting an in-service date of 2016. The authorization was preceded by a six-year permitting process culminating in receipt of a Record of Decision from the U.S. Bureau of Reclamation, as well as authorization from neighboring Pueblo County under the State of Colorado 1041 permit process. The completion date of 2016 was chosen to enable the Board to allow for an orderly and systematic series of rate increases necessary to finance the project. Because determination of probable construction costs were critical, the owner and program manager[1] requested the design engineer[2] to undertake systematic value engineering of the water conveyance pipeline. This was essential, as the SDS completion schedule was contingent on early construction of several pipeline segments. Among the value engineering proposals accepted was the use of WAB. This paper will provide background on the application of WAB for SDS, projected cost savings and emerging technologies associated with WAB for pipe of variable wall thicknesses, joint welding techniques and backfill systems required for the Program.

EXPLANATION OF WAB PROCESS

WAB is a construction technique for steel water conveyance pipelines in which the bell and spigot lap joint is internally welded after the exterior joint coating is applied and the pipe trench backfilled. WAB offers several potential advantages for large-diameter pipeline construction. In open-country installations, joint welding is a slower process than excavating a trench and setting pipe; completion of backfill can be delayed while exterior joint welding is ongoing. WAB allows completion of interior pipe welding independent of pipe joint assembly and backfilling operations, which makes it possible for faster pipe installation rates. Welding and follow-up inspection on the inside of a large-diameter pipe is also cited as safer and more practical than welding on the pipe joint exterior, where work is performed in a shored trench and often under adverse weather conditions. From a design standpoint, an advantage of WAB is the minimization of pipe thermal stresses across the welded joint. Because the adjoining pipes are near thermal equilibrium to the surrounding soil at the time of welding, stresses which may be

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induced at the joint due to differing pipe body temperatures or temperature of the fluid conveyed through the pipe are greatly reduced (Luka, 2008).

INVESTIGATION OF WAB FOR SDS

During preliminary engineering, much of the 45-mile, 66-inch diameter raw water conveyance pipeline was designed as bell and spigot joints with full fillet lap welds on both the interior and exterior (per owner preference). The double lap weld was designed to allow for an air test of each completed joint. However, there were sufficient examples throughout the county for single lap welded joint pipelines of similar diameter and design pressure. While the redundancy and ability to air test was a clear advantage of a double lap weld joint, the axial strength of a single lap weld joint is considered sufficient to meet typical thrust conditions (Luka, 2008). Ultimately, a value engineering proposal was accepted to allow single lap weld joints for operating pressures of generally 300 psi and lower. In select areas where future accessibility to the pipeline was considered to be difficult such as deep cover areas and stream crossings, double lap welded joints were specified at the discretion of the design engineer with input from the owner. While the allowance of single lap joints would reduce welding costs, it would also make WAB a practical consideration for the Program.

Benefits to Program: To complete an exterior fillet weld, several hours to nearly a day may be needed depending on the pipe diameter and wall thickness. The contractor can backfill over the barrel of the pipe where granular material is required and use a smaller trench shield to maintain access for joint welding and coating. Once complete, the shoring must be relocated to a joint location further down the construction heading; the remaining hole must also be filled and compacted. Satisfactory compaction at the joint area can be more difficult to achieve than the mainline pipe, where better means of mechanical compaction are available. Where controlled low strength material (CLSM) is used for backfill in place of granular material, several hundred feet of assembled pipe must remain exposed in open trench, as the CLSM must be placed in lifts to prevent pipe flotation. In either case, the pipeline construction heading can be significantly spread out where joint welding and coating limits backfill completion. In absence of WAB, the contractor will incur slower installation rates with correspondingly higher labor costs and greater equipment overhead.

In addition to potential cost savings with WAB, portions of the easement for SDS were in close proximity to residential areas. Typical of most pipelines, construction of the 66-inch diameter pipeline entailed impacts on the public due to noise, dust and traffic disruption. Many restrictions on construction activities were made part of the SDS permit conditions, and the high profile nature of the project made mitigation of public impacts especially critical. In this respect, WAB was viewed as beneficial to minimize public impacts through achieving efficient pipe installation rates.

Industry Practice: WAB has a relatively long history in the steel water pipe industry. Dating back to the 1980s, WAB has been used on cement mortar coated steel pipe where the joint hold-backs were grouted. In 1992, a steel pipeline project in Texas, consisting of polyethylene tape coating per AWWA C214 (2007), utilized WAB with hand-applied polyethylene tape wrapped joints per AWWA C209 (2006). Today, WAB is most typically associated with heat shrink joint wrap sleeves consisting of cross-linked polyolefin or polyethylene furnished in accordance with AWWA C216 (2008). Pipeline projects utilizing WAB with heat shrink sleeves have been documented back to 1998. In 2005, 45 major pipeline projects in the United States were documented using some form of WAB including grouting, hand-applied polyethylene tape or heat shrink sleeves applied at the joint (Buchanan, 2005). AWWA C216 currently considers WAB as an acceptable construction practice insofar as requirements of the standard, and any other applicable standard, are met. WAB is also allowed per AWWA C604 (2011) covering installation of steel pipe. Nevertheless, there is no set prescribed method for WAB, and the end user, under AWWA Standard, has the option whether to use it.

An understandable concern with WAB is the stress the shrink sleeve is subjected to from the heat of welding. Common mitigation methods of a WAB procedure may include controlling the weld heat input levels, welding speed as well as limiting the size and number of weld passes. The design of the heat shrink sleeve itself is also a consideration. Holiday testing of an applied sleeve is required by AWWA C216, regardless of WAB. However, after the sleeve is buried and interior joint welding takes place, no holiday testing can be undertaken to verify the integrity of the sleeve application. Thus, for WAB to be successfully implemented, a high degree of confidence in the heat shrink sleeve and installation method is required.

A heat shrink sleeve consists of a pressure-sensitive adhesive laminated to a polyethylene backing that is heat-activated by propane torch for application. The adhesive assures the sleeve bonds to the steel substrate of the joint holdback, as well as the overlap of the machine-applied coating of the pipe barrel, which for SDS is AWWA C222 (2008) polyurethane minimum 30 mil thickness. The polyethylene backing provides mechanical protection and dielectric strength ensuring an effective corrosion barrier for the exposed steel substrate of the joint area being coated. By the nature of WAB, significant heat is transmitted through the pipe bell wall from internal welding; however, the backfill material acts as a sink to absorb heat around the shrink sleeve. Whereas a typical heat shrink sleeve can be applied to pipe at around 160° F, welding can generate pipe wall temperatures well into a range of 600 – 800° F based on manufacturer testing. Temperatures will peak under the sleeve in a relatively narrow width, or heat affected zone, following the circumference of the spigot engagement as welding proceeds. The heat from welding may re-activate and melt the sleeve adhesive in the heat affected zone but the pressure and the heat absorption properties of the backfill material greatly confine the affects. To the extent that polyethylene backing retains its thickness, physical properties and is not otherwise breached, the steel substrate remains hermetically sealed and the corrosion protection integrity of the heat shrink sleeve is maintained.

Two heat shrink sleeve products are commercially available for WAB and offer different approaches to accommodating weld heat stress. One manufacturer recommends a two-layer, or double sleeve, system consisting of a 6-inch wide polyethylene inner sleeve applied over the heat affected zone of the bell[1]. This inner sleeve is then covered by the manufacturer's standard AWWA C216 sleeve and provides additional mechanical and thermal protection to the outer sleeve that remains the primary corrosion barrier. A

[1] Referenced sleeve manufacturer is Canusa-CPS, The Woodlands, Texas

different manufacturer offers a single layer system using a specially formulated sleeve for WAB. This sleeve includes a thicker polyethylene backing and a mastic formulation with a higher melt temperature[1].

References and Evolving Technologies: During SDS's evaluation of both manufacturers' products, project references were reviewed. Collectively, 101 pipeline projects have been installed using WAB, representing 41 end users over a 10-year period. Propriety manufacturer test data was available, as were reports of several plant tests where WAB was performed on sample pipe in soil boxes to simulate backfill conditions.

Of particular interest in Program's evaluation of WAB were recent advances in heat shrink sleeve products. Heat shrink sleeves, whether or not used for WAB, are typically installed with filler mastic applied at the edge of the bell and encapsulated under the sleeve. The mastic fills the small void that may result as the sleeve bridges across the joint wall transition. The mastic also reduces stress at the bell edge where the sleeve shrinks inward at the step down. In WAB, the heat from welding migrates through the gap between the bell and spigot and can melt the filler. Melting filler can run back into the steel surface being welded or run vertically along the bell edge, allowing voids or gasses to collect under the sleeve. As an improvement to the WAB process, both manufacturers recently introduced filler mastics with much higher melt temperatures. Also, the single sleeve manufacturer had also recently introduced a reformulated backing material and adhesive with greater heat stress capabilities. Taken together, such improvements were a significant consideration.

WAB was ultimately accepted as a value engineering proposal for SDS. Before commencing work, the specifications required contractors to demonstrate the performance of the sleeve under WAB project conditions while maintaining an acceptable level of quality.

COST SAVINGS TO SDS USING WAB

An initial portion of the SDS raw water conveyance pipeline bid December 2010 designated as Segment S4B/N1A. Located in southeastern El Paso County, it consists of 20,474 lf of 66-inch diameter cement mortar lined and polyurethane coated steel pipe with wall thicknesses ranging from 0.280 to 0.490 inches. For S4B/N1A, the specifications required WAB as the base bid. However, the contractors also were required to bid an alternate whereby all joints would be double lap welded before backfill (WBB) with the basis of award remaining WAB. Five prequalified contractors submitted bids.

Table 1 includes the total bid amounts by contractor for both WAB and WBB methods with 424 single lap weld joints assumed based on pipe manufacturer[2] joint counts provided at bid time. WAB was less expensive, saving $558 to $1,635 per joint (depending on the contractor) or $988 per joint on average. On the basis of best value, the order of contractors was the same for both WAB and WBB methods. Averaged across all bids, WAB saved $419,000 or 3.6 percent of the WBB option. The contractors

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[1] Referenced sleeve manufacturer is Berry Plastics Corporation, Franklin, Massachusetts
[2] Northwest Pipe Company, Denver, Colorado

assumed a generic WAB process with no distinction between the single and double sleeve WAB products.

Table 1. SDS S4B/N1A Bid Tabulation, December 2010

Contractor	WAB Bid	WBB Bid	WAB Savings	Savings per Joint*
HCP Constructors	$10,224,342	$10,917,686	$693,344	$1,635
Garney Construction	$10,759,868	$11,269,000	$509,132	$1,201
Reynolds, Inc. (now Layne Heavy Civil, Inc.)	$11,501,670	$11,788,306	$286,636	$676
K.R. Swerdfeger Construction, Inc.	$12,156,481	$12,393,117	$236,636	$558
Barnard Construction Company, Inc.	$13,651,945	$14,021,425	$369,480	$871
Average	**$11,658,861**	**$12,077,907**	**$419,046**	**$988**
*424 single lap joints assumed; 50-ft. standard pipe lengths				

Subsequent bid packages did not require contractors to price both WAB and WBB options. Five other segments, N1B, S2, S3, S4AW/S4AE, and N1C/N2A, totaling 191,000 lf of 66-inch diameter pipe have since bid (as of December 2012) with WAB specified for single lap weld joint areas of the plan and profile. Approximately 2,000 joints have been completed using WAB. If the average per joint savings of $988 identified from S4B/N1A is assumed, SDS has saved about $2 million using WAB with single lap welded joints.

The savings associated with WAB verses the allowance of single lap welded joints also can be approximated. Joint field welding costs will vary by pipe wall thickness. However, based on inquiries to contractors who installed various segments of the SDS 66-inch raw water pipeline, $300 per joint average is a reasonable cost assumption for providing single fillet welds. Extended over the same 2,000 joints, weld cost savings in the magnitude of $600,000 can be attributed to the allowance of single lap weld joints. The balance of the savings, or about $1.4 million, arguably can be attributed to WAB.

SDS WAB DEMONSTRATION PROGRAM

The contractor demonstration was required to duplicate as close as possible actual site conditions using test pipe of the same wall thickness and lap joint configuration to be used on the pipeline. The demonstration had to account for a number of variables including multiple pipe wall thicknesses, different welders and weld methods as well as the use of native and CLSM backfill materials. In addition to meeting AWWA C216 requirements, specified WAB acceptance criteria stated the heat shrink sleeves could not have any visual burns or excessive wrinkling, the sleeves had to pass holiday testing, and the sleeves had to maintain adhesion to the steel substrate. The owner also reserved the option to excavate and examine any joints completed using WAB in the contractor's actual pipeline installation.

Control groups were not used to isolate variables nor were the demonstrations intended to serve as research. The demonstrations nevertheless produced a significant amount of data, particularly adhesion peel values. However, given the range of variables under which adhesion peels were undertaken, particularly temperature and length of time the sleeves had to cure, caution should be exercised if making comparisons[1]. Most importantly, peel values far exceeded the AWWA C216 the laboratory minimum requirement of 15 pounds/lineal inch (PLI), often by substantial margin. Visual observation and holiday testing were also acceptable. A small number of joint excavations were also preformed with no issues revealed. All three demonstrations were deemed successful with the design engineer issuing technical memoranda summarizing the results and observations. Demonstration results are summarized in **Table 2**.

Table 2. Summary of Peel Test Results

Segment	Site Demonstration	Field Test of Actual WAB Joint
S4B/N1A (July 2011)	Range 27 – 50 PLI, 44 PLI average	1 excavation @ 50 PLI; 6 additional excavations visual only, accepted
S2 (November 2011)	Range 25 – 50 PLI, 48 PLI average	6 excavations, 48 PLI, average
S3 (December 2011 and January 2012)	Range 25 – 50 PLI, 46 PLI average	None performed

WAB demonstrations were performed onsite for segments S4B/N1A, S2 and S3 by three separate contractors between July 2011 and January 2012[2]. The owner waived demonstration requirements for segments S4AWE and N1C/N2A, which both bid in 2012, accepting the contractors' previously qualified WAB method and welders used on preceding segments. For the first construction segment demonstration, S4B/N1A, both single and double sleeve products were tested[3]. For subsequent demonstrations on S2 and S3, only the single sleeve product was tested. The performance of both single and double layer sleeves were deemed comparable under the S4B/N1A demonstration; however, contractors overall viewed the single sleeve as less labor intensive to install and elected its use for all segments of pipeline requiring single lap welded joints.

Demonstrations for each construction segment were conducted using 66-inch diameter polyurethane coated pipe spools 5 to 7 feet long of representative wall thickness. The spools were assembled with bell and spigot lap joints held together with tack welds. Heat shrink sleeves were applied per the manufacturer's recommendation with representatives onsite. After holiday testing, the spools were placed in a simulated trench and backfilled to different configurations depending on the requirements of the construction segment. Both native material backfill and CLSM were tested covering over the crown of the pipe or with CLSM to spring line and native material placed from spring line to approximately 2 feet over the pipe.

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[1]Peel values from the S4B/N1A/N1B demonstration are provided in Appendix A.

[2]S4B/N1A Segment constructed by HCP Constructors, Pueblo West, CO, demonstration July 2011; S2 Segment constructed by Garney Construction, Kansas City, MO, demonstration November 2011; S3 Segment constructed by Layne Heavy Civil, Inc., Denver, CO, demonstrations December 2011 and January 2012.

[3]Referenced single sleeve product manufactured by Berry Plastics consisting of 24-inch Covalence WaterWrap – WAB (Black) and Polyken 939 mastic filler for bell/spigot transition. Referenced double sleeve product manufactured by CANUSA consisting of 24-inch AQW-HS (Blue) outer sleeve, 6-inch AQW-WAB inner sleeve and SG-79 mastic filler for the bell/spigot transition.

Interior welding was conducted under qualified weld procedures, as proposed by the contractor. Each certified welder was required to demonstrate the ability to perform under project WAB conditions and was tested by welding approximately one quadrant of a joint. Both wire (FCAW) and stick (SMAW) weld methods were used, with multiple passes not exceeding one eight inch per pass. Heat inputs were monitored as welding progressed, and surface temperatures were checked by an infrared heat gun in order to maintain temperatures below 800° F per sleeve manufacturer recommendation. Based on S4B/N1A, where both wire and stick methods were used in the same demonstration, no difference in sleeve performance was noted. Pipe spools were typically left in situ for 12 – 24 hours before starting interior welding and completely removed from the trench 12 – 24 hours after welding was complete, followed by visual observation, holiday testing and adhesion peel testing.

Visual Observations: Sleeves appeared tightly adhered to the steel pipe with no voids or other defects evident. Some small creasing was apparent in the vicinity of the weld heat affected zone as shown in **Figure 1**. Thinner wall pipe also tended to be more affected. The backing directly over the weld zone usually exhibited a slight depression or crease approximately one-eighth inch wide. According to the manufacturer, such creasing is caused by heat from welding, whereby the mastic liquefies and partially flows away from the weld zone, termed carbonization, reducing the mastic thickness. However, according to the manufacturer, the integrity of the backing itself is not affected during the welding process and the weld area remains hermetically sealed by the sleeve.

Creasing was generally reduced where heat shrink sleeves were in contact with CLSM. Where CLSM was used to springline and native material covered the upper portion of the pipe, a clear difference was evident with creasing more pronounced in the top portion of the test pipe spool. Where CLSM was used completely over the top of the pipe, creasing was minimal around the entire circumference of the sleeve. However, the result with CLSM may be largely cosmetic, as peel testing revealed no difference between sleeves in contact with CLSM compared to native material.

Holiday Testing: Prior to pipe burial, holiday testing of the applied shrink sleeve was performed per AWWA C216 to assure no holidays. After welding, the pipe was allowed to cool and removed from the trench. Since the shrink sleeve thickness is a minimum 90 mils, the final holiday testing was performed at 12,000 Volts per the specification requirements that referenced NACE RP-0274 (2011) as shown in **Figure 2**. No holidays were detected on any WAB heat shrink sleeves tested.

Adhesion Testing: AWWA C216 requires a heat shrink sleeve meet an average adhesion, or peel, value of 15 PLI minimum as tested per ASTM D1000 (2010). D1000 is considered a laboratory test, and field-conducted peel tests are rarely, if ever, required for heat shrink sleeves in actual installation. Nevertheless, peel testing was extensively incorporated into the contractor demonstrations for SDS and provided a greater degree of confidence in the WAB process.

Figure 1 – Heat shrink sleeve after removal from trench

Figure 2 – Holiday testing of sleeve after removal from trench

Adhesion peel testing was conducted by cutting completely to the base steel a 1-inch wide strip of the heat shrink sleeve approximately 18 inches long. The heat shrink sleeve strip was then peeled off the pipe surface near a 180 ° angle using a scale to measure the adhesive strength at approximately 1-inch increments. The target pull speed was approximately 10 readings per minute with 10-12 adhesion values usually obtained per pull. The digital test gage maximum limit was 50 PLI. The high and low readings were typically discarded, and the remaining 8-10 readings averaged to provide a single reported value per pull.

Adhesion values reported as an average of individual readings is consistent with AWWA C216 and ASTM D1000 methodology; any single individual value from a peel test should be considered in context, as many variables can affect results obtained in the field. Even and consistent pull rates are important in conducting peel tests and can be difficult to achieve for pipe that is not optimally positioned for test personnel. Also, too high or too low of pipe surface temperature can affect the accuracy of the adhesion peel pull values. In ASTM D1000, the recommended room conditioned temperature is 64°F to 82°F. Testing onsite under this optimum ASTM ambient temperature range is not always feasible. Direct sunlight may also cause significant sleeve temperature fluctuation. In the S4B/NIA demonstration performed in July, adhesion peel values were near 50 PLI maximum values when the pipe surface temperatures were in the 60 - 70°F range. The values were much lower (23 - 41 PLI) when pipe temperatures were elevated in the range of 71 - 85°F.

Also observed on S4B/N1A, peel values were consistently higher the more time elapsed between sleeve application and testing. Sleeves that were not tested until three days later and stored in direct sunlight had better values than sleeves tested within 12 hours. On the S3 segment, to beat an approaching winter storm, peel testing was attempted within 4 hours of weld completion with unsatisfactory results. When peel testing resumed a few days later, all results were satisfactory.

For SDS, peel tests were performed both in the longitudinal (horizontal) and vertical (circumferential over the weld) direction for each welder being qualified with a horizontal test shown in **Figure 3**. Vertical pulls measure peel values over the heat affected zone almost entirely and tended to be lower. Longitudinal pulls essentially measure the sleeve adhesion to several surfaces including the shop applied polyurethane coating, the filler mastic at the step down, the holding primer on the steel substrate and the heat affected zone. Individual values obtained during a pull were often higher over the holding primer on the steel substrate than over the polyurethane coating. Also, adhesion values over the step down area with the filler mastic tended to be lower. Either the sleeve does not adhere to the mastic filler at this lap joint as compared to the holdback primer, or the sleeve is not making firm contact with the filler at this location. Moreover, these issues would probably be observed if a non WAB sleeve was tested.

Peel testing also allowed for the mode of failure, or separation mechanism, to be evaluated, although AWWA C216 and the project specification did not include this as acceptance criteria. Nevertheless, observation of the separation mechanism provided additional confidence of WAB suitability. The three basic modes of separation are cohesive, where some of the mastic is left on the pipe and some on the pipe backing; delamination, where there is nearly complete separation of the mastic from the backing; and adhesive, where no mastic is left on pipe.

Cohesive separation is most desirable, as it identifies good surface preparation, a quality sleeve product and testing done under correct conditions and temperatures. Delamination is usually related to temperature effects or rate of pull and not indicative of the true mastic condition. Adhesion separation may be indicative of poor surface preparation or cleanliness, inadequate heat used for application or carbonization of the mastic due to weld heat. Any given peel test may include multiple modes of separation with changing installation variables, as shown in **Figure 4**. It is also entirely possible to get a cohesive separation (more desirable) at a lower peel value than an adhesive separation (less desirable) at a higher peel value.

Figure 3 – Horizontal peel test

Figure 4 – Sleeve after completed test

Over the three WAB demonstrations, mode of separation was mostly all cohesive at high PLI values, a desirable combination. Some adhesive separation directly over the weld heat affected zone was observed, but also somewhat expected. Excavations of actual heat shrink sleeves installed in the field had similar test results as those of the demonstration.

During some peel tests, a sudden loss of pull resistance, or a skip, was observed at the heat affected zone or step down area filled with mastic. At a few locations, the backing elongated and broke during the peel. Due to the nature of manual field testing, maintaining constant tension within a controlled range of temperatures was difficult given the variability of conditions encountered. A sudden acceleration likely resulted as the peel crossed differing levels of adhesion, exacerbating the difference in measured adhesion values.

WAB AND INITIAL CATHODIC PROTECTION SYSTEM TESTING

While a high level of confidence in WAB was developed through the SDS demonstration program, ancillary evaluation of coating and heat shrink sleeve performance under WAB also can be made with pipe-to-soil potential measurements available through the pipeline cathodic protection (CP) system. The CP system for the 66-inch raw water conveyance pipeline consists of two 48 lb, high potential magnesium galvanic anodes directly connected by exothermic weld to each 50 foot section of pipe. Mainline test stations are located at approximately 2,000 foot intervals.

Under NACE SP0169 – 2007, a minimum pipe-to-soil potential of -0.850 Volts DC is required to meet the CP system acceptance criteria. Initial measurements for various SDS pipeline segments ranged from approximately -1.100 to -1.650 Volts DC. It is anticipated that these measurements may become more negative with time as some anodes were installed less than one month at time of testing. Holidays, or defects, in the pipeline coating system, including the heat shrink sleeves, would characteristically increase the current requirements, therefore reducing potentials. Based on initial CP test reports, all indications are the pipeline coating system is performing extremely well and WAB did not impact the effectiveness of the heat shrink sleeves.

CONCLUSION

SDS is critical to providing Colorado Springs and neighboring communities a reliable and ample supply of water. SDS represents a major infrastructure investment, and design must be cost effective. The 45-mile, 66-inch diameter raw water conveyance pipeline presented the opportunity for value engineering by allowing single lap weld joints for some portions, which in turn allowed the consideration of WAB as an additional value engineering opportunity.

WAB, using heat shrink sleeves, has a well established history in the water industry, with newer innovative product formulations recently becoming available. In addition to significant potential cost savings, the use of WAB could greatly mitigate construction impacts of SDS on the public by speeding pipeline installation. The merits of WAB were ultimately accepted and comparative bid information indicates substantial savings were realized by SDS.

Three contractor demonstrations confirmed the technical merit of WAB for SDS. All sleeve tests exceeded the requirements of AWWA C216 and met project specifications. Consistent performance of WAB was demonstrated using different sleeve products, welders and weld methods, and backfill materials.

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Appendix A. S4B/N1A Demonstration Peel Values (PLI), July 8 and 11, 2011

Test	Peel Direction		Backfill		Test Temp (°F)		Weld Method		Sleeve		Wall Thickness (in)			Sleeve Cure	
	Vert.[1]	**Horiz.[2]**	**Native**	**CLSM**	**<68**	**>68**	**FCAW**	**SMAW**	**Covalence**	**CANUSA**	**0.295**	**0.365**	**0.500**	**4 hr[3]**	**3 day[4]**
1	23.8		26.2	26		23.8	23.8		23.8			23.8		23.8	
2		37.5				37.5		37.5		37.5		37.5		37.5	
3	35.1		37	36.5		35.1		35.1		35.1		35.1		35.1	
4		31.5				31.5	31.5		31.5			31.5		31.5	
5	45.5		44.5	46.5	45.5		45.5			45.5	45.5			45.5	
6		37.4			37.4		37.4			37.4	37.4			37.4	
7		36.8			36.8			36.8	36.8		36.8			36.8	
8	33		31.7	33.6	33			33	33		33			33	
9		50			50		50			50			50		50
10	50		50	50	50		50			50			50		50
11		50			50			50	50				50		50
12	50		50	50	50			50	50				50		50
13		45.7			45.7		45.7		45.7				45.7		45.7
14	50		50	50	50		50		50				50		50
15		50			50			50		50			50		50
16	50		50	50	50			50		50			50		50
17		50			50		50			50		50			50
18	50		50	50	50		50			50		50			50
19		35				35		35	35			35			35
20	40.9		40.9	40.9		40.9		40.9	40.9			40.9			40.9
21		50			50			50		50	50				50
22	50		50	50	50			50		50	50				50
23	50		50	50	50		50		50		50				50
24		50			50		50		50		50				50
AVG[5].	**44.02**	**43.67**	**44.19**	**44.46**	**47.13**	**34.00**	**44.48**	**43.21**	**41.40**	**46.29**	**44.08**	**38.00**	**49.45**	**35.07**	**48.24**

[1]The vertical adhesion test was approximately 1/2 in native and 1/2 in CLSM.

[2]The horizontal adhesion test was near the border between native material and CLSM.

[3]Pipe demonstration spool piece was removed from ground and adhesion tests were performed within 4 hours in ambient temperatures.

[4]Pipe demonstration spool piece was removed from ground and placed above grade for 3 days in ambient temperatures before performing adhesion tests.

[5]AWWA C216 requires 15 PLI as tested in laboratory condition; field verification is not required