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# Use of Dielectric Coated Spiral Weld Steel Pipe in Horizontal Directional Drilling

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**ABSTRACT**:

This paper details how new construction and rehabilitation needs of public works infrastructure can be fulfilled using spiral welded steel pipe with dielectric coatings. Specifically, economical and structurally sound spiral welded steel pipe solutions are available for the developing and expanding Horizontal Directional Drilling (HDD) industry. Much of our nation's water and wastewater underground infrastructure is badly in need of repair. Many areas across the country are in need of water for an ever-growing population or industrial use. Balancing the need for new water transmission lines and repair/replacement programs with social, environmental and economic issues bring new challenges that must be addressed. Over the past several years HDD has steadily grown from its small diameter roots in the oil and gas industry to a routine public works construction practice. As the industry has grown in knowledge, experience and success the diameter and length of HDD projects has grown. The need for a material capable of diameters to 48 in. plus and or installations of thousands of feet in length can only practically be served by steel pipe. Spiral weld steel pipe best serves the needs of the public works HDD market. The paper will focus on the manufacture, design and installation of spiral weld steel pipe in water transmission HDD applications. Two case histories will be presented to review the practical side of large diameter HDD installations utilizing dielectric coated and lined spiral weld steel pipe.

## INTRODUCTION

Steel pipe has one of the longest histories of any water transmission product used in the public works market today. Many major US cities have steel pipelines dating back to the early 1900's in service. The strength and ductility of steel pipe is demonstrated by many years of use in high-pressure oil and gas pipelines around the world. In the public works segment, AWWA C-200 steel pipe is used today for carrying potable and wastewater in both above ground and underground applications. Linings and coatings per AWWA standards are utilized for corrosion protection. In structural applications, steel pipe is utilized for HDD, casing, pipe piles, aerial crossing and power plant cooling lines. All these applications call on the unique capabilities of steel to resist bending, internal and external pressure, and provide high tensile strength capabilities for HDD installation.

Modern spiral weld steel pipe is truly an "engineered" product. The manufacturing process offers a great deal of flexibility regarding diameter, thickness and lengths. Spiral weld pipe is made from various grades of steel coil in thickness of 0.135 in. to 1.0 in. depending on the project requirements. Pulling the coiled steel into the pipe machine and spirally wrapping the steel against buttress rolls forms the pipe. The edges are then welded in and out by the double-submerged arc process as shown in Figure 1.

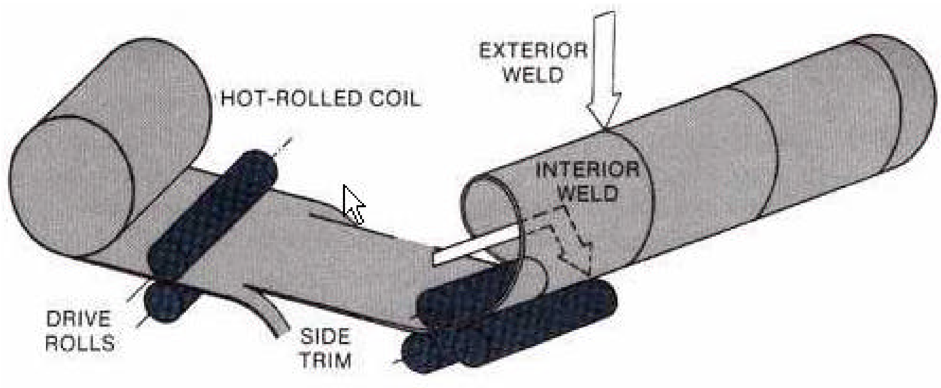


Figure 1. Manufacturing Process of Spiral Weld Pipe

The spiral weld provides a flawless weld with 100% seam efficiency. The helix angle or the swing of the machine determines the diameter. This process gives great flexibility in what outside diameters can be produced. The standard in the public works market is to provide inside diameter pipe after lining. Hence a 36 in. nominal diameter pipe with .500 in. wall thickness and polyurethane lining and coating would have an outside diameter of 37 in. To assure the quality of the pipe AWWA C-200 requires the pipe to be hydrostatically tested to a pressure equal to 75% of the yield or external strength of the steel. In the heavier wall thickness pipes generally used in the HDD applications, this can often require test pressures in the 700 to 900 psi range. In extreme applications the spiral weld can also be 100% ultrasonically tested per API 1104 standards. Full design values for pulling loads of $F_t$ = 90% of steel minimum yield strength are available due to the 100% efficient weld seams and the helical orientation of the spiral weld itself. Rolled and welded pipes have circumferential weld seams that must carry the entire pulling force and can limit pulling capacities. AWWA C-200 spiral weld steel pipe can be produced from the grades of steel detailed in Table 1 to the diameter you specify. The availability of sizes and wall thickness provides flexibility to the designer and the HDD contractor.

Table 1. Sample AWWA C-200 Steel Grades and Allowable Tensile Stresses

| **ASTM – A 139** | **Minimum Yield psi** | **Allowable Tensile ($F_t$ ) psi** |
|---|---|---|
| **GRADE B** | 35,000 | 31,500 |
| **GRADE C** | 42,000 | 37,800 |
| **GRADE D** | 46,000 | 41,400 |
| **GRADE E** | 52,000 | 46,800 |

Pipe ends prepared for field welding provides a smooth exterior with uniform outside diameter. Flanges, mechanical couplings or welded joints can be shop prepared for connections to the transmission lines once the HDD pipeline has been installed.

Modern spiral weld steel pipe is available in wall thickness of 0.135 in. to 1.0 in. and in lengths up to 60 ft. with transportation being the normal restriction. Diameters up to 144 in. are available with the most common large diameter HDD applications being in the 24 in. to 48 in. range. It is important to differentiate piling or casing grade spiral weld steel pipe (often made per ASTM A-252 standards) from AWWA C-200 steel pipe. The C-200 pipe is made to the most exacting requirements that include steel coil certifications, hydrotesting and different pipe welding requirements. HDD and water transmission projects should specify a spiral weld steel pipe per AWWA C-200 in lieu of structural grades such as ASTM A-252. The “old fashioned” way of producing steel pipe for HDD is the rolled and welded “can” style. In this process plates of steel are rolled into cans between 6 ft. and 12 ft. long and welded both circumferentially and longitudinally. Unlike spiral weld pipe, flat spots or high-lows can form where the longitudinal seams are formed from the rolling and welding process. Generally the excess labor costs and slow production rates make rolled and welded pipe noncompetitive in the HDD market.

## STRUCTURAL DESIGN CONSIDERATIONS

Design of a HDD spiral weld steel pipe installation differs from the design of a buried water transmission line because of the high tension loads, bending stresses and the external fluid pressures acting on the pipeline during the installation. In normal transmission lines a designer is concerned primarily with internal pressures and external loads from live and dead loads as spelled out in the AWWA M-11 Design Guidelines. Transmission lines typically specify a "Pressure Class" that incorporates the performance or design criteria. HDD pipe installation load requirements are normally far in excess of those required for the specified Pressure Class.

During a HDD installation, spiral weld steel pipe is subjected to high tensile loads, bending and external pressure as it is pulled back through a pre-reamed bore. Tension results from frictional drag between the pipe and the wall of the bore, fluidic drag as the pipe is pulled through the drilling fluid and the (submerged) weight of the pipe as it is pulled through elevation changes within the bore. Bending stress is induced as the pipe is forced to negotiate the curvature of the bore. External pressures from the pumped drilling fluid and drill cuttings surrounding the pipe induce hoop stresses unless the pipe is filled with a fluid of equal or greater density (Jeffrey S. Puckett P.E., J.D. Hair & Associates).

The design process for determining spiral weld steel pipe's wall thickness is a complex one involving numerous variables. While this paper will give some guidelines as to the wall thickness design, it is recommended that those inexperienced in the design and installation of HDD projects reference the American Gas Association manual "Installation of Pipelines by Horizontal Directional Drilling: an Engineering Design Guide" or similar. The services of a HDD consultant or a geotechnical engineer versed in the design of HDD projects is beneficial.

During an HDD installation the bore is generally reamed 12 in. larger than the pipe. Depending on its size and weight, spiral weld pipe will either float or sink in the drilling fluid that occupies the excess space. In either case, the pipe is "dragged" through the drilling fluid and cuttings as detailed in Figure 2. For diameters 36 in. and larger, the pipe is normally filled with water to reduce buoyancy and resulting pulling loads. Tensile stress should be generally be limited to 90% of the yield strength of the steel as detailed in Table 1.

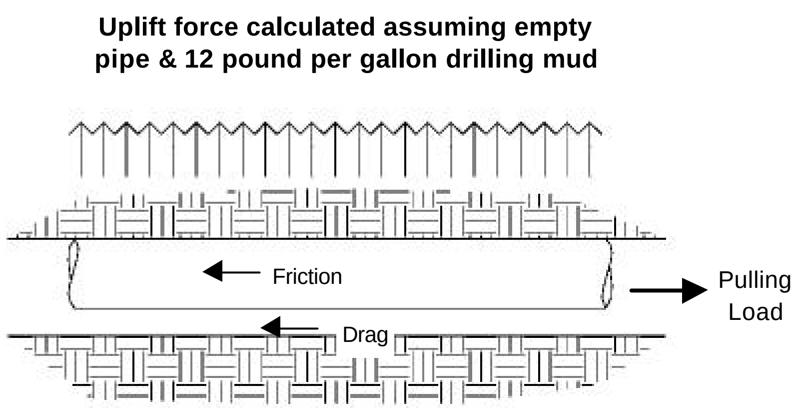


Figure 2. Demonstration of friction and drag forces during pullback

The HDD installation will also have elastic bending generally creating the highest bending stresses near the entrance (closest to the rig) and exit pits. Elastic bends can actually occur almost anywhere as the pipe follows the reamed bore. Figure 3 demonstrates how in these areas of curvature the pipe bears against the bore creating bearing stresses from bending (John D. Hair P.E., J.D. Hair & Associates). External hoop stresses result from the hydrostatic pressure exerted by the drilling mud surrounding the pipe. The worst external hoop stresses occur at the deepest point in the line and when the pipe is empty. By filling the pipe with water the external head pressures are equalized and hoop external stresses minimized.

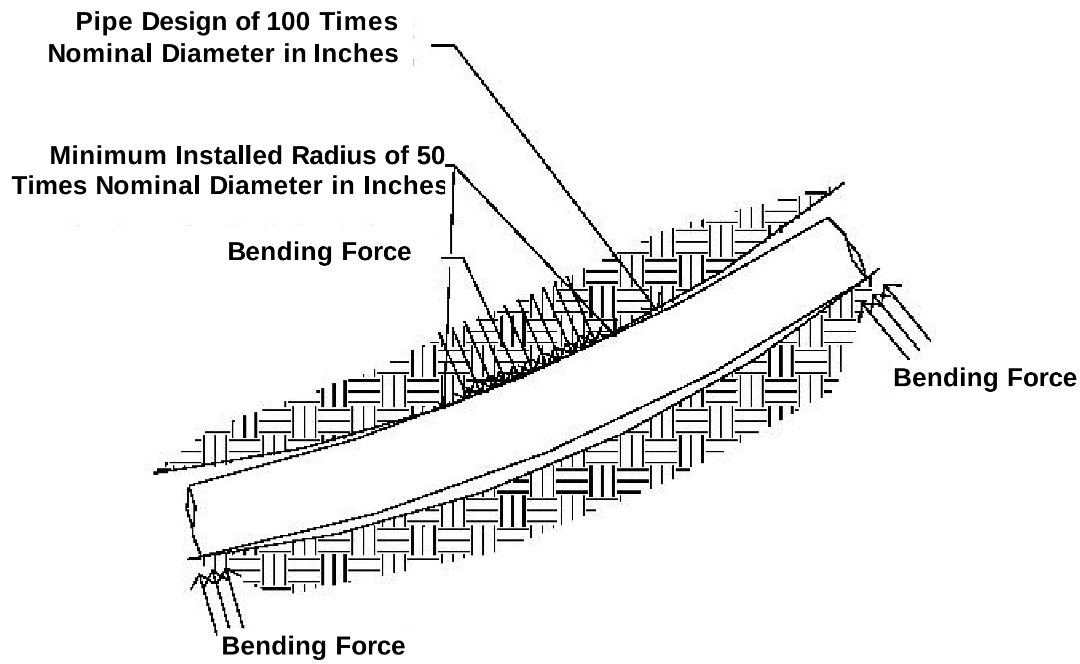


Figure 3. Demonstration of bending stresses during pullback

HDD segments are generally designed using a radius of curvature in feet of 100 times the nominal diameter of the pipe in inches. During installation the actual radius can get as low as 50 times the nominal diameter in inches over short segments due to irregularities in the reamed bore. Diameters to wall thickness (D/t) ratios are generally kept below 80. For example, a 36 in. spiral weld pipe with a 0.45 in. wall thickness would have a D/t = 80. Pulling load design should utilize a rate of 90% of the steel's yield strength as found in Table 1.

Recommended analysis examines the areas of highest tension (closest to the rig), tight radius bending (sags or side bends) and highest hydrostatic head (deepest point). The analysis is dependent on a large number of variables including contractor practices. The American Gas Association Design Manual should be referenced for a more complete discussion of this issue.

Recommended rules of thumb for HDD wall thickness design:

- Utilize a D/t of 80 or less.
- Design with a radius of bend of 100 times the diameter in inches.
- Limit allowable tensile stresses to 90% of the steel yield point ($F_t$).
- Check stresses in the area of highest tensile stresses, tightest radius and highest head (if pipe is unfilled) for worst case.

**CORROSION CONSIDERATIONS**

Owners of public works projects such as watermains or sewer forcemains expect long service lives from their pipelines. For an HDD or water transmission pipe to fill this need, corrosion protection needs to be addressed. Bentonite drilling fluid is normally used For HDD pipe. This low ph material, when combined with air, moisture and insitu soils, may create a corrosion cell. A high quality barrier coating should be applied to any ferrous based pipeline by a certified applicator. The coating in the HDD drill process must be able to resist abrasion during installation conditions that can range from soft soils to hard rock. It must be flexible enough to bend without cracking or disbonding. The coating should also have good dielectric capabilities that are capable of resisting stray currents and compatible with cathodic protection systems when designed.

Polyurethane coatings and linings per AWWA C-222 fill the needs described. The 100% solids material is an excellent chemical and dielectric coating that is greatly extending the diameter range of HDD pipe. In the past fusion-bonded epoxy was the standard but is limited by diameter, complexity of field joint coating and coating thickness. In contrast, polyurethane is applied in liquid form after a SPC-10 blast by a certified applicator to a thickness of 40 mils (much thicker than fusion-bond epoxy) to resist abrasion during the pulling operations. Joint coating is accomplished by re-blasting after field welding and applying per AWWA C-222 requirements. Because of polyurethane’s quick setting times and cold weather capability, polyurethane joint coating can be quicker than fusion-bond epoxy.

Polyurethane materials are manufactured by firms such as Madison Chemical or Futura. The peformance advantages that made polyurethane a standard in the water transmission market also qualify it as an leading candidate for HDD applications:

- outstanding adhesion values: tightly bonded material won’t scrape or be torn off like polywrap materials,
- excellent chemical, impact and abrasion resistance,
- flexibility: able to flex while the pipe is bending at the tightest radius,
- resistance to cathodic disbonding or undercutting: ability to be protected by cathodic protection and resist stray currents.

Cathodic protection should be considered for most HDD applications involving ferrous materials such as ductile iron or steel pipe. Cathodic protection is an electrical method of preventing corrosion attack on a ferrous based pipe. There are two basic methods of applying cathodic protection. The first uses galvanic anodes, which naturally offer a different potential than the ferrous structure. The other method uses anodes which are energized by an external DC power source. Both are effective supplements to the tightly bonded polyurethane coating. The purpose of the cathodic protection in this instance is to protect the areas of the coating damaged during the installation process. Case histories show that the efficiency of the polyurethane coating is very high even after installation. It is recommended that corrosion consultants be contacted when considering cathodic protection.

Linings for water or wastewater transmission HDD pipe should be epoxy per AWWA C-210 or polyurethane per AWWA C-222. For potable water, there are numerous NSF approved formulations. Wastewater projects can rely on numerous formulations that resist $H_2S$ gas, abrasion and even the formation of Microbiologically Induced Corrosion (MIC). Dielectric coatings and linings preclude the necessity for a casing pipe.

**<u>Case History 1</u>: Lake Texana to Corpus Christi HDD Water Pipeline**

Two HDD crossings were critical links for a 1998 installation to deliver raw water from Lake Texana to a water treatment plant owned by the City of Corpus Christi, Texas. The $125 million project consisted of 104 miles of 64 in. pipeline and three pump stations that were all to be completed within two years. The urgently needed 100 mgd pipeline was designed to aleviate projected summer shortages of water in the Corpus Christi area.

The 100+ mile pipeline was nearly complete and had to be connected at two critical locations. The first was a crossing of the Guadalupe River and adjacent Cypress Swamp. Due to enviornmental restrictions the 2,360 ft. 48 in. pipeline could not be open cut. The second location included a 1,800 ft. 48 in. crossing of the Victoria Barge Canal. The canal also could not be open cut since it was a commercial shipping route.

HDR Engineering Inc. of Austin, Texas, was the design engineer and specified the use of HDD utilizing polyurethane lined and coated spiral weld steel pipe to make the critical crossings. Design called for a 225 psi working pressure and a 75 psi surge allowance. Entrance and exit angles of 8 and 6 degrees respectively were specified. HDR also specified a minimum installed radius of 3,600 ft. (75 times the inside diameter (ID) in inches). Russell Corrosion Engineers of Columbia, Maryland, provided the cathodic protection design. The HDD crossing was publicly bid and Michels Pipeline of Brownsville, Wisconsin, was the lowest qualified bidder at $3,887,720. Michels purchased the 49.5 in. outside diameter (OD) .750 in. thickness (D/t = 66) polyurethane coated spiral weld pipe from Thompson Pipe and Steel of Denver, Colorado (now Northwest Pipe Company).

Thompson began the process by preparing engineered lay out drawings and submittals for the owner and HDR. Once the drawings were approved, a delivery schedule for the pipe materials was agreed upon. The project called for a very tight construction window and large liquidated damages if not completed in time. The agreed upon schedule allowed Michels only a 45 day window to receive, stage, weld and pressure test the pipe prior to installation. The pipe was manufactured per AWWA standards (955 psi hydrotest) in 50 ft. lengths. Thompson, like all Northwest Pipe plants, is a certified applicator of Madison Chemical polyurethane materials. HDR chose Madison Chemical’s CorroPipe II TX-15 for the exterior coating at 40 mils and the CorroPipe II PW (NSF approved) for the interior coating at 20 mil thickness.

Severe rains caused flooding in the construction site area and delayed the delivery of the pipe material. By the time Michels could receive pipe there was less than 30 days remaining to complete the project. After 20 days of expert planning regarding staging, welding, and coating, the pipe was ready to install. Michels then arrived on the site with an Armada of equipment. The centerpiece was a Hercules 1200 drill rig that had a pulling capacity of approximately 1.2 million pounds. The fact that flooding was a constant threat further emphasized the need for work to be completed quickly.

Once started, the Victoria Barge Canal site took just six days to ream and install the 1,800 ft. crossing. The pull back itself took just six hours to complete. The 2,360 ft. Guadalupe River crossing was complete in eight days which included eight hours for the pull back. Of special note is the fact that the actual pull was just 325,000 pounds or 27% of the rigs capacity. The Guadalupe River crossing was the largest HDD crossing in the world at the time. Russell Corrosion reported that the installed polyurethane coating performed at a high efficiancy after cathodic protection system tests indicated very little damage to the coating during installation. The event was noteworthy enough for the City of Corpus Christi to issue a press release expressing their pleasure with the HDD project and the newly established HDD record. After five years of service, Rich Shoemaker, Project Manager with HDR in Austin, indicated the project was well done and that all parties are pleased with the performance of the polyurethane coated spiral welded steel pipe. This job demonstrates large diameter and/or lengthy sprial weld steel pipe can be used with confidence on HDD projects.

Figure 4.Entrance of 48 in. pipe at Guadalupe River Crossing.

Figure 5. Field joint coating with polyurethane

**<u>Case History 2</u>: Anacortes, Washington Waterline Replacement at Swinomish Channel**

The City of Anacortes installed 14,000 ft. of 36 in. steel water transmission main for the subject water main replacement project. To complete the 2002 project, the pipe had to cross the Swinomish Channel. The area around the channel presented environmental problems such that open cutting the channel or the surrounding wetlands was not feasible. Design engineer Montgomery Watson Harza of Bellevue, Washington specified a 1,300 ft. HDD crossing utilizing 36 in. OD .625 in. thickness C-222 polyurethane coated spiral weld steel pipe per AWWA C-200. RCI Construction of Sumner, WA won the bid and subcontracted the HDD work to Henkles & McCoy Construction. The pipe was supplied by Northwest Pipe Company's Portland, Oregon facility. Northwest chose the Madison Chemical CorroPipe TX-15 CM on the exterior and NSF-approved CorroPipe II PW to line the pipe. The material was delivered, welded and the drilling completed within a week. The actual pull back process took approximately 12 hours, all without a hitch. Per Bob Stager of RCI Construction, "The spiral weld pipe was of excellent quality with no high-low fit up problems or egg shaped ends that is normally associated with rolled and welded pipe." As Ron Wika, Project Manager of RCI, stated, "Job went real sweet." Project Engineer Brandt Barnes of Montgomery Watson Harza offered a testament to the abrasive resistance of the polyurethane coating, "The contractor used the welded dished head for hydrotesting the pipe prior to installation as the pulling head for the pull back. The pulling head was polyurethane coated and emerged with no damage to the coating after the pull."

The project used a design radius of 3,550 ft. (roughly 100 times the OD in inches), a 10 degree entrance and exit angle and a pipe thickness based on a D/t of 57. The installed radius was actually 2,800 ft. (roughly 79 times the OD in inches).


Figure 6. Preparing for pullback of prewelded 36 in. pipe

Figure 7. Entrance of 36 in. pipe at Swinomish Channel

**<u>Case History 3:</u> Hart Street Forcemain, Honolulu, Hawaii**

In 2001, the City of Honolulu installed two harbor HDD crossings with 46 in. diameter steel pipes, each 3,100 ft. in length. The 46 in. pipe acted as a casing pipe in this application and was lined with HDPE pipe after the 46 in. casing was installed. The API-5L steel casing pipe was not coated and or lined and was .875 in. in thickness (D/t = 55). Pull back loads were reported to be less then 1,800 KN. This case history demonstrates that steel pipe has successfully been used in 46 in. diameters for lengths in excess of 3,100 ft.

## CONCLUSIONS AND OBSERVATIONS

Dielectric coated spiral weld steel pipe combined with the advances and success of HDD projects, have and will continue to grow the use of HDD as a standard construction practice in the water transmission market. Case histories have demonstrated that HDD projects of up to 48 in. nominal diameter and lengths over 3,100 ft. are feasible. AWWA C-200 spiral weld steel pipe provides consistent strength, flexibility, and bottle tight joints necessary for HDD installations. As a result, spiral weld steel pipe will continue to fill the needs of the designer, owner and installer alike.

As demonstrated, the advantages of dielectric coated spiral weld steel pipe include:

- An engineered pipe system that is custom designed and produced to AWWA standards.
- Pipe manufactured to the diamater, wall thickness and steel grade required, not to a generic "one size fits all" approach of standard sizes, wall thickness and lengths.
- The 100% efficient weld seams provide full strength of the pipe wall and the flexibility needed during installation.
- A coating system that tightly bonds to the steel pipe surfaces, providing excellent protection.
- 100% welded connections that assure the leak-free installations critical in enviornmentally sensitive areas.
- Pipe wall that has no obstructions or bells which would require larger reamed bore or develop higher tensile stresses.
- No need for a carrier pipe. The AWWA C-222 polyurathane to AWWA C-210 linings can protect against corrosion from sewage to potable water scenarios.
- A coating that is abrasion resistant and able to flex while the pipe bends during installation.
- A pipe that is electrically continuous, allowing for the addition of cathodic protection at any time.
- Substantial pull back strength in the pipe wall and spiral weld, which provide high factors of safety.
- Lengths up to 60 ft., which reduce field welding needs.
- Coating application performed at a certified coating facility per stringent requirements.
- Product that is generally less expensive then rolled and welded or straight seam steel pipe.
- Pipe that can be easily modified to include fittings, special connections, or special lengths.

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