The City of Lafayette, Louisiana Another Positive First Experience with HDD Installation Using Ductile Iron Pipe

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Abstract
In early 2015, Lafayette Utilities System (LUS) in Lafayette, Louisiana, completed plans and was finalizing the specification for a sewer force main, which would include approximately 9,000 linear feet of ductile iron pipe with no alternate materials specified. However, three areas were exceptions. These areas would be installed using horizontal directional drilling (HDD) and two pipe materials were evaluated: HDPE and flexible restrained joint ductile iron pipe.

This paper will discuss the decision to use ductile iron pipe for the HDD portion of the project, as this was not an installation methodology the utility was familiar with. The major emphasis of the paper, however, will be on the successful HDD installation of three separate sections of flexible restrained joint ductile iron pipe. There will also be a discussion of the experiences each of these sections of 1,140 feet, 940 feet, and 740 feet delivered.

Introduction
The engineering firm of Domingue, Szabo & Associates, Inc. (Engineer) was retained by LUS to design upgrades and improvements necessary at the South Sewage Treatment Plant (SSTP) to comply with the Clean Water Act. These improvements include treatment modifications, equalization of sewage flows, flow rerouting for better handling of peak/wet weather flows, and sludge management. The Engineer worked with LUS in analyzing the existing system, determining the requirements for meeting the mandated compliance, and determining the most cost effective and efficient means of meeting these needs.

With the increasing growth in south Lafayette, it became apparent in the 2000s that there was a need to upgrade the SSTP and redirect flows from one of the City's other WWTPs back to SSTP. The existing 16-inch cast iron force main from the Old Maurice Lift Station to the SSTP was too small to accommodate the needed flow rate, necessitating a larger force main. The first step in the design process required the Engineer to perform the necessary hydraulic analysis, which determined the line would need to be 24 inches in diameter.

With the size determined, alignment options were prepared and submitted to the Owner for review and approval. This alignment would require approximately 9,400 feet of pipe with three areas that presented some construction challenges. Although the Engineer looked at other pipe materials for the open cut portion, the Engineer knew the line being replaced was grey cast iron pipe, and it had served the Owner well throughout its lifetime, approximately 65 years. The Engineer also knew the Owner's experience with both ductile cast iron pipe and the older grey cast iron pipe in the City's system was extremely positive, and that the utility had a preference for ductile iron pipe, selecting it for the portions of the line that would be installed using conventional open-cut construction.

Familiar with the Ductile Iron Pipe Research Association (DIPRA) and its reputation as a very credible industry association, the Engineer contacted DIPRA to verify some design calculations that were completed and to discuss the three areas they suspected would need to use trenchless technology. It was during this conversation that the Engineer discovered ductile iron pipe could be installed using horizontal directional drilling (HDD). Through other sources he determined that AMERICAN Ductile Iron Pipe (ADIP) had been promoting its Flex-Ring® flexible restrained joint ductile iron pipe for HDD installation since 1996. (Conner, 1998) The Engineer felt this information was worthy of additional research. ADIP provided several technical papers that addressed the joint functionality and listed the benefits over visco-elastic materials, like HDPE and FPVC, which are often used in HDD. Impressed with the list of benefits shown in Table 1, the Engineer felt the ability to install the pipe using the "cartridge" method would provide an option that wasn't available with plastic pipes, HDPE, FPVC, and steel pipes. In addition, these pipe types would require assembly using fusion or welding in a continuous assembled-line. This assembly configuration requires proper planning and logistics to avoid excessive obstruction of driveways and access to businesses along the alignment.

Table 1 - Benefit of Ductile Iron Pipe (Dorwart-Carpenter, 2010)

- Pipe wall impermeable to volatile hydrocarbons, minimizing the potential of water system contamination in the present and future.
- Standard pressure capabilities up to 350 psi (2.4 MPa), or greater upon special request.
- Quick, easy joint assembly.
- Can be located from surface with commonly used locators.
- Performance capabilities of the pipe are not impacted by elevated temperatures.
- Material strength suitable for handling pull-back, and external dead and live loadings without buckling.
- High hardness material that is not as easily abraded, gouged or punctured by rocky surrounds.
- Material strength that does not creep or decrease with time.
- No significant residual bending stresses after installation, which could adversely affect future serviceability.
- No significant recoil and minimal pipe movement after installation due to minimal thermal expansion and Poisson pressure-testing effects.
- Lack of movement and the inherent strength of ductile iron eliminate potential for shearing of tapped lateral outlets or breakage of pipe after pulls (due to thermal expansion and contraction, Poisson and Bourdon effects, etc).

Convinced that ductile iron pipe installed using HDD was a viable option, the Engineer completed the plans and specifications using 24-inch ductile iron pipe for the open-cut portions of the force main and 24-inch flexible restrained joint ductile iron pipe for the HDD portion. As an alternate to the ductile iron flexible restrained joint, the Engineer chose to provide an option for 30-inch HDPE, which has an effective inside diameter that is much closer to the larger inside diameter of 24-inch ductile iron pipe. See Table 2 for comparison of actual inside diameters of various pipe types.

Nominal Size - in.	DIP [1]	STEEL [3]	PVC [4]	HDPE [5]
6	6.28	6.00	6.09	5.57
8	8.43	8.00	7.98	7.31
10	10.46	10.00	9.79	8.96
12	12.52	12.00	11.65	10.66
14	14.55	14.00	13.50	12.35
16	16.61	16.00	15.35	14.05
18	18.69	18.00	17.20	15.74
20	20.75	20.00	19.06	17.44
24	24.95	24.00	22.76	20.83
30	31.07	30.00	28.77	25.83
36	37.29	36.00	34.43	32.29
42	43.43	42.00	40.73	38.41
48	49.63	48.00	46.49	44.47
54	56.29	54.00	—	51.34
60	60.28	60.00	—	—
64	64.30	—	—	—

Table 2 – Inside Diameter Comparison

Although not familiar with installation of ductile iron pipe of this size using HDD, the low bidding contractor chose ductile iron pipe in part because of significant differences in cost, over $70,000 on this project. The Owner was not only able to realize the benefits of using ductile iron pipe for the force main, but also its significant cost savings. The successful contractor was Wharton-Smith (General Contractor) of Baton Rouge, Louisiana, using Spartan Directional of Lafayette, Louisiana (Driller).

Joint Functionality

The installation of ductile iron pipe using HDD is possible because of the flexible restrained joint. To realize the advantages, it is necessary to understand the mechanics and the unique functionality of the flexible restrained joint. The joint components and the process are as follows. First, both the Fastite sealing gasket and the yellow Flex-Ring segments with rubber backing may be pre-installed into their respective positions in the bell socket. See Figure 1. Next, after the application of lubricant to the Fastite gasket and liberal application to the spigot, the ADIP flexible restrained joint is ready for assembly.

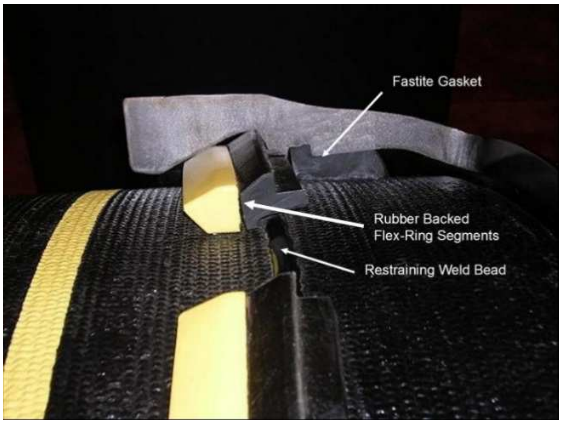

Figure 1 – Flex-Ring Flexible Restraint

The quick and easy assembly of the Flex-Ring joint starts with the pipe sections in reasonably straight alignment. The operator then places the spigot end into the bell and using the load line, or other means, generates an axial assembly force. As the spigot moves into the bell socket, the restraining weld bead that is factory-welded on the spigot end pushes on the front tapered surface and drives the Flex-Ring segments up and backward on the as-cast incline surface. The movement of the segments (up and back) within the bell socket compresses the resilient rubber-backing, which rebounds to its tight fitting position on the restraining side of the weld bead with an audible "snap."

When the 24 inch pipe sections deflect to a maximum allowable 3-degrees during installation and pipe pull-back through the bore path, the rubber backing attached to each segment either compresses, expands, or remains static, depending on its position around the joint circumference in relation to the defection of the joint. Mechanically, this change in the geometric configuration between the inclined surfaces of the Flex-Ring segments and the as-cast inclined surface of the bell socket is very important, as this is the mechanism that effectively redistributes the pulling load to eliminate flexural tension or flexural compressive stresses in the pipe. Bending of continuously fused or welded pipe results in flexural tension within the pipe wall, which adds to the tension induced in the pipe wall from being pulled through the bore path. Flexural stresses, tension, or compression with flexible restrained joint ductile iron pipe is virtually eliminated by the redistribution of thrust loads in the bell. Thus, pulling the flexible restrained joint ductile iron pipe through the bore path can be compared to pulling a chain with a link (bell) every 20 feet.

Installation – Background and Pull No. 1

As noted previously, the project was designed with an alignment totaling 9,000 feet. This included three sections using HDD installation totaling 2,820 feet. The three HDD sections were 740 feet, 1,140 feet, and 940 feet, in order of execution.

The initial installation was a challenging 740-feet pull that took place at “The Horse Farm.” Established as a working horse farm in 1903, the site is approximately 100 acres of rolling hills, open meadows, and forested ravines spotted with large oak trees. Since the mid-1990s, no livestock has grazed at the site that today is the last remaining, significantly sized piece of undeveloped public property located within central Lafayette. The challenging part of the alignment was the crossing under Coulee Mine, an urban creek that meanders through the site with its flow confined to a concrete-lined trapezoidal open channel with a depth of approximately 70 feet by 10 feet by 18 feet at the crossing location.

Figure 2 – Start of 740-Feet Pull

This first pull was made using the assembled-line method as illustrated in Figure 2. The General Contractor started the pipe assembly with the first joint laid spigot end toward the HDD rig at the stake, where the drill rod was proposed to emerge. By pulling the spigot first into the bore path, drilling slurry can easily flow over the smooth contour of the bell joint. The authors highly recommend that before a commitment to purchase is made, owners, contractors, and their engineers should look closely at the contour of each manufacturer’s joint and specify or purchase only the smoothest and least obtrusive joint available, particularly in a rock bore path. There have been several incidences where the pipe string have locked up in the bore path as a result of a contractor pulling back a coupling type joint or a bell that has an abrupt change in the bell contour causing it to lock onto a rock fragment or other obstruction in the bore path.

Laying the pipe on a long gentle curve, the General Contractor completed the preassembly of all 740 feet of flexible restrained joint pipe well ahead of the final swabbing of the bore path on April 1, 2015. Figure 2 clearly shows that with the drill rod, cutting head, and barrel reamer attached, the alignment and the points of connection to the pipe string remained approximately 8- to 10-feet apart. The combination of these two alignment anomalies were issues that on-site ADIP personnel quickly pointed out to the General Contractor.

With the experienced field representatives observing, the realignment of the pipe string for connection to the drill string was accomplished using multiple excavators working in concert to avoid over deflecting the joint. Then during pipe pull-back, the pipe string, having been preassembled in a curved alignment, had a tendency to move and deflect naturally into a straight line. Therefore, it was necessary to stage several excavators strategically along the pipe string to redirect it to avoid damaging several old oak trees. In executing this realignment for both areas, the operators were instructed to limit the deflection for the 24-inch Flex-Ring joint to The maximum allowable deflection of 3 degrees or 12 inches per 20-feet standard length. This was accomplished without incident.

Spartan Directional used an American Auger DD-140 to drill the pilot bore, ream the bore path inside diameter to 42 inches, and pull-back the ductile iron pipe force main. This inside diameter is based on the industry's best practices and HDD guidelines provided by ADIP personnel and defines the dimensional requirement for the bore path inside diameter to be equal to the ductile iron pipe maximum bell dimension plus 12 inches.

24-inch Flex-Ring Joint Bell outside diameter:	29.88 inches
Plus 12-inches for 24-inch and larger ductile iron pipe:	12.00 inches
Required Bore Path inside diameter:	41.88 inches (round to 42 inches)

This pilot bore for the first pull started on March 26, 2015, and the bore path, reamed to 42 inches, was ready for pipe pull-back on April 2, 2015. Prior to starting the pull-back, ADIP requested that the Driller provide: (1) the pull force required to move the carriage up the ladder of the drill rig without drill rods; (2) the pull force required to move the drill rods with reamer, no pipe; and (3) the force required to move the pipe for every rod length. This data would help justify the use of the model best described by the following formula. (Dorwart, 2010)

Equation 1

$$F_{RIG} = F_P + F_R + F_C$$

Where:

F_{RIG} = Pull Force applied by the drill rig (pounds)
F_P = Drag Force from the Product Pipe (pounds)
F_R = Drag Force from the Drill String (pounds)
F_C = Drag Force from the Drill Rig Carriage (pounds)

The total force seen by the drill rig is apportioned to the drag of the new product pipe, the drag of the drill string with reamer, and the drag from the drill rig carriage. By maintaining this, a more accurate assessment of the load on the pipe can be determined.

Spartan Directional determined that the combined drag force for $F_R + F_C$ was approximately 10,000 pounds. That meant the force registered by the machine during pipe pull-back on April 2, less the 10,000 pounds, would be the actual load on the pipe. This first pull-back saw a maximum load at the drill rig of 70,000 pounds, which meant the pipe only saw 60,000 pounds, well short of the allowable pull load of 210,000 pounds for 24-inch Flex-Ring joint pipe.

Industry best practices suggest there are a number of variables that impact the force required to deliver a successful HDD installation. Listed below are these variables that contributed to the success of this first pull:

- Soils were primarily sandy-clay, which supported a very well prepared bore path.
- Radius of the bore path was not less than 1,225 feet (51 feet per inch of diameter).
- Drilling fluid, mix control and strategic delivery, and pressure and volume controls were monitored.
- Buoyancy of pipe was approximately +104 pounds, which indicated the pipe would float to the top of the bore path without counter-buoyance measures taken.
- Experience of the drilling contractor; Spartan was well prepared.
- Pull loads did not exceed 70,000 pounds.
- Installation of the 740 feet occurred on April 2, 2015, by the assembled line method and took approximately four hours.

Installation – Pull No. 2

Figure 3 – Cartridge Assembly

The second pull was a 1,140-feet HDD bore that was flagged by ADIP because of the length and alignment, which were designed with a compound curve where the tightest radius was 1,950 feet (81 feet per inch of diameter). Unlike Pull No. 1, this pull had a limited laydown area for assembling the pipe; therefore, the General Contractor used the cartridge assembly method**.** See Figure 3. In the cartridge method, pipe is assembled one joint at a time, then pulled into or toward the opening of the bore path 20 feet or the length of the standard joint. This process is repeated until the line is completely installed. Spartan Directional began pushing the 30-foot drill rod through the sandy-clay soil on April 3, 2015, and completed the pilot bore in a day and a half. As in Pull No. 1, Spartan first reamed the bore path with a 24-inch reamer, starting on April 5 and finishing on April 7. Maintenance issues shut down the installation for a few days while Spartan prepared the 42-inch reamer.

Having completed the 42-inch reamer and final swabbing of the bore path, Spartan was ready for the pipe pull-back on April 15, 2015. The pull-back continued and the pipe string was negotiating the area of the compound curve, which was on the last 1/3 of the pull distance. At this time, rig pressures began to increase. Spartan continued to pull until the rig was maxed out at 140,000 pounds. Spartan, consulting with the General Contractor and ADIP representatives, was open to suggestions on how to get the pipe moving again, since maximum pulling force on the DD-140 at 140,000 pounds was reached. ADIP personnel suggested adding water, which to this point in Pull

No. 2 had not been introduced into the pipe. By adding the water, the weight would overcome the positive buoyancy of the pipe, which should drop the lead pipe section off the soffit of the bore path. ADIP explained that with the combination of the positive 104-pound buoyancy of the pipe and the impact of the drill rod attempting to straighten out the pull alignment, it was likely the pulling head was plowing through the soffit of the bore path. This phenomena was demonstrated during a record 36-inch pull installing 1,740 feet in Pasco County, Florida. The HDD drilling sub-contractor maintained water flow into the pipe through a 3-inch HDPE pipe, but periodically the subcontractor would have to stop the rapid assembly-line installation and allow the water to catch-up with the lead pipe sections. By remaining diligent with monitoring the rate of installation, the pulling loads, and the water level in the pipe, pulling loads were controlled to reasonable levels.

Spartan and the General Contractor added water to the pipe until it met the estimated volume to get the lead section off the soffit of the bore path. To the surprise of many, especially after being stopped for nearly 90 minutes, the pipe began to move once again at a substantially reduced force of just 60,000 pounds. Including the time that was devoted to solving the plowing and buoyancy challenge, the General Contractor and Spartan completed the pull in 12 hours.

The following is a list of variables that contributed to the success of this second pull:

- Soils were primarily sandy-clay, which supported a well prepared bore path.
- Radius of the bore path was not less than 1,950 feet (81-feet per inch of diameter).
- Drilling fluid, mix control and strategic delivery, and pressure and volume controls were monitored.
- Buoyancy of pipe was approximately +104 pounds, which indicated the pipe would float to the top of the bore path and counter-buoyance measures were taken after pulling load reached 140,000 pounds.
- Experience of the drilling contractor; Spartan was well prepared.
- Pull loads increased to 140,000 pounds prior to adding water weight to inside of pipe, then they did not exceed 60,000 pounds.
- Installation of the 1,140 feet occurred on April 15, 2015, by the cartridge assembly method and took approximately 12 hours.

Installation – Pull No. 3

The third and final pull by Spartan Directional, with the General Contractor responsible for pipe assembly, was nothing short of textbook execution. Drilling of the pilot bore for Pull No. 3 began on April 23, 2015. This installation used the assembled-line installation method, but Spartan chose to use pipe rollers rather than subjecting the HDD rig to the frictional drag of pulling the pipe over the ground surface. The first two pulls were reamed, first with a 24-inch reamer and then with the final 42-inch reamer, which opened up the bore path to the desired inside diameter. With Pull No. 3 having to negotiate another compound curve beneath a 20-feet deep earthen channel, a highway crossing next to a bridge, and a concrete boat ramp, Spartan made a decision to make an intermediate reaming pass using a 36-inch reamer. This would reduce any possibility of a frac-out or humping of the road and the boat ramp.

Pipe pull-back began on May 5, 2015, and the 940-feet pull of Flex-Ring joint pipe was completed in just four hours with a pull-back force that never exceeded 40,000 pounds.

The following is a list of variables that contributed to the success of this third and final pull:

- Soils were primarily sandy-clay, which supported a well prepared bore path.
- Compound curve was negotiated.
- Drilling fluid, mix control and strategic delivery, and pressure and volume controls were monitored closely. As a result, no issue with the highway or boat ramp occurred.
- Pipe rollers and buoyancy control significantly controlled the frictional resistance and lowering the pull-back loads to 40,000 pounds.
- Experience of the drilling contractor; Spartan was well prepared.

Conclusion

The Engineer required a hydrostatic test of the entire completed line at 150 psi for two hours. In addition, both the General Contractor, Wharton-Smith, and the Driller, Spartan Directional, chose to test each pull independent of the open-cut portion of the 9,400-linear-feet force main. Each of the three pulls tested with zero leakage at 150 psi. This successful test is evidence of the quality of the Flex-Ring joint, the HDD experience and expertise offered by AMERICAN Ductile Iron Pipe personnel as well as the efforts of Wharton-Smith and Spartan Directional.

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