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Trenchless Installations on the Lake Oswego-Tigard Partnership Project: Use of Steel Water Pipe and Steel Casing Pipe for HDD and Microtunneling

Joel Komarek, Project Director, City of Lake Oswego, Lake Oswego, OR
Shah Rahman, Director–Trenchless Technology & Pipeline Rehabilitation, Northwest Pipe Company, Saginaw, TX
Kim Staheli, Staheli Trenchless Consultants, Bothell, WA
Bill Austell, Construction Manager, Frank Coluccio Construction Company, Seattle, WA
Joel Staheli, Staheli Trenchless Consultants, Bothell, WA
Greg Smith, Western Regional Engineer, Northwest Pipe Company, San Diego, CA

1. ABSTRACT

The Lake Oswego-Tigard Partnership Project is an agreement between the City of Lake Oswego and the City of Tigard, in the State of Oregon, to upgrade their existing drinking water infrastructure to meet the current and future needs of residents. Water from the Clackamas River has been the main source of raw water for the City of Lake Oswego for almost fifty years, with an existing raw water line that transmits water from the Clackamas River by crossing underneath the Willamette River to a water treatment plant. The expansion of this line to convey water to a new treatment plant, then distributing the treated water to customers is a key feature of this project, and includes more than 10 miles of primarily AWWA C200 steel water pipe. Traditional cut and cover methods of pipe installation across major water bodies, highways and environmentally sensitive streams were not allowed by federal and state agencies, and therefore, various trenchless methods of pipe installation had to be utilized. A Horizontal Directional Drill (HDD) undercrossing of the Willamette River was successfully undertaken using 3,800-ft of 36-inch diameter polyurethane lined and coated steel water pipe. In another location, microtunneling was specified to install 600-ft of 60-inch diameter Permalok® steel casing pipe under two major roadways and two private properties, through which a 48-inch diameter steel carrier pipe would be installed. This paper provides a discussion of the selection of the appropriate trenchless construction methods and pipe materials from the Owner, Engineer and Contractor's perspectives. A discussion on the specification and fabrication of the steel water pipe and the Permalok steel casing pipe for these trenchless installations from a manufacturer's perspective is provided. Installation challenges of the HDD crossing from a Contractor's standpoint are also discussed.

2. INTRODUCTION

In August 2008, the cities of Lake Oswego and Tigard (Program Sponsors) formally endorsed an intergovernmental agreement for sharing drinking water resources and costs. While the City of Lake Oswego undertook the management and construction of the infrastructure improvements, the financing of the project was shared by both entities, with an oversight committee consisting of representatives from both cities. The Lake Oswego-Tigard Partnership represents an important step forward for cooperative and regional, as opposed to purely local, water supply planning. This regional approach will help ensure that the more than 90,000 residents of both cities will continue to have a safe, affordable, and sustainable supply of drinking water.

Project Needs
Lake Oswego currently withdraws water from the Clackamas River in Gladstone as it has been for almost 50 years. The existing facilities are too small to meet the current and anticipated future water supply needs of Lake Oswego in addition to being seismically vulnerable, and challenging to operate and maintain due to outdated, obsolete equipment. Tigard needs certainty of supply and the ability to control future water supply costs. The Partnership with Lake Oswego offers the best opportunity to achieve those objectives relative to Tigard's other supply options.

Project Components
The partnership project, estimated to cost $254 million, will replace and expand six existing facilities located in the cities of Gladstone, West Linn, Lake Oswego, and Tigard, Oregon. These new, state-of-the-art seismically resilient facilities include:

1) A new 38 million gallon per day (MGD) river intake pump station located on the Clackamas River in the City of Gladstone
2) Over 10 miles of new large diameter, mostly steel pipe, raw and finished water transmission mains ranging in diameters of 24-inch to 48-inch
3) A new 38 MGD water treatment plant located in City of West Linn
4) A new 3.5 million gallon (MG) reinforced concrete water storage reservoir located in Lake Oswego
5) A new, dual pressure zone, 20 MGD booster pump station located in Tigard

Figure 1 highlights the major components of this expansion project along with a construction timeline of each activity, as well as the two major trenchless projects discussed in this paper.

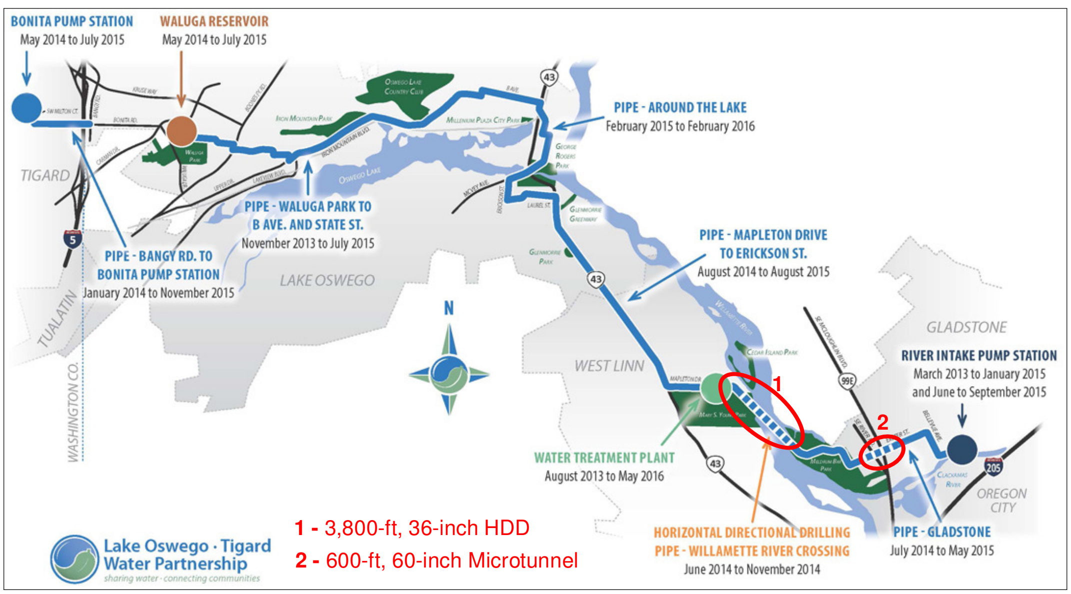


Figure 1: Major Project Features and Construction Timeline, Projects Discussed in Paper

As Managing Partner, Lake Oswego is responsible for securing all regulatory permits and approvals from local, state and federal agencies necessary to construct the new facilities and contracting for design, and construction. The terms of the partnership agreement also obligate Lake Oswego to deliver water from the new facilities to Tigard no later than July 1, 2016.

Project Challenges
Major challenges to the program include the following:

- A project completion span of eight-years from concept development.
- Legal challenges from local project opponents and conservation groups
- Construction within, across, and under a major river – home to endangered salmon and steelhead.
- Project financing amidst the Great Recession and global economic instability

- Construction of a new water treatment facility located within a residential neighborhood
- Property Acquisition
- Maintaining full time operation of the existing WTP while the new WTP is constructed
- Transitioning from the existing system to the new system
- Construction of large diameter pipelines within and along narrow local roads in residential neighborhoods and across two major highways and railroads

Mitigating Risk with Trenchless Pipeline Construction Methods
Traditional cut and cover methods of pipe installation across major water bodies, highways and environmentally sensitive streams were not allowed by federal and state agencies. Therefore, the Program Sponsors turned to the use of horizontal directional drilling and microtunneling to secure permitting agency approvals and mitigate against potential environmental contamination of sensitive ecosystems or loss of endangered fish species. A 3,800-ft long HDD undercrossing of the Willamette River and a 600-ft long microtunnel crossing under two major roadways and two private properties were needed to allow raw water from the Clackamas River to be pumped from the new intake in the City of Gladstone to the new WTP in the City of West Linn, Figure 2.

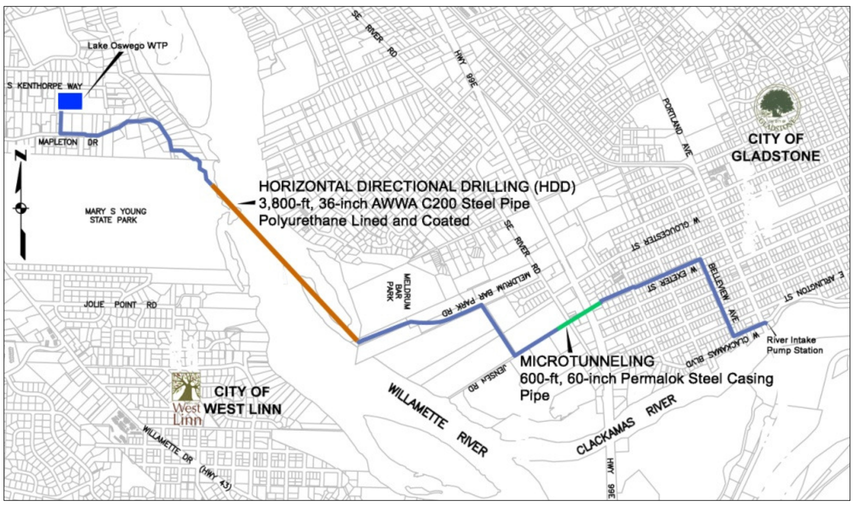


Figure 2: Location of HDD and Microtunneling Segments

This paper focuses primarily on the two main trenchless portions of the pipeline construction, and provides discussions on the selection, specification, manufacture and installation of the welded steel water pipe and Permalok® steel casing pipe for these trenchless sections. Since the 600-ft microtunneling project was still in progress during the writing of this paper, construction and installation discussions are limited to the HDD section only, which was completed on October 28, 2014.

3. DIRECTIONAL DRILLING UNDER THE WILAMETTE RIVER

Staheli et al (2014) discuss a two-phase trenchless feasibility analysis and an extensive geotechnical investigation and testing program that was utilized to select HDD instead of microtunneling for the crossing of the Willamette River, whereby the former method was identified as the lower cost and risk option compared to the latter.

HDD is typically a three-step trenchless construction process which involves the drilling of a pilot bore that first defines the bore path, back reaming along this path until the desired borehole diameter is achieved, and finally, pulling the product pipe into the reamed borehole. Pressurized drilling fluids comprised of a mixture of water, bentonite, and/or polymers are continuously pumped through the drilling equipment during all three phases, which stabilizes the borehole, cools the cutting tools, lubricates the drill pipe, and carries soil cuttings back to the entry location. During the first phase of construction, the pilot bore is drilled by a steerable bit with its position along the alignment measured using a remote tracking system. In the second phase, a reamer is advanced through the pilot bore one or more times to increase the diameter of the bore to a size suitable to accept the designed pipeline, typically a minimum of 12 inches larger than the pipe. In the third and final phase, the assembled product pipe is pulled into the reamed bore. Preferably, the pipe should be fully assembled prior to pullback; however, due to practical constraints, it may be necessary to perform mid-pull welds. These should be kept to a minimum as stops during pullback increase the risk of the product pipe getting stuck down-hole due to borehole collapse or drill fluid thickening. Steps can be taken during design and construction to mitigate these risks.

Geotechnical Conditions

Selection of a final route as well as the method of construction, HDD, of the pipeline crossing was directly related to being able to mitigate risks associated with the challenging geotechnical conditions along the proposed crossing alignment. The HDD would have to successfully cross through high-strength basaltic bedrock with unconfined compressive strengths approaching 50,000 psi. Previous investigations in the project area suggested that the Columbia River Basalt would be found within 10 to 20 feet below ground surface (bgs) over the majority of the crossing. Based on the selection of the preferred HDD alignment, five borings were drilled in order to characterize the subsurface nature of the project area, particularly with respect to depth and strength of rock. The locations of the borings can be seen in Figure 3a. Bore geometry for the HDD alternative was developed for the 36-inch steel pipeline. The profile view of the proposed bore geometry showing the locations of the borings is shown in Figure 3b.

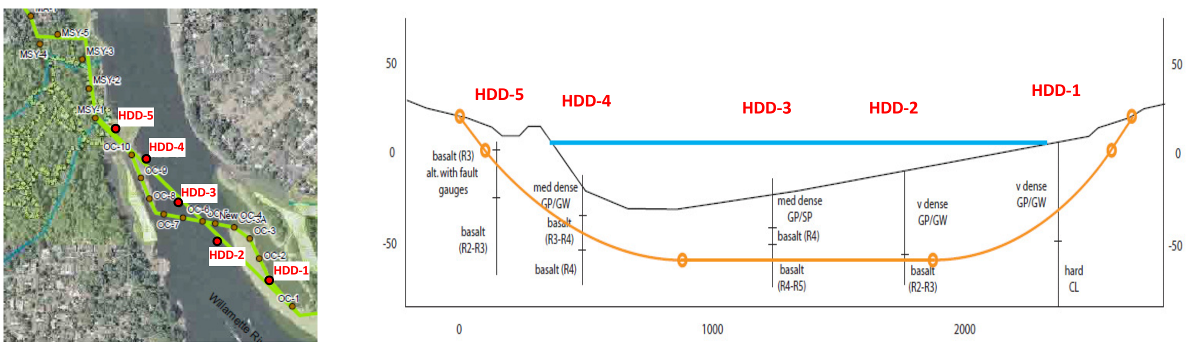


Figure 3a, b: Geotechnical Investigation; Geotechnical Cross Section

The geotechnical conditions encountered during the borings confirmed the feasibility of using HDD. Although the rock cores tested significantly higher in strength than originally assumed during the feasibility study, the impact of the increased strength would potentially be on the project schedule and the project cost. The impacts to both schedule and cost are associated with the replacement of reamers and bits due to wear. With rock strengths in the 50,000 psi range, the retooling costs for the bore could be significant. However, when these cost and schedule impacts were evaluated and incorporated into the feasibility analysis, HDD remained the preferred alternative for the crossing of the Willamette River.

Pipe Material Selection

Pipe material evaluations for horizontal directional drilling began with consideration of the use of high density polyethylene (HDPE) pipe, as thermoplastics are often used in the water industry for trenchless applications involving tensile loading rather than jacking. However, there were several reasons the use of HDPE was abandoned following due diligence:

1. Based on internal pressures and tensile pull requirements, wall thickness of HDPE would need to be in the 3-inch to 4-inch range, thereby raising the OD to over 48-inch. This would require a bigger borehole, resulting in more construction costs
2. With such high wall thicknesses, the Engineer was told by manufacturers that they could not be given a guarantee on the homogeneity of the pipe material, or on the quality control of the pipe wall dimensional tolerances. Both could ultimately lead to problems with the joint butt-fusion process
3. Excessive stretching of the HDPE during directional drilling was a concern
4. Availability of this diameter and wall thickness was also an issue
5. Owner did not have any experience with HDPE in their system

Due to the wide use of steel water pipe for the open-cut portions of this project, as well as their level of familiarity with steel water pipe for water transmission in their existing system, combined with the ability to design and fabricate steel pipe to exacting application requirements, the Owner decided that spiral welded steel pipe, manufactured to AWWA C200 would be utilized. Using steel would keep the OD of the pipe to a minimum for a 36-inch ID pipeline. Details of the steel pipe specification for the HDD follow:

1. Steel pipe manufacturer would need a minimum of five years of experience with spiral welded steel pipe, as well as have experience with manufacturing pipe for five similar projects (trenchless construction)
2. Pipe was designed for 150 psi working pressure, surge pressure of 225 psi, and full vacuum of 14.7 psi. Maximum allowable stress was 50% of yield strength of steel, with 2% maximum allowable deflection.
3. The steel coil specified was ASTM A1018, GR 36, SS, with minimum yield strength of 36,000 psi and a minimum tensile strength of 53,000 psi. Minimum elongation was specified at 21%. Steel would also have to be fine grained, fully killed and continuously cast
4. Specified minimum wall thickness for the pipe was 0.625-inch (5/8-inch) – this would be sufficient for both internal pressure and external loading, as well as all loading conditions encountered during construction
5. For quality control of the pipe material and welding, pipe would undergo all AWWA C200 requirements, including tensile testing, bend testing, spot x-ray testing, weld seam testing and hydrostatic testing to 75% of minimum yield strength of steel for each cylinder
6. Butt welded joints were specified, to handle tensile loadings of pipe-pullback. Typical open-cut installed steel water pipe is specified with gasket joints, or if needed, with single internal lap welded joints based on diameter.
7. Though the original specification called out for 48-ft maximum lengths for the steel pipe, the project was supplied with 60-ft lengths of pipe to minimize the number of joints that would have to be welded in the field
8. Specified lining and coating was polyurethane, per AWWA C222
9. The polyurethane was required to meet a 1500 psi adhesion value
10. The Dry Film Thickness (DFT) for the lining was 40 mils, while DFT for coating was 80 mils. Even though AWWA C222 requires a minimum DFT of 20 mils for lining and 25 mils for coating of steel pipe, the higher lining and coating thicknesses on this project was an insurance to compensate for bend radius of the steel in the HDD application, as well as the highly abrasive conditions the pipe would need to endure externally during the pull-back
11. Surface preparation of the steel substrate for polyurethane application required a minimum anchor profile of 2 mils, though a profile of 3mils to 5 mils was used for spraying of the LifeLast polyurethane. Anchor profiles were required to be tested using Testex tape and recorded

The process of manufacturing spirally welded steel water pipe per AWWA C200 is discussed in detail by Maughn et al. (2014). The application of polyurethane for both the lining and coating of steel water pipe is discussed by Budge and Rahman (2012).

Bend Radius of Steel Pipe

In accordance with MOP 108 (ASCE 2014), the allowable bend radius for the steel pipe on this project was specified at 1200 times the nominal diameter of the pipe, resulting in a stated allowable radius of bend of 3600-ft for the 36-in ID pipe. The “1200 times nominal diameter relationship” has been developed through experience with constructability in the HDD industry, primarily in oil and gas applications, as opposed to being based on pipe stress limitations (ASCE 2014). The maximum allowable tensile stress imposed on a steel pull section during installation is typically limited to 90% of the pipe material’s minimum yield strength. Bending stresses imposed on a steel-pull section during installation are also limited per conditions discussed in MOP 108. Typically, the minimum radius derived using a stress-limiting criteria is substantially less than 1200 times the nominal diameter. For this reason, bending stress limitations rarely govern geometric drilled path design but are applied, along with other stress limiting criteria, in determining the minimum allowable radius of curvature.

Given the space limitations on this project for the staging of the HDD, the Contractor proposed utilizing a bend radius of 2000-ft for the 5/8-inch thick 36-inch ID pipe (OD of 37.25-inch). As this tighter bend radius (compared to the 3600-ft stated bend radius) did not in any way compromise the allowable stresses in the pipeline, it was permitted and used.

4. MICROTUNNELING ACROSS HIGHWAY OR-99E

Microtunneling consists of a remote-controlled, steerable pipe-jacking operation which is closed-faced and provides continuous support to the face of the excavation. As soils and rocks are excavated by the cutter head of the microtunnel boring machine (MTBM), they pass through the crushing chamber into the slurry chamber. The spoils mix with water within the chamber to form slurry which is then pumped out to the surface. It is important that the velocity of the slurry flow, as well as the pressure, be closely regulated and monitored because the slurry chamber pressure is used to counter-balance the groundwater pressure. Microtunneling is suited for deep installations below the water table in a variety of geotechnical conditions and is typically used where high grade accuracy is required (Staheli et al. 2014).

For the crossing of OR-99E / Pacific Highway E (McLoughlin Blvd) as well as SE River Road in the City of Gladstone, Figure 2, microtunneling was selected due to the following reasons:

1) An easement was not granted by the Oregon DOT to open-cut across OR-99E
2) Water table was close to the ground surface
3) The 600-ft crossing was too long to perform by auger boring
4) The 48-inch diameter of the carrier pipe and the 60-inch diameter of casing pipe made microtunneling ideal; auger bores are usually performed for smaller diameters

Figure 4 shows the geotechnical profile along the length of the crossing. The alluvium, consisting of silts, sands and gravels would not present any cutting challenges during microtunneling.

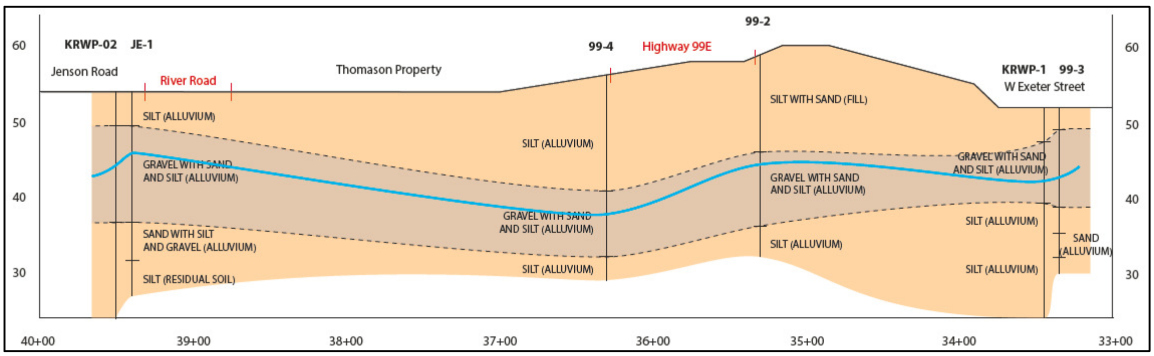


Figure 4: Geotechnical Profile of Crossing Underneath OR-99E and River Road

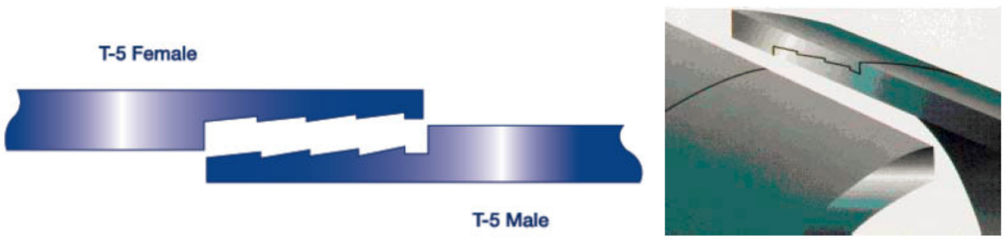
During the writing of this paper, the shaft for the microtunnel had been constructed using an engineering shoring system with piles and steel plate. Tunneling was scheduled to begin within a week. An Iseki TCC 1200 Unclemole® microtunneling machine would be used for the construction of this segment. Figure 5 shows the MTBM used for the project.

Figure 5: Iseki TCC 1200 Unclemole® MTBM Used for Microtunneling Across OR-99E

Casing Pipe Material Selection

The specifications for this microtunneling segment permitted the use of either traditional plain ended steel casing pipe where joints would be butt-welded in the field prior to installation, or the use of the proprietary interlocking ("integral press fit system" per Project Specification 02315, p. 11) Permalok® joint that is assembled in the field by mating a stepped male-end into an interlocking female end, Fig. 6a and 6b. According to the Contractor, Permalok was chosen instead of plain-end casing pipe for the following reasons:

1) to offset the high cost of butt-welding sections of traditional steel casing pipe. For 60-inch diameter plain-end steel casing, it would take a minimum of 3 to 4 hours to butt-weld each joint. This would be approximately 87 to 116 hours of butt-welding time (assuming 20-ft casing sections, and 29 joints for the full 600-ft length). So in addition to substantially slowing down the microtunneling process, the Contractor would be paying a specialized welding crew for their labor, as well as costs associated with welding equipment for that added amount of time,
2) the relatively short, 20-ft long *segmental* Permalok joints would also allow the microtunneling and jacking equipment better directional control versus jacking a 600-ft long monolithic continuously butt-welded casing pipeline.



Figures 6a, b: Cross-Sections of the Permalok T5 Joint

The Permalok steel casing pipe consists of a rolled-and-welded steel cylinder, typically 20-ft in length, fitted with a precision machined interference fit male connection on one end and a female connection on the other. The unique joint profiles are machined to tolerances of less than ±0.005-inch, resulting in a tight fit joint of consistent quality.

Exactly sized and cut steel plates are rolled and welded, Figure 7a, to first make 10-ft long cylinders of the required diameter; two such cylinders are then welded together utilizing a jig for alignment, Figure 7b, resulting in the 20-ft long standard casing sections. All welds are full-penetration double submerged arc welds. Use of the jig ensures good alignment of the 10-ft sections before application of the full penetration girth welds, an added quality control measure in Permalok® casing pipe that is not typical of traditional casing pipe manufacture. Prior to full-penetration welding of the proprietary male and female connections to each end of a 20-ft long cylinder, the diameter of the cylinder is again tested for roundness to the tight tolerances. If specified, lining and coating is added to the completed Permalok® steel casing cylinders. Cylinders as thick as 2.5-inch can be manufactured if specified. Figures 7c and 7d show completed Permalok female and male connections, respectively.

7a, b, c, d: Cylinder Rolling, Jig for Alignment During Girth Seaming Welding, Completed Permalok® Casing

The minimum steel thickness specified for the Permalok cylinders on this project was 0.75-inch, with 35,000 psi minimum yield strength of steel. During joint assembly, a silicone sealant was specified for lubrication, then for sealing purposes upon curing.

5. CONSTRUCTION OF THE HDD SEGMENT

Construction of the 3,800 foot, 36 inch steel pipeline began in June of 2014 with the installation of nearly 1,800 lineal feet of steel casing. The contractor installed a combination of telescoped conductor and wash-over casings 14, 20, 54, and 60-inches in diameter, with the Mary S. Young site cased approximately 106 feet from ground surface and the Meldrum Bar Park site cased approximately 600 feet to bridge unstable soils. As shown in Figure 8a, pipe ramming techniques were used to install the conductor casing. The general contractor, Frank Coluccio Construction Company of Seattle, WA, teamed with Michels Directional Crossings of Brownsville, WI, and elected to perform the HDD utilizing the *intersect method* with 840,000 pound drill rigs, Figure 8b, set up at both ends of the bore.

Figures 8a, b: Pipe Ramming of 60-inch Conductor Casing; 840,000 lb HDD Rig

Pilot Bore from Mary S. Young State Park

The pilot bore from Mary S. Young State Park began on July 15, 2014. Michels began the pilot bore using an energized surface grid and a magnetic beacon to track the bore, but due to magnetic interference from high iron content rock and the steel conductor casings inserted at both ends of the bore, they elected to supplement their tracking systems by using a gyroscopic survey and down-hole wireline system to track the vertical and horizontal location of both drills. The contractor drilled until they reached 1,445 feet, where the pilot bores intersected. This pilot bore was completed in ten drilling days, averaging approximately 144 feet of drilling each day.

Pilot Bore from Meldrum Bar Park

The pilot bore from Meldrum Bar Park began on July 22, 2014. The contractor drilled to a distance of approximately 2,420 feet, where the pilot bores intersected. Drilling averaged 242 feet per day on the Meldrum Bar Park side. The two bores intersected within a few feet of one another at a depth of over 120 feet beneath the river. Once the two bores had intersected, Michels advanced the drill string from the Meldrum Bar Park side all the way to the Mary S. Young side to prepare for the reaming process.

Reaming

Michels elected to ream the hole in three separate passes: 36 inch, 42 inch and 54 inch. All reaming occurred by pulling the reamer from the Mary S. Young State Park side to the Meldrum Bar Park side of the bore. Tail string was added for the reaming passes as specified.

The first ream pass began on August 15, 2014. The contractor was initially planning on beginning with a 48 inch reamer, but quickly changed their plan to a 36 inch reamer. The 36 inch ream pass continued until reaching the end of the 14 inch conductor casing on the Meldrum Bar Park side, approximately 3,150 feet. The first pass occurred over a thirteen day period, averaging 242 feet a day. Once the reaming pass was complete, the reamer was advanced back to the Mary S. Young State Park side, where the contractor was able to change out the reamers. The second ream pass began on September 9, 2014. As they did in the first pass, the contractor pulled the 42 inch reamer from the Mary S. Young State Park side to the Meldrum Bar Park side. The contractor saw much faster production rate this time, as they were not cutting as much material at the face. The second ream pass was completed in five days, averaging approximately 630 feet of production a day. The third, 54 inch, ream pass began on September 15, 2014 and was completed in twelve days, averaging approximately 263 feet of production a day. After the final ream pass, the contractor, again, advanced the reamer back to the Mary S. Young State Park side of the bore. At this point, they removed the 54 inch reamer and added an 80 foot section of 36 inch steel casing to the drill string. This 80 foot section was then pulled through to proof the hole.

Pipe Preparation and Pullback
Beginning on October 15, 2014, welded 240-ft sections of steel pipe were transported upriver from Advanced American Construction's marine contracting yard/staging area in North Portland near the St. Johns Bridge, Figure 9a, by a large derrick barge to Meldrum Bar Park, 9b. There, on a custom constructed platform alongside the barge, Coluccio completed the final field welding, lining and coating of the 4,000 feet of pipe, Figure 9c. This process lasted ten days.

Figure 9a, b, c: 240-ft Welded Segment of Steel Pipe, Transportation of 240-ft sections by Derrick Barge, Final Joint Assembly Prior to Pull-in

As each 240-ft section was prepared by butt-welding 4 pieces of 60-ft long steel pipe, Figures 10a and 10b, internal and external lining and coating completions were performed on the polyurethane, per AWWA C222, Figures 10c and 10d.

Figure 10a, b, c, d: Joint alignment for Butt Welding, Completed Butt-welded Joint; Surface Grinder Used for Substrate Preparation for External Joint Completion, Surface Preparation for Internal Joint Completion

Records were kept of ambient temperature conditions and surface temperatures, and anchor profiles were tested and recorded using Testex tape, Figures 11a, b and c, respectively. Completed external coating on a pipe section is shown in Figure 11d.

Figure 11a, b, c, d: Ambient Temperature Conditions, Surface Temperatures, Testex Tape for Anchor Profile Testing, Completed Joint Coating

The pipe was floated into position along the river prior to pullback and lofted over 100 feet into the air to achieve the correct lineup and angle with the 54 inch diameter borehole, using two land-based cranes and four barge-based cranes fitted with roller slings, Figure 12a and 12b. Buoyancy control water was pumped via tremie pipe inserted into the steel pipeline during installation to decrease pullback loads. Pullback, Figure 12c, began on October 28, 2014 and was successfully completed, without incident. What was expected to be a 24 to 48-hour pullback time (Staheli 2014) was attained in 14.5 hours.

Figure 12a, b, c: Lineup of Pipe in Preparation for Pull-back; Complete Line Ready for Pull-back; Pull-back Commencement by Insertion into

6. CONCLUSION

Water from the Clackamas River has been the main source of raw water for the City of Lake Oswego for almost fifty years, with an existing raw water line that transmits water from the Clackamas River by crossing underneath the Willamette River to a water treatment plant. The expansion of this line to convey water to a new treatment plant, then distributing the treated water to customers is a key feature of this project, and includes more than 10 miles of primarily AWWA C200 steel water pipe. Traditional cut and cover methods of pipe installation across major water bodies, highways and environmentally sensitive streams were not allowed by federal and state agencies, and therefore, a Horizontal Directional Drill (HDD) undercrossing of the Willamette River was successfully undertaken using 3,800-ft of 36-inch diameter polyurethane lined and coated steel water pipe. In another location, microtunneling was specified to install 600-ft of 60-inch diameter Permalok® steel casing pipe under two major roadways and two private properties, through which a 48-inch diameter steel carrier pipe would be installed. The HDD project was successfully completed in late 2014, with a pull-back time of 14.5 hours. The microtunneling segment was underway during the writing of this paper and is anticipated to be over by mid-to-late March, 2015.

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