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THERMALLY FUSED PVC PIPE HELPS ACCELERATE ADOPTION OF TRENCHLESS PIPE INSTALLATION TECHNIQUES IN NORTH AMERICA

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ABSTRACT

In North America, trenchless pipe installation methods continue to see rapid adoption in municipal markets with well over 70 percent of utilities having used some form of trenchless methods in the recent past according to a 2012 survey. This adoption rate is a function of improving equipment, installation experience, improved materials, and seasoned installers.

The three most recognized trenchless installation methods for pressure pipe; horizontal directional drilling (HDD), sliplining and pipe-bursting are seeing rapid growth in application. Improvements in methods and materials have stretched the boundaries of these technologies, allowing longer lengths of pipe, larger sizes and an increased range of project constraints to be managed. Pipe joining methodologies for thermoplastic pipe materials and specifically the increasing use of thermally butt-fused PVC pipe (FPVCP) (over 1,500 miles or 2,400 km in service) have had the largest impacts on the growth of these installation modes in North American water and wastewater infrastructure.

This paper discusses the FPVCP technology that is enabling trenchless growth and highlights two cases studies where FPVCP was utilized based specifically on its material properties; a 3,800 foot (1,1140m) HDD installation with 24-inch (600mm) and 6-inch (150mm) pipe pulled in simultaneously under a live airport runway in Portland, Oregon and a water utility in Colorado that has installed over 150,000 feet (45,000m) of FPVCP via the pipe-bursting method.

Fusible Polyvinylchloride Pipe, Horizontal Directional Drilling, Pipe Bursting, Trenchless Technologies,

INTRODUCTION

Trenchless technologies have taken the underground infrastructure industry by storm over the last 20 to 30 years. These installation means, methods, and materials have transformed the way that utility owners, engineers and installers view underground construction. Oil and gas, as well as power and telecommunication industries have long used trenchless methods for installation of underground assets and water and wastewater markets are not that far behind. The water and wastewater industry has been the sector with the largest growth in the use of trenchless techniques and technologies over the past 15 years. In a survey conducted in 2012 of municipal utility owners by Carpenter (1), 70 percent of those respondents said that they have used some form of trenchless construction methods in the recent past and another 15 percent stated that they would use these methods in the coming year.

One of the primary drivers of this acceptance is the pipe materials that are available for use with these innovative technologies. Pipe material selection is a primary decision regardless of the specific underground construction project being undertaken. It is often based on factors outside of the construction process, including things like past experience with the pipe material, operations and maintenance familiarity, and compatibility with existing parts and tooling inventory. Because of these reasons, the manufacturers of each pipe material that is popular in each respective industry has striven to create joining methods for their products that are compatible with trenchless installation techniques used in those industries.

The three most common and popular installation methods for whole pipe replacement or installation, meaning that a new, 'whole' pipe is installed, rather than relying on some form of an existing pipe asset to be renewed, are horizontal directional drilling (HDD), sliplining, and pipe bursting. Each of these methods provides a new, whole pipe installation capable of resisting all internal and external loading for the required design life of the asset. In the oil and gas market, the most common pipe materials for trenchless processes are steel and high density polyethylene (HDPE) pipe. In the power and telecommunications market steel is being replaced by thermoplastics like PVC and HDPE. And in the largest growth sector of trenchless installation work, the water and wastewater market, historically, multiple materials have been used to complete trenchless projects. In each of these markets the trenchless pipe materials used are typically the same that are used with conventional direct bury construction methods, except for the water and wastewater market. Here, the most popular pipe materials are cast or ductile iron and PVC pipe, each with considerable market share of the vast majority of distribution and collection system infrastructure in the ground in North America today. Both ductile iron and PVC manufacturers have created proprietary technologies and products that may be effectively applied in trenchless, whole pipe applications. One unique product that was born from this effort for PVC pipe was the use of butt-fusion methods to create a thermally fused pipe joint, capable of the same tensile and internal pressure parameters as the PVC pipe material itself. Using similar equipment but significantly different fusion parameters, this joining technique not only allowed the application of PVC pipe in trenchless whole pipe installations, but it also provided a material that could stretch the industry limits of thermoplastic pipe for use within these methods.

Fused PVC pipe (FPVCP) is joined by a thermal butt-fusion process which includes heating the ends of two pieces of pipe to create a fusible bead of material on each, and then pressing and holding the ends together under pressure until the joint cools to ambient temperature, creating a fused PVC joint. This process utilizes standard and readily available equipment in the underground utility market, though certain modifications are made to account for the PVC plastic. The process also utilizes a datalogger device to record the critical time-based parameters of the fusion joint process. Using the thermal butt-fusion joining method allows for the assembly of long lengths of monolithic FPVCP, however, after assembly, the pipe may be cut, connected, tapped and otherwise installed in the same manner as PVC pipe with segmented joints (Marti and Botteicher, (2)). The use of this product in trenchless applications is supported by an extensive testing program of the PVC pipe and fusion properties as well as a quality control program that includes third party testing of each extrusion lot commercially produced. This quality control program has been justified over the last 10 years by the projects that have been completed with longer, larger, and deeper installations than could previously be considered with trenchless techniques and thermoplastic pipe. Based on this success, FPVCP fills a wide capability void between HDPE and steel pipe in terms of whole pipe trenchless installation methods. The key, however, to market acceptance of the product for these methods still lies in the pipe material itself. PVC is still one of two pipe materials that are favored by the water and wastewater industry and thus would be chosen for use in trenchless as long as it could be installed successfully.

In terms of pushing the limits of current installation practice, FPVCP has been used in some of the longest and deepest HDD installations ever completed by an uncased, thermoplastic pipe material. One such project in Portland, Oregon required the installation of both a conveyance and pump back line underneath an active airfield. In order to achieve project success, the 3,800 LF (1,140 m) HDD needed to be around 70 to 80 ft (21 to 24 m) underneath the airfield, and FPVCP provided a thermoplastic material that could withstand the installation loading associated with such a long and deep alignment for both a nominal 24-inch (610 mm) and 6-inch (150 mm) dual-pipe application.

In terms of providing a material that is well known and fits within existing utilities comfort zone when it comes to pipe materials, the successful Consolidated Mutual Water Company (Consolidated) waterline pipe bursting rehabilitation program demonstrates how FPVCP dovetails with existing operations. Winner of the 2013 Rehabilitation Project of the Year (Rush (3)), Consolidated is using a pipe material that they are familiar with; in a way that allows them to take advantage of the trenchless technology benefits of pipe bursting. They are replacing their aging infrastructure with minimal impact to their constituents and at the same time, saving about 50% on construction costs versus traditional dig and replace rehabilitation methods.

NOMENCLATURE

C – Celsius
F – Fahrenheit
LF – linear foot
km - kilometer
km^2 – square kilometer
kN - kilonewton
m – meter
mm - millimeter

PORTLAND INTERNATIONAL AIRPORT DE-ICING PROJECT

The Portland International Airport (PDX) is a busy travel hub, serving more than 15 million travelers per year. PDX covers approximately 2,600 acres (10 km^2) of airport operations and surrounding airfield immediately adjacent to the Columbia River. Stormwater runoff management is a critical aspect of PDX operations, especially in light of aircraft and pavement anti-icing chemicals used when temperatures at the airport drop below 40^0 F (4^0 C) (Marti (4)).

In order to maintain stormwater discharge into the Columbia River at required State and Federal levels, significant investments needed to be made to the existing stormwater management system. PDX, using the design work of CDM-Smith, constructed a new modified stormwater treatment and discharge system, as a modification to the existing stormwater collection and discharge network. Figure 1 shows a general schematic of the additional facilities added at the airport site, including the new treatment facility, shown as PS-P on the western side of the property, and the new outfall for treated stormwater into the Columbia River on the north side of the property. The treatment facility was located on the western edge of the airport property due to the difficulty in siting it within the existing facilities closer to the hub of airport operations. Since the treatment facility was located outside of the airport, this meant that a reject transfer line would be needed to bring the concentrated pollutants, removed from the bulk stormwater, back to the eastern portion of the property, where existing treatment process could be employed. The challenge for this aspect of the design and construction process was bringing not one, but two new pipelines across an active airfield in order to make the necessary connections to the system.

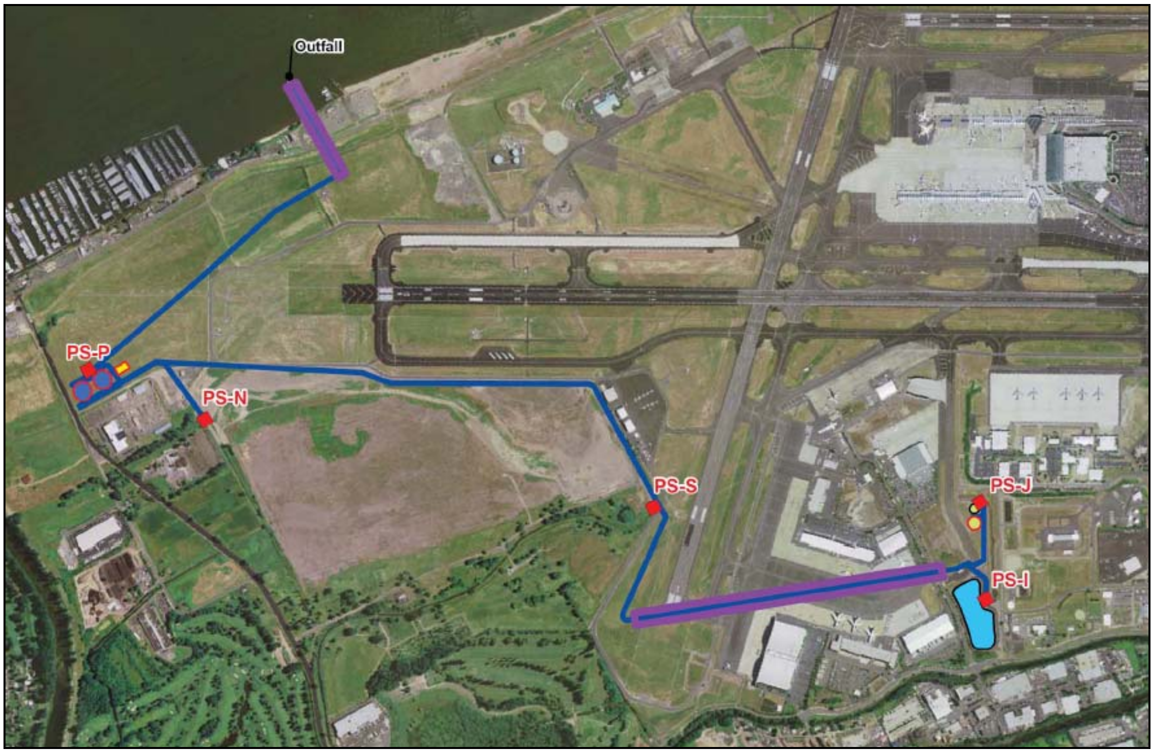

Figure 1. Final site plan showing new treatment and conveyance facilities on the left side of the figure corresponding to the western side of the PDX property. The HDD installation is highlighted in purple and shown schematically between points PS-S and PS-J/I (Ostlund and Sarin (5)).

The design team considered several alternatives to construct this section of the project, including routing the pipeline around the entire airfield or utilizing a hybrid method of direct bury construction and jack and bore construction methods through the impacted airfield space. These options were not preferred due to the costs and impacts to ongoing operations at the airport. One final option was evaluated, which included utilizing HDD techniques to bore underneath the active airfield location and install both conveyance and reject piping in a single borehole. After further review of the potential design solutions, HDD was advanced as the most cost efficient, viable option to complete the crossing. This final horizontal alignment chosen is shown schematically with heavy purple shading in Figure 1 between points PS-S and PS-J/I. This alignment crossed under the very end of an active cargo carrier runway, as well as the tarmac and cargo facilities portion of the airport.

Due to the poor soils prevalent at the project site, the bore alignment was designed to be deep. The proposed trajectory took the bore to a depth of 75 ft (23 m) as it crossed under the active airfield so that competent soils could be relied upon. The other constraint for the bore was the required length. In order to cross the impacted area of operations, including the runway, the designed bore length would need to be approximately 3,500 LF (1,067 m) long (see Figure 2).

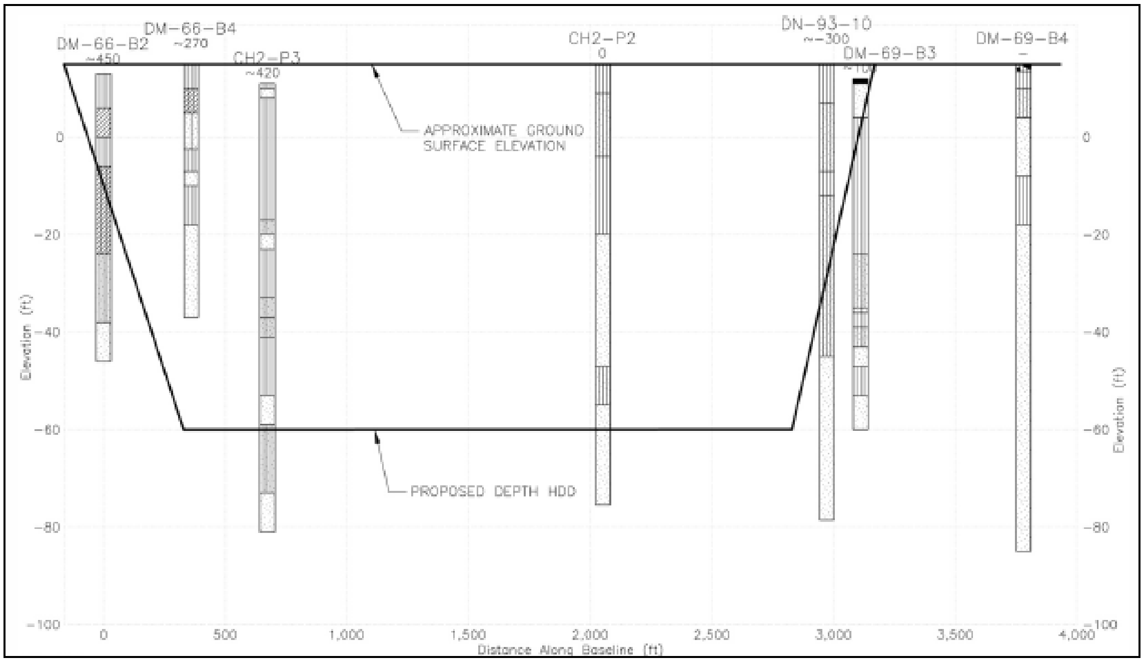

Figure 2. Schematic boring log results along the initial vertical HDD alignment. Multiple strata made selecting an appropriate alignment difficult in terms of HDD methods (Ostlund and Sarin (5)).

The actual pipelines required included a nominal 24-inch (610 mm) pipeline that would be designed for conveyance of collected stormwater to the new facility for treatment. The second pipeline, the reject line, would move concentrate from the treatment process at the new facility back on-site to be handled at the existing treatment facility at the airport. This pipeline was much smaller, only requiring a nominal 6-inch (150 mm) line.

When evaluating pipe materials for this crossing, the first choice of the design team was to use the same thermoplastic pipe materials used for the rest of the project, which included HDPE and PVC pressure pipe. These materials offered superior chemical resistance and compatibility with the conveyed fluids and would not see any impacts related to long term corrosion. In order to provide the largest buffer against installation risk for this long and deep installation, FPVCP was chosen as the preferred material for this particular crossing. The greater tensile strength of PVC plastic compared to HDPE plastic meant that risk could be minimized for this installation in three ways. First, the FPVCP alternative would require a smaller borehole, since both sections of pipe would require a smaller overall diameter compared to HDPE due to the significant difference in wall thickness required between the two materials. The lower tensile capacity of the HDPE plastic means that a thicker wall is required to handle the internal pressure and in the case of this installation, the higher buckling loads encountered at depth. With an increased wall thickness, the overall diameter of pipe required increases to assure that the required internal flow area is maintained. Second, FPVCP provided a greater strength-to-dead-weight ratio than HDPE. The greater tensile capacity of the plastic means that PVC has more capability with tensile loading compared to its weight than equivalently designed HDPE pipe. This reduces risk for the HDD installer, providing more tensile capacity and reduced dead weight for the installation. Third, proven installation experience for these types of installed HDD depths and lengths for FPVCP, particularly in the smaller diameter, provided assurance and further risk reduction for a difficult installation such as this. Due to these reasons, 24-inch (610 mm) DR18 DIPS and 6-inch (150 mm) DR14 DIPS FPVCP were selected for the crossing.

During the construction phase of the contract, some significant challenges were overcome by the construction team. The joint venture of Northwest Underwater Constructors and Kinnan Engineering (Kinnan) performed the HDD for the airfield crossing. After initial site set up, the bore was lengthened from the planned alignment length of 3,500 LF (1,067 m) to 3,800 LF (1,140 m) due to conflicts at grade. During the initial drilling of the pilot bore, Kinnan encountered difficult and complicated drilling conditions. Weak soil formations at the entry and exit had to be considered in performing the work. Kinnan used a steel casing for the first 120 ft (36 m) of the installation to stabilize the bore and keep the weaker formation from caving in on the work.

3,800 LF (1,140m) of pipe is a long length to stage as a single string of pipe. This project also required the pipe to be staged in an open space area that had specific wetland zones that could not be impacted. The construction team ultimately identified an alternate alignment that did not disturb the wetlands, yet allowed for the full lengths for both the 24-inch (600mm) and 6-inch (150mm) sections to be laid out in single strings (see Figure 3).

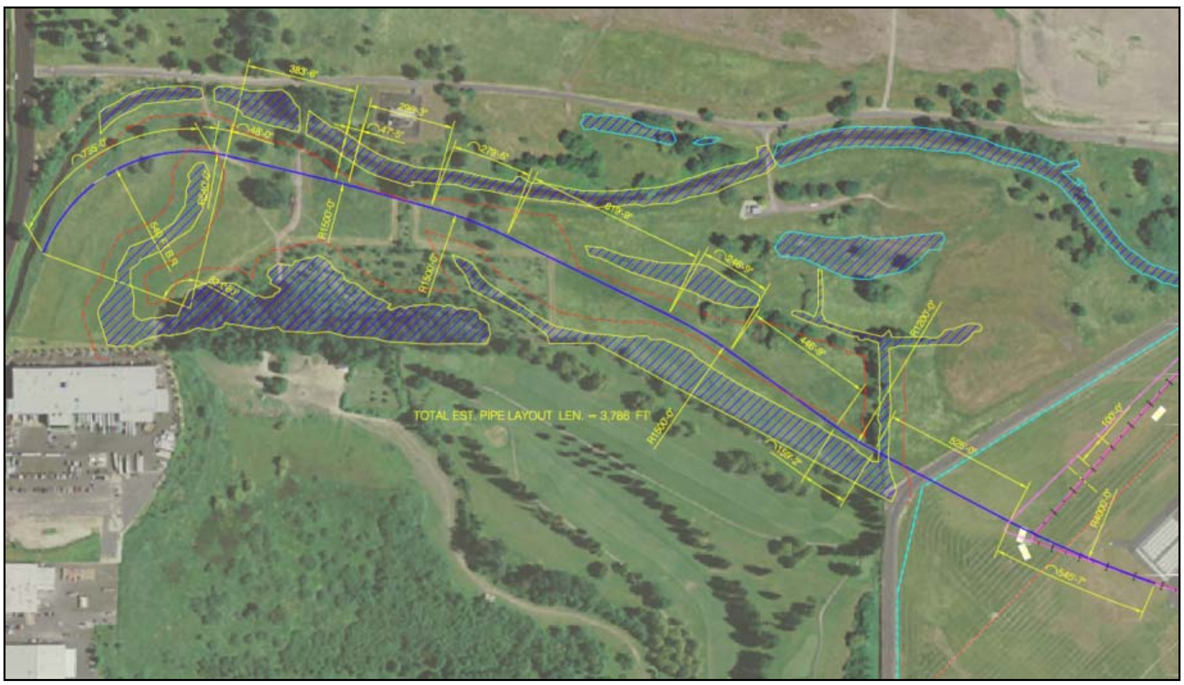

Figure 3. Schematic fusion alignment for stringing of the fused FPVCP sections.

Kinnan custom-fabricated a manifold-style pulling shield to simultaneously link and separate the 6-inch (150 mm) and 24-inch (600 mm) pipes and their individual pullheads (see Figure 4) during the pullback insertion. Pullback commenced on July 27, 2010, with water ballast in the 24-inch (600 mm) pipe to reduce frictional force in the bore. The pull was completed successfully in 13 hours, exerting a maximum pull force of 117,000 pounds (520 kN) (see Figure 4). A successful pressure test was completed several weeks later.

Figure 4. Pipe Bundle at Borehole Exit and Casing, also showing the arrangement with the manifold pulling shield and pipe pullhead configuration (Ostlund and Sarin (5)).

CONSOLIDATED MUTUAL WATER COMPANY PIPE BURSTING PROGRAM

The Consolidated Mutual Water Company (Consolidated) is located in Lakewood, CO, a city that falls on the western side of the Denver Metro area, and serves about 90,000 residents. Treated water is delivered through 380 miles (1,638 km) of existing pipelines and 21,100 tap connections over a service area of approximately 27 square miles (70 km^2) (Botteicher et al. (6)). Consolidated, like the very idea the name of the cooperative would suggest, was originally formed from four smaller well-based utilities in 1926. Since that time, it has incorporated many changes to the system – adding distribution, treatment and supply – however, it is still a not-for-profit corporation, owned by the very customers it serves. Consolidated currently purchases approximately 70% of the total distributed water it provides from Denver Water (Denver). The balance comes from Consolidated's own Maple Grove Water Treatment Facility and the water rights that is has accumulated over its history. Consolidated and Denver Water's relationship would play a role in Consolidated's exploration of alternate pipe rehabilitation and replacement methods.

Over the last half century, Consolidated has been more focused on maintaining service and updating their assets than anything else. They are bound on almost all sides by existing utility systems and the potential for system expansion, while not completely out of question, is not something that they are required to do. They have budgeted money annually for system upgrades and asset replacement since the mid-50's. Over time, Consolidated has brought all aspects of operations and maintenance, along with construction and design, in-house. Everything except capital improvement projects are tackled in-house, including system replacement and upgrades.

The issues that Consolidated faces with its existing system are not unlike the same issues faced by utility systems in other locations. As infrastructure assets age they run closer to unsustainable repair and eventual failure. This is true of all designed systems and system components. The other aspect of the system that was causing issues was the sizing. Many parts of the system also had undersized mains in order to attain the required life safety flows required of today's communities. For Consolidated, the most problematic sections of their systems contained large amounts of undersized cast iron piping that was nearing the end of its useful life. Main breaks, water quality issues and restricted flow due to tuberculation and small nominal pipe sizing all contributed to large sections of their system that needed replacement (see Figure 5).

Figure 5. Typical water main in areas to be replaced, both outside and inside pipe showing tubercles (Botteicher et al. (6)).

Money was budgeted in 2009 to begin a large-scale systematic replacement program of the undersized and underperforming portions of the distribution system. Those areas of the system that showed the greatest issues with repair records, water quality complaints and flow issues were slated for replacement first. The total budget for the 2010 program year was approximately $2.4 (US) million and was intended to replace approximately 24,000 LF of pipe. Around this same time, Consolidated first heard about alternate methods for pipeline rehabilitation and replacement. The one method that caught their attention was 'pipe bursting'. Pipe bursting is a means to replace an existing pipeline by using the existing pipeline alignment to guide the installation of a new pipe. A 'bursting' unit is pulled through the existing pipe, which fragments the existing pipe and pushes it radially into the surrounding soil and bedding. A new pipeline is simultaneously pulled in behind the 'bursting' operation. In this manner, a length of pipe can be replaced in whole by a new pipe by bursting; expanding and inserting the new line (see Figure 6). Pipe bursting provides numerous advantages compared to other trenchless rehabilitation methods or traditional dig and replace methods. First, it utilizes the same existing corridor as the pipeline to be replaced. Utility strikes or conflicts and over-crowded right of ways are largely avoided by using the method. Second, it allows the existing pipe to be sized larger than the existing pipeline, and does so in a trenchless manner. Third, it provides a new, whole pipe for the application and does not rely on the existing pipeline for any integrity of the asset going forward. Finally, compared to open cut, dig and replace methods, it limits the impacts to paved streets, surface treatments, and the constituents of the utility – allowing streets and access to driveways to stay open during construction and reducing the impact of the construction activities to businesses and residents.

After learning about pipe bursting and evaluating the benefits that it would hold for their waterline replacement program, Consolidated began trialing equipment, pipe materials, and methods. They first started with HDPE pipe for the replacement waterlines but were dissuaded for two reasons. The first reason was that HDPE represented a new pipe material per their experience and use. Existing stock items, as well as utility operator knowledge were not compatible with HDPE pipe. The pipe materials that are common for Consolidated included cast and ductile iron, as well as PVC. The second reason was that Denver Water did not allow the use of HDPE pipe within their distribution standards. Consolidated provides around 70% of their water from Denver Water and as part of that agreement, have to abide by Denver Water standards of system design and construction for the area of the system that distributed that water. Due to these facts, Consolidated was interested in another pipe joining technique that would allow them to use the product for pipe bursting, but also meet the requirements of Denver Water and the predilections of their operations group. The material that they settled on was FPVCP. The thermally fused joint for FPVCP provided the required tensile capacity to be installed via a trenchless method like pipe bursting, but the PVC material was familiar to the operations group, and it coupled, tapped, and repaired in the same manner as the rest of the PVC pipe in their system.

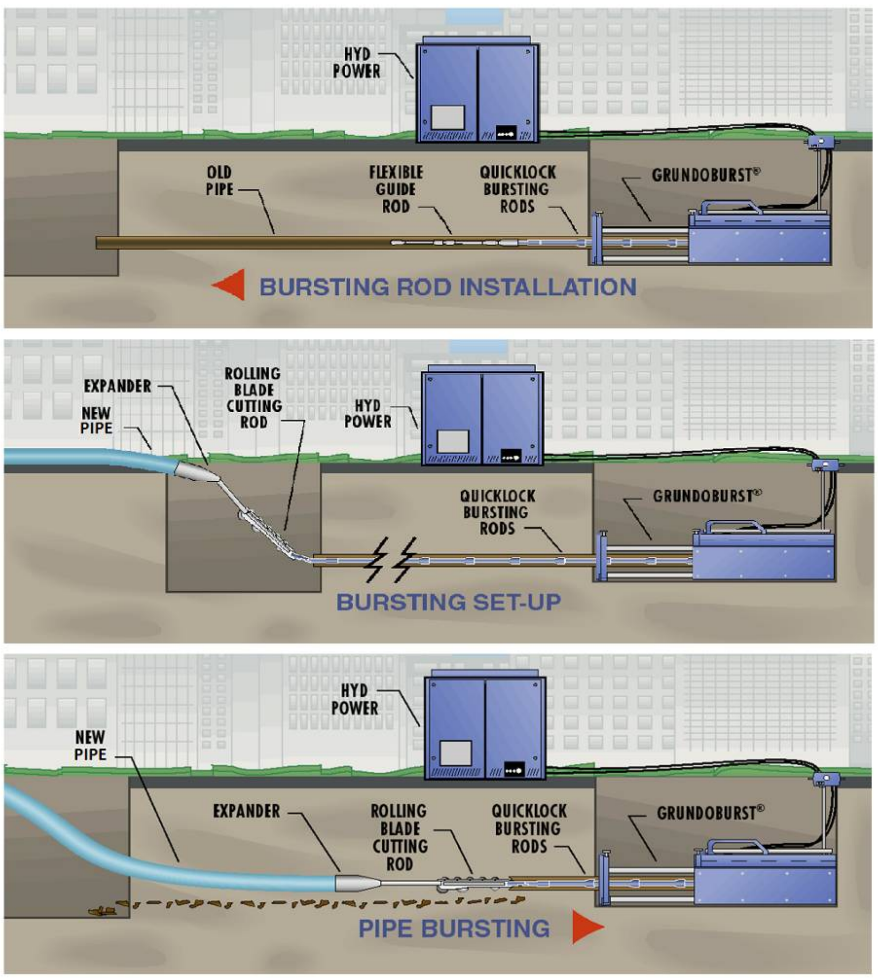

Figure 6. The static pipe bursting process illustrated (Botteicher et al. (6)).

Denver Water agreed to the use of FPVCP for the pipe bursting program and after evaluating whether or not a savings would be realized by using the pipe bursting rehabilitation method, Consolidated decided to embark on their first year of pipe bursting rehabilitation in 2010. Consolidated purchased fusion equipment and had employees trained in the proper procedure for the fusion process, thus bringing the pipe joining in house. They also purchased specialized pipe bursting equipment and trained their crew with the use of existing industry expertise including pipe and equipment suppliers, as well as a contractor that was familiar with pipe bursting potable water distribution piping on a commercial scale.

Consolidated's first year included many learning opportunities for the group on how best to manage the construction and the program. They learned how to effectively set up a temporary water system and move that system from block to block to follow the pipe bursting sequence. They learned how to manage the temporary service disruptions and construction impacts to their customers and shareholders. They also learned the most efficient way to manage the pipe fusion and staging, as well as movement and installation at the various locations of the required construction. Consolidated work for 6 months that first spring through fall of 2010 on their program, and were able to install all 24,000 LF of slated pipe replacement. Considering that the 24,000 LF had been planned for open cut, dig and replace construction practice for year round (12 months) work schedule, timing-wise the program was a huge success. When they evaluated the final accounting on what it cost them to install those 24,000 LF, they found that it was about half of what it cost them to do it by digging trenches.

Since 2010, Consolidated has maintained their program and expanded each year, targeting more water replacements and more footage. In 2014, their 5^{th} full year of the program, they are slated to install around 54,000 LF, or well over twice what they originally did the first year. They have added more equipment and labor each year, but they continue to gain in efficiency, which is what has allowed them to continue to see the continued success that they are currently seeing with pipe bursting and with their program. To date they have replaced over 145,000 LF or over 26 miles of their antiqued system. They also continue to save about 50 cents on every dollar compared to dig and replace technology over that same time, even in the face of rising operating costs.

The use of FPVCP for their pipe bursting program provides them with a familiar pipe material. A typical block of pipe bursting rehabilitation would proceed in the following manner. First the street is surveyed for existing utilities and the water system layout. A temporary water line is installed at grade along the street and commissioned. The ends of the pipe bursting runs are excavated and coincide with valves, tees, and bends – appurtenances that will not be 'burst through' but need to be removed. The service line connections to the existing water line are also exposed and reconnected to the temporary waterline. The temporary water runs back through the existing water service lines and meters, so there is no need to provide temporary metering or connections to the house. The new FPVCP pipe run is fused together and staged for insertion. The pipe bursting unit is placed on one end of the run and rods are fed back through the existing waterline. The new FPVCP pipe run is then attached to the rods and the pipe bursting train is pulled back through the existing line.

As the new pipe is pulled in, the existing pipe is fragmented and expanded into the surrounding soil. Once the new line has been installed, it is hydrostatically tested and disinfected. After the disinfection is confirmed, the new FPVCP pipeline is connected at the existing appurtenances using standard ductile iron fittings and restrainer glands, in the same manner that standard bell and spigot would be connected. The services are then taken off of the temporary water line and reconnected to the new pipeline using standard tapping saddles and equipment for PVC pipe. After all the service lines are connected and service is returned to all residents, the new pipe is bedded and backfilled at all required locations. Finally, all surface restoration is completed, including landscaping and asphalt resurfacing (see Figure 8).

By combining a new trenchless process with a well understood pipe material in PVC, Consolidated have sped the adoption of the installation method by their own crews and thus gained the labor, surface restoration, shareholder and constituent hassle, and overall cost savings that pipe bursting can provide to them.

Figure 8. Final restoration in areas of pipe bursting. Asphalt patches shown in relation to rest of street.

SUMMARY

Trenchless technologies used as alternate methods of pipeline installation have had a massive impact on the underground utilities industry over the last 20 to 30 years in North America. The water and wastewater industry has come to see the benefits of these installation methods, but it has taken some time for the industry find pipe materials that are capable of trenchless installations while at the same time are familiar to them and their experience.

When it comes to the three most common and popular installation methods for whole pipe replacement or installation, horizontal directional drilling (HDD), sliplining, and pipe bursting, FPVCP has provided a material that is both capable and familiar for water and wastewater industry professionals. FPVCP is providing not only a capable material, but one that is stretching the limits of trenchless thermoplastic installations. FPVCP has been used in some of the longest and deepest HDD installations ever completed by an uncased, thermoplastic pipe material, such as the PDX DE-Icing project. FPVCP is also providing a very familiar and compatible pipe material that fits within a utilities' comfort zone such as the successful and award winning Consolidated Pipe Bursting Rehabilitation Program.

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