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THE HILLS HAVE PIPES…AND THEY NEED TO BE REPLACED! – A TALE OF A WATER MAIN REPLACEMENT PROJECT IN A GEOHAZARD AREA IN BERKELEY AND OAKLAND

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ABSTRACT: East Bay Municipal Utility District (District) recently began construction for a multiphase High-Density Polyethylene (HDPE) water main replacement project in a fire-seismic geohazard zone known as the Panoramic Hill, located in the Cities of Berkeley and Oakland, California. The pipeline replacements are part of a $12M water system improvement project for the Panoramic Hill, which is a historic residential neighborhood with narrow, winding roads and only one entrance where traffic is limited to one direction at a time. Given its proximity to East Bay Regional Park District land and challenging access for the fire departments, the neighborhood has an extreme high fire risk. Additionally, the Hayward Fault Zone traverses the lower portion of the neighborhood. To improve the reliability of the area's domestic and emergency water service, the District will replace approximately 7,800 feet of primarily 4-inch unlined cast iron water mains with 2- to 12-inch HDPE pipe. This paper will discuss the project's planning and design phases, including full-scale HDPE testing to verify the minimum bend radius for installation of electrofusion service saddles. This paper will also provide insight on multi-city coordination and lessons learned through the permitting process, and detail some preliminary construction challenges and how they were addressed.

1. INTRODUCTION

The District provides water and wastewater services to the eastern region of the San Francisco Bay Area in California. The District's potable water sytem provides drinking water to 1.4 million customers within its 331-square-mile service area. The service area spans portions of Alameda and Contra Costa Counties and contains 6 treatment plants, 167 reservoirs, 136 pumping plants, and approximately 4,200 miles of distribution pipelines. Among the active distribution pipelines, 34% are older cast iron pipes primarily installed between the 1920s and 1950s and many of these are in need of replacement. In order to improve pipeline replacement project efficiencies and deliver more cost effective projects, the District has recently developed larger replacement projects by selecting clusters of pipelines that are in poor condition instead of picking shorter segments of pipes to replace. These pipeline clusters are selected based on risk scores, which are determined by analyzying likelihood and consequence of failure. One such pipeline replacement cluster project that is currently in construction is the Panoramic Hill Pipeline Replacement Project.

2. BACKGROUND

Panoramic Hill is a historic residential neighborhood with approximately 122 residences spanning portions of the Cities of Berkeley and Oakland, located above the University of California, Berkeley (UCB) California Memorial Stadium. The Hayward Fault Zone is located near the bottom of the hill and East Bay Regional Park District land surrounds the neighborhood, as shown in Figure 1. The single point of entry is Panoramic Way, a steep and narrow road with multiple switchback turns where traffic is limited to one direction at a time. Given that the community is located adjacent to the wooded Claremont Canyon Regional Preserve and has limited access for fire departments, Panoramic Hill has an extreme high fire risk category designation. Due to the community's fire and seismic risks, it is critical to provide reliable water service in this area.

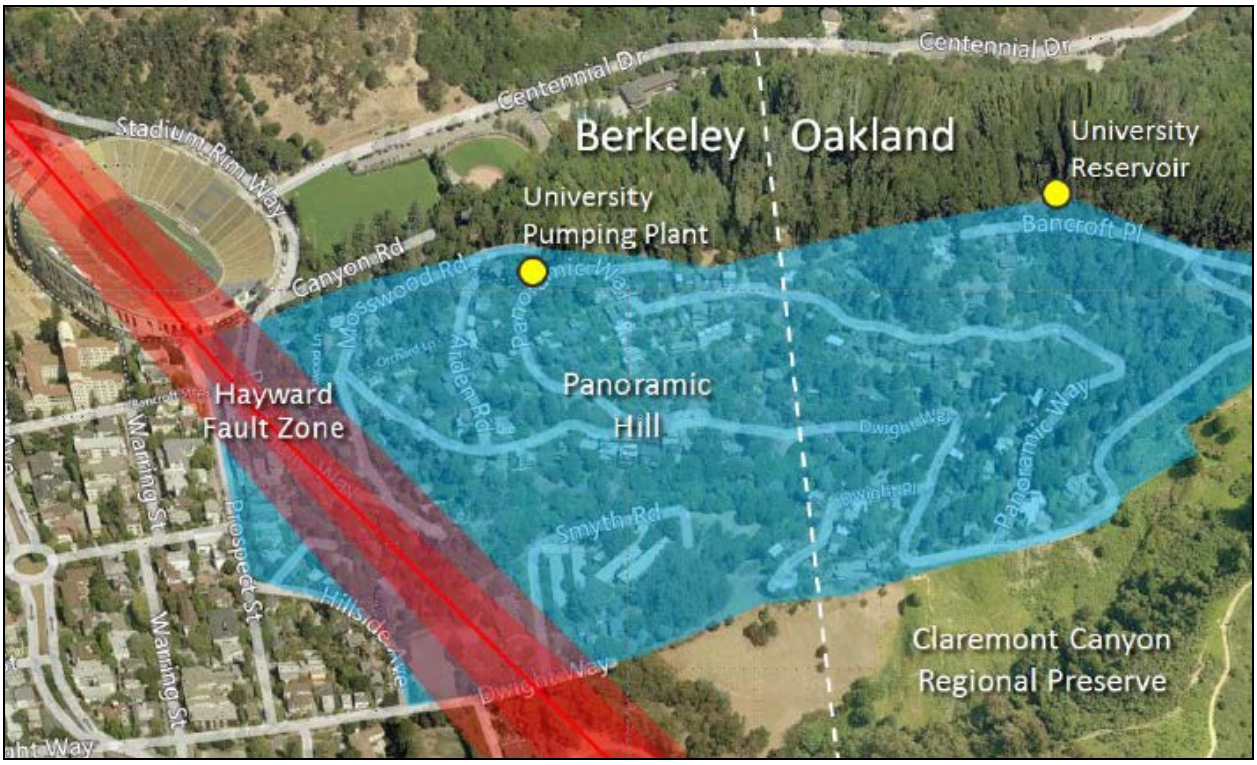

Figure 1. Panoramic Hill Location Map

Existing District facilities serving the neighborhood include a reservoir, a pumping plant, and a network of pipelines. These facilities are over 50 years old and in poor condition, and therefore need to be replaced. To improve the reliability of the area's domestic and emergency water service, the District has initiated a water system improvement project for the Panoramic Hill estimated at $12M. The project will replace the existing reservoir with two smaller tanks, the existing pumping plant, and the majority of the water mains on the hill. The focus of this paper will be the water main replacements.

3. PROJECT DEVELOPMENT

Most of the pipelines on Panoramic Hill are 4- and 6-inch unlined cast iron pipes that were installed in the 1940s or earlier. These pipes are likely to have significant interior corrosion and reduced interior diameters. Furthermore, the existing pipes in the vicinity of the Hayward Fault Zone have a history of leaks and are in need of replacement. After completing a cost benefit analysis of the historic maintenance costs and anticipated future repair costs for this area and comparing them to the cost of

immediate pipeline replacements, approximately 7,800 feet of water mains on Panoramic Hill were selected for replacement as part of the Panoramic Hill Pipeline Replacement Project.

Initial steps in the planning and design process included determining the pipeline replacement material and replacement construction method. Since the neighborhood is in a seismic area, HDPE pipe was selected as the pipeline replacement material for its flexibility and resilience to ground movement. After confirming the pipeline material, District staff conducted hydraulic analyses to adequately size the replacement pipelines to meet minimum fire flow requirements. The recommended replacement pipe sizes range from 2- to 12-inch DR-11 PE4710 HDPE pipe. Given the narrowness of the roads in Panoramic Hill, pipe bursting installation was evaluated as an alternative to open cut trench pipeline construction for these pipe replacements in an attempt to minimize the temporary construction traffic impacts. Several components were considered during this evaluation including existing water main depths, horizontal clearances from other utilities, number of service transfers, and potential temporary main locations. Ultimately, it was concluded that pipe bursting was not feasible for this area due to existing utility congestion, short potential bursting lengths constrained by the winding roads, the potential for ground heaving, and the large number of service transfers required. Thus, design proceeded with respect to an open cut trench pipeline installation method.

A critical design consideration for this project was the minimum allowable bending radius for pipe with and without fittings or flanges present. Industry advice for the minimum bending radii of HDPE pipes is given as a ratio of the radius of the bend over the diameter of the pipe, as shown in Equation 1.

$$\alpha = R/D \quad [1]$$

α is the minimum bending ratio
R is the radius of the bend
D is the outside diameter of the pipe

For DR-11 pipes, the value is R/D = 25 (The Plastics Pipe Institute, Inc.). For a nominal 6-inch pipe, the outside diameter is 6.625 inches and the minimum bending radius is 13.8 feet. The minimum bend radius is related to strain as described in Equation 2.

$$\varepsilon = r/R \quad [2]$$

ε is the strain in the pipe
r is the outside radius of the pipe
R is the radius of the bend

For 6-inch pipe, the radius is 3.313 inches (or 6.625 inches divided by 2) and the minimum bending radius is 13.8 feet. Using Equation 2, the strain is calculated to be 0.02, or 2 percent. The maximum strain is 2 percent for pipe of any diameter or thickness with the same bend ratio.

HDPE pipe is flexible, and when it is bent into a curve it will flatten or ovalize and eventually buckle on the inside of the curve. Thicker pipes (of equal diameter) are more resistant to ovalization and buckling, so the minimum bend for a DR-9 pipe is 20 times the OD (The Plastics Pipe Institute, Inc.). For a 6-inch DR-9 pipe, the minimum bend is 11.0 feet with a corresponding maximum strain of 2.5 percent.

The guidance described above is limited to prismatic pipes. When there is a change of section, as occurs at a fitting or flange, then the moment required to make the smooth circular curve must be higher and the adjacent pipe will be exposed to strains exceeding 2 percent. For this reason, industry advice is to increase the bending ratio to 100 at fittings and flanges for a distance of about 5 times the pipe diameter on either side of the fitting location (The Plastics Pipe Institute, Inc.). Anything placed on the pipe after shaping to the curve on either side is acceptable.

The roads in the Panoramic Hill neighborhood are narrow, winding, and congested with other utilities, so the initial proposed pipe alignment included bends following the tight curvature of the road. While this

level of pipe bending is acceptable per the pipe bending ratio, it is not acceptable when fittings or flanges are introduced. In the latter case, the pipe must be significantly straightened out to increase the bending ratio and reduce the strain on the pipe with fittings. Since this is a residential neighborhood with approximately 122 customers, the required service saddle connections along the pipe restrict the bending radii that can be used throughout the alignment. As the design developed, so did the challenge to adhere to the minimum bending ratio for fittings and the curvature of the road. Prior to this project, the District had minimal experience with designing or installing HDPE pipe in curved alignments, and therefore District staff reached out to industry professionals and HDPE manufacturers to ask for clarification about the bend limitations that should be observed for service saddle installations. Unexpectedly, there was some discrepancy between the manufacturer's recommendations and the industry advice discussed previously. Manufacturers claimed that the service saddles could be installed on pipe bends as small as the minimum allowable bends for the pipe. In order to confirm the minimum bending radius to which an electrofusion service saddle could be applied, District staff developed and performed a full-scale HDPE bend and tapping test. Details about the test and results are discussed in the following section.

DISTRICT BEND AND TAPPING TEST

The District sought to verify the aforementioned bend limitations with a full-scale HDPE bend and tapping test. District staff excavated, installed, and buried a 6-inch DR-11 PE 4710 HDPE pipe with varying bend radii: 14.2 feet (α = 26), 33.6 feet (α = 61), and 53.25 feet (α = 96). The pipe was filled and pressurized and allowed to relax for 14 days. Then District staff excavated and installed electrofusion service saddles on the inner and outer parts of the curve for each of the three radii. Victaulic couplings were used as re-rounding tools on the pipe at each installation location. After observing the proper electrofusion cooling time, each saddle was hydrostatically tested at 200 psi for 5 minutes to ensure that the saddle was fully fused to the pipe and that it could hold water pressure. All six of the saddles passed the hydrostatic test in the field. These saddles were cut out two days after installation and then destructively tested two days later per ASTM F-1055 in the District's Machine Shop. The destructive test consists of placing a saddle joint specimen in a vise and closing the jaws of the vise on the pipe until the inner walls of the pipe meet. If the saddle separates from the pipe at the fusion interface, it is considered a failure. The results from the District's tests are summarized in Table 1.

Table 1. Electrofusion Service Saddle Destructive Test Results

Bend Radius	**Destructive Test Results**	
	Service saddle on inside of curve	**Service saddle on outside of curve**
14 feet (α = 26)	Pass	Fail
34 feet (α = 61)	Pass	Fail
53 feet (α = 96)	Pass	Pass

The District's results validate the industry recommendation that the bending ratio should be about 100 when fittings are present in the bend. Based on the results from these tests, the District adopted the industry HDPE bending requirements as described earlier in this paper. District staff revised the design alignment for the Panoramic Hill pipeline replacements prior to issuing the job to construction in order to comply with these verified bending requirements. The design was adjusted by straightening out the pipeline alignment in accordance with the bending requirements and inserting additional fabricated elbows to angle the pipe around the winding curves. Although the bending ratio of the pipe does permit bending the pipe itself around windy roads, the bending radii that can be observed in residential areas is limited by service saddle connections.

4. COORDINATION WITH CITIES AND OTHER AGENCIES

There was a considerable amount of coordination required for this project with the respective cities and other agencies. This section will summarize the coordination efforts.

Due to the narrow widths of the roads in Panoramic Hill, road segments within the vicinity of the pipeline work must be closed to vehicular traffic during construction. The average road width in this neighborhood is only approximately 16 feet, which is too narrow to maintain a lane for traffic while having an open trench. Therefore, the pipeline replacement work was split up into various phases as summarized in Figure 2 to minimize road closure impacts on the community and the road closure hours are limited to 9 am to 4 pm. In order to maintain a traffic detour for residents to access all parts of the hill during the majority of the pipeline construction, Phases 1 and 2 will not be constructed simultaneously and the two portions of Phase 2 will be constructed separately. Phase 3 will shut down the only entrance to the hill, so the District coordinated with the City of Berkeley and Berkeley Fire Department to develop an agreement for providing standby emergency responders during this work phase. The District will pay the Berkeley Fire Department to station two fire personnel and two paramedics in their vehicles above the work zone each day that the road is closed during Phase 3. This will prevent emergency responders from being blocked or delayed by the pipeline construction in a medical or fire event. The project schedule was adjusted to allow the Berkeley Fire Department adequate time to secure and acquire appropriate equipment for this effort.

To reduce the burden of the Phase 3 construction on the community, the District will reopen the road each day from 12 pm to 1 pm to allow residents access in and out of the hill. Additionally, the District will provide temporary parking passes to the residents by request, so that they can park their vehicles outside the hill near the entrance and have access to them throughout the day during the Phase 3 work. The District met with the community ahead of construction to discuss the project and road closure impacts. Due to the size of the project disruption, a District community affairs representative is providing frequent updates to the community throughout construction to keep them apprised of closure locations and dates. Separately, the District also coordinated with Berkeley and Oakland waste management and recycling services to schedule pick-ups on Monday mornings before the 9 am road closure start, so that the service trucks would not be impacted by any of the pipeline construction.

Figure 2. Panoramic Hill Water Main Replacement Construction Phases

Since the project spans two cities as shown in Figure 2, the permit efforts for this job had to be duplicated for both Cities of Berkeley and Oakland. Typically following pipeline construction, the District is responsible for restoring the asphalt pavement in the areas where project trenching occurred. However, the City of Berkeley plans to rehabilitate the roads in the Berkeley portion of Panoramic Hill in 2018, following the District's water pipeline replacement project. The City of Berkeley instead requested a cost-sharing pavement restoration fee that can be used for rehabilitating these streets in 2018. After some negotiation about the interim pavement maintenance terms, the District and the City of Berkeley reached an agreement. The District will install a temporary paving patch prior to completing the pipeline project in fall 2017 to provide the community with a serviceable road until the City of Berkeley paves in 2018. In lieu of providing the City of Berkeley's standard asphalt pavement restoration over the trench area, the District will pay a restoration fee based on the cost it would have otherwise incurred. This agreement allows the District and the City of Berkeley to consolidate the asphalt pavement repair and pavement rehabilitation into a single construction effort to minimize impacts to the community. Partnering with the City of Berkeley on the pavement rehabilitation will also support sustainable practices by conserving oil resources required for asphalt production and reducing greenhouse gas emissions from additional truck hauling. Furthermore, this agreement eliminates final paving from the District's scope of work and will shorten the District's construction period on Panoramic Hill. City of Oakland is currently working with the District to develop a similar agreement. These paving agreements will provide the community with new paved roads for the entire alignment of the pipeline construction, along with the new water infrastructure.

Although District staff started the city coordination and community outreach efforts early on in the planning stage of the project, these components continued to be significant elements of the project throughout design and into the initial stages of construction. The City of Berkeley paving agreement took time to develop and negotiate, which delayed the issuance of the Berkeley permit. Consequently, the District pushed back the project construction start date and eventually re-sequenced the work phases to start work on the Oakland side of the hill to keep the project moving forward while finalizing the agreement with Berkeley. The execution of the Berkeley paving agreement prompted City of Oakland to consider a cost-sharing paving agreement as well. For such a large job with various stakeholders, it is crucial to start outreach and coordination efforts early on to work through all of the details well in advance of construction. It is also important to carefully document ideas and communication in meeting minutes, so that verbal agreements and decisions can be carried forward despite staff turnover or other changes. Additionally, project decisions may be challenged along the way, so it is important to maintain the documents that are able to defend them.

In addition to working with two cities, the District also coordinated with UCB. UCB owns the Upper Jordan fire trail land near Bancroft Place, where the District recently installed a 12-inch HDPE pipe as part of the Phase 1 pipeline work. During design, the District worked with UCB to secure an easement for the new pipeline. The District also negotiated an agreement with UCB to use a portion of Prospect Court, a narrow access road outside of the California Memorial Stadium, as a staging area during the project construction. This staging area will be a critical fusion location during the Phase 3 pipeline work, as there are no other laydown areas close to the entrance of the hill. The Prospect Court staging area cannot be used during UCB's football season or other stadium events, so the construction schedule was adjusted such that the Phase 3 work will occur outside of the August to December football season. Additionally, the District negotiated with UCB to secure an offsite staging area owned by UCB at Fernwald Road to store equipment and materials throughout the project.

Besides the agencies having jurisdiction of the land in the project area, the District also worked with P&F Distributors on this project. P&F will provide third party support services to the District to ensure the proper installation of HDPE electrofusion service saddles. Prior to installations, P&F provided a preconstruction meeting for District staff to review the proper electrofusion installation techniques for HDPE service saddles. With P&F's help, the District developed a detailed inspection checklist for the installation of the electrofusion service saddles. P&F will provide guidance and support during installation and oversee hydrostatic tests on each service saddle prior to the District tapping the service. Upon completion of the service connections, P&F will lead a post construction meeting to discuss the lessons learned. These support services and supplemental meetings will help to verify the integrity of the HDPE service saddles installed on Panoramic Hill. Additionally, the guidance provided by P&F will help District

staff become more proficient at installing HDPE electrofusion service saddles and inspecting these installations in the future.

5. CONSTRUCTION

Pipeline construction commenced in July 2016 and is ongoing at the time that this paper was completed. Despite a few initial challenges, the District has continued to work through the job and make consistent progress toward completion.

Soon after construction began, it became clear that there would be significant challenges with transporting pipe up through the winding, narrow roads. District staff explored several options for transporting the standard 40-foot long HDPE pipe segments. Options included using a crane to lift pipe above the Panoramic Way switchback turns, bringing pipe through the fire trail near Bancroft Place, and using a pipe dolly through Panoramic Way. After taking turn radius measurements and analyzing each of these options, District staff concluded that none of these alternatives were feasible. The pipe dolly option was the most practical, but the second switchback turn on Panoramic Way was too tight of a turn to make it with the 40-foot long pipe. Instead, District staff had to cut the pipe in half before delivery through the neighborhood. Cutting the pipe requires additional labor, and the shorter pipe segments require twice the number of fusions to install the pipe.

The District then began exploring the idea to airlift pipe to the top of the hill. After extensive permitting and outreach efforts with City of Berkeley, City of Oakland, the Federal Aviation Administration, fire and police, and the Panoramic Hill neighborhood, the helicopter delivery plan was put into action. On Wednesday, September 21, 2016, District crews assisted a qualified contracted helicopter transport company to airlift 2,500 feet of HDPE pipe in 16 bundles to the top of the hill. The pipe was taken from below the hill at Fernwald Road to Panoramic Way at the edge of the canyon. Figure 3 shows the helicopter flight path described above. The helicopter transport of one of the 16 bundles is shown in Figure 4, and the delivery location on Panoramic Way is shown in Figure 5.

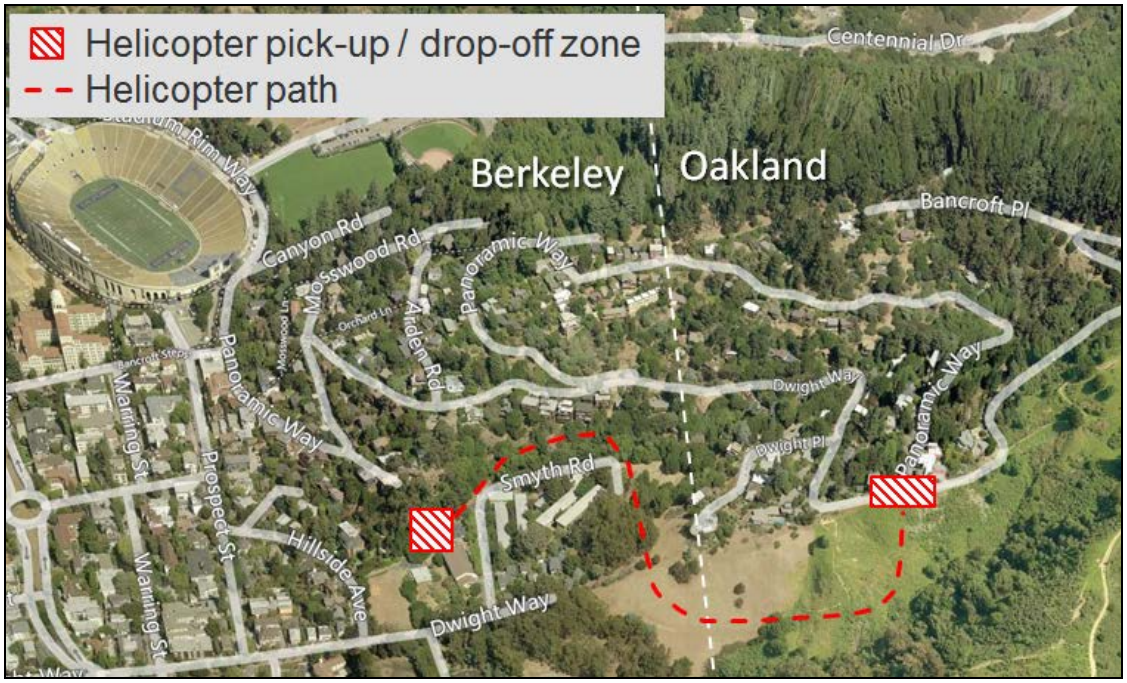

Figure 3. Helicopter Flight Path for Delivering Pipe to the Panoramic Hill Pipeline Replacement Project

Figure 4. Helicopter Delivering Bundle of HDPE Pipe for the Panoramic Hill Pipeline Replacement Project

Figure 5. Airlift Delivery Location on Panoramic Way for the Panoramic Hill Pipeline Replacement Project

The helicopter delivery eliminated the need to cut the HDPE pipe into shorter segments that could be trucked up the hill, reduced labor that would otherwise have been required to fuse the segments back together, and will reduce the overall project duration on the hill. The helicopter contract cost approximately $20,000, which comes out to $8 per foot for the time-saving delivery of the pipe.

6. NEXT STEPS

Based on the research and the bend and tapping test conducted in support of the project design, the District refined its HDPE design standards and specifications for bending pipe with and without fittings. The District also produced inspection checklists for electrofusion service saddle and coupling installations from the information gathered. These checklists were reviewed by members of the Municipal Advisory Board (MAB) and will be piloted by other MAB members.

In addition to the District's HDPE design developments, this project has been beneficial because it brought many groups within the District together to resolve issues related to HDPE installation. There were several internal constructability review meetings with District Engineering, Construction, and Maintenance staff and countless coordination and outreach meetings held throughout the design process to discuss the project details. Having this multidisciplinary project team enabled the District to work more effectively with the various cities and agencies involved, since all components of the project could be discussed. The District's Engineering group will continue to work with Construction and Maintenance to improve the District's design and construction practices on future projects.

At the time that this paper was completed, the Phase 1 pipeline construction was nearing completion. The overall project completion is anticipated for fall 2017. Another paper focused solely on the project construction will be submitted after construction completion.

7. REFERENCES

The Plastics Pipe Institute, Inc. "Underground Installation of PE Piping." Chapter 7 in *The Plastics Pipe Institute Handbook of Polyethylene Pipe*, 2nd ed., 291-292, <http://plasticpipe.org/pdf/chapter07.pdf> (Jan. 10, 2017).