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King County uses Large Diameter On-Grade HDD to Reduce CSOs

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1. ABSTRACT

King County owns and operates a combined sewer in Magnolia, a neighborhood in Seattle, WA. The sewer currently exceeds maximum capacity during peak storm events causing combined sewer overflows (CSOs) into Elliott Bay. King County is under a consent decree to limit CSOs to one per year by December of 2015. The Magnolia CSO Conveyance Pipeline project was designed to capture excess flows during storm events and transfer them to a 1.5 million gallon storage tank where they remain until the flow within the sewer conveyance system subsides and is able to accept the stored volume from within the storage tank.

This case history details the design and construction of the gravity conveyance pipeline, approximately 3,000 feet long. The pipeline was originally designed as an on-grade horizontal directional drill (HDD); however, at 60 percent design a value engineering study was conducted and Direct Pipe was suggested as an alternative to HDD. King County decided that it was in their best interest to specify both methods, bidding the two trenchless methods against one another to increase the bidder pool and competition for the project.

This paper describes the development of the competing technologies in the bidding phase as well as the bid evaluation process and results. Construction of the pipeline will also be presented, providing details on how the contractor was able to maintain line and grade at depths exceeding 100 feet. It also provides details on bore stability with significant elevation differences from entry to exit.

2. INTRODUCTION

This project is part of a long-term King County plan to help protect Puget Sound and control combined sewer overflows (CSOs) in local waterways. When completed, the project will meet current Washington Department of Ecology requirements of no more than one CSO discharge per year on a long-term average. The project is included in a federal consent decree that required completion of the project by December of 2015.

The project included the construction of a 3,074-foot pipeline that delivers excess flows from the approximate location of the existing CSO diversion structure to a 1.5 million gallon storage tank. The tank holds the excess combined sewage until the flows in the existing sewer conveyance system decreases. The stored combined sewage is then pumped from the storage tank to the existing sewer, which then flows to the treatment plant. A map showing the general location of the project area can be seen in Figure 1.

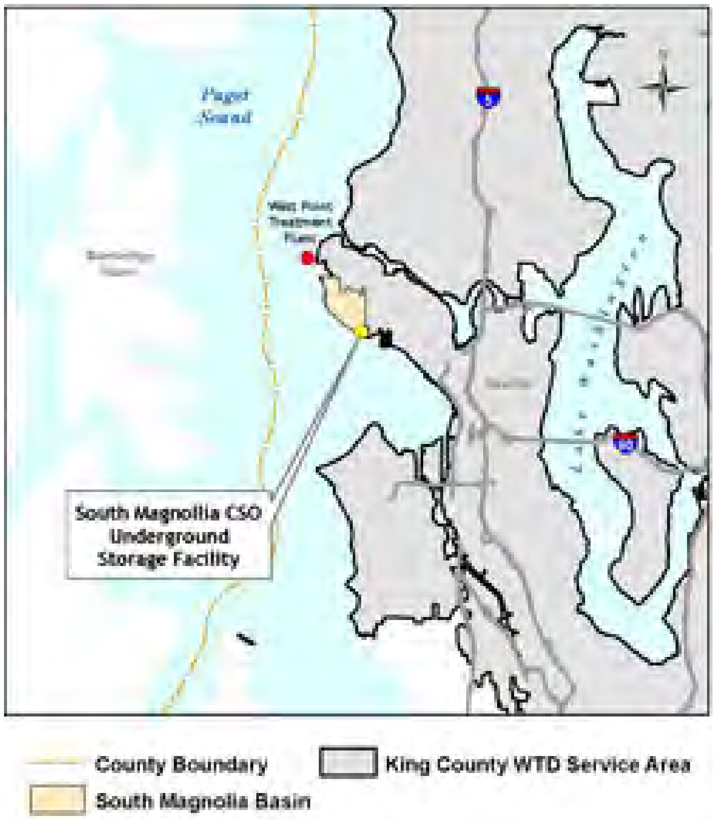

Figure 1. Project Location

Prior to the construction of the project, the sewer system would route sanitary and storm flows within the basin to 32nd Ave West (located on the western boundary of Figure 2), where a diversion structure (marked Existing Diversion Structure) would direct low flows to the South Magnolia Trunk Sewer and overflows to the Puget Sound.

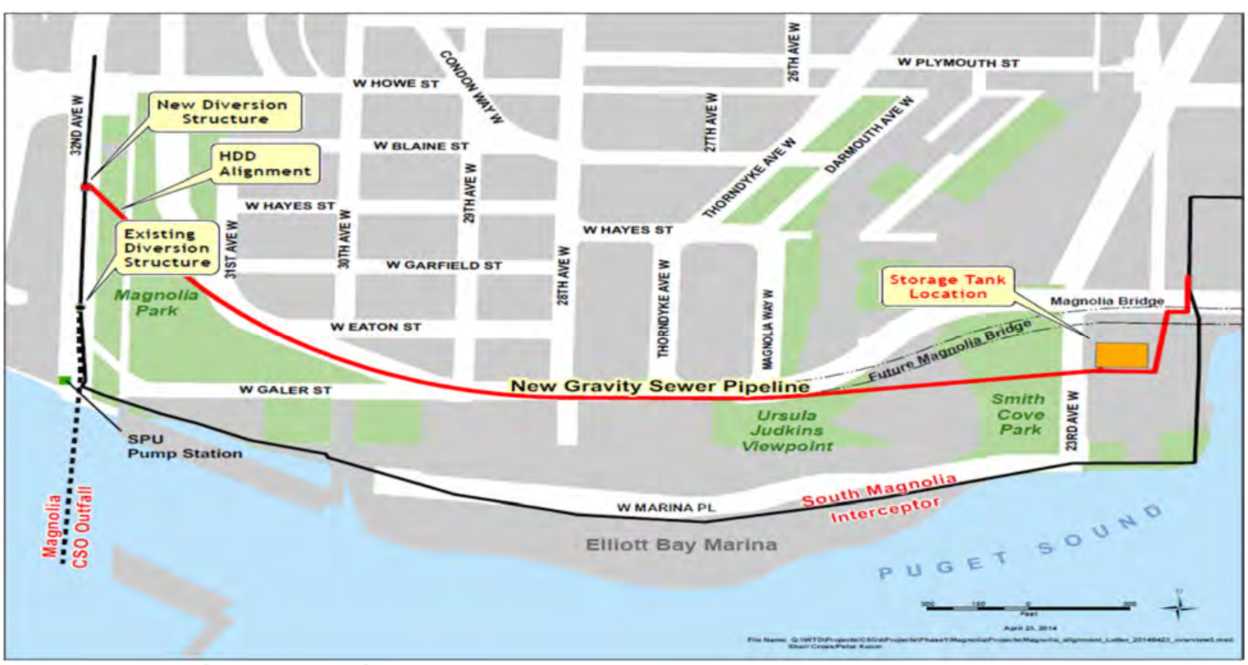

Figure 2. HDD and Direct Pipe Alignments

3. GEOTECHNICAL CONDITIONS

The geotechnical conditions along the project site are characterized by soils of glacial origin. The soils generally consist of glacial till underlain by glacial outwash and glacial clays. Magnolia Bluff is often referred to as having a glacial till cap. The topography along the pipe alignment is highly variable with 10 to 20 feet of cover at either end and a mid-depth of over 160 feet. The steep hillsides have resulted in slope instability and historical landslide scarps found throughout the project area. Remedial measures, such as drains and retaining walls, have been constructed in the project area to increase slope stability. A profile of the geotechnical conditions is found in Figure 3.

The extensive geotechnical investigation that was performed for the project revealed that the glacial outwash contained very dense, silty sand with trace gravel. The glacial clay was characterized as very stiff to hard sandy silt, clayey silt, and silty clay. (Shannon & Wilson, 2009).

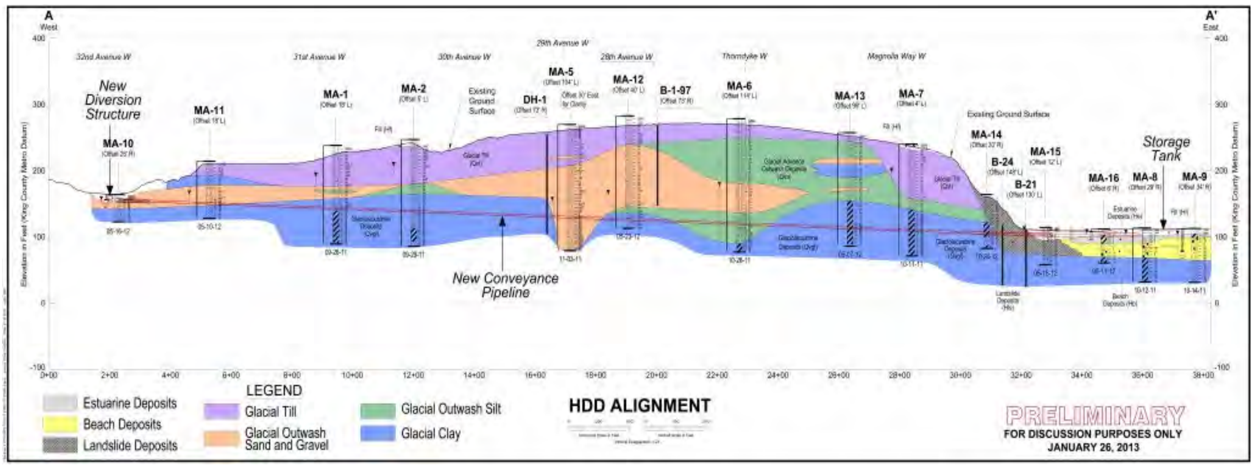

Figure 3. Geotechnical Profile along HDD Alignment

4. CHOICE OF TRENCHLESS METHOD

A number of trenchless techniques were considered for the construction of the 3,074-foot pipeline. HDD was evaluated and was found to be feasible in the site soils. However, there were many challenges to the HDD alternative including a 40-foot elevation difference from entry to exit, the need for the pipe to sustain gravity flow within tight tolerances, a relatively tight bend radius to remain within the public right-of-way, and the necessary installation of conductor casings on both the entry and exit sides. Additionally, King County was concerned about fostering a competitive bidding environment if only one technology was specified. King County's history includes successful completion of a number of challenging HDD projects; however, the competitive bidding environment on these projects has been limited. This led the design team to investigate alternative trenchless installation methods.

For a gravity installation through the hillside that was over 150 feet deep, open cut was not a viable construction alternative. Open cutting and installing the gravity sewer following the path of the existing sewer was also considered as an alternative. Although deep excavation was not necessary, this alternative required construction within the water, under private boat launches, and through the marina. As such, this alternative would spawn many permitting requirements as well as create strong public resistance.

Tunneling with an earth pressure balance (EPB) shield and pre-cast liner segments was considered feasible; however, the minimum diameter of an EPB shield is approximately 10 feet to allow assembly of the segments. Since the required flow diameter was only 28 inches, it was clear that the EPB, segmentally lined tunnel would not be cost competitive with other trenchless alternatives.

Microtunneling was evaluated and was considered feasible in the site soils. However, the design team concluded that the microtunneling machine would need to have a minimum diameter of 54-inches to provide enough space to house a motor capable of crushing cobbles and boulders that are known to exist within glacial outwash in the Pacific Northwest. Due to the length of the bore, it was decided that a prudent design would include an intermediate shaft, splitting the drive into two 1,500-foot drives. This intermediate shaft could also be used to evaluate the wear on the head of the microtunneling machine and change or adjust cutters at the mid-point of the bore. Although an intermediate shaft appeared to be technically favored, this shaft would be approximately 150 feet deep – a significant excavation and cost component for the project. In addition, there was no "good" location for the intermediate shaft as the tunnel traversed beneath a well-established neighborhood that was very congested and a historic park. The microtunneling alternative with an intermediate shaft was sure to create strong public resistance.

Direct Pipe was then considered as it allowed the use of microtunneling technology without the need for deep entry, exit or intermediate shafts. The Direct Pipe alternative could provide excellent line and grade control for the gravity combined sewer application and could be designed from two relatively shallow shafts on either side of Magnolia Bluff. As with microtunneling, a minimum diameter machine would be required and specified to ensure that the machine was capable of crushing cobbles and boulders known to occur in the glacial outwash deposits. A larger machine was also necessary to allow the installation of booster pumps within the tunnel to ensure that the hydraulic components of the machine were functioning. Without booster pumps, the hydraulic head losses in the hydraulic lines would result in a machine that was unable to function.

After intense evaluation and comparison, the County decided to design both HDD and Direct Pipe, letting the Contractor select their preferred method at the time of bid. Each of the designs had a number of nuisances that were method-specific. For example, the HDD alternative required the construction of a new diversion structure whereas the Direct Pipe alternative allowed use of the existing diversion structure. Each of these factors impacted the cost of the option. A complete overview and evaluation of the trenchless method selection process is detailed in Wetter et al. (2013).

5. BIDDING THE PROJECT

After much analysis and deliberation within the project team, the County decided to prepare two sets of contract documents – one for HDD and the other for Direct Pipe. Contractors could evaluate both sets of bid documents, decide which technology they preferred, and bid the project accordingly. This approach allowed the market to drive the selection of the trenchless technology installation method.

Contractor experience qualifications were very important to the County, yet difficult to specify, particularly for Direct Pipe. King County typically does not use a traditional pre-qualification process. Instead, they include a qualification section within the bid documents that specifies the minimum level of experience for the contractor performing the trenchless work. Once the bid is opened, the low bidder and second low bidder are required to submit their qualification information within a limited time period (typically 24 to 48 hours) and the County evaluates the contractor submittal to ensure that the qualifications are met. If the qualifications are not met by the bidder, the bid is considered non-responsive.

Minimum HDD qualifications were relatively simple to draft; however, in the case of Direct Pipe, this method is relatively new and less than 10 installations in the United States had been completed at the time of the design. In addition, the Direct Pipe installations that had been installed in the US were much shorter than was specified for this project. Therefore, a severely limited number of Contractors could provide qualifications based on Direct Pipe experience. Because Direct Pipe is essentially microtunneling with a different thrusting mechanism than traditional microtunneling, the Direct Pipe qualifications were largely based on microtunneling qualifications at the specified diameter of the Direct Pipe option.

King County is bound to accept the low responsive bid on public projects. As such, it was not until bid date that the trenchless method for construction was selected. When bids were received, the low bidder was general contractor Walsh Construction with Mears Group as their primary sub-contractor. The bid indicated that HDD methods would be used to install the conveyance pipeline. There were several other bidders who bid the Direct Pipe alternative; however, the bids for Direct Pipe were several million dollars higher than those with the HDD alternative.

6. HDD DESIGN ATTRIBUTES

The HDD design had many interesting features that were unique to this project. The installation of a large diameter pipe for a gravity application is relatively rare for HDD technology. The design was intended to maximize the slope of the pipeline within the constraints of the design. It was also desirable to keep the bore within the public right-of-way as much as possible to minimize the number of private easements that had to be obtained by the County. Clearly the most simple bore geometry would have been a straight trajectory between Smith Cove Park and the existing diversion structure (See Figure 2). However, this resulted in a slope less than one percent. 32nd Avenue West is a gully that is flanked by steep hillsides and slopes downward toward Elliot Bay; therefore, the bore exit was moved upslope on 32nd Avenue West to increase the slope between entry and exit to 1.8 percent.

Although HDD is typically a surface-to-surface installation, shafts were designed at each end of the bore due to the topography, site constraints, and need for a gravity pipeline. At the upper end of the bore, a curve was introduced that allowed the shaft on 32nd Ave West to be constructed in only one lane, requiring a temporary traffic road revision to pass two way traffic open during construction, as shown in Figure 4. At the lower end of the bore, in Smith Cove Park, a shaft was designed to accommodate a rig, allowing the Contractor to use the shaft for the on-grade installation should they choose.

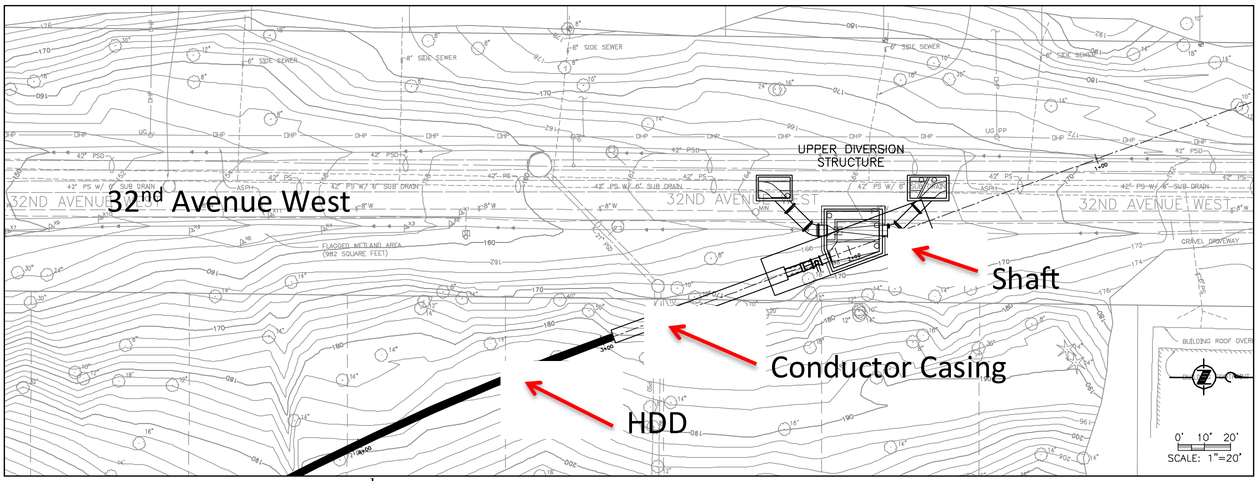

Figure 4. Location of Shaft on 32nd Avenue West (upper end of bore)

Conductor casings were designed at the upper and lower end of the bore to traverse the hillsides due to historic landslide activity and reduce the potential for inadvertent returns. The casings were designed with a minimum 60-inch diameter, although the Contractor could select a larger diameter at their discretion. Conductor casings were 65 feet long at the upper end of the bore and 200 feet long at the lower end of the bore. The conductor casings were specified as auger bore installations in lieu of pipe ramming to prevent the construction vibrations from impacting slope stability along the steep slopes found at the upper and lower ends of the bore. Once the conductor casings were installed, the design called for contact grouting on the outside of the casings to prevent the creation of a preferential flow path along the outside of the casing. Along with protecting the landslide-prone slides, the conductor casings also reduced the risk of hydro-frac to the ground surface.

The design contained specifications for two pipe materials: high density polyethylene (HDPE) and fusible polyvinyl chloride (FPVC). The designed minimum thickness for the HDPE was 4 inches, yielding a flow diameter of approximately 28 inches and an outer diameter of approximately 36 inches. The FPVC wall design was much thinner, on the order of two inches, due to the higher strength properties of the material. With FPVC the pipe flow diameter was approximately 28 inches, with an outer diameter of 32 inches. Either pipe could be installed with a one-pass method. The County decided to leave the choice of material to the Contractor to allow the market to drive the selection of the pipe material.

The slope tolerance of the pipeline was very important to achieve the design hydraulic capacity of the system. The design called for a slope ranging from 1 to 3 percent over two drill pipe joints (approximately 60 feet) with no reverse slope allowed along the alignment. The upper end of the bore was the most sensitive to grade deviations because a slope less than one percent had the potential to markedly decrease the hydraulic capacity of the system. Due to the importance of the grade, the contract called for monitoring the location of the bore during both the pilot and reaming passes to monitor the grade during all phases of the construction. The contract documents specified that the borehole remain full of drilling mud during all boring operations. It was incumbent upon the contractor to develop a way to achieve these results.

7. CONSTRUCTION

Construction of the pipeline began in August 2014 with installation of the conductor casings. The conductor casings were designed to isolate the slope from pressurized drilling fluid. Auger boring techniques were used to install the conductor casings and the annular space on the outside of the casing was grouted per specification. The conductor casing within Smith Cove Park was installed with auger boring first, followed by construction of the conductor casing in the shaft on 32nd Avenue West.

Unlike the presumption of the designers, the Contractor did not use the shaft within Smith Cove Park to start the pilot bore. Instead, they moved the equipment back (east) of the design starting point and set up the drill rig on the surface. They then drilled down to design elevation, intersecting the shaft, as shown in Figure 5.

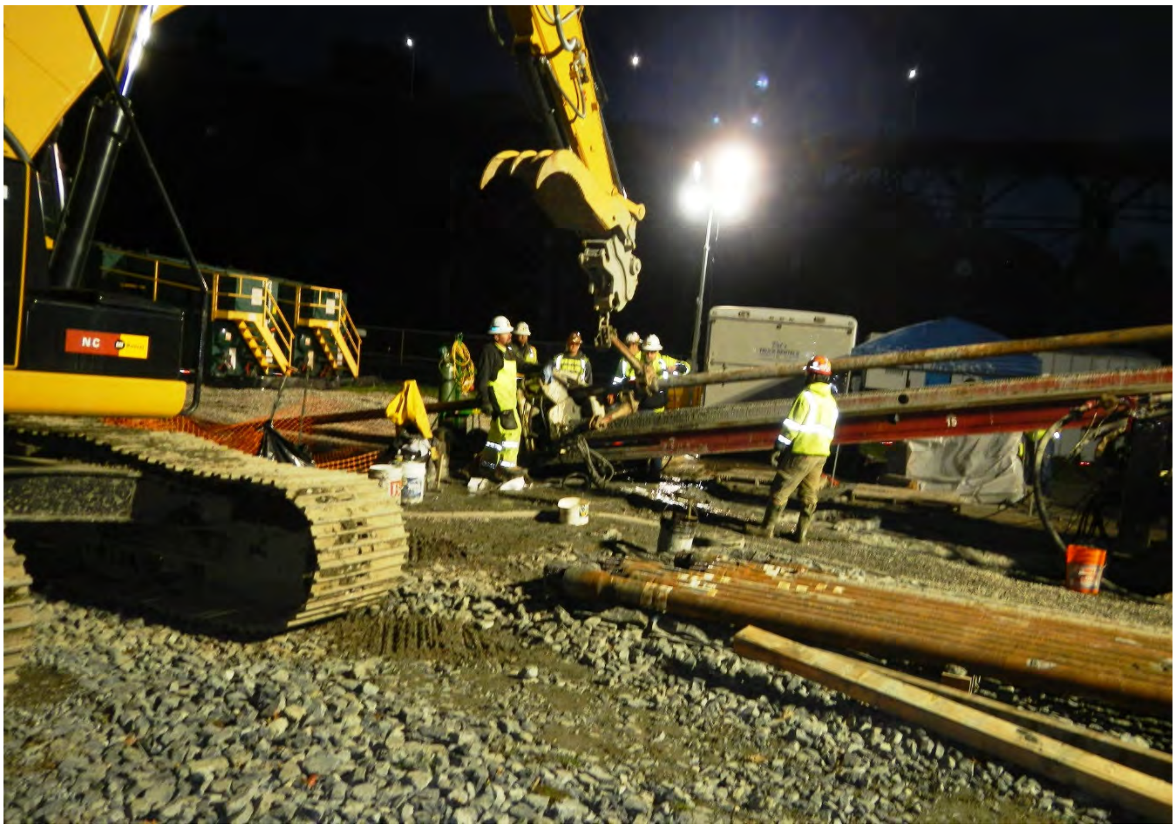

Figure 5. Drill Rig Set-Up in Smith Cove Park (lower end of the bore)
(Photo courtesy of www.kingcounty.gov)

The Contractor elected to perform an intersect to construct the pilot bore and used two 140,000-pound rigs for the drilling-- rigs much smaller than expected for a 32-inch OD pipe that was designed to be approximately 3,000 feet in length. At the downstream end of the bore, housed within the shoring, the Contractor elected to install an in-line Blow-Off-Preventer (BOP) on the low end of the conductor casing. This BOP was attached to a 60-inch blind flange at the entrance of the conductor casing, enabling the borehole to remain full of drilling fluid throughout the drilling process, despite the significant drilling fluid pressure head difference between entry and exit. The BOP and its connection to the conductor casing is depicted in Figure 6.

Figure 6. Blow-Off Preventer located in Shaft in Smith Cove Park
(Photo courtesy of www.kingcounty.gov)

Pilot Bore from Smith Cove Park

The pilot bore from Smith Cove park was started on September 23, 2014. After two days of drilling the pilot bit was approximately 720 feet into the bore from the entry point. At this time, the Contractor began the pilot bore from the upper end of the bore on 32nd Avenue West. Drilling from the lower end continued to a length of 1,320 feet, where the pilot bores intersected. The lower pilot bore was completed to the point of intersection in 6 days, averaging approximately 220 feet per day of drilling.

Pilot Bore from 32nd Avenue West

The pilot bore from 32nd Avenue West began on October 4, 2014 and would proceed to drill the pilot from the upper end of the bore to the point of intersection, approximately 1,930 feet from the upper end. The upper pilot was constructed over 12 days of drilling, averaging approximately 160 feet per day. Drilling from the upper end of the bore created more difficulty maintaining circulation, simply due to gravity; therefore, to improve drilling mud circulation, the Contractor elected to install 210 feet of 10-inch wash-over casing.

Figure 7. Shaft at Upper End of Bore on 32nd Avenue West
(Photo courtesy of www.kingcounty.gov)

The Intersect

The two pilot bores were guided by a gyro, allowing two pilots to intersect at an intermediate point along the bore. At the intersect location the two pilot bores rarely line up directly. On this project, the upper bore was slightly higher than the lower bore, causing a minor hump in the alignment. Although the slope at the intersect location was less than one percent, no reverse grade was measured and the pilot bore was accepted by King County. The lower pilot then followed the upper pilot to the upper end of the bore, where the drilling bits were removed. Removal of the bits at the upper end of the bore was necessary to prevent removal of the BOP and the resulting drainage of drilling fluid from within the bore at the downstream end.

Reaming

The borehole was reamed to the final diameter in three reaming steps: 24-inch, 36-inch, and 46-inch. All reaming occurred by pulling the reamer from the upper end of the bore to the lower end in Smith Cove Park. Before reaming could begin, the wash-over casing that was installed for the pilot was removed for reaming.

The first reaming pass started on October 30, 2014 and was drilled from the upper end of the bore but was terminated prior to the lower conductor casing, creating a "plug" in the lower portion of the bore to reduce bore pressures on the lower end of the bore. The 24-inch reamer was used to ream a total length of 2,450 feet. Tail string was added to the bore during reaming as was specified. Once the 24-inch downhill reaming pass was completed, the reamers were pushed back to the top of the bore where they were exchanged with reamers that would further increase the diameter of the bore. The first reaming pass occurred over 9 days, averaging 272 feet per day.

The second reaming pass was constructed with a 36-inch reamers. Like the first reaming pass, reaming commenced from the upper end of the bore to the lower end. The second reaming pass was initiated on November 10, 2014. The second pass was reamed from the upper bore to the lower conductor casing in Smith Cove Park, a length of approximately 2,840 for the second reaming pass. The second ream was completed in 13 days, with an average drilling rate of 218 feet per day. Once the reaming was completed, the reamers were pushed back to the upper end of the bore for exchange with reamers with a 46-inch diameter.

Akin to the previous reaming passes, the 46-inch reaming pass was constructed from the upper end of the bore to the lower conductor casing. Reaming was initiated on November 24, 2014 and continued for 10 days. A distance of 2,870 feet was reamed to 46 inches, averaging 287 feet per day. Similar to the second reaming pass, reaming was terminated prior to entering the lower conductor casing, leaving a “plug” in the casing. The reamers were pushed back to the upper end and removed prior to the swab pass.

Prior to the initiation of the swab pass, a 48-inch casing was installed for swabbing and pull-back. This was done to ensure a stable bore at the upper end within the glacial outwash. The swab pass was accomplished with a 44-inch outer diameter barrel reamer and started on December 8, 2014. The swab took two days to complete. The bore was swabbed for 340 feet on the first day and the remaining 2,820 feet the following day. Swabbing rates averaged approximately 1,580 feet per day. During the swab pass, the drilling data, including torque and pull-force indicated that the bore was stable and well prepared for pull-back of the product pipe. Upon completion of the swab pass, the 48-inch wash-over casing was removed.

Pullback

The Contract Documents allowed for pullback of the pipe from either the upper or lower side of the bore. The Contractor elected to pull the pipe with the rig at the lower end of the bore, pulling down hill. Set-up for the pullback of the pipe was initiated on December 13, 2014. Preparation included moving assembled segments of fused FPVC north on 32nd Avenue West to align the pipe with the entry location as seen in Figure 8. The pipe was laid out in five segments, requiring four mid-pull welds. The rig that was used at the lower end of the bore to construct the pilot and reaming passes was exchanged for a drill rig with 440,000 pounds of pull capacity.

Figure 8. Assembling the FPVC on 32nd Ave West for Pullback
(Photo courtesy of www.kingcounty.gov)

The contract documents required the contractor to fill the pipe with water during pullback to achieve neutral buoyancy to lower side-wall frictional forces; however, the Contractor submitted a plan to cut slots in the pull head that would allow drilling mud to enter the pipe during pullback. This innovative idea reduced the pipe’s buoyancy and resulting frictional forces without the need for adding water to the pipeline. The slotted pull head is shown in Figure 9.

Figure 9. Slotted Pull Head to Allow Drilling Mud to Enter Pipe
(Photo courtesy of Staheli Trenchless Consultants)

The pipe was pulled approximately 30 feet into the leading end of the downhill conductor casing in approximately 30 hours, including the time spent for mid-pull welds. Drilling was then stopped and the drilling mud was allowed to solidify within the lower conductor casing to allow removal of the BOP. The solidification of the drilling mud and excavated/pushed material surrounding the pipe within the lower conductor casing resulted in increased frictional loading around the pipeline. Once the Contractor removed the BOP and the centralizers in the conductor casing, the pipe would not move under the maximum 440,000 pound pull force of the rig. The contractor attempted to pull the pipe with the lower rig several times; however, the high pull force resulted in shearing the pull head from the pipe string, marking the end of the directional drilling installation for the pipeline. The Contractor then excavated the material out of the lower 60-inch conductor casing and made a piping connection to the pipe that was installed with horizontal directional drilling. The area between the product pipe and the conductor casing and the lower conductor casing was grouted, marking completion of the installation.

8. CONCLUSIONS

The uses for horizontal directional drilling are constantly expanding as Owners, Designers, and Contractors push the limits of the technology. With these advances come great challenges that require the three parties to work as a team. Without a collaborative working environment, lessons will not be learned and certainly will not be shared between the parties, hindering the industry's potential for advancement. This project was successful largely due to the dedication and endless efforts of a large group of people, from the Owners, Designers, and the Contractors.

9. REFERENCES

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