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CHALLENGES AND SUCCESSES OF OPEN SHIELD PIPE JACKING CONSTRUCTION IN A CONGESTED NEIGHBORHOOD

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ABSTRACT:

Seattle Public Utilities (SPU) has recently completed construction of a new storm water pipeline and storage system to reduce the potential for flooding in the Madison Valley neighborhood of Seattle, Washington. As a significant part of the Madison Valley NW Diversion and Washington Park Storage Project, the pipeline conveys storm water away from Madison Valley to a new 1.3 million gallon partially-buried storage tank in Washington Park. This paper describes the trenchless construction of the pipeline, which consisted of approximately 2,500 linear feet of 60-inch diameter steel casing pipe installed with open shield pipe jacking. Creative equipment layout was required to facilitate shaft construction in congested neighborhood streets with narrow access and multiple businesses, spanning an affluent community located minutes from the shores of Lake Washington. The trenchless alignment encountered challenging geotechnical conditions including areas of contaminated soils, glaciated soils, alluvial channels, and a historic landfill. Lessons learned during the construction of the first few drives of the project were applied to the later drives, leading to the successful completion of the project.

1. INTRODUCTION

The Madison Valley area of Seattle, WA (Figure 1) embodies a large and steep watershed area flowing into Lake Washington east of Downtown Seattle. The natural drainage route in Madison Valley has been cut off since the early 1900s, when the Madison Street Trestle was replaced with sluiced fill from the surrounding hillside, essentially blocking the natural watercourse. The sewer system built to convey sewage and storm water out of the basin has not been adequate to convey the storm water flows generated by extreme storm events, and subsequently there have been ongoing flooding incidents in the area. To alleviate local flooding and attenuate peak stormwater flows, Phase II of the Madison Valley Long Term Solution, Northwest Diversion and Washington Park Storage Project was implemented, in which storm water and/or combined sewer flows from the western slope of the Madison Valley drainage basin are diverted to a 2 million gallon storm water storage area consisting of both an above ground retention berm and below ground partially buried storage tank (GDR Nov 2009). The design of the project was awarded to Montgomery Watson Harza (MWH), Bellevue, WA with Staheli Trenchless Consultants, Bothell, WA as their trenchless design sub-consultant. The project was publically bid and awarded to IMCO Construction of Bellingham, WA with Northwest Boring, Woodinville, WA as their trenchless sub-contractor. The Engineer's Estimate for Construction was 13.2 million dollars. The low bid was 12.4 million dollars. SPU hired MWH and Staheli Trenchless to assist in the construction management and specialty inspection of the project. This paper focuses on the trenchless design and construction of the 48-inch conveyance pipeline used to transport flows to the newly constructed storage area. Open shield pipe jacking was selected as the preferred trenchless construction method to construct nearly 2,500 lineal feet of 60-inch diameter steel casing in which the 48-inch ductile iron conveyance pipeline was installed.

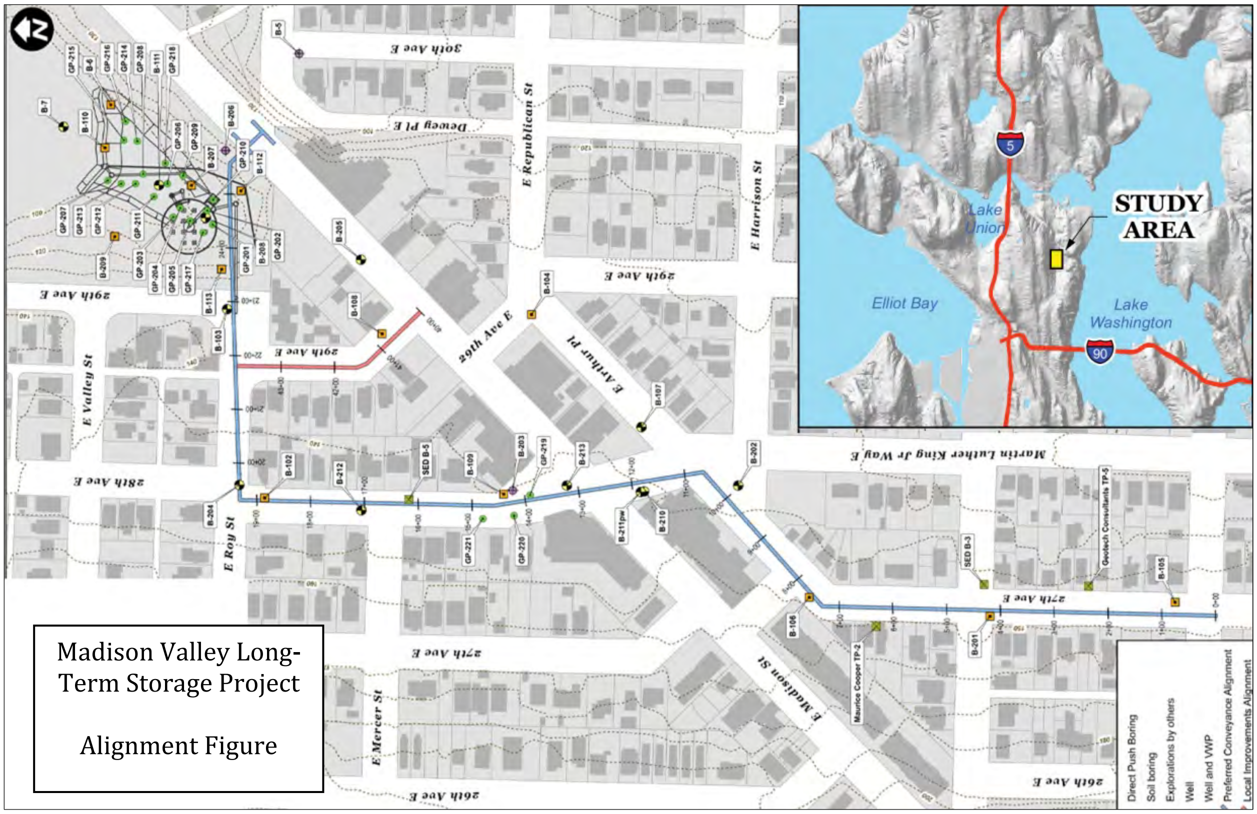

Figure 1. Overview of the Madison Valley Project Alignment in Seattle, WA

2. PREDESIGN AND ROUTE IDENTIFICATION

During the preliminary design of the project, an extensive geotechnical investigation was conducted to explore a number of alignment alternatives for the pipeline. SPU used their in-house geotechnical division to perform the investigation and develop the geotechnical report for the project. Figure 2 shows a plan view of the borings that were completed along with several potential alignment alternatives.

The geotechnical investigation revealed that the overall geology of the site consisted of a thick lacustrine layer that was primarily stiff to hard silt. This layer had very low permeability with perched groundwater overtop. Through the middle of the site, in the approximate area of East Madison Street, was an alluvial channel that had previously served as the primary drainage for the area prior to the development of Madison Valley. In this area, Alluvial Outwash was discovered consisting of medium dense silty sand with gravel with the potential for cobbles and boulders. Groundwater was seasonally present within this unit. In addition, a buried trestle was discovered along with a timber road that was abandoned and contained within the fill material.

The alignment was chosen to avoid fill material and alluvial outwash as much as possible while maintaining gravity flow to the site of the storage tank. During the pre-design, MWH determined the necessary flow diameter for the pipe to be 48 inches and SPU declared their preferred pipe material to be ductile iron.

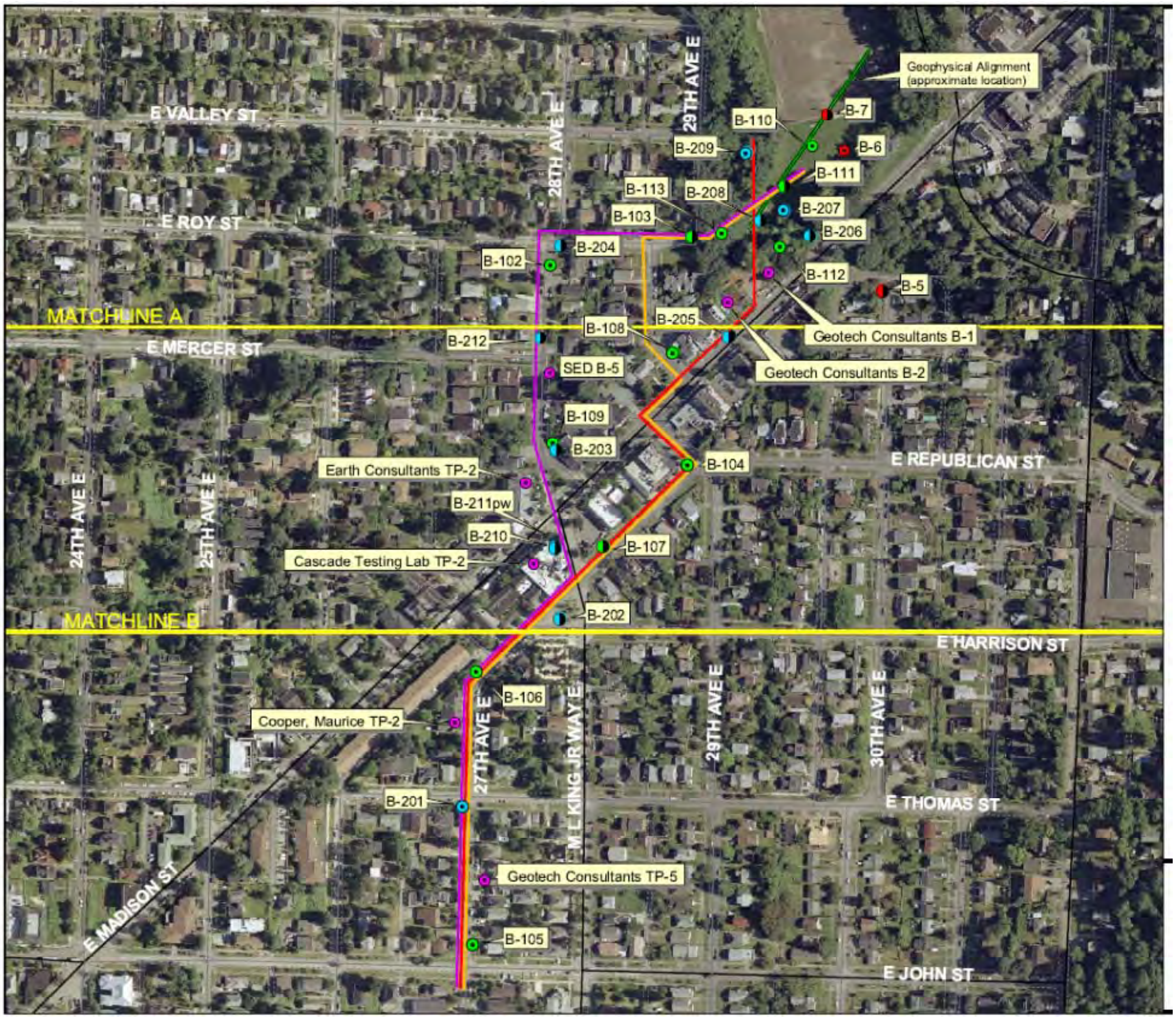

Figure 2. Locations of the Borings for the Alignment Study

3. TRENCHLESS ALTERNATIVES

Once the preferred alignment was selected, a feasibility study was conducted to identify the trenchless technologies that would be carried forward for further consideration. The technologies that were considered were microtunneling, auger boring with pilot tube guidance, and open shield pipe jacking. Horizontal directional drilling was not considered due to the size of the pipe and the necessary accuracy required for the on-grade installation. Since the preferred pipe material was ductile iron (DI), it was necessary to select a casing pipe that could accommodate the installation of the 48-inch DI pipe. To compare the trenchless alternatives, a “base case” of jacking 60-inch steel was considered.

Early in the feasibility study, pilot tube technology was categorized as having a high risk of failure due to the presence of hard over-consolidated silts. These lacustrine silts covered approximately 75% of the alignment and had blow counts high enough to make advancement of the pilot tubes impossible. Auger boring was feasible in the soil conditions but could not provide the accuracy necessary to maintain the grade requirements to allow gravity flow of the pipeline.

Both microtunneling and open shield pipe jacking were carried forward into a detailed evaluation for final selection of the preferred trenchless method. Figure 3 shows the layout of the proposed shafts for either microtunneling or open shield pipe jacking.

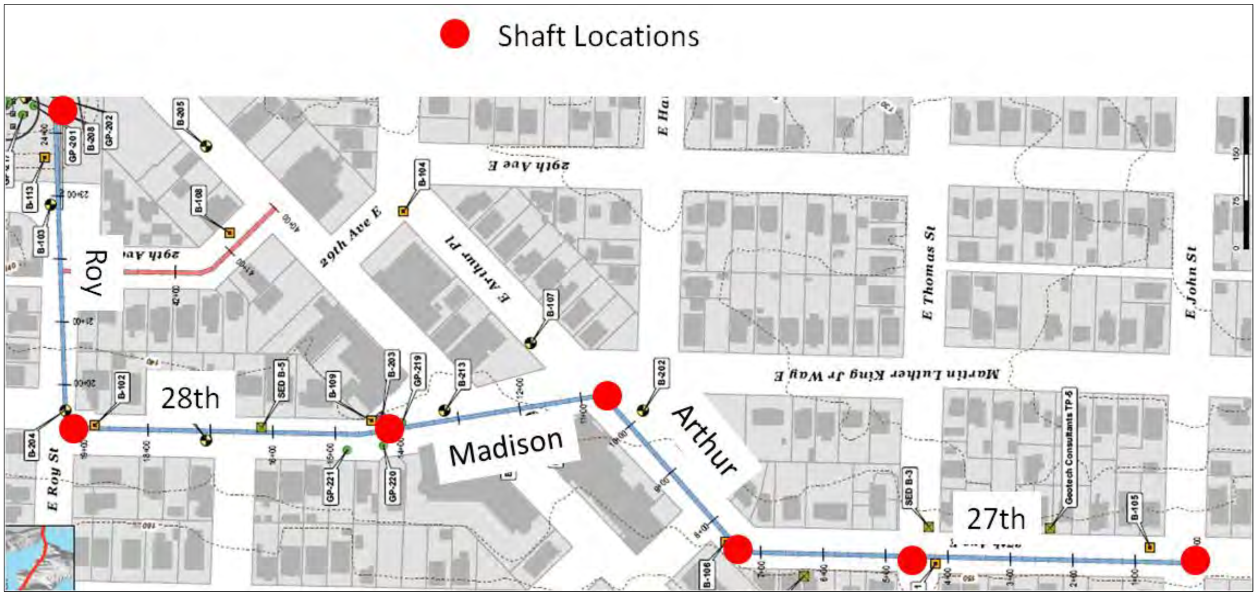

Figure 3. Layout of Jacking and Reception Shafts for Madison Valley Project

Geotechnical conditions were the primary factor for determining the preferred trenchless method. Microtunneling was favorable in the alluvial soils where groundwater was seasonally present and where soils were potentially unstable; however, these soils were only present along the Arthur and Madison drives comprising approximately 25% of the alignment. In addition, the alluvial soils had the highest chance for encountering cobbles and boulders which are more problematic to microtunneling than to open shield pipe jacking where access to the face is possible for removal of obstructions. Open shield pipe jacking was ideal for the lacustrine soils that comprised 75% of the alignment but could have stability issues beneath Madison Street – the street with the most traffic flow on the project.

Figure 4 shows the geotechnical cross section beneath Arthur Street which was the area of concern for both trenchless methods.

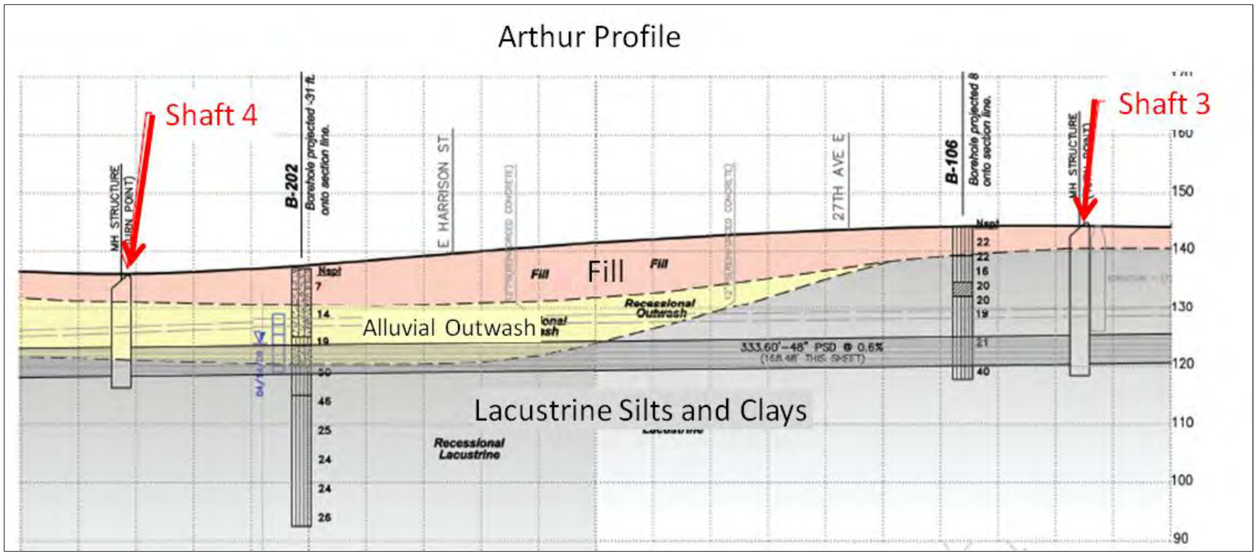

Figure 4. Cross Section of Soils along Arthur Alignment

This alignment was of particular concern for open shield pipe jacking due to the potential instability of the alluvial outwash and the groundwater, and for microtunneling due to the potential of encountering cobbles and/or boulders.

To assist with the selection of a preferred trenchless alternative, a risk matrix was created to identify the various risks associated with each technology along the preferred alignment. The risks were further refined by identifying the potential impacts (costs) of each risk. The risks were then quantified by determining the likelihood that each risk would occur and then multiplying the risk of occurrence by the cost of the impact. This exercise allowed the Owner to systematically characterize the actual trenchless risk on the project based on the nuances of each technology and choose the trenchless method that provided the lowest overall risk profile for the project. It was also a valuable tool to allow the Owner to clearly understand the range of risks for each trenchless method, and, working with the Engineer, the Owner identified project risks that were deemed acceptable and those that were not. The "acceptable" risks were carried through the project and appropriately budgeted for in the project contingency. The risks that were not acceptable were eliminated through design.

Evaluation of the risk matrix led to the selection of open shield pipe jacking as the preferred trenchless method for the construction of the project. This method was ideal for the soils along 75% of the alignment. For the other 25%, the Owner decided to pursue the permits necessary to allow dewatering across Madison Street and Arthur Street should it be required to ensure face stability. In addition, the Owner wanted to specify a trenchless method that allowed access to the face of the machine should an obstruction be encountered under East Madison Street in order to protect against having to excavate from the ground surface.

Figure 5. 60-inch Diameter Open Shield Pipe Jacking Machine Used on the Project.

In order to better characterize the material on the Madison drive, Staheli Trenchless recommended an additional boring along the alignment and was on site to evaluate the soil behavior during drilling at the tunnel elevation. It was discovered that although the lenses of silty fine sand below the groundwater table were indeed water bearing, the material exhibited slight dilatancy and would not freely allow water to flow. This discovery provided further comfort to the design team regarding the use of open shield pipe jacking through this area of the project, and caused the project team to be hopeful that this portion of the tunnel could be excavated without the use of dewatering wells. As such, dewatering wells were not specified across Madison and Arthur; however, the Owner was aware that they might need to be installed for successful installation of the tunnel. Using open shield pipe jacking in lieu of microtunneling for the Madison and Arthur Crossings resulted in considerable cost savings to SPU as well as a reduction in surface impact due to a smaller construction footprint for open shield pipe jacking than for microtunneling.

4. CONSTRUCTION OF THE TUNNELS

The soils along the vast majority of the alignment proved to be consistent with the Geotechnical Baseline Report which identified both upper and lower lacustrine deposits. The upper lacustrine unit ranged from medium dense to dense silt and clay beds with sandy lenses that were saturated but with low permeability which would produce only small amounts of water (GBR, 2010). The lower lacustrine was mostly silt and clay, was very stiff to hard, and did not contain water. Both lacustrine units proved ideal for open shield pipe jacking as they were excavated; the face stood vertically and allowed a consistent stable annular space. Figure 6 shows the excavated lacustrine material in the muck bucket being removed from the shaft.

Figure 6. Very Stiff Lacustrine Spoils Excavated During Open Shield Pipe Jacking

Fill, as shown in Figure 7, ranged from very loose to medium dense silty sand and stiff sandy silt, and was present at the surface along the majority of the alignment. Of concern was an area of the alignment that posed a risk of containing wooden supports from the abandoned trestle which had been sluiced-in with surrounding material in the early 1900’s (Aspect GDM, 2009). The tunnel alignment was positioned to decrease the likelihood of excavating through the remnants of the old trestle and during tunneling there was no indication that the trestle was ever encountered.

Figure 7. Fill Material Excavated During Open Shield Pipe Jacking

The geotechnical investigations performed along the tunnel alignment revealed approximately 200 feet of contaminated soils in two general areas: an abandoned landfill/dump site located adjacent to the buried storage tank and near a local drycleaner adjacent to the alignment. Contaminated soils did not ultimately affect the tunneling activities to a great extent. The material identified as having contamination near the drycleaner was carefully handled, but little material was discovered to be contaminated when excavating the tunnel. While tunneling in the landfill area, there were many old glass bottles and at one point tunneling was suspended briefly due to a pungent odor that was thought to have resulted from one of the sealed bottles shattering while being excavated. Circulating air to the tunnel face proved sufficient to “air out” the face overnight and allowed tunneling operations to continue.

5. SITE CONSTRAINTS

The project alignment traversed an older affluent community of Seattle with narrow neighborhood streets and an active business community. Figure 88 illustrates the creative shaft layouts that were necessary adjacent to professional offices and in areas where the streets were narrow with steep inclinations. Shafts were shifted to intersections that could be isolated in order to provide the Contractor with adequate space for equipment. With careful layout, the equipment was leveled and positioned to maximize space around the shafts during construction.

Figure 8. Reception Shaft Positioned in Neighborhood Street

Several shaft locations were positioned immediately adjacent to local businesses in which noise was a critical concern for the business owners. Among the businesses most sensitive to noise and access constraints were a local kindergarten, small offices, and a psychiatry practice. Efforts were made by the Engineer and Contractor to mitigate shaft construction noise. One key concept was to be proactive with educational outreach to the community and particularly the businesses most directly affected. By communicating early on in the design process, business owners were provided the opportunity to voice concerns, and the design team had the time necessary to respond to those concerns. In educating the local business owners using actual site visits to experience noise levels, photographs of similar trenchless and shaft construction projects, and detailed discussions to address the concerns, the design progressed without delay.

Tight controls were implemented to ensure site security and safety throughout construction. One tunnel alignment was alongside a local daycare facility with heavy traffic in the mornings and evenings to drop off and pick up children. The Contractor remained flexible and aware of the construction impacts to the local community and utilized near-daily sidewalk discussions with the neighbors in order to communicate progress and schedule, specific timing of elevated traffic disruption periods, and time windows of increased construction noise. Intermittent “field trips” to the neighboring lawn overlooking the jacking shaft continued to fascinate the local school children (as well as adults) during construction. Figure 9 shows one of the jacking shafts overlooked by the front lawn of a neighborhood home in which pedestrians would watch the construction.

Figure 9. Constrained Jacking Shaft Site Overlooked by Adjacent Homes

6. CONCLUSION

Choosing the most appropriate trenchless method can be the most critical decision the design team makes for a trenchless project. Careful analysis of the available geotechnical data, site constraints, cost, risks (including the associated impacts), and how all of these factors influence one another is not only challenging, but crucial for the success of the project. The decision to select one technology over another on this project was ultimately impacted by considering a balanced risk approach to geotechnical impacts and having the Engineer work side by side with the Owner to develop an understanding of how trenchless risks can be mitigated. Open shield pipe jacking was chosen as the tunneling installation method and it proved to be the best fit for the ground conditions and the overall project constraints. The Contractor was able to perform the work with expediency and successfully completed the nearly 2,500 feet of casing installation.

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