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Horizontal Directional Drilling: Not Every Bore Is Boring

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1. ABSTRACT

The use of Horizontal Directional Drilling (HDD) method for pipeline installations has been a component of water distribution and wastewater transmission system projects for numerous years. While most utilities have experience with HDD, many have limited experience when it comes to more complex installations (i.e. large diameter pipes, long bore paths, difficult subsurface soil conditions, limited ingress/egress, limited laydown areas, high potential for inadvertent return, environmental issues, etc.). As environmental regulations become stricter and subsurface conflicts become more prevalent, utilities and municipalities will increasingly turn to complex HDD installations to implement pipeline projects. The goal of this paper is to increase participant's knowledge of HDD so that they can better understand the challenges of complex installations and utilize better risk management practices to increase the likelihood of project success.

The audience will learn best practices for reducing the risks associated with complex HDD installation. The paper which includes a case study of the City of Naples Golden Gate Canal Intake and Transmission Main Project-presents key concepts including:

1. The engineering design process for HDDs including the geotechnical investigation and laboratory testing program requirements and development of minimum and maximum constraints for the construction contract,
2. Procurement methods that utilities can utilize to hire a qualified Contractor,
3. Typical submittals Engineers require and why,
4. The submittal process and how risk mitigation meetings with the Contractor can be utilized to better engage the Contractor and reduce risk,
5. Critical communication for monitoring and tracking, and
6. Other lessons learned and critical success factors.

2. INTRODUCTION

The Horizontal Direction Drilling (HDD) process, installing underground pipelines or conduits around or underneath obstructions, is typically used to avoid surface conflicts such as waterways, environmentally sensitive areas, major roads and buildings and subsurface conflicts including existing utilities and buried infrastructure. This paper is a case study of the challenges of complex HDD installations and how better risk management practices can be implemented to increase the likelihood of project success and thereby reduce risk to all parties. This paper includes these key concepts:

1. The engineering design process for HDDs including the geotechnical investigation and laboratory testing program requirements and development of minimum and maximum constraints for the construction contract,
2. Procurement methods that utilities can utilize to hire a qualified Contractor,
3. Typical submittals Engineers require and why,
4. The submittal process and how risk mitigation meetings with the Contractor can be utilized to better engage the Contractor and reduce risk,
5. Critical communication for monitoring and tracking, and
6. Other lessons learned and critical success factors.

The case study project is the City of Naples, Florida Golden Gate Canal Intake and Transmission Main project. Water and wastewater services are provided by the City's Utilities Department to over 65,000 residents and tourists within the 33 square mile service area. The objective of this project was to withdraw 10 million gallons per day (MGD) of surface water from the Golden Gate Canal upstream of the final weir and pump the water to the City's Wastewater Treatment Plant (WWTP). At the WWTP the water is blended with reclaimed water (prior to filtration and disinfection) and thus supplements the supply to the City's reclaimed water system.

At the outset of the project a route study was performed to determine possible routes for the pipeline. The selected route is outlined in black on **Figure 1**. While the route identified was considered to be the best alternative, it was not without challenges. The route included multiple property owners with challenging demands and several environmentally sensitive areas. These complications necessitated the need for utilizing better risk management procedures which is the focus of this paper. Two HDD crossings were selected during the route study. One HDD crossing was approximately 700-feet in length under the Gordon River and the second HDD crossing was nearly 3,300-feet in length under two environmentally sensitive areas and the Golden Gate Canal. The optimum hydraulic design for pipe diameter resulted in selection of 20-inch nominal pipe diameter. The pipe materials under consideration included high density polyethylene (HDPE) and fusible polyvinyl chloride pipe (fPVC).

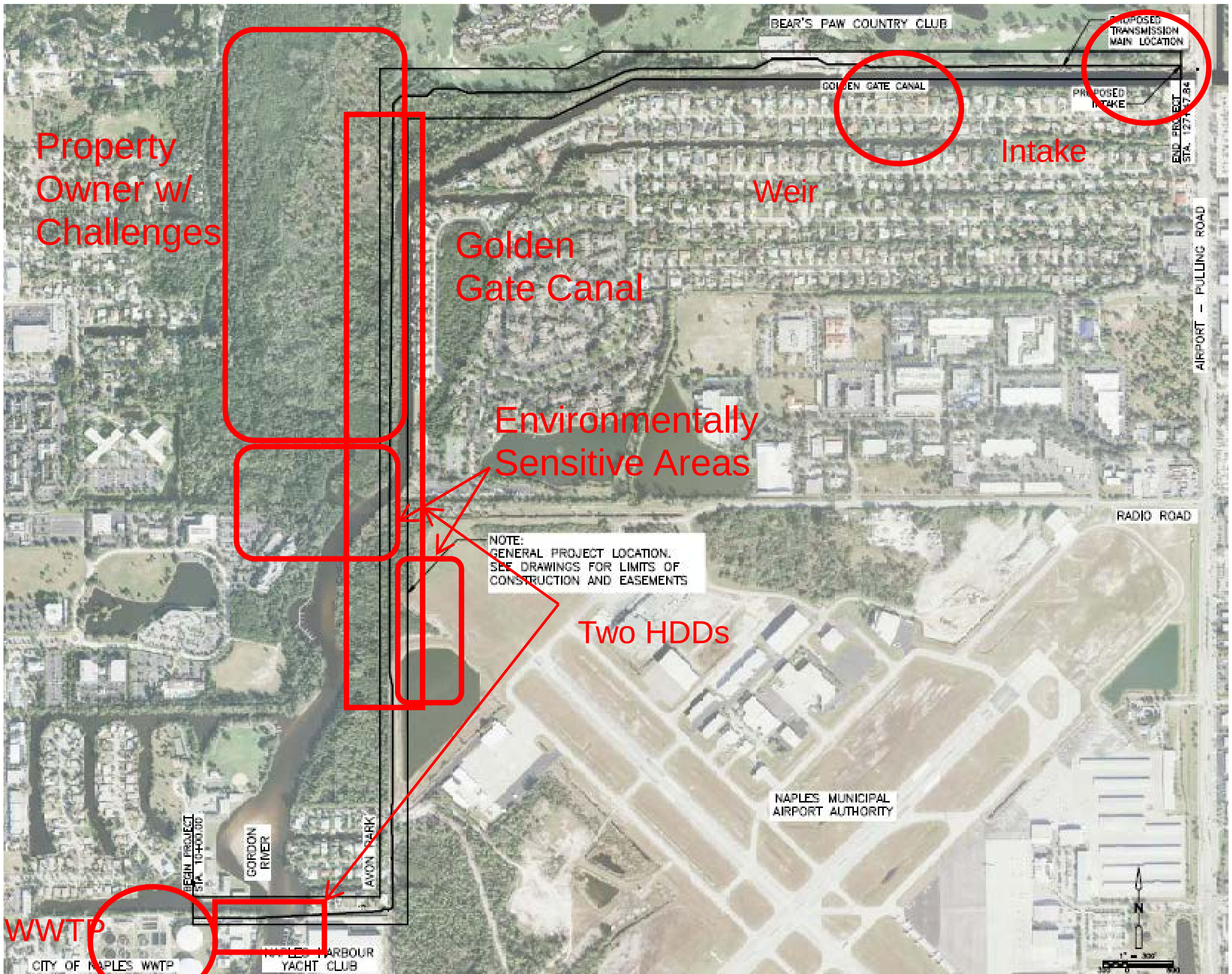


Figure 1. Selected Route for City of Naples Golden Gate Canal Intake and Transmission Main project

The first (i.e., short crossing) HDD bore was under the Gordon River from the WWTP (entry pit) to a stormwater swale (exit pit) and had complex site requirements. Both entry and exit sites were very narrow. As with any work on an active plant site, coordination with plant personnel, ingress and egress, equipment layout were all key.

The second (i.e., long crossing) HDD bore was equally complex. The entry side of the HDD bore was an undeveloped property, with no access to potable water and the need to build a temporary road for ingress and egress of equipment. The exit side was more challenging as it was the berm of an active municipal airport. The rectangular boundary shown on **Figure 2** is the staging area provided to the Contractor. One of the planning mistakes made by the Contractor was to fuse the pipe early and layout the pipe across the staging area prior to the HDD being completed as shown in **Figure 3**. This reduced the available staging area and created an even tighter site. In addition, the Contractor also faced significant coordination challenges with the airport operations staff.

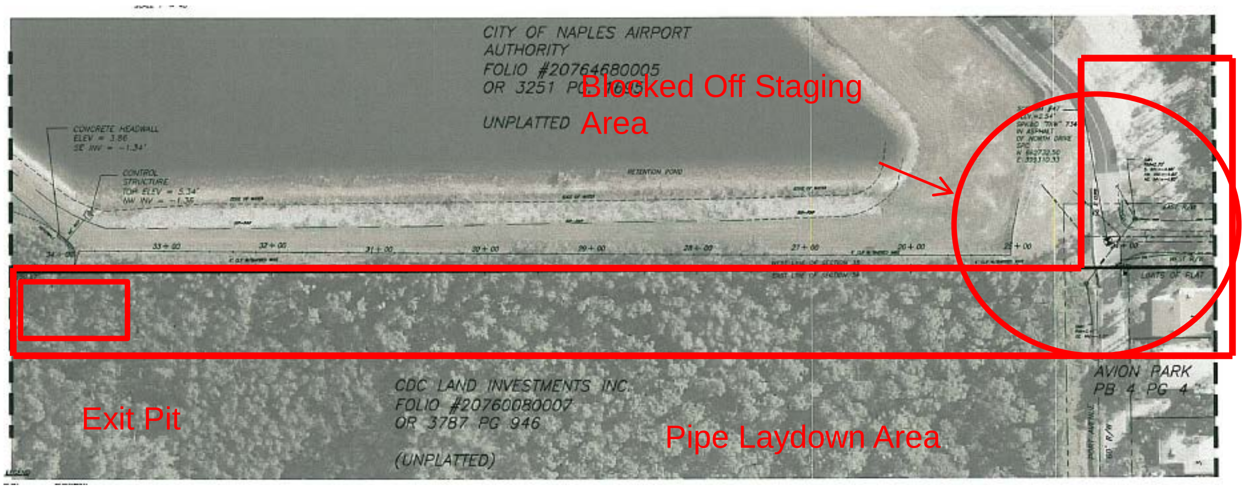


Figure 2. HDD Exit Pit and Staging Area Provided to Contractor for Long Bore

Figure 3. HDD Exit Pit and Staging Area Blocked by Pipe Layout for Long Bore

3. ENGINEERING DESIGN PROCESS

Typical best practice for risk mitigation requires that the Engineer design a preliminary HDD vertical profile and select the pipe material based on results of preliminary inadvertent return (also known as hydro-fracture or frac-out) and pull back design calculations. Important conclusions from the preliminary design calculations on this project were that the

- depth of cover was adequate to minimize inadvertent return potential;
- depth of cover was acceptable for pipe deflection limits;
- product pipe would need to be ballasted; and
- pipe material would be limited to fusible polyvinyl chloride pipe (fPVC) due to the large forces during pull back of the long HDD bore.

The specifications and drawings provided the Contractor with the pipe material, the minimum and maximum criteria for entry and exit angles, minimum radius of curvature, minimum and maximum depth so that the Contractor applied selected means and methods to the project. The contract documents required the Contractor to provide signed and sealed calculations by a registered Engineer in the state to verify the entry and exit angles, radius of curvature, pipeline alignment, pull-back forces and inadvertent return risk.

In support of the design, a thorough and detailed geotechnical investigation and laboratory testing program was developed. This requires identifying the proper number and type of soil borings to be collected.

For this project where the minimum depth of cover under the waterways was selected as 25-feet, there were three primary types of soil borings performed:

- Shallow land borings: one (1) every 500-feet (adjusted 50-feet +/- for field conditions) to a depth 15-feet below ground surface, (bgs) (where open cut was expected)
- Deep land borings one (1) at each planned entry and exit pit for each HDD to a depth 60-feet bgs
- Deep water borings: one (1) every 300-feet, no closer than 25-feet from bank parallel to pipe route to a depth 60-feet below mud level (i.e., canal bottom)

Consistent with industry best practices, the soil boring locations for this project were selected with a minimum distance of 25-feet from the proposed alignment and properly sealed upon completion to minimize the risk of inadvertent return during HDD installation. The Geotechnical Engineer marked the soil borings so that the surveyor accurately located the soil borings in the survey drawings. The geotechnical investigation also included these key recommended soil parameters for design: soil type, unit weight (pcf), angle of internal friction, cohesion (psf), Poisson Ratio (v) and Modulus of Elasticity (psf).

The geotechnical investigation revealed the presence of weathered fractured limestone. Based on blow counts, the weathered fractured limestone material appears to be hard, however, in coring and sampling it fractures and breaks apart. Since weathered fractured limestone cannot be cored or tested for RQD (Rock Quality Designations) and percent recovery, unconfined compressive strength (ASTM D2166), and Moh's hardness, these typical rock parameters were not available as key indicators. To a driller not experienced with weathered fractured limestone, the material can appear to require a drill head for hard rock; however, the material in practice breaks apart rather easily. In the case of this project, the HDD driller was unable to steer the drill head he selected through the weathered fractured limestone to intersect the entry and exit tangents of the bore path. Ultimately, the driller replaced the drill head with one more suitable for the weathered fractured limestone and re-drilled the pilot hole.

4. PROCUREMENT METHOD

For most construction projects, municipalities are not simply free to select the most qualified Contractor for the work since work must be competitively procured. One way to add quality assurance to the selection process and select a qualified HDD Contractor is to establish minimum experience criteria for both the HDD Contractor and the key employees in the specifications. In this case, to further minimize risk in the HDD Contractor selection process the specified qualifications were required to be submitted as part of the bid package. The qualifications of the apparent low bidder were evaluated prior to award. If the qualifications were not met the second low bidder would be evaluated.

The criteria we used on this project included:

- Minimum 5 years licensed underground Contractor in Florida,
- minimum 5 years of experience in HDD,
- three representative projects similar to current project.

An important aspect of the qualification criteria were that it specifically identified the minimum length, diameter pipe material and soil material of the representative projects to be submitted by the contractor. For this project, the HDD Contractor was required to provide at least three representative projects that were 16-inches minimum diameter and 2,500 feet minimum length. Furthermore, at least one project was required to use fPVC. The criteria also required the experience record of the superintendent for at least 10 years and with at least one project meeting the qualification criteria. Similarly, the criteria required the experience record of the HDD equipment operator for at least 5 years with at least one project meeting the qualifications criteria.

It is critical that if such criteria are used in the specifications, they should be confirmed prior to award of the contract. In the case of this project, the Engineer of Record reviewed the submitted qualifications and references and called the reference for each project to confirm the criteria and that it was successfully met. If it was determined that the HDD Contractor for the apparent low bidder was not qualified, it could be grounds for disqualifying the low bidder.

5. SUBMITTAL PROCESS

In the HDD specification for this project, there were 21 different submittals required of the HDD Contractor prior to construction. The purpose of each submittal is to engage the HDD Contractor to explain how the general standard type procedures in the industry for each submittal will be applied to the specifics of this construction site and conditions. The submittal process also initiates and fosters the Contractor's planning process so that it is coordinated with the product pipe to be installed, the site constraints and the Owner's ordinances, the project permits, agreements, easement conditions, and overall project Schedule. Planning and communication of the planning process through documentation (i.e. the submittal process) is a key factor for success. It is key that the calculations for inadvertent return and pull back forces are signed and sealed by a registered Engineer in the project state. General calculations submitted by the Contractor which cover a range of "likely" conditions should not be found acceptable by the Engineer.

The Engineer and Owner should be prepared for give and take during the submittal process. One example is the accuracy of the pilot hole to the alignment. In this case the HDD Contractor requested a relaxation of the accuracy from 2 feet to 5 feet during the submittal process due to the nature of the mixed face and his choice of rock drilling head and expected increased difficulty in steering. The request was reviewed and granted as the permanent utility easement was sufficiently wide to accommodate the request; however, the pilot hole was closely monitored on a daily basis from the daily logs.

We also learned the HDD Contractor wanted to distinguish between minor and major inadvertent return and not communicate the minor inadvertent return. The Engineer, Owner and permits required that all inadvertent return be reported to the Engineer immediately.

Due to restoration requirements of the pipe laydown areas, the HDD Contractor also proposed to switch the entry and exit pits for the long bore and this became another area for give and take during the submittal process.

The following list points out the purpose of each submittal

1. Contact Grouting Plan: A plan for grouting around the product pipe at the entry and exit pit once installation is complete to provide stability and sealing of the bore hole annular space; can be up to 100 feet in length.
2. Contingency Plan for Remediation of Potential Problems: Response planning so that the number of unforeseen issues is reduced.
3. Disposal of Spoils and Drilling Fluids Plan: A plan to identify where the spoils will be disposed of offsite and that the location is acceptable to permitting agencies and is approved by the land owner.
4. Equipment Layout Plan: A plan to confirm all the necessary equipment will be laid out in such a fashion as to remain within the limits of the temporary construction easement and comply with the ingress/egress of the neighbors.
5. Inadvertent Return and Surface Spill Contingency Plan: The Frac-Out Plan (frac-out is the colloquial term for Hydrofracture meaning the unintentional release of drilling fluids to the surface) .
6. Horizontal Directional Drilling Work Plan: A submittal which provides detailed plan and profile drawings and sequence of operations during construction.
7. Maximum Allowable Drilling Fluid Pressure Calculations: This calculation allows the HDD Contractor and Engineer to be aware of the maximum allowable pressure (which is based on reducing the risk of inadvertent return) so it can be monitoring during construction.

8. Methods, Equipment, and Materials Description Plan: A plan to communicate the equipment and materials the HDD Contractor will use onsite.
9. Pipe Filling Methods and testing: A plan that calculates the ballast water per every drill rod length so that the HDD Contractor and Engineer can monitor and double check the correct water has been used for ballast if needed.
10. Protection of Adjacent Structures and Facilities Plan: A plan which requires a pre and post survey of adjacent structure to monitor them for settlement and identify if remediation is necessary.
11. Pipe Stress Calculations: A signed and sealed submittal which includes calculations of the expected pipe stresses during pull back including bending, earth loads, buckling loads, and groundwater loads.
12. Pullback Calculations: A signed and sealed submittal which confirms the maximum allowable safe pull back forces for the product pipe as established by the manufacturer of the pipe will not be exceeded during the pull back. Maximum pull back forces during construction are to be recorded and submitted to the Engineer as a confirmation.
13. Qualifications: The superintendent and key personnel are provided, this can be submitted at bid time with the bid package (as the case for this case study) or after the award. Qualifications can also be established by pre-qualification before the project is advertised.
14. Radius of Curvature Confirmation: A signed and sealed submittal which confirms the maximum allowable radius of curvature for the product pipe as established by the manufacturer of the pipe will not be exceeded during the pull back.
15. Rig Capacity Plan: A submittal which confirms the rig capacity is adequate to provide the maximum pull back force as calculated in the pullback calculations.
16. Safety Plan: A submittal which includes the Site Safety Representative and all relevant contact information in the event of an emergency.
17. Schedule: A weekly update of the HDD Schedule is required.
18. Soil Separation Plan: A plan which submits the detail of the soil separation plant to check the capacity and the noise ratings.
19. Surveying Equipment and Procedures: A submittal for the calibration of the survey equipment to be used including the downhole survey tools (probe).
20. As-built pilot bore profile: This profile is submitted for acceptance prior to the reaming process; required to be submitted daily to the Engineer for verification of the alignment as construction progresses.
21. Daily logs and records: A daily report and ongoing communication to the Engineer from the HDD contractor.

6. CRITICAL COMMUNICATION

Effective communication between the Owner, Engineer, General Contractor and HDD Contractor is critical and should take the form of Progress Meetings, Risk Mitigation Meetings, Daily Logs/As Builts and RFI, if needed, for tracking and monitoring:

- Communication between the General Contractor and Engineer should be more than just the submittal process. Both parties need to know the stages of the work to be performed and the expected Schedule of the work.
- Communication between the General Contractor and Owner should have regular planned updates on progress and should identify potential public relations issues and permitting issues.
- Communication between the General Contractor and HDD Contractor (subcontractor) should be open and easily accessible to each other. Continued communication throughout the project should continue to clearly define the details of each party’s responsibilities and which party is responsible for each action.
- Communication between the General Contractor/HDD Contractor and property owners should keep property owners informed early, especially if special requests are needed. On this project it was essential to pre-coordinate stages of the work on certain portions of the airport property as they were deemed to be active areas of the nearby runways.

Traditionally progress meetings are typically required on construction projects, whether monthly or more frequently. Progress meetings are necessary and facilitate the coordination efforts of all parties. However, progress meetings alone are not sufficient for the mitigation of risks associated with HDD, especially on complicated crossings.

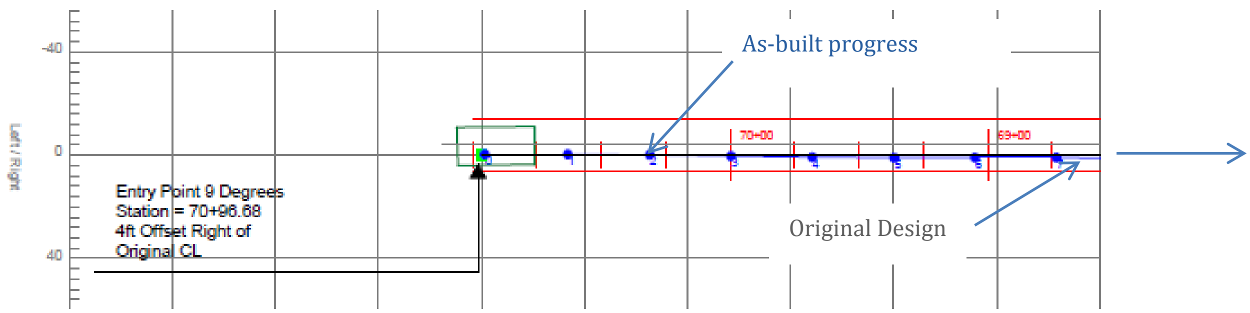
For this project, risk mitigation meetings were specified in the contract documents. The risk mitigation meetings serve the purpose of getting both the General Contractor and HDD Contractor engaged in the planning process. Many Contractors, even very experienced ones, want to “shoot from the hip” and address a problem if it occurs. Unfortunately, trying to find an impromptu solution to a problem such as a inadvertent return in a river, wetland or canal is not a viable option. The meetings usually turn into a lot of asking the Contractor, “how do you plan to do…” and “what will you do if x happens”. Without forethought and planning, the Contractor may be unprepared to address on site issues. For example, on inadvertent return planning, without containment curtains and a inadvertent return kit on-site, the best response by the Contractor will be limited and too late. While it will be the Contractor on the hook for fines and clean-up, the Owner must still address the media and public relations issues.

Risk mitigation meetings should be required in the specifications so the Contractor is fully aware and includes the efforts in the Bid Price. Risk mitigation meetings for this project were required to be scheduled at least 15 days before each stage of the work; however, in practice, several risk mitigation meetings were scheduled the same week that they were held. Required attendees included the HDD Contractor’s project manager, HDD superintendent, General Contractor’s project manager, Engineer of Record, Owner’s representative and Engineer’s Project Manager. With the attendees scattered in various locations, the risk mitigation meetings were held by conference call, and successfully done. For this project, the key stages requiring risk mitigation meetings were specified as follows:

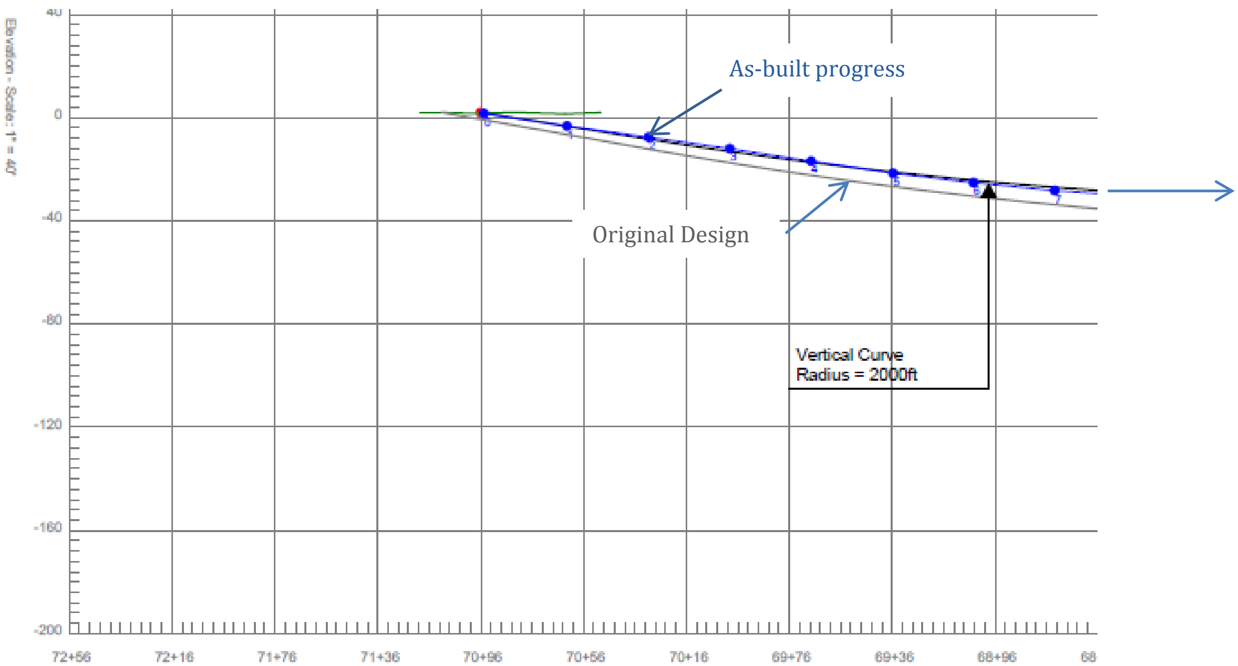
1. Prior to drilling of pilot hole to discuss
    a. Traffic Control
    b. Rig Mobilization and setup
    c. Pilot bore drilling
    d. Pre-survey and monitoring of adjacent structures, roads, sidewalks and utilities
2. Prior to reaming to discuss
    a. Pre-Reaming and reaming
    b. Layout and fusing/welding of pipe
3. Prior to pull back to discuss
    a. Pressure Testing prior to pull back
    b. Final reaming and Pullback of pipe
4. Prior to pressure testing to discuss
    a. Pressure testing of pipe after installation
    b. Pig test
    c. Post survey and monitoring of adjacent structures, roads, sidewalks and utilities

Another special form of communication is the daily logs and as-built submittals. These are a good way for the HDD Contractor to communicate progress and identify if any issues are occurring. Shown here **in Figure 4** are the plan and profile views submitted by the HDD Contractor. Each shows the actual location of the constructed bore hole as well as the pre-construction planned bore path. Deviations from the plan are easily identified and the Engineer can quickly evaluate if a potential negative impact could be realized from the deviation.

For this project, the Engineer agreed during the submittal process to approve/reject the as-built pilot hole within 24 hours from completion of the pilot hole.



Plan View



Profile View

Figure 4. Partial Example of HDD Plan and Profile As-Built Daily Logs

Communication in the form of Requests for Information (RFI) also represents an area of give and take between Engineer and Contractor. Changed field conditions or the application of the specifications to the site specifics in the field can require additional clarification be provided by the Engineer to the Contractor. In this project, the General Contractor through the RFI process suggested an alternative laydown of the fused/welded pipe that was creative and reduced risk during pull back. Due to the length of the HDD crossing and limited laydown area, the project was designed for at least one mid-weld during pull back, however, the General Contractor was clever and realized the installation of an oversized HDPE casing underneath a driveway for very large trucks would allow for the entire 3,300 feet of fPVC to be fused and pulled in one section, where otherwise the trucks used at the facility were too tall for elevated rollers. The Engineer accepted the change at no additional cost to the Owner and required the casing be extended from entry to exit point of the driveway to avoid any rock outcroppings and potential to gouge the pipe.

7. CONCLUSIONS

As environmental regulations become stricter and subsurface conflicts become more prevalent, utilities or municipalities will increasingly turn to complex HDD installations to address pipeline projects. As presented in this case study, there are planning steps which can be taken to minimize the risk and increase the likelihood of project success. Several lessons learned were identified in the above discussions of key concepts. Some other valuable lessons learned for implementing complex HDD projects include the following:

- When possible, it is advantageous to store the core borings collected during the geotechnical investigation until after the project is closed out. The core borings could become a key piece of evidence should the driller encounter problems or file a claim that the subsurface conditions were not as presented in the geotechnical investigation report and other contract documents. Storage of the samples should be a scope item included in the agreement with the geotechnical firm involved in the project.

- The planning for layout of the HDD energized surface grid system through environmentally sensitive lands should be initiated during the Engineering Design Phase and the submittal process should require a detailed layout plan from the HDD Contractor of the surface grid system. In the case of this project, over 2,800-feet of the crossing was underneath mangrove wetlands and 300-feet was under a river. The difficulty for the Contractor in meeting the specification requirement for a continuous surface grid system became fully realized in the risk mitigation meetings. The Contractor requested a clear 4-foot wide path for surveying of the surface grid system; however, state regulations limited the trimming of mangroves for the purpose of survey to 3-feet. The give and take on both sides resulted in a non-continuous surface grid system where a coil system was used on each end of the HDD and a mid-coil system was placed by barge towards the middle of the HDD.

- Additional depth of the HDD profile is not always desirable. The Engineering Design Phase should calculate the maximum allowable deflection for the specified material and if appropriate, consider the deflection that could be caused as a result of overburden collapse onto the pipe. If there is a limit of maximum depth, it should also be included in the contract documents as well as the more typical minimum depth of cover. In this case study, the weathered fractured limestone was considered a soil material that could collapse onto the pipe. It was noted previously the HDD driller had difficulty in steering the drill head in the weathered fractured limestone. As a result, the first constructed shorter HDD crossing was deeper than the design profile. Fortunately, calculations for pipe deflection should the overburden soil collapse indicated the pilot hole had been installed at the maximum depth allowable. However, for the long crossing, the Contractor's first attempt of the pilot hole was done without the aid of the mid coil wire grid system, resulted in excessive depths and the Contractor elected to re-drill the pilot hole with the addition of the mid-coil wire grid system for greater accuracy and was successful in staying well within the minimum cover and the maximum allowable depth.

- The fused pipe must be carefully inspected prior to pullback and yet allow sufficient time for remediation if needed. Long lengths of fused pipe can be challenging to handle with care such that gouges in the pipe are not beyond tolerance. The contract documents should specify requirements for handling and the allowable tolerance for gouges and also specify the corrective action to be taken by the Contractor if gouges are made in the pipe. In this case study, special care and pipe handling were specified and enforced. It was required that the fusion technician be provided by the Pipe Supplier as part of the qualifications. Even with these special requirements, several gouges were observed in the pipe prior to pull back. Through the RFI process, the following requirements were implemented: if gouges or scratches were made and clearly not the result of a blow or dropping of the pipe (which would be grounds for rejection), the depth of the gouge was to be measured by an independent testing lab and the results certified in writing. In accordance with the PVC manufactures general recommendations, the following were allowed:

    - Less than 10% of the wall thickness, the gouge does not require remediation
    - If the gouge is equal to or more than 10% of the wall thickness, the pipe would be rejected and a section of the pipe was to be removed and re-fused or replaced.

For this case study, both the HDD short crossing and long crossing were completed within the Owner's Schedule and budget and the pipeline is successfully functioning to supplement 10 MGD of supply to the City's reclaimed water system.