HDD Allows Water Pipeline Construction across Pearl Harbor

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1. ABSTRACT

The Pearl City Peninsula to Ford Island Waterline Crossing Project involved the replacement of roughly 3,800 linear feet of deteriorated 24-inch cast iron waterline, of which approximately 2,500 linear feet was underwater. The new waterline serves as a primary potable water artery connecting the existing Pearl Harbor Complex with its primary source in Waiawa. The project supports the mission of COMNAVREG Hawaii to supply an adequate, efficient, and safe transmission line for potable and fire protection water for Ford Island, Pearl Harbor Naval Shipyard Area, and Hickam Air Force Base.

Approximately 3,500 linear feet of the waterline was installed using horizontal directional drilling (HDD) methods. This alignment included a crossing from the Pearl City Peninsula, under the Pearl Harbor channel, before surfacing on Ford Island.

Design phase planning included selection of an alignment and profile to tie into the existing waterline, provide minimum cover below harbor mudline, and avoid utilities, pile-supported docks, buildings, and other structures and facilities. The HDD alignment included a horizontal curve through varied subsurface conditions, including very soft slurry-like estuarine deposits, coralline deposits interbedded with coral limestone, stiff alluvial deposits, contaminated fill materials, and possible submarine slope failure. To provide adequate HDD work area, the Navy allowed temporary access and staging within their area. Special traffic control including road closures was granted to facilitate assembly, staging, and pullback of the entire pipe string. This paper will review the design focus, bidding procedure, and construction results of this critical project.

2. INTRODUCTION

The Pearl City Peninsula to Ford Island Waterline Crossing Project is located in the Pearl Harbor Naval Shipyard (PHNS) in Hawaii (Figure 1). Two construction methods were utilized to install the new 24-inch waterline: horizontal directional drilling (HDD) and conventional open trench excavation. HDD was the primary method of pipe installation to navigate the horizontal and vertical alignment of the crossing. Of the approximately 3,800 linear feet of waterline to be replaced, 3,500 linear feet was to be installed by HDD methods, with 2,500 feet below the Pearl Harbor channel. The existing waterline consisted of 24-inch cast iron pipe, which at the channel crossing lays on the mudline surface.

The HDD alignment begins within the Navy area on the Pearl City peninsula, approximately 1,200 feet inland. The HDD alignment crosses under the Pearl Harbor channel, with mudline, or harbor bottom elevations 30 to 40 feet below mean sea level (MSL) in the deepest parts of the alignment. The HDD alignment ends on Ford Island near Navy residential housing. A future 24-inch waterline crossing from Ford Island to Landing C in PHNS will continue the water transmission to the PHNS, and is indicated in gray on Figure 1. The operating pressure of the new waterline is 65 to 75 psi and the required hydrostatic acceptance test pressure was 150 psi.
3. HDD ALIGNMENT SELECTION

Project design began with preliminary selection of the horizontal alignment and vertical profile, which necessitated identification of alignment constraints such as buildings, structures, piers, docks, and existing utilities. Straight horizontal alignments are preferred for HDD construction. However, a horizontal curve was necessary to avoid two docks on the Pearl City peninsula, and two piers on Ford Island (see Figure 2). The horizontal curve was also necessary to place the entry and exit points in locations accessible for the connections to the existing waterlines, and avoid buildings on both sides of the alignment. This horizontal curve resulted in compound (horizontal and vertical) curves along portions of the alignment at each end.

The preliminary alignment was also dependent on available 24-hour work and staging areas on one side of the alignment for the HDD drill rig and associated equipment, and on the opposite side of the alignment for pipe fusion, laydown, and pullback. A critical aspect of this project was obtaining these 24-hour work and staging locations within the Navy controlled areas on both sides of the alignment during the design phase. Consideration of the vertical bends, vaults, flow tube boxes, and expansion coupling vaults, as well as proximity of numerous existing utilities on both ends, also needed to be accounted for when determining the HDD entry and exit point.
The initial design was to replace approximately 3,330 linear feet of the existing waterline. However, the alignment was extended another 500 linear feet on Pearl City peninsula, moving the work area further away from the Navy facilities near the shoreline, but still within the overall Navy area. This facilitated easier access for the Contractor to their work area through Navy property, and provided a larger work and staging area that would otherwise not be available if the alignment terminated closer to the shoreline, or within the Navy residential area (see Figure 3). Extending the alignment also allowed for a larger vertical radius of curvature – approximately 5,500 feet – to be designed, and for more of the existing deteriorating waterline to be replaced. However, because the HDD staging area was now closer to the Navy residential area, requirements for sound dampening walls were placed in the specifications to alleviate noise concerns.

Similar alignment constraints were present on Ford Island, as the exit point was surrounded by Navy buildings, structures, and residential housing (see Figure 3). However, because of the location of the existing waterline that was to be connected to, there was a limit to how far the alignment could be extended. Consequently, the HDD exit point was within 250 feet of the shoreline, requiring a tighter vertical radius of curvature – approximately 2,000 feet.

Further inland and beyond the exit point was a grassy park area, sandwiched between residential homes to the west and Navy buildings to the east. This provided a corridor for the pipe fusion, laydown, and pullback area. Without such a corridor, the design may have required a pipe laydown area on the Pearl City peninsula side, along the two-lane roadway through Navy residential area. With the corridor, a pipe laydown staging area could be demarcated through the grassy park area, and along the shoulder area of Chafee Boulevard (see Figure 4).
The historic runway south of Chafee Boulevard and adjacent areas were not available during design, as the Navy initially reserved the runway for a future photovoltaic power station. However, prior to construction, these areas became available, allowing the HDD contractor to utilize the wider shoulder area between Chafee Boulevard and the runway, and a more spacious 200 foot by 200 foot area on the east end of the runway for pipe storage, assembly, and staging.

4. REGIONAL GEOLOGY

Review of the geologic history of the project area aided in the selection of the preliminary project alignment and profile. In particular, based on past project experience in the area and hydraulic fracture calculations, a minimum cover of 40 feet below the mudline was selected to reduce potential for inadvertent fluid returns through the very soft estuarine deposits anticipated. Background on the regional geology of the project area also helped identify key subsurface conditions that the geotechnical exploration could expect to encounter, and at what relative depths. In particular, the subsurface investigation could expect to encounter coralline deposits at elevations higher than the current sea level, deep alluvial channels with basalt cobbles and boulders, layers of hard volcanic tuff at shallow depths, and very soft estuarine deposits extending deep into the middle of the channel.

Pearl Harbor is essentially a series of drowned river valleys (MacDonald, 1983) with a complex geologic history. The island of Oahu was built by the coalescing of two separate volcanic islands, the Waianae volcano to the west and the younger Koolau volcano to the east. A great amount of the Waianae and Koolau volcanos were removed by fluvial and marine erosion during the Pleistocene Epoch. After these erosion cycles, the island of Oahu subsided and was submerged more than 1,200 feet, and the deep valleys that were formed through erosion were subsequently drowned and alluviated with deltaic sediments. At the same time, regressions and transgressions of the sea level occurred. This resulted in renewed erosion through the deltaic sediments during periods of lower sea level, extending alluvial channels well below the current mean sea level. Tropical rains eroded the highlands, carrying down and depositing silt and clay soils first in an alluvial environment, then transgressed into back-reef and lagoons. These alluvial deposits were encountered during the geotechnical exploration in the form of stiff to hard silts and clays, with occasional basalt cobbles and boulders.

![Figure 5. Regional geology map of the project area (Sherrod, D.R. et al, 2007).](image)

Also encountered during the geotechnical exploration were reef deposits, marine sediments, and coral limestone, which were produced during periods of higher sea levels while the river valleys were drowned. The varying cycles of advance and retreat of the sea levels resulted in interbedding and intermixing of the terrigenous sediments, marine sediments, reef sediments, and coral limestone. The resultant river valleys were eventually submerged to form the individual lochs that are present today. Ford Island and the nearby Waipio Peninsula are the old divides between ancient valleys extended by coral reefs and marine sediments (Stearns, 1966).
Many submerged buried deep canyons exist in low-lying areas and to thousands of feet beyond the current shoreline, such as within Pearl Harbor. Where these ancient canyons eroded through fringing reefs, and were buried during interglacial sea level rises or subsidence of the island, the resultant harbor sediments were very soft to slurry-like. Past marine geophysical survey indicated possible depths of these harbor sediments on the order of 200 feet.

Finally, scattered sporadically above the Koolau basalt are lava flows and vent deposits of the rejuvenated stage of Hawaiian volcanism, the Honolulu Volcanic Series. Volcanic ash in the form of tuff from the nearby Salt Lake and Makalapa craters can be found throughout the southeast portion of Ford Island and Pearl Harbor.

5. GEOTECHNICAL EXPLORATION

Using the preliminary HDD alignment and profile, and knowledge of the regional geology of the area, a geotechnical exploration was planned to investigate the subsurface conditions at the necessary locations, depths, and spacings. The geotechnical exploration for the project included on-land borings ranging from 64 to 142 feet below ground surface, and overwater borings ranging from 142 to 148 feet below Mean Sea Level (MSL), or approximately 96 to 111 feet below the mudline. Both the on-land and overwater borings extended below the proposed pipeline depth, which allowed for possible deepening of the pipeline if necessary to mitigate inadvertent fluid returns; identify geologic contact lines particularly near the entry and exit points; and evaluate settlement potential of the very soft estuarine deposits at the channel crossing.

Laboratory testing included classification testing (moisture content, dry density, gradation, plasticity index, and specific gravity), as well as one-dimensional consolidation tests for settlement potential analyses, unconfined compressive strength (UCS) tests and unconsolidated-undrained triaxial compression for soil strength, and UCS and Moh’s hardness on recovered rock cores from drilling for rock strength.

6. SUBSURFACE CONDITIONS

Based on the geotechnical exploration and regional geology of the area, a geologic profile along the HDD alignment could be generated (see Figure 6). This geologic profile not only identified key geotechnical and trenchless considerations associated with the materials expected to be encountered, it provided a uniform basis for interpretation of subsurface conditions for bidding. The geologic deposits along the HDD alignment consisted primarily of:

- Estuarine Deposits, consisting primarily of very soft to slurry-like, saturated, highly compressible, elastic silts and fat clays. Based on laboratory consolidation tests, the estuarine deposits were expected to be normally consolidated to under-consolidated, with expected settlement below the installed pipeline of approximately 10 inches during a 75-year design life for the waterline.
- Interbedded Coralline Deposits and Coral Reef Limestone, consisting primarily of loose to dense, coralline sands and gravels, with cobbles and porous, moderately hard to hard, closely to moderately fractured, and moderately to strongly cemented reef limestone. Based on past experience on previous projects on Ford Island and the Pearl City area, local cavities and voids were expected within the coral reef limestone.
- Older Alluvium, consisting primarily of medium stiff to hard elastic silts and fat clays, with some basalt cobbles. Based on the regional geology of the project area, basalt boulders were also expected within the older alluvium, and at the base of their buried slopes.
- Marine Deposits, consisting primarily of medium stiff to very stiff, silts and clays, and loose to medium dense coralline sands and gravels with shell fragments.
- Fill Materials, consisting primarily of medium dense to dense silty sands and gravels, and stiff to very stiff silts and clays.
- Volcanic Tuff, consisting primarily of moderately to slightly weathered, closely fractured, hard to very hard volcanic tuff rock layers.

The overwater drilling confirmed the presence of very soft estuarine deposits at the middle of the harbor crossing which were expected based on the regional geology of the project area. The estuarine deposits encountered were
very soft, with SPT blow counts of zero with penetration from the weight of rods and hammer, and would likely present steering difficulties during pilot hole drilling. Therefore, the HDD alignment and profile were refined to avoid vertical curves through the estuarine deposits on the Pearl City peninsula side. However, because of the project site constraints, the horizontal curve and part of the vertical curve on the Ford Island side through the estuarine deposits was necessary. The horizontal curve was kept as large as possible, at approximately 6,500 feet, but the vertical curve needed to be approximately 1,500 feet to exit at a location that enabled tie-in to the existing waterline. The preliminary profile was kept at 40 feet below mudline to mitigate inadvertent drilling fluid returns through the estuarine deposits.

Figure 6. Generalized geologic vertical profile along the HDD alignment.

Because of the site constraints on both sides of the alignment, and the limitations of the allowable bend radius of the HDD drill path, the HDD alignment also needed to pass through the possible slip arc of a suspected submarine landslide. It was not anticipated that the HDD operations would significantly affect the existing submarine landslide due to the relatively small size of the HDD reamed hole and pipeline. However, as part of the HDD work plan, the HDD contractor needed to be mindful of their fluid pump rates while drilling near the landslide to minimize potential impacts.

7. TRENCHLESS CONSIDERATIONS AND QUALITY ASSURANCE AND QUALITY CONTROL (QA/QC) REQUIREMENTS

After the geotechnical exploration and evaluation of the subsurface conditions along the HDD alignment, key geotechnical and trenchless design considerations were identified and addressed. These findings and recommendations were summarized in a geotechnical report, consisting of a geotechnical baseline portion and a geotechnical data portion, and were made available to bidding contractors.

Surface settlement from over-excavation of reamed holes and ground heave from not properly flushing the reamed hole of debris, caverned material, cobbles, or boulders, would cause damage to the numerous existing utilities in the area as well as to the overlying pavement, roads, and unprotected structure foundations. To monitor potential surface settlement and/or ground heave, the contractor was required to perform a pre-and post-construction survey consisting of photographs and video of existing on-land site conditions. Settlement monitoring along the on-land alignment and nearby structures and facilities was also required.

Potentially contaminated soils were encountered during exploratory drilling on the Pearl City peninsula side. An environmental engineering subconsultant was contracted by the civil designer to obtain soil and groundwater samples for further testing. Because the HDD work would involve drilling through groundwater with drilling fluid returns passing through the groundwater and to the surface, requirements were included for a larger diameter steel casing to be installed to isolate possible contaminated soils and groundwater from the HDD drilling fluid returns on the Pearl City peninsula side of the alignment.
The very soft estuarine deposits presented several concerns. Based on past HDD projects through similar slurry-like material, substantial fluid loss is possible during pilot hole drilling, reaming, and pullback. To minimize the potential for this occurring, the HDD profile was kept at least 40 feet below the mudline, or the bottom of the harbor. The long-term settlement of the normally to under-consolidated estuarine deposits below the pipeline meant that the pipeline was expected to drop over time. The project team’s civil engineer designed expansion coupling vaults on both sides of the alignment to compensate for any downward movement of the pipeline and subsequent lengthening of the alignment.

Steering difficulties were also anticipated through the estuarine deposits and at the interfaces of those deposits with marine deposits, alluvial marine/deposits, and alluvial deposits on each side of the main harbor canal or channel. The coralline deposits, cobble to boulder sized coral chunks, and fractured volcanic tuff rock layers were also expected to be problematic, as they may cave into the borehole during the various reaming stages, obstructing or diverting the reaming tools, which could cause a meandering drill path with kinks or ‘doglegs.’ that may substantially increase the pipe pullback stresses. Cavities and voids in the coralline limestone, reef rock ledges, and coralline deposits would also increase the potential for fluid loss during all phases of the HDD process.

The length and depth of the alignment, and the subsurface conditions, presented a difficult and challenging project, but one that was feasible for an HDD contractor and work crew experienced in this type of work. As such, the HDD contractor, and their key personnel including project manager, superintendent, drill rig operator, and tracking specialist, were required to submit to the NAVFAC construction manager for approval, their experience records and examples of past projects through similar subsurface conditions. The qualification requirements included having an HDD pilot hole rig operator experienced in drilling and steering through extensive slurry-like soils, and an accurate tracking system capable of tracking through brine water conditions.

Required pre-construction submittals included an HDD work plan that needed to demonstrate that their selected drill rig, equipment, tools, methods, procedures, drill fluid program, and tracking system were capable of drilling, reaming, steering, tracking, and installing the proposed waterline in the anticipated subsurface conditions. Furthermore, the work plan needed to include contingency measures for steering problems, inadvertent fluid returns, excessive fluid loss, caving-in of the reamed hole, ground heave, clearing obstructions, and stuck or failed product pipe during pullback. Finally, the contractor was required to retain a QC specialist, who was to be full-time, onsite during HDD operations. These requirements for qualifications, submittals, and QA/QC measures were placed in the bid documents and potential bidders would need to include these items in their construction cost.

The contract documents included plan sheets and specifications. The plan sheets included pre-approved areas on both sides of the alignment for pipe laydown, staging, fusion, and pullback. The project specifications were based on the Unified Facilities Guide Specifications (UFGS), and modified for project-specific needs. In particular, fusible polyvinyl chloride pipe (FPVCP) was the sole-sourced pipe material to be directly installed by HDD methods. FPVCP was the only material that met the standardized water distribution pipe requirements of the UFGS, and that had the track record of HDD direct installation of pipe size, pullback length, and depths similar to this project.

8. HDD CONSTRUCTION

The construction contract was awarded to Watts - Healy Tibbits A JV, and construction began in April 2014. The HDD subcontractor was Southeast Directional Drilling, out of Casa Grande, Arizona. HDD construction began with the installation of 170 feet of 48-inch steel isolation casing on the Pearl City peninsula (drill rig) side, with the tip of casing extending below groundwater, to isolate potential contaminated soils. The HDD subcontractor used the HDD rig as a platform for the steel isolation casing to maintain the proper entry angle, and used a pneumatic hammer to drive the casing to the desired depth. Augers were used to remove spoils from within the steel casing, where potentially contaminated soils were set aside for testing and proper disposal.

The design HDD alignment was to pass near a small structure near the Pearl City Peninsula shoreline. Prior to pilot hole drilling, the contractor-retained HDD QC specialist indicated that the small structure is actually pile-supported, as he had worked on the design of the structure. The general contractor and HDD contractor made a slight field adjustment in the HDD drill path to provide more clearance from the structure and its piles.
Pilot hole drilling commenced from the Pearl City peninsula side with a 10-5/8 inch drill bit, and a gyroscopic tracking system. By using this gyroscopic tracking system, tracking wires did not need to be laid along the alignment and on the mudline at the harbor channel crossing. Tracking data was monitored and recorded every 30 feet, or at every drill rod length. The pilot hole drill bit broke through into an excavated exit pit on Ford Island, approximately 3 feet below target (see Figure 7). Despite the very soft estuarine deposits present along the channel crossing, the HDD subcontractor steered the pilot hole through the horizontal and vertical curves along the alignment with line and grade deviations less than the +/- 10 feet of tolerance required in the specifications.

Figure 7: HDD rig on the Pearl City peninsula side during pilot hole drilling (left), and pilot hole breakthrough on the Ford Island side (right). Pilot hole drill bit is at the bottom center of the right photograph. The exit point target is indicated by the wooden stake with pink ribbon, at the top middle-right of the right photograph.

The initial plan by the HDD subcontractor was to ream in two stages; first with a 24-inch reamer, then with a 38-inch reamer. After the pilot hole creation, however, the HDD subcontractor elected to ream the entire length in one pass with a 38-inch reamer. This decision was primarily based on the idea that one reaming pass would limit deformation of the alignment, particularly in the curved sections in the soft estuarine deposits. Drill and spoil returns were occasionally lost during the reaming stage, in particular through the estuarine deposits, during which time the HDD subcontractor regained return by retracting drill rods and re-reaming. As a contingency measure in their HDD work plan, the HDD subcontractor devoted adequate time during reaming for the restoration of drilling fluid returns, including tripping the reaming assembly back to the entry pit until returns were restored. The HDD subcontractor also installed weeper subs at 20-joint intervals (approximately every 600 feet) to improve drilling circulation through the reamed hole. After reaming but prior to product pipe pullback, a 36-inch ball reamer was pulled through the reamed hole to ‘swab’ and condition the borehole.

In total, the installation of the steel isolation casing took 1 week, the pilot hole drilling took approximately 2 weeks, while the reaming and swabbing stage took approximately 3 weeks. Based on discussion with the HDD subcontractor and review of subcontractor’s drill logs and daily reports, the drilling rates and conditions generally correlated with the subsurface conditions in the geologic profile. The settlement monitoring records indicated little to no detectable surface settlement or ground heave along the on-land HDD alignment.

9. PIPE FUSION, STAGING, AND PULLBACK

The FPVCP was supplied by Underground Solutions, Inc. of Poway, California. Pipe assembly and insertion was performed on the Ford Island side of the alignment. Due to the constraints of the project site, which were primarily related to keeping traffic access open at all times during the project, pipe assembly took place between Chafee Boulevard and the historical runway (see Figure 8) present on Ford Island. Thermal butt fusion was used to assemble the 40-foot lengths of FPVCP delivered to the site into a single length of approximately 3,500 feet. This length was staged along the historical runway until the borehole was adequately prepared and the pipe insertion operation was ready to commence (see Phase 1 of Figure 9).
In order to place the pipe in the appropriate alignment for the insertion process, extensive work was needed to facilitate the movement and assure that traffic access was maintained to all residences and facilities on Ford Island. The pipe was first pulled back away from the insertion location (see Phase 2 of Figure 9), and into a park area, to a point where the curvature of the pipe alignment could be reached as it was turned toward the insertion pit. It was then moved through a radius, through the green space between residential housing and facility buildings, across Wasp Boulevard, and finally into the insertion pit (see Phase 3 of Figure 9).

The final alignment into the borehole required the pipe to be curved both horizontally and vertically by the use of excavators and roller cradles to ensure the appropriate alignment for insertion (see Figure 10). Throughout this effort, traffic patterns were coordinated such that no area that required access by vehicle was isolated. During the backwards movement, this included the primary roundabout entry area for all of Ford Island. As pipe was then realigned, the roundabout was opened again, while other roadways, such as Chafee Boulevard and Wasp Boulevard, which ended up being blocked along the insertion alignment, were closed off. All pipe fusing, stringing, staging, handling, and movement was coordinated with rollers or other friction reducing elements to limit drag and required pull forces and also to assure that the proper alignment was maintained.

Initial coordination and movement of the pipe began at 2 AM, and the pipe was finally hooked up to the drill stem and ready to be installed at approximately 10 AM. The pipeline reached the Pearl City Peninsula at approximately 9 PM on the same day to complete the insertion process and mark the successful completion of the crossing.
Per the specification requirements, the HDD-installed pipeline was hydrotested in accordance with the applicable AWWA standards, and passed. Subsequent construction efforts consisted of open-trench connections from the HDD-installed pipeline to existing waterlines, and construction of reaction blocks and expansion coupling vaults.

Estimated pipe pullback forces for the installation phase were calculated using a buoyancy-based with capstan effect modifier model (ASTM F1962, 2011). Comparison shows that the actual pipe pullback loads observed during pullback operations generally followed the estimated pipe pullback forces (see Figure 11). Meanwhile, the actual maximum pullback force observed of 140,000 lbs was well within the safe pulling force of 307,100 lbs for the 24-inch FPVCP used. Further examination of the actual pipe pullback forces revealed lower frictional resistance through the very soft estuarine deposits. For the estuarine deposits, this may be indicative of a sufficiently oversized and open reamed hole and the very soft, slurry-like nature of the estuarine deposits.

Approximately 27,000 lbs was required to move the HDD carriage, and was factored out of the observed pullback loads at the drilling rig.

10. CONCLUSIONS

The importance of acquiring adequate, 24-hour HDD work and pipe staging areas during the design phase for this project should not be underestimated. The project was located within Navy property and near critical facilities and residential housing. A considerable amount of effort was put forth by the design civil engineer and NAVFAC’s design team to provide work and staging areas available for the contractor and provide a uniform basis of bid. If left up to the contractor and they were unable to obtain adequate staging areas, HDD would become impractical and infeasible.
The contract documents included qualification requirements for the HDD contractor to ensure that a highly trained and experienced work crew would perform the HDD work, adjust fieldwork as necessary, and be able to implement necessary contingency measures should any problems arise. The contract documents were carefully reviewed by NAVFAC during design and the requirements were strictly implemented by NAVFAC’s construction management team. NAVFAC and the project design team also reviewed the HDD work plan and design calculation submittals for conformance with the contract documents.

Finally, for all the design effort, a key contributing factor for the successful completion of the project was the construction effort from the contractor’s team. Collaboration by a group of experts in their respective fields results in unique solutions to both pre-existing design challenges and the inevitable ‘field challenges’ that pop up during construction. Cooperation between the general contractor, HDD subcontractor, and the FPVCP pipe supplier during the preconstruction and construction phases was critical for the success of the project. Watts - Healy Tibbits brought extensive experience with working on Navy projects in Pearl Harbor, and employed a QA manager to review all submittals for conformance with the project requirements. Southeast Directional Drilling provided a highly qualified work crew and support to complete the HDD work through very challenging site and subsurface conditions. Underground Solutions, Inc. provided submittal support to the contractor in the form of pipe staging, pullback, and long-term design guidance; qualified fusion services; and onsite representatives during construction to provide field consultation to the HDD contractor.

### 11. REFERENCES


