HDD under Pearl Harbor Provides Joint Base Pearl Harbor-Hickam with New Water Supply Line

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1. ABSTRACT

Joint Base Pearl Harbor-Hickam (JBPHH), a combination of the Pearl Harbor Naval Station and Hickam Air Force Base on Oahu, required installation of a new water supply line across Pearl Harbor as part of its mission to provide a safe and sufficient supply of water to meet potable water and life safety requirements on the base.

This recently completed project replaced approximately 3,500 feet of existing, deteriorated 24-inch cast iron water line with a new 24-inch fusible polyvinylchloride (FPVC) water line in an HDD-installed 30-inch steel casing from Ford Island to Landing C on the JBPHH. Soft soil conditions with unstable sediments and existing historical features were the main design considerations. This paper will focus on the design and construction of this primary replacement potable water artery, including unexploded ordnance avoidance, historical features on Ford Island, annular space treatment concepts between the steel casing and FPVC water line, and expansion coupling vaults on each end of the HDD-installed water line.

2. INTRODUCTION

The Pearl Harbor Naval Station and Hickam Air Force Base, now a joint facility known as Joint Base Pearl Harbor-Hickam (JBPHH), became an indelible part of our Nation’s history when on December 7, 1941 the Japanese launched a surprise attack on Pearl Harbor and other surrounding military bases, precipitating the United States’ entry into World War II. Since the war, the JBPHH has continued to play an important role in our Nation’s defense readiness. The vision statement for the base is, “JBPHH enables maximum mission readiness of our tenant commands and activities by providing the highest quality installation services, facilities support and quality of life programs.” Keeping the potable water system, as well as other base utilities, in reliable working condition is a key component of this mission and the Navy has been in the process of upgrading the water mains feeding this vital facility as portions reach the end of their serviceable life.

2.1. History and Development of the Area

In April 1998 the Admiral Clarey Bridge opened, linking Ford Island to the rest of the Pearl Harbor Naval Base, now part of the JBPHH. For the first time in its long and storied history, one could drive to Ford Island. Before the bridge opened, Ford Island was only accessible by ferry. This opened the door to better utilization of the over 440 acres of land on the island. To develop the island effectively, the Navy embarked on a plan to upgrade the infrastructure allowing construction of nearly 500 housing units, essential training facilities, preservation of historic elements that are an important part of the World War II Valor in the Pacific National Monument, repurposing war-era historic seaplane hangars that became the Pacific Aviation Museum, and allowed the USS Battleship Missouri
Memorial to be realized. Another benefit of the Ford Island Master Development was the ability for the Navy to begin replacing vital water utilities going through the island to the Pearl Harbor Naval Shipyard (PHNSY), improving utility service and security to the vital shipyard facilities.

2.2. Existing Water Main and Issues Spurring the Proposed Construction

One of the key potable water pathways to the PHNSY area is through an under-channel water main from Ford Island to the area known as Landing C (Figure 1). It was built in the 1950’s by laying a 24-inch diameter flexible-joint cast iron water pipe on the mud of the channel bottom. This water main was in need of replacement to improve the mission readiness of the JBPHH. The exposed pipe was vulnerable to accidental anchor drags or other shipping mishaps and was at the end of its serviceable life, thus subject to possible breaks due to its age. With the replacement of this line with a new HDD installed pipe under the channel bottom, the reliability of the potable water service is greatly elevated and thus mission readiness of the entire JBPHH is enhanced.

2.3. Installation Method and Potential Unexploded Ordnance

As technologies are constantly improving, the options available for the installation of the new water pipe were studied to ensure the Navy receives the best value for the project. Laying a new pipe on the channel bottom was studied; however, the vulnerability of the pipe to damage from shipping accidents was a key deterrent of this method. Even adding concrete “armor” over the pipe to protect it had issues due to the very soft channel mud that could allow movement of the armor that could, in turn, damage the pipe. Trenching the channel bottom was also a consideration during planning.

During the Pearl Harbor attack on December 7, 1941, Japanese military aircraft deployed torpedoes in and around the project site, including two torpedoes that may be resting on or below the surface of the mudline near the project alignment (Figure 1). Based on research documents (Adams, 1993), both torpedoes did not travel the necessary 200 meters to arm their warheads. It is not known how deep the torpedoes may have sank since 1941, or the effect of past dredging efforts along the channel on the depth and location of the torpedoes. Thus, it was not known how far below the mudline the torpedoes may be located. Three other unexploded torpedoes are also located further northeast of the project alignment.

![Figure 1. Project location and map of contributing objects (CNRH, 2008).](image)

NAVFAC commissioned an underwater geophysical survey of the project area to identify potential areas that appear free of surface/metallic anomalies that would allow anchoring of a barge/vessel in order to complete geotechnical borings into the channel bottom. Data collection during the geophysical survey uncovered 51 surface anomalies (on channel bottom) and 24 buried anomalies (Figure 2).
The geophysical survey of the channel bottom was not able to locate the torpedoes. Dredging the mud would expose construction and base personnel to the possibility of injury or death as a result of an unexploded ordnance incident if dredging equipment hit one or both of these torpedoes. Even if the torpedoes could be remediated, the environmental impacts of dredging the soft mud of the channel bottom and the length of time dredging and pipe laying barges would be blocking this vital shipping channel made this option infeasible. Due to the risks of dredging and laying the pipe on the channel bottom, it was determined that an HDD pipe installation method would be the best option.

The piping needed to connect the HDD portion of the water main were by conventional open trench. On the Ford Island side, the Contractor carefully excavated within existing trench cuts to avoid damaging any World War II era features.

A further benefit of HDD was the ability to go under historic resources located on Ford Island. The seaplane ramps, parking aprons and hangars are war era features and still show damage from the 1941 attack. Preservation of these areas was a key constraint on the construction. Although HDD has a relatively small impact on ground disturbance, the entry pit needed on the Ford Island terminus would have damaged the historic features in the vicinity. Therefore, the entry pit was moved 2,000 feet away from the shoreline to avoid any possibility of damaging a valuable historic resource.

2.4. Pipe Size Determination

The internal pipe diameter was determined by modeling the water system to ensure adequate flow can be delivered to the PHNSY with one of the other under-channel pipes to Ford Island out of service. The model was calibrated using data for the flow and pressure through the existing cast iron pipe that was to be replaced. It was determined a 24-inch pipe to match the existing cast iron pipe diameter would improve the flow and pressure of water to the PHNSY due to the improved friction characteristics of a new pipe. Pressure rating of the new pipe would be to take the 150 psi test pressure and 65 to 75 psi working pressure.

2.5. Material Determination

To reduce risk during installation due to the variable geology of the area, the design included a 30-inch outside diameter, 1/2-inch thick steel casing pipe for the HDD pipe installation. The use of a steel casing pipe allowed the consideration of several different carrier pipe materials. However, the soft channel mud could, over time, allow the entire casing and pipe string to settle, pulling on the pipe at one or both on-land terminal ends. To reduce the stress on the pipe, two expansion couplings on each end of the underwater water main were included in the design. These couplings have a sliding section that will allow the pipe to elongate as it settles. Even with expansion couplings, the long length of pipe inside the steel casing could bind, or develop stresses unpredictably and cause a jointed pipe to fail anywhere along the entire underwater run. Therefore, the design team determined that a “jointless” pipe would be most beneficial to the project. Due to a moratorium on the use of HDPE for potable water piping at the time the design was developed, FPVCP was found to be the only suitable “jointless” pipe material. In addition, the ability of
FPVCP to take the pull stresses for installation would allow it to take the stresses developed in the pipe should it bind or settle unpredictably. Corrosion protection of the steel casing was not provided, as the steel casing was installed only for the subsequent installation of the FPVCP pipe inside the steel casing.

2.6. Funding and Permitting

Funding of the project was through Naval Facilities Hawaii (NAVFAC-HI) Utilities and Energy Management (UEM), the organization tasked with maintaining the JBPHH water, wastewater and energy utilities. The final project bid was $16.5 million.

The two main permits required for the project were a Department of the Army (DA) Permit for work in navigable waters of the United States, and the Stormwater National Pollutant Discharge Elimination System (NPDES) Permit for construction disturbed areas of one acre or more. Although the pipe installation would be below the channel mud and would not be touching the waters in the channel, a DA permit was still required for the crossing. The permit covered not only the proposed construction work, but also covered contingencies in the event that sediment were unexpectedly disturbed due to drilling material blowing out of the bore in the channel. The NPDES permit covered the necessary best management practices (BMPs) to prevent contaminants from the construction site from entering the ocean.

3. SITE CONDITIONS

The HDD entry point on Ford Island was initially placed closer to the shoreline. This would have involved open trenching from the HDD entry point to the connection to the existing waterline. However, there were several historical features that necessitated extending the HDD alignment further inland. Based on a historic pre-World War 2 aerial photo (Figure 3), an aircraft hangar was located over the HDD alignment near the shoreline of Ford Island. This aircraft hangar was destroyed during the bombing of Pearl Harbor. Research into existing as-builts and drawings did not reveal whether the hangar was supported on deep foundations, though nearby building such as the Firefighting Training Buildings and the Pacific Warfighting Center were supported on shallow foundations.

Associated with the bombing of the aircraft hangar, there were historical features within the surrounding concrete pavement, including bomb splatters, bomb craters, fire damage, strafing, and historical graffiti (Figure 3). To avoid open trenching through these historical features, the HDD alignment was extended further inland, past the historical pavement. In doing so, the HDD entry point was now immediately west of the historic Compass Rose, which then necessitated protective measures that were implemented during construction.

![Figure 3. Pre-World War 2 aerial photograph (NAVFAC, 2011), and photograph of patched bomb splatters.](image)

On the Landing C side, the HDD alignment crossed under a shoreline dock supported on concrete piles; however, the tip elevation of these concrete piles were not known. The HDD alignment was extended further from the shoreline to avoid an entry/exit point in front of housing, and to place the 24-hour HDD work area within an existing empty lot. To do this, the HDD alignment would then have to cross under the footprint of the now-demolished Building 98, and the currently abandoned warehouse Building 1660. The as-built drawings did not indicate whether these buildings were supported on deep foundations, though nearby buildings were built on shallow foundations.
4. SUBSURFACE CONDITIONS

The geotechnical exploration included on-land and overwater drilling along the HDD alignment. Based on the geotechnical exploration, and the regional geology of the area, a geologic profile was generated identifying the main geologic deposits anticipated to be encountered (Figure 4). The anticipated subsurface conditions in the pipe zone along the proposed HDD alignment were expected to include fill, volcanic tuff, coralline deposits interbedded with coral reef limestone, older alluvium, coralline and alluvial deposits, and estuarine deposits.

Figure 4. Generalized geologic vertical profile along the HDD alignment.

At one of the geotechnical borings along the open trench alignment on Ford Island, a subterranean cavity of at least 5 feet in size was encountered. This subterranean cavity is believed to be a part of the karst system commonly encountered near the interface between the volcanic tuff and the coralline deposits on Ford Island. Similar subterranean cavities were also encountered during past nearby projects. The project specifications included requirements for the Contractor to include in their contingency plan the option of installing a larger diameter protective steel “conductor barrel” that extends through the interface between the overlying volcanic tuff and the underlying coralline deposits. Furthermore, during construction of the open trench segment on Ford Island, the Contractor encountered a cavity at the interface between the volcanic tuff and the coral reef limestone (Figure 5).

Figure 5. Photographs of observed cavity along open trench segment on Ford Island.

Steering the pilot bit and drill string through the very soft to slurry-like estuarine deposits near the middle of the alignment under the harbor was expected to be very difficult. The HDD profile was refined to avoid vertical curves through the estuarine deposits on both sides, and the curves themselves were kept as large as possible, at approximately 6,000 feet in radius. At least 40 feet of ground cover below mudline was maintained to reduce to potential for inadvertent drill mud returns through the estuarine deposits and into the harbor.
The amount of vertical deviation allowed for this project (up to 10 feet) led to concern about potential inadvertent high points along the waterline profile. These high points may result in trapped air, which would then reduce the flow of water. To reduce the potential for high points during HDD, the straight portion of the alignment between vertical curves had an approximate 0.7% slope over approximately 1,090 linear feet, with a difference in elevation between each end of approximately 8 feet.

5. HDD CONSTRUCTION AND STEEL CASING PULLBACK

The construction contract was awarded to Healy Tibbits Builders, Inc. (HTBI), and their HDD subcontractor was Michels Directional Crossings (Michels). Michels commenced pilot hole drilling from the Ford Island side in May 2017, and drilled approximately 1,300 feet along the alignment. Because drill mud circulation was lost during pilot hole drilling, and to avoid potential frac-out, Michels moved their HDD equipment and re-commenced pilot hole drilling from the Landing C side. By mid-May, the two drill strings were within 3 feet of each other. The Ford Island drill string was pulled back while the Landing C drill string was steered into the Ford Island pilot hole. The Ford Island drill string was then retracted while the Landing C drill string followed until it reacted the Ford Island entry pit. The HDD alignment was tracked using a gyroscopic steer tool system. Reaming passes were performed with 30-inch and 42-inch reamers, and continued from mid-May to the end of June.

Figure 6: Steel casing pullback.

The 30-inch steel casing pullback was pulled back in one continuous pipe string on June 28, 2017 (Figure 6). The Contractor elected to pull back the steel casing un-ballasted. Comparison with the estimated steel casing pullback forces calculated during the design phase, and modified for the deeper profile and un-ballasted steel casing, shows that the actual observed pipe pullback loads were generally lower than the estimated pipe pullback forces, and well below the allowable steel casing pullback load (Figure 7).

Figure 7: Estimated calculated pipe pullback loads, and actual pullback loads observed during construction.
Pipe assembly and insertion for this project was performed on the Ford Island side of the alignment. Pipe assembly had to take place between Chafee Boulevard and the historical airstrip on Ford Island due to the project site constraints, primarily related to keeping essential traffic access open at all times during construction. The FPVCP was delivered to the jobsite on February 6, 2017. Thermal butt fusion was performed by a qualified fusion technician to assemble 45-foot lengths of FPVCP into a single length, approximately 3,450 feet long. The fused length was staged along the historical runway while the steel casing was pulled into place.

The goal was to install FPVCP in the designed alignment while maintaining traffic access to all residences and facilities on Ford Island. Fortunately, the pipe entry was located near the southwest end of the historical airstrip. The entire pipe length was fused and staged in a straight line between Chafee Boulevard and the airstrip (Figure 9). Pipe fusion started on March 13, 2017 and took 18 days to complete. The pipe was then moved into place for insertion into the steel casing by horizontally curving a 600-foot radius across the end of the airstrip and O’Kane Boulevard, and into the insertion pit at an 11.25-degree vertical angle (Figure 8). Part of O’Kane Boulevard between Wasp Boulevard and Enterprise Boulevard was closed, but access to all residences and facilities remained open through a temporary, short detour route.

The final alignment into the borehole required the pipe to be curved both horizontally and vertically. Excavators equipped with roller cradles were used to ensure that the appropriate alignment at pipe entry was achieved (Figure 9). During pipe fusing, staging, and handling, all pipe movement was coordinated with rollers and other friction reducing implements to minimize drag, reduce potential damage, and lower pull forces. Rollers were also used to maintain proper alignment without excessively bending the pipe. The FPVCP was allowed to curve along the alignment within its allowable bending radius, so restraints along the curve were not needed.

During the design process, annular space treatment between the FPVCP and the steel casing was an especially important topic. Potential concerns pertaining to the annular space included gouging, scratching, and abrasion of the exterior of FPVCP during insertion due to dragging the pipeline inside the steel casing, point loads imposed on the FPVCP by steel casing internal weld beads, and potential debris inside the casing. Post-installation concerns
included movement of the FPVCP within the casing due to water flow and pressure fluctuations, thermal expansion and contraction of the FPVCP, as well as the potential sinking of the steel casing due to continued settlement of the existing geological strata that the alignment passed through. These factors may contribute to potential wear and tear on the FPVCP exterior, affecting the actual design life of the transmission main. Multiple annulus treatments were explored to protect the carrier pipe.

The first treatment concept was to grout the annular space between the FPVCP and the steel casing along the entire length of the HDD alignment. Highly flowable, low-density, cellular grout would be used. This method would offer the most robust way of securing the FPVCP, reducing the potential for point loads along the pipeline, and preventing potential cave-in of the surrounding soils if the steel casing deteriorated. However, grouting along this length and depth would be very complicated since the annular space was relatively small, and the distances are relatively long. Increasing the annulus for grouting meant increasing the steel casing size, and this would require a larger reamed hole; thus, increasing the project cost and risks.

The second treatment concept was to use casing spacers without grouting the annulus. Casing spacers, with rollers or skids, would reduce contact between the FPVCP and the steel casing, preventing damage during pullback. However, the FPVCP would not be completely secured inside the casing and would be able to move laterally to a certain extent. Furthermore, casing spacers tend to get pinched in curvilinear alignments. When one spacer is pinched at one location, the following spacers stack up at the same location as more pipe is pulled. Consequently, this creates undulations, allows contact between the FPVCP and the steel casing, and presents potential point loads along the alignment.

Finally, the third concept was to fill the annulus with water prior to installation inside the steel casing. This method does not require either grouting or casing spacers. The internal weld beads of the steel casing and external fusion beads of the FPVCP must be removed to eliminate potential point loads. The HDD-installed steel casing should be pigged to clear out any remaining slag or debris and the FPVCP should be water-ballasted in order to reduce frictional forces and buoyancy effects, thus reducing the necessary pullback force needed during insertion. The annulus would be left full of water after installation to dampen pipeline movement inside the casing. Upon evaluation by engineer, owner, and pipe supplier, this method of annular space treatment was selected for the project.

FPVCP insertion into the steel casing began at 11 AM on July 1, 2017, and the pipe was successfully pulled in place by 6 PM, marking the completion of the crossing. A modified pull head was used to allow water in the casing annulus to enter the FPVCP during the insertion (Figure 10). This facilitated a unique self-ballasting mechanism.
At the end of the installed section, non-rigid sealant with a polyethylene wrap and pipe boot was installed in order to avoid cave-in of surrounding soils into the annulus (Figure 11). The FPVCP rested on the bottom of the steel casing at the end of the casing to ensure that the transmission main was supported at the transition point from casing to direct bury. Lightweight flowable fill (70 to 90pcf) was used around the FPVCP immediately outside the steel casing. The backfill provided bearing area under the pipe, reduced loading on top of the pipe, and acted as an added measure to reduce cave-in of surrounding soils into the annular space between the casing pipe and the FPVCP.

The transmission main was required to be hydrotested in accordance with the applicable AWWA standards per the project specifications. On August 2, 2017, the pipeline was tested at 150 psi for two hours and passed. The transmission line is anticipated to be placed into service by the 2nd quarter of fiscal year 2019.
7. **EXPANSION COUPLING VAULTS**

Pearl Harbor is an estuary to numerous streams and springs that constantly add sediment to the harbor. This mud continuously collects on the channel bottom, settling and consolidating over time. Based on consolidation tests, the estuarine deposits below the installed pipeline at the proposed depths were estimated to potentially settle approximately 12 inches during the 75-year design life of the waterline. There is also evidence of past underwater landslides and mud flows toward the channel exit into the Pacific Ocean. This process can drag the casing and pipe downward. If the pipe is fixed too rigidly at the land terminations, the massive amount of mud and deposits settling and dragging on the pipe could cause very high tensile forces to develop in the pipe. If these forces exceed the ultimate tensile strength of the pipe, the pipe will catastrophically fail. The expansion couplings address the settlement by allowing the pipe to elongate using a sliding sleeve. To maintain proper function, the expansion couplings are installed to allow a linear horizontal movement of the pipe. This design has been used successfully on three similar underwater crossings in similar conditions. To translate the allowed horizontal motion to the vertical dragging of the pipe by the mud of the channel, there is a large sliding concrete block at each end of the HDD pipe. As the pipe is dragged down, the concrete blocks will slide toward the channel over time as the passive side pressure of the soil will begin to fail before the upward bearing pressure of the ground below the block. This serves to transform the downward pull of the pipe into a horizontal motion at the expansion couplings. Two expansion couplings are provided, one at each terminal of the HDD pipe (Figure 12).

![Figure 12. Expansion coupling vault on Landing C side.](image)

8. **CONCLUSION**

The unexploded ordnance near the project alignment necessitated additional precautions and joint cooperation between the design team and NAVFAC. The Navy contracted a geophysical survey along the proposed alignment, which the geotechnical subconsultant used to identify potential borehole locations, and anchor drop points for the drill platform. Additional precautions such as use of a down-hole magnetometer was required by the Navy and used during geotechnical drilling.

The discussions on annulus treatment concepts illustrated the importance of the design team collaborating with manufacturers and contractors to reach a solution that is both meaningful and practicable. While annulus grouting would have offered the most robust way of securing the FPVC pipeline inside the steel casing, the constructability of grouting a relatively small annulus over lengths and depths of the pipeline was anticipated to be very difficult and problematic. The FPVC pipeline was ultimately designed with no annulus grouting or casing spacers, with requirements for the steel casing to be filled with water during installation, internal welds of the steel casing smoothed down, and external beads from the FPVCP removed.
Because of the long-term settlement of the normally to under-consolidated estuarine deposits below the pipeline, expansion coupling vaults were designed for both sides of the alignment to compensate for any downward movement of the pipeline and subsequent lengthening of the pipe profile.

9. REFERENCES


NAVFAC (2011) - Pavement Survey, Southwest Corner of Ford Island.