The Environmentally Sensitive Force Main Replacement for Boca Ciega Bay: Taming Horizontal Directional Drilling Technology

Francisco J. Bohorquez, David Wilcox, Mathew Francis, Dennis Simpson, Dinesh Kamath, Dalas Lamberson, and David Hunniford

Francisco J. Bohorquez, P.E., is project manager (and was engineer of record for the project), and David Wilcox, P.E., is group manager, with AECOM in Tampa. Mathew Francis, P.E., is tunneling and trenchless technology senior engineer with AECOM in Salt Lake City. Dennis Simpson, P.E., is engineering section manager, and Dinesh Kamath, P.E., is project manager, with Pinellas County Utilities in Clearwater. Dalas Lamberson, is vice president with TLC Diversified Inc. in Clearwater. David Hunniford, P.E., is regional sales manager with Underground Solutions Inc. in Sarasota.

The more-than-40-year-old 24-in. prestressed concrete cylinder pipe (PCCP) force main at Boca Ciega Bay (bay) conveys wastewater from a high-density area in Madeira Beach to the South Cross Bayou Water Reclamation Facility located approximately 5 mi inland. The pipeline alignment includes two subaqueous crossings: one under the waterway and the other under the bay.

The aging condition of the PCCP main posed an unacceptable risk to Pinellas County (county), which retained AECOM as the engineer of record (EOR) to evaluate alternatives, design, and support construction for the replacement of a 5,000-lin-ft portion of the pipeline located under the bay. Previously, the EOR had designed a 2,000-lin-ft replacement force main for the portion of the pipeline under the Intracoastal Waterway.

The challenge was replacing the mi-long force main without impacting the environment. The EOR evaluated horizontal directional drilling (HDD) alignment and pipe material alternatives. For the final, selected 4,000-lin-ft alignment, 24-in.-diameter fusible polyvinyl chloride (FPVC) pipe was specified, providing robust strength and a lean bore diameter. Temporary and permanent construction easements were negotiated with property owners for the construction and for permanent use. Alignment selection considered available routes, easements, and permitting.

Although the originally proposed alignment under the bay is approximately 1,000 lin ft less than the existing alignment, an additional 620 lin ft of FPVC via HDD and 2,300 lin ft of open cut PVC were required to connect the HDD installation to the existing force main. The original alignment included over 1,700 lin ft along the Pinellas Trail (trail), a former railroad corridor turned into a public access trail by the Rails to Trails project, and another section along heavily traveled Park St. North. The final project design and construction documents were developed by using similar HDD crossings the EOR had designed in the area, including:

- 2,000 lin ft of 20-in. high-density polyethylene (HDPE) crossing the waterway at the beach at minus 75 feet to avoid the Tom Stuart Causeway Bridge piles.
- 1,850 lin ft of 15-in. HDPE crossing the waterway at Indian Shores, with a reverse compound horizontal curve to avoid a property boundary.
- 3,000 lin ft of 30-in. HDPE water main crossing the Manatee River at Fort Hamer.
- 3,500 lin ft of 20-in. HDPE water main crossing the waterway at Cortez Road.

This article discusses the alternatives, assessment, design, and successful construction of the project within the beautiful and strict environmental setting of the bay, drawing upon lessons learned from preceding projects.

The county has the sixth largest population in Florida, with approximately 970,000 residents. It's the second smallest in area and boasts over 600 mi of coastline and eleven barrier islands. The service area is significantly developed, composed of commercial areas, condominiums,

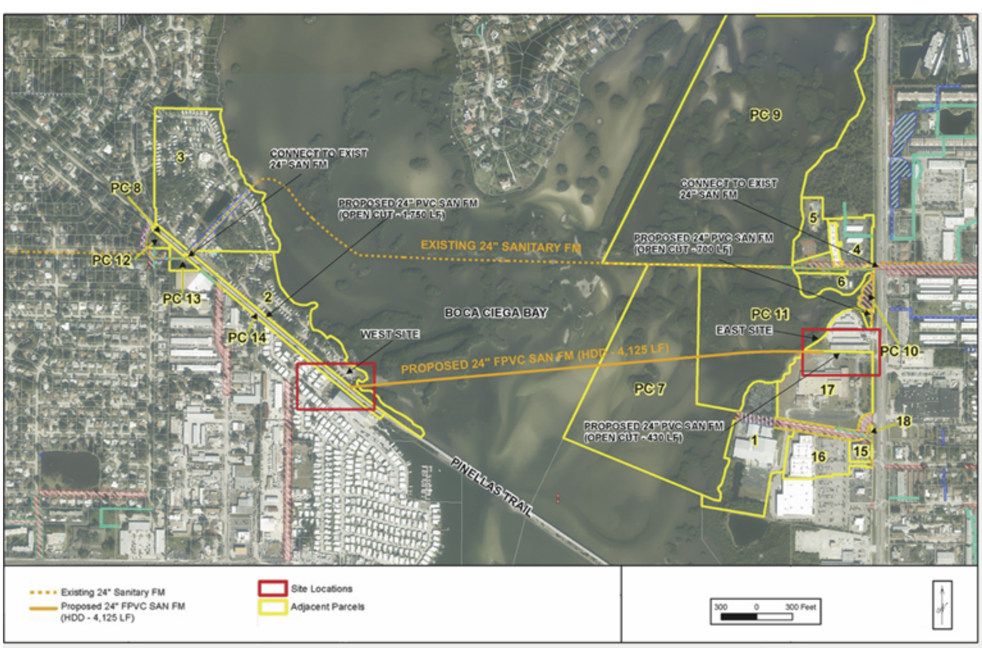

Figure 1. Existing and Proposed Alignments

apartments, and hotels. The Madeira Beach Pump Station and force main system conveys wastewater generated by the barrier island community to the county's South Cross Bayou Water Reclamation Facility, a distance of approximately five mi. The force main is PCCP and consists of approximately 6,900 lin ft of 20-in. pipe and 19,400 lin ft of 24-in. pipe. Constructed in the early 1970s, the alignment includes two subaqueous crossings: a 2,000-lin-ft crossing of the waterway and a 5,000-lin-ft crossing of the bay. The crossings were originally installed by cut and cover approximately 2.5 ft below the bay bottom. Figure 1 illustrates the existing and proposed pipeline alignment under the bay.

The existing force main is the sole method to convey the collected wastewater from the beach area to the county's treatment facility. As such, the county determined that the more-than-40-year-old force main posed a significant risk in the event of failure at the subaqueous crossings and selected the EOR to design new crossings at both the waterway and the bay. The plan was to install an additional force main at both crossings, while retaining the existing pipeline crossing as a redundant backup.

The available as-built drawings from the county showed that the existing force main at the bay is a 24-in.-diameter PCCP that was installed by direct bury in 1973. The existing pipe alignment is located in the county right of way until the subaqueous crossing. Along the east and west shorelines, the pipeline is located in 20-ft easements. Along the west side, the easement runs through a Kampgrounds of America (KOA) facility. On the east side, the easement is located near the Otter Key Condominiums, Bay Area Heart Center, and other businesses. The pipeline located in these easements is difficult to access and would cause significant impact to the public should the county need to perform maintenance or repair work.

Alignment Alternatives and Selection

The main goal of this project was to install a second pipeline crossing of the bay so the existing 40-year-old crossing could be taken out of service, rehabilitated, and eventually act as a redundant crossing. A secondary goal was to develop an alignment that provided the county with better accessibility to the pipeline prior to it crossing under the bay. Taking these goals into account, three alternatives were developed for consideration by the county:

- Alternative 1 considers a subaqueous crossing alignment parallel to the existing force main.
- Alternative 2 considers a subaqueous alignment south of the existing force main that includes some open cut installation.
- Alternative 3 considers a significant amount of open cut installation, with the bay crossing being achieved by attaching the proposed pipeline to an existing pedestrian bridge.

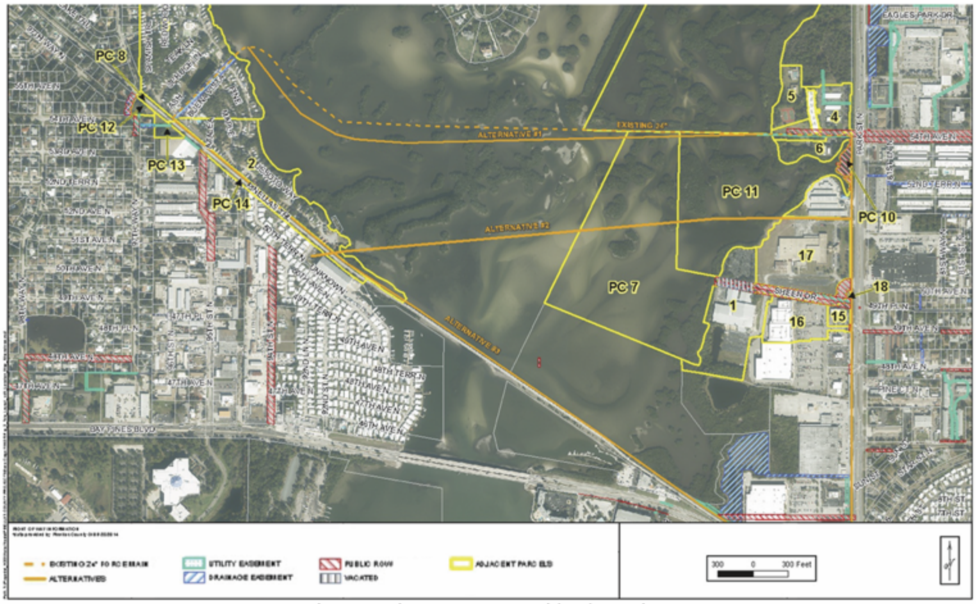

Figure 2. Site Layout Map with Alternatives

The alternatives proposed for evaluation and the adjacent parcels are shown in Figure 2.

Alternative 1 was eliminated because HDD could not follow the S-shaped alignment of the existing pipeline near the west shoreline of the bay. To perform an HDD crossing using this alignment, additional easements and relocation of buildings would be required in the KOA area that would necessitate the relocation of existing structures. Alternative 3 was eliminated as it would present a much longer, and therefore more costly, alignment. In addition, it was determined that the existing trail bridge crossing the bay could not support the additional loads that would be imposed by the proposed pipeline.

Alternative 2 was determined to be the most feasible. The proposed alignment required the installation of 1,700 lin ft of pipe along the trail, a 4,000-lin-ft crossing of the bay, and a 650-lin-ft HDD installation along Park St., which only required the acquisition of two permanent easements and one construction easement, and resulted in the least impact to the public during the construction phase.

Easement Acquisition

Based on the selected alignment, the county contacted representatives of KOA and Park Place Medical to discuss the proposed alignment and the need for permanent easements for the new force main. The representatives indicated that the properties would likely be sold or redeveloped in the future and requested that the county minimize any possible additional easement that would dissect the property and thereby affect the sale. Based on these requirements, the proposed alignment was somewhat modified so that the required easements would be located in portions of the respective parcels that could not be developed. Finally, a temporary construction easement was acquired from the Bay Pines Marina along the west side of the trail. This easement was needed for drilling operations.

The existing force main was installed via direct bury from the west side easement through the KOA property in an easterly direction across the bay, to an easement on the east side and to the intersection of Park St. and 54th Ave., continuing east along 54th Ave. The final proposed layout connected the existing force main from its location on the trail near the entrance of the KOA southeast via open cut to the southernmost edge of the KOA property, minimizing easement requirements and avoiding dissecting the property. It then crossed the bay via HDD to an easement along the property boundary between Park Place Medical and a moving and storage facility, continued via open cut to Park St., then ran north via HDD on Park St. to the intersection of Park St. and 54th Ave., where it connects to the existing force main before it crosses Park St. The proposed alignment required temporary and permanent easements. The existing force main and proposed alignment configurations are depicted in Figure 1.

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East Side

Park Place Medical offered a large area where temporary construction easements could be acquired to support drilling operations. There was sufficient space available in the surrounding landscaped green area of the facility to expedite the staging of the required HDD drill rig, store associated support equipment, and locate the entry pit for the drill. In addition, for the staging of the individual pipe sections, there was sufficient space to stage six prefused pipe sections of approximately 670 ft in length in preparation for the final more-than-4,100-ft of pipe pull, since the connection point on the trail would be overshot to the marina property. The 670-ft sections would then be pulled individually and fused as needed during the installation procedure to come to the full length. This was required because it was not possible for the entire length of pipe to be fused along Park St., as it would block both entrances to Park Place Medical.

There was some risk associated with starting to pull the pipe, stopping to butt-fuse the next section (about 45 minutes of downtime), and then restarting the pulling operation, but it was minimal due to the soil conditions along the recommended alignment. There was also significant available area for the staging of equipment, necessary support vehicles, and tanks. A permanent easement (583 ft by 20 ft) would also be required on the property. A 430-ft section would be installed along the easement to reach the Park St. right of way. Easements were negotiated with property owners and are further discussed.

West Side

Space was much more restricted on this side as there was insufficient space to stage the drill, pipe, or required supporting equipment on the trail; however, directly west and adjacent to the trail was the marina. There was a boat storage lot within the marina that could support the exit pit during drilling operations and the required equipment to support the proposed alignment. The storage lot was surrounded by a mobile home park that is part of the marina on two sides, a boat storage warehouse on a third side, and the trail on its east side; therefore, drilling operations would take place from the east side (as well as pipe layout), while pulling operations would take place from the west side from the marina's empty lot, as shown in Figure 3. The pipe would be intercepted at the trail where it would continue north. Appropriate sound attenuation was provided to minimize disturbance to the mobile park residents. A small (65-ft by 20-ft) and mostly submerged permanent easement would be required on the southernmost-edge wetlands of the KOA property, which avoided dissecting the property. A temporary construction easement would also be required.

Pinellas Trail

The installation of the approximately 1,750 ft of force main did not represent a significant problem along the trail, and there appeared to be sufficient space along the east side for the force main to be placed. The county requested that the trail remain open during construction of the force main, and as such, the contractor would need to take into consideration maintaining safe public access. The force main could be installed via open cut or HDD, while maintaining access through the trail.

Park Street

Installation of the approximately 700 ft of proposed force main along Park St. connecting the bay crossing to the existing force main at the 54th Ave. intersection presented some difficulty due to the number of existing utilities. In addition, there were plans to expand Park St. in the near future, with associated new and existing relocated utilities, so the recommended method of installation was HDD with a 24-in. FPVC dimension ratio (DR) of 18. The proposed section of force main was installed at approximately 30 ft below ground, taking into consideration existing and proposed future utilities, including a 36-in. reclaimed water main, also installed via HDD. The construction of the connection to the existing force main located in the grass median in the entrance to a condominium complex and two medical facilities would be done in phases to maintain access at all times.

Figure 3. Bay Pines Marina Temporary Construction Easement

Geotechnical Investigation Along Proposed Alignment

The EOR staff reviewed maps, plans, historic aerial photographs, geologic reports, and other project-specific information in order to evaluate surface and subsurface conditions along the proposed force main route. Some of the documents reviewed include the following:

- U.S. Geological Survey (USGS) Seminole 3123 N.E. Area Quadrangle Maps History (topographic)
- National Oceanic and Atmospheric Administration (NOAA) Nautical Chart 11412, Tampa Bay and Joseph Sound
- U.S. Department of Agriculture/Surveillance Collaboration Services (USDA/SCS) Soil Survey of Pinellas County
- Geotechnical Report, developed by MC Squared Inc. (MC^2) in June 2016 and based on six subaqueous borings, four land-based borings, and three hand augers performed to support construction of the force main.

Additionally, site reconnaissance of the proposed pipeline route was performed by EOR staff to assess site conditions. No areas of specific concern with respect to possible poor soil conditions were identified during the site visit; however, some limitations were identified on both land sides.

Based on the data review, the grade for the land-based work varies approximately between elevation (EL) +13 and +8 ft on the west side and +4 and +7 ft on the east side. The bottom ELs in the bay are shallow and vary from around EL -1 to -2 ft mean sea level (MSL).

The geotechnical boring (soil and rock) information presented was collected by the project geotechnical engineer, MC[2], using a total of eight standard penetration test (SPT) borings along the proposed alignment across the bay, ranging in depth from 40 to 80 ft below the existing ground surface or mud line. Soil samples recovered were visually examined and select samples were used to develop the soil legend using the Unified Soil Classification System. Laboratory testing included natural moisture content tests, percent passing a No. 200 sieve, organic content tests, and Atterberg Limits. Corrosion series testing, should a steel casing be required, and specialized testing, such as Mohs Hardness Scale and Abrasiveness of Rock Testing, were also performed on selected samples. The data collected were used to provide a general characterization of soil and groundwater conditions along the force main alignment and to generate the HDD boring and installation calculations.

Subsurface conditions were explored via eight SPT borings at select locations along the alignment. Two of the SPT borings were land-based near the entry and exit pits and performed to a depth of 40 ft below ground surface (bgs). The remaining six SPT borings were performed to a depth of 80 ft bgs (below the bay bottom) from a barge-mounted drill rig. Six undisturbed Shelby tubes were collected for laboratory testing. In addition, a total of three hand auger borings were collected along the trail to obtain soil and groundwater information.

In general, the soils were found to be mostly poorly graded sand (silt to fine sand and clayey fine sands), with cemented layers from ground surface to approximately EL -68 to -78. Cementitious noncohesive soils with high N-values were found at varying depths ranging from EL -10 to -30 in B-1 to B-3, to EL -36 to -45 in B-4 to B-8. Hand auger borings along the trail, or the west side of the alignment, revealed fine sands with silt from ground surface to the termination depth of 6 to 6.5 ft bgs at the groundwater table, which was recorded at 3 ft bgs at B-8 (on the east side of the proposed alignment). The seasonal high water table is estimated at 3.5 ft bgs.

In addition, the potentiometric surface in the vicinity of the project is reported as ranging from approximately 0 to +10 ft, National Geodetic Vertical Datum (NGVD) 83.

Table 1. Comparison of Crossing Techniques

Comparison Item	*HDD*	*Conventional Tunneling*
Cost per lin ft	\$600 - \$800	\$8,000 to \$15,000
Staging area requirements	Large area required	Relatively smaller area required
Risk of mud leak into surface	Yes	Nominal
Future maintenance, pipe replacement, use of space for other utilities	No	Yes
Alignment control and accuracy	Medium	High
Risks from presence of Karst formation	Potentially problematic	Less problematic

Table 2. Soil Properties

Soil Parameters	*Soft Sands, Silts, and Clays*	*Partially Cemented Sediments*	*Elastic Silts*
Unit weight[1]	115	135	130
Phi (deg)[1]	25	35	30
Cohesion (psf)[1]	0	0	300
Poisson ratio[1]	0.8	0.6	0.3
E - Elastic modulus (psf)[2]	40320	403200	403200
G - shear modulus[3]	11,200	126,000	155,077
Plastic radius FS[4]	2	2	2

1. Properties estimated from bore logs and laboratory data.
2. Calculated in accordance with American Association of State Highway and Transportation Officials (AASHTO) using E=8064*N for silts and E=13968*N for sands. Average blow counts for each formation were used.
3. G=E/(2*[1+Poisson's Ratio]).
4. The Delft equation requires an FS for the soil formation that can range from 1.5 to 2. For the formations encountered, 2 was used due to the variable nature of loose and partially cemented sediments.

Evaluation of Crossing Techniques

The EOR evaluated the trenchless technology techniques currently available in the marketplace for construction of the proposed 24-in. force main that's over 4,000 ft in length crossing beneath the bay. The following four trenchless techniques were considered as potential alternatives:

- Microtunneling
- Horizontal auger boring
- HDD
- Conventional tunneling techniques

The horizontal auger boring and microtunneling techniques were eliminated as potential construction alternatives due to the practical and experience limitations on the maximum installation length, thereby causing the need for intermediate shaft construction within the bay.

Horizontal Directional Drilling

The HDD method is comprised of a two-stage process. A small-diameter pilot hole is drilled along the desired alignment, which is excavated using a drill head with a rod stringing for the entire length of the proposed crossing. The pilot hole is then enlarged (reamed) to a larger diameter by attaching a reamer to the drilling rod until the required proposed borehole diameter is obtained. This reaming process can be completed in one step or several steps, depending upon the proposed diameter required.

Throughout the reaming process, the hole is kept open (or kept from collapsing) by the use of thick drilling mud to fill the annulus space. The drilling mud is usually a bentonite-based compound.

The final borehole diameter is typically 50 percent larger than the proposed pipe diameter. Upon completion of the last reaming step, the product pipe is then pulled through the hole. The HDD technique can be used in a variety of soil and rock materials.

The HDD technique requires a relatively large staging area on both sides of the operation at the entry and exit points of the proposed force main. Preferably, a long section of the pipe should be assembled and pulled in one operation to reduce starts and stops and downtime for the pipe welding process during the pipe pull phase.

This is typically a cost-effective method for pipe installation of diameters up to 48 in. It's commonly used for pressurized pipelines similar to the proposed force main crossing and is an ideal method where precision and accuracy of installation is not critical or detrimental to the installed pipe or existing surface and subsurface facilities/utilities. A potential risk of the HDD method is the occurrence of drilling mud

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seepage creating inadvertent returns or frac-out through the surrounding soils and rock to the ground surface that may affect existing facilities and/or cause contamination of groundwater and/or surface water. Based on the obtained soil information, however, the drill alignment was located at more than 70 ft bgs below the bay mudline in cemented soil and clay layers, thereby minimizing the likelihood of frac-outs.

Conventional Tunneling Methods

This method involves the use of a tunnel boring machine (TBM) or enlarged microtunnel boring machine with a temporary lining support system consisting of liner plates or precast concrete segments. The method requires main entry into the tunnel during the construction phase. The minimum diameter planned for conventional tunneling was 72 in. The proposed force main pipe would be installed inside the temporary-lined tunnel. A launching pit and receiving pit are required to launch and retrieve the TBM from the ground. In addition, a relatively small staging area is required, compared to that of the HDD technique.

This method proved significantly more costly than the HDD alternative and required a longer duration of construction to complete; however, with conventional tunneling, access for pipe maintenance could be available throughout the design life of the pipeline. In addition, other utility pipes or replacement pipes could be installed inside the tunnel in the future.

A comparison between the HDD and conventional tunneling methods for the bay crossing is presented in Table 1.

Based on this evaluation, the recommended crossing technique for installing a new pipeline under the bay was HDD. The next step in the process was to evaluate pipe materials to determine which type was feasible for the installation. The pipe materials evaluated included FPVC, HDPE, and steel.

Borehole Pipe Stability Analysis

A borehole stability analysis was performed to determine the factor of safety (FS) for the borehole drilling conditions using the Delft equation (van Brussell and Hergarden, 1997). Eight soil borings were drilled up to 80 ft bgs to assess subsurface conditions. Bore logs, laboratory testing data, and a geotechnical report were issued in June 2016. Explorations for nearby projects were also reviewed, including borings provided by the Florida Department of Transportation and by geotechnical reports from other related projects (Tierra, 2014).

An interpreted subsurface profile was developed and three distinct units were interpreted. Soft, loose, and unconsolidated siliciclastic marine sediments with SPT blow counts less than 25 were observed from the surface to depths that ranged from greater than 40 ft bgs to approximately 15 ft bgs. Hard, partially cemented siliciclastic marine deposits with SPT blow counts above 25 and averaging greater than 50 were observed from 15 ft bgs to greater than 80 ft bgs. A third unit of very firm elastic silt was observed in five borings at elevations greater than EL -72 ft bgs. These same units were also identified in nearby explorations and are consistent with the marine environment. The soil input properties that were used are shown in Table 2.

Figure 4. Fusible Polyvinyl Chloride Installation and Fusing Operations

A few key points of the bore path geometry used include:

- 12-degree entry and exit angle
- Bottom tangent below -70 feet EL
- 3,000-ft bend radius to accommodate steel pipe
- 2 percent grade on bottom tangent to promote fluid flow
- 30-in.-diameter pipe with a 42-in.-diameter borehole for HDPE and 24-in.-diameter pipe and 36-inch-diameter borehole for FPVC

The following are the results of the borehole stability analysis:

- In general, when drilling from west to east, the borehole stability FS was acceptable (FS>2) from the start of the alignment to approximately station 336+00. The final approximately 500 ft of the drilling may present a challenge to the driller to maintain proper borehole stability. When drilling from east to west, the initial 200 ft of the boring would present unstable conditions, as well as the final 500 ft. The limiting factor to borehole stability was the soft sediments found in the upper 40 ft of the exploration boreholes. These soft marine sediments have SPT blow counts that range from 0-25, with an average of approximately 6.
- Due to the variable nature of marine sediments and partially cemented sediments, the conditions encountered were expected to vary, possibly significantly, from what is presented in the calculations. There is some evidence for fractures and soft zones in the partially cemented sediments shown in the bore logs, and therefore conditions were constantly monitored by a qualified driller with experience in similar environments.

Pipe Stress Analysis

The pipe analysis considered a 24-in. (for steel or FPVC) to a 30-in. (for HDPE) transmission force main at a range of pipe thicknesses to be installed using HDD in the 4,100-ft subaqueous crossing of the bay. Calculations were performed for the three types of pipe. The purpose of these calculations was to determine the minimum pipe requirements, materials, and pullback conditions to achieve acceptable pipe stresses during pullback. Calculations were performed in accordance with Pipeline Research Council International (PRCI, 2008), Plastic Pipe Institute (PPI, 2008), and American Society for Testing and Materials (ASTM, 2005) guidance, and con-

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sidered allowable tensile, bending, and buckling stresses under assumed "favorable" and "adverse" conditions. Calculations utilized the accompanying Excel workbooks. Two calculations were performed for each of the three pipes: a "best estimate" case that follows design and assumes favorable pullback conditions, and an adverse case that assumes adverse installation geometry and pullback conditions.

The following parameters were used for steel pipe to calculate the appropriate minimum wall thickness:

- Diameter: 24 in.
- Specified Minimum Yield Strength: 65,000 pounds per sq in. (psi)
- Young's Modulus: 2.9E+07 psi
- Poisson's Ratio: 0.3
- Coefficient of Thermal Expansion: 6.5E-06 in/in/0F

The following parameters were used for FPVC pipe:

- Diameter: 24 in.
- Specified Minimum Yield Strength: 7,000 psi (reduced in calculations using an FS of 2.5)
- Young's Modulus: 400,000 psi (reduced using the formula Epvc = 2800*t^-0.067, where t is time in minutes) from AASHTO (McGrath and Sagan, 2000)
- Poisson's Ratio: 0.38
- Specific Gravity: 1.4

The following parameters were used for HDPE pipe:

- Diameter: 30 in.
- Allowable Yield Strength: 1,100 psi
- Young's Modulus, Short Term: 57,500 psi
- Young's Modulus, Long Term: 28,200 psi
- Poisson's Ratio, Short Term: 0.35
- Poisson's Ratio, Long Term: 0.45
- Specific Gravity: 0.95

The following properties were assumed for HDD installation conditions under the best estimate case:

- Drilling Mud Density: 12 lbs/gal (mud properties may have varied at the discretion of the HDD contractor)
- Hydrokinetic Pressure: 10 psi
- Fresh water was assumed as ballast (sea water may also be used)
- Coefficient of Soil Friction: 0.25 for favorable conditions and 0.5 for adverse conditions
- Fluid Drag Coefficient: 0.025 psi for favorable conditions and 0.05 psi for adverse conditions

The following are the results of the pipe stress analysis:

Under both the favorable case and the adverse case, a steel pipe with the stated specifications and a wall thickness of 0.375 in. would have adequate performance under the anticipated pipe stresses; however, ballasting the pipe during pullback would be required to keep pipe stresses in an acceptable range for the adverse case. Ballast in the pipe may need to be used during installation if conditions vary significantly from the best estimate case.

A 24-in. FPVC pipe, with DR-18 (the thickest-common 24-in. FPVC size), has an acceptable FS for pullback tensile stresses. The FS came to 1.5 for the adverse case; however, the FPVC pipe must remain ballasted during installation and its entire service life in order to maintain an adequate FS against buckling and acceptable deflections. With the pipe fully ballasted, the critical case would be during pullback where deflections up to 5 percent may be experienced, with an allowable deflection of 6 percent of the pipe's diameter. The FS against buckling is 3.5.

A 30-in. HDPE pipe, with DR-7.3, would have adequate performance under the anticipated pipe stresses if the pipe were ballasted during drilling and in long-term use; however, the FS for tensile stresses during pullback in the adverse case was unacceptable, as it was 1.1. If adverse conditions were encountered during pullback, care must be taken by an experienced driller to limit tensile stresses on the product pipe, as the pipe would risk being damaged or lost. Alternative methods of installation, such as intersect technology, should also be explored.

Recommended Material of Construction

Based on the recommended crossing technique of HDD, 30-in. DR-7.3 HDPE, 24-in. (C-905) DR-18 FPVC, and 24-in. steel pipe with a 0.375-in. wall thickness were retained for further evaluation and HDD calculations. As discussed, a pipe stress analysis using allowable tensile, bending, and buckling stresses under assumed favorable and adverse pullback conditions was performed for the pipe types; adverse pullback conditions represent poor installation geometry. Calculations showed that 30-in. DR-7.3 HDPE did not have the required tensile FS during pullback in the adverse case scenario, and therefore, it was not recommended. Note that this was a risk-based decision, recognizing that HDPE could perform adequately within allowable stresses if the pipe is ballasted and a qualified experienced driller used best practices to limit tensile stresses.

Alternative HDD installation methods of HDPE, such as intersect technology, were not considered due to the increased cost and anticipated overwater access risk factors. The DR-18 FPVC and a steel pipe with a wall thickness of 0.375 in. both performed adequately under favorable and adverse pullback conditions; however, steel pipe is not only more costly than FPVC, but laboratory testing revealed the soils to be corrosive, requiring the added costs of cathodic protection against corrosion. As such, FPVC was recommended and retained for the basis of design, including provisions that FPVC remain ballasted during installation and service life (see Figure 4).

Permitting Requirements

A variety of federal, state, and local permits were required for this project.

Florida Department of Environmental Protection

Pursuant to Chapter 62-604.600, Florida Administrative Code (F.A.C.), a Florida Department of Environmental Protection (FDEP) permit was required for the addition of a new force main to the existing wastewater collection and transmission system. A permit application form 62-604.300(8)(a), Notification/Application for Constructing a Domestic Wastewater Collection/Transmission System, with the respective fees, was completed and submitted to FDEP for review and approval.

Pinellas County Right of Way Utilization Permit

A right of way utilization application and permit from the county, including maintenance of traffic (MOT), was anticipated for the proposed work along Park St. North, a county road. The MOT plans were developed and included in the design drawings. The contractor was required to obtain the right of way utilization permit.

Federal Permits

A 404 federal dredge and fill permit from the U.S. Army Corps of Engineers required for this project involved a complex permitting process, considering the degree of the potential impacts to jurisdictional wetland areas. A nationwide permit 12 (utility line activities) was required for the proposed pipeline installation since waters of the United States could be temporarily impacted by construction. The nationwide permit required compliance with the general conditions for nationwide permit 12, including the restoration of all impacted wetland areas to preconstruction grade, no adverse impacts to fish or wildlife, use of only clean fill (if needed), no impounding of water or draining of waters of the U.S., and the use of proper sediment and erosion controls during construction.

State Environmental Resource Permit

An environmental resource permit (ERP),

also from FDEP, was submitted as part of this project. Like the 404 federal dredge and fill permit, the complexity of the permitting process depends on the degree of the impact to jurisdictional wetland areas. A noticed general permit (NGP) was required for the proposed project since wetlands could be impacted during construction. The NGP requires compliance with Chapter 62-341.453, F.A.C., including a construction corridor less than 30 ft wide, less than 0.5 acres of wetland impact, no permanent fill in wetlands, no impounding of water, the use of proper sediment and erosion controls, and restoration of impacted wetlands to preconstruction grades.

In addition to the ERP, a National Pollutant Discharge Elimination System (NPDES) permit was required pursuant to 40 CFR, Part 122, for point source discharges of stormwater associated with construction of the pipeline. Under FDEP's delegated authority to administer the NPDES program, operators that have stormwater discharge associated with 1 acre or more of construction clearing must file for and obtain either coverage under an appropriate generic permit contained in Chapter 62-621, F.A.C. (1 to 5 acres of construction) or an individual permit issued pursuant to Chapter 62-620, F.A.C. (greater than 5 acres of construction). A major component of the NPDES permit is the development of a stormwater pollution prevention plan (SWPPP), which identifies potential sources of pollution that may reasonably be expected to affect the quality of stormwater discharges from the site and discusses good engineering practices that were used to reduce the pollutants. The contractor was required to obtain the NPDES permit.

Chapter 253, Florida Statutes (F.S.), requires authorization from the board of trustees of the Internal Improvement Trust Fund for any activities in, on, or over state-owned, sovereign submerged lands (state lands). A public easement was not required in accordance with Chapter 18-21.005, F.A.C., for installation of the utility pipeline across state lands. The force main is processed and recorded by FDEP concurrently with the ERP application. The installation required compliance with Chapter 18-21.004, F.A.C., including minimizing adverse impacts to state lands not being contrary to the public interest and the applicant having sufficient upland interest in the adjacent riparian properties.

Miscellaneous Permits

A spill management and prevention plan was also developed and implemented during construction of all HDD crossings of wetlands and surface waters. This plan was developed prior to the permitting phase of this project and submitted as part of the ERP application. The plan needs to contain monitoring procedures for inadvertent loss or spills of drilling fluids, the types and storage locations of sediment and erosion control materials to be used in the event of a loss or spill of drilling fluids, and procedures for restoring the disturbed areas.

Project Bid and Award

Bids were received by the county on June 13, 2017. A total of five responsive contractors submitted bids for consideration, with a sixth nonresponsive one due to inadequate prequalification information. Bid prices ranged from a high of $8,545,318 to a low of $4,747,565, which was submitted by TLC Diversified Inc. (TLC). The engineer's estimate provided by EOR was $5,483,775.

In reviewing the bids, some differences were noted in the price for the directional drill cost per lin ft of installation of the subaqueous crossing between the bidders. The cost for the directional drill ranged from $531 per lin ft, submitted by the lowest bidder, TLC, to a high of $1,122 per lin ft, submitted by the highest bidder. The second lowest price for this bid item, $614.88 per lin ft, was provided by the second lowest bidder. The EOR's estimate for this bid item was $700 per lin ft.

Relevant project experience and qualifications required by contract documents were requested from the lowest bidder and reviewed for conformance with project specifications. The bidder subcontracted with Centerline Directional Drilling Services (Centerline) for the HDD segments of the project.

The Florida Department of Business and Professional Regulation website was used to verify the status of the bidder's licenses. Based upon the information provided, and in consideration of contract requirements, the project was awarded to TLC as the contractor, with Centerline as the HDD subcontractor, for the amount of $4,747,565.

Construction

This project was a challenge as it was a record-setting HDD subaqueous crossing in the county and the second longest in Florida for its diameter and kind. Construction lasted approximately nine months, from Jan. 3, 2018, to substantial completion on Sept. 20, 2018, with final completion achieved on Oct. 3, 2018. To complete the pilot borehole, two drill rigs were mobilized: an American Auger DD-440T, capable of generating 440,000 lbs of thrust/pullback; and a Vermeer inline D330x500, capable of generating 330,000 lbs of thrust/pullback, which performed the intersecting pilot borehole utilizing Sharewell HDD Services and True Gyde software (see Figure 5).

By using the intersect method, a smaller rig can be used than with a single crossing. There is logic to sizing the rig so that it is incapable of overstressing the pipe during pullback. The Vermeer rig was then used to perform the multiple reaming passes of 18 in., 20 in., 24 in., and 32 in. The multiple reaming passes of relatively small upsizing increments per pass were used to condition the borehole to minimize abrasions from cemented zones and to ensure that the borehole was well stabilized before pullback. A 28-in. barrel reamer was then used to provide final cleaning before pulling the FPVC pipe. The subaqueous crossing final pullback was completed in 36 hours, including 13 intermediate fuses. The maximum pullback forces

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Figure 5. Horizontal Directional Drilling Operations at Park Place Medical Easement

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observed did not exceed 160,000 psi, less than half of the allowable pull force for 24-in. DR-18 FPVC. The project also included the additional 620-ft HDD section along Park St. and almost 2,300 ft of open cut force main along the trail and along a permanent easement by Park Place Medical. By carefully considering all of the challenges, the team planned well and finished the project on time, and the owner was very satisfied with the outcome.

The major concern during the HDD operation was a potential frac-out under the protected bay during the drilling operation; in particular, near the location of the entry pit and the mangrove-populated shoreline on the west side of the drill. This coincided with the location of the force main HDD tie-in to open cut within only a narrow section of upland, and TLC worked with Centerline, the county, and the EOR to minimize any possible impact to the bay. In order to prevent a frac-out, approximately 40 ft of 30-in.-diameter steel conductor casing from grade was installed, extending far enough below the bay to contain the drilling mud within the casing, which protected against the "path of least resistance" into the bay shallows near the exit. It worked as intended and the drill was a complete success, with no frac-outs experienced (see Figure 6).

An additional challenge was maintaining ingress and egress of the two businesses that had to be open to the public during construction: Park Place Medical on the east side of the bay, and KOA on the west side of the bay. This was successfully achieved with proper traffic control means and methods, nighttime work for underground pipe installations across entry/exit driveways, and most importantly, a competent project manager, superintendent, and crew.

Maintaining safe access to the trail during open cut construction also presented a challenge. The popular trail is a main pedestrian and bicycle artery through the county that provides a safe asphalt path for users to walk, jog, and ride their bikes, and it also provides a route for many daily commuters who use it to get to and from work. The contract documents required this trail to be kept open during construction with no shutdowns. The design included approximately 2,300 ft of force main along the trail. The county and TLC worked with the EOR to revise the alignment 2 ft east to eliminate any disturbance to the pavement, while maintaining appropriate trench shoring, except at crossings.

Finally, maintaining the project schedule was extremely important since legal easement agreements had been executed by the county with the property owners. All easement work was completed on time, including restoration to the property owner's satisfaction.

Summary

The use of FPVC with HDD provided a cost-effective solution for the county for the installation of the new subaqueous force main crossing of Boca Ciega Bay, replacing the existing 40-year-old pipeline within the environmentally sensitive bay. Figure 7 shows the leading head of the drill exiting the bore hole.

After minimizing the risk in design by performing a detailed geotechnical investigation of the sub-bay soil conditions, selecting the appropriate material of construction at a depth of minus 70 ft below the bay, evaluating alignments that limited easement acquisition and disruption to businesses and the public, and awarding the project to an experienced contractor that could complete the work, the new 24-in. crossing was installed quickly and under the engineer's estimate.

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Figure 6. Tail End of Fusible Polyvinyl Chloride Pipe After Completing Pullback Under Boca Ciega Bay

Figure 7. Leading Head of Fusible Polyvinyl Chloride Pipe