Horizontal Directional Drilling an Emergency Water Main Replacement under Matlacha Pass – Challenges & Innovation

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The Greater Pine Island Water Association Inc. (GPIWA) is located on the west coast of Florida in a barrier island community west of Cape Coral and Fort Myers. The association owns and operates a groundwater/reverse osmosis potable water system that serves a population of approximately 15,000 in the cities of Bokeelia, St. James City, and Matlacha, as well as the "off-island" portion of Southwestern Cape Coral. Matlacha is an island separated from Cape Coral by Matlacha Pass, which is designated as a Class II Outstanding Florida Water and located within the Charlotte Harbor Aquatic Preserve.

In October 2005, Hurricane Wilma severely damaged a portion of the existing 12-inch, sub-aqueous water transmission main under the Matlacha Drawbridge, resulting in the water main being breached, isolated at the bridge, and taken out of service. The GPIWA service area east of the bridge was provided temporary domestic potable water via an emergency interconnect from the city of Cape Coral.

The disruption of water flow through this water main created an emergency situation in which the GPIWA was not able to provide adequate fire flow to the Matlacha area east of the bridge and also to its "off-island" commercial and residential customers on Cape Coral (see Figure 1).

The original sub-aqueous pipeline was constructed in the mid-1960s by an open-cut pipe installation method and has approximately three feet of cover below the mud line. Over the years, this depth of cover decreased because of soil erosion and the pipe was susceptible to damage by moving objects.

At the beginning of the project, it was decided to use horizontal directional drill (HDD) technology to replace the existing pipe to achieve greater depth of pipe cover, and thus longer pipe service life. Also, HDD technology is the best available technology (BAT) for minimizing adverse environmental impacts in environmentally sensitive waters and has very little impact compared to conventional dredging methods. The most viable fast-track permitting approach required HDD technology to minimize impacts to wetlands, mangroves, and water quality in the sensitive Matlacha Pass waterway.

Issues & Project Challenges

This complex directional bore required significant planning and execution. Some of the more critical planning, design, and construction considerations included:

- Selection of HDD alignment.
- Design Challenges to reduce risk of hydraulic fracturing (frac-out) of the geologic formation.
- Geotechnical considerations.
- Environmental considerations (waterway, mangrove, and seagrass protection paramount).
- HDPE fused pipe string-out options – staging and floating pipe in surrounding waterways.
- Large upland easements essential.
- Fast-track permitting approach.
- Construction challenges.

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Preferred HDD Alignment not Viable

During the planning and design phase, several alternative pipe routes were evaluated, including the preferred option of an emergency replacement bore in the vicinity of the original transmission main south of the bridge. In fact, a 1,200-foot directional bore design within the rights-of-way of the existing Matlacha Drawbridge was granted an emergency authorization from the Florida Department of Environmental Protection

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Figure 1 - Project Site Map

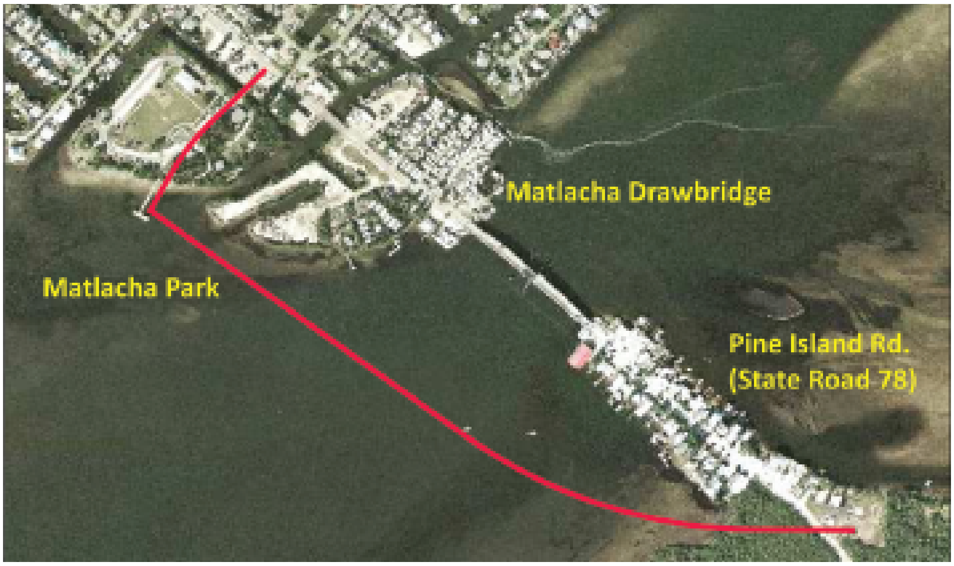

Figure 2 - Alternate Pipe Route 1

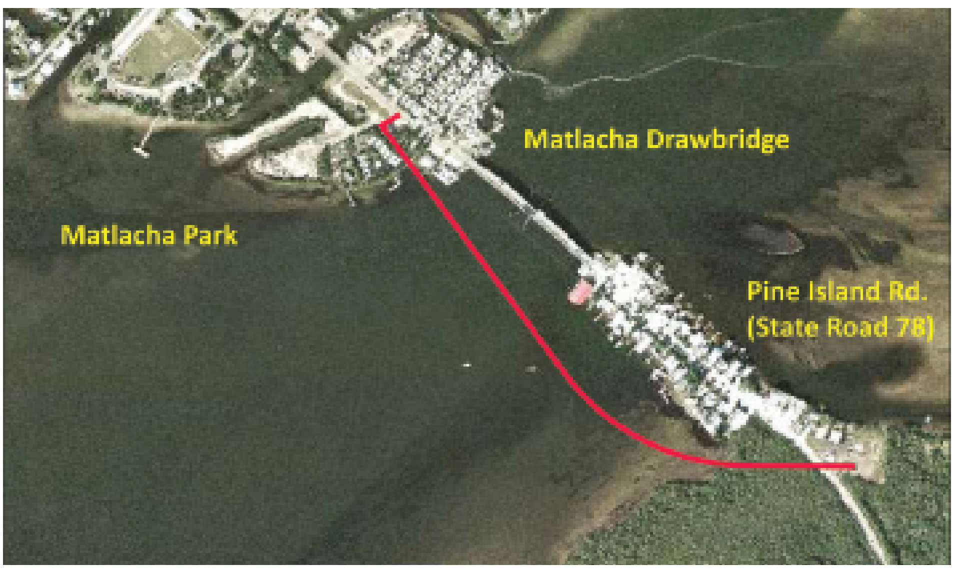

Figure 3 – Alternate Pipe Route 2

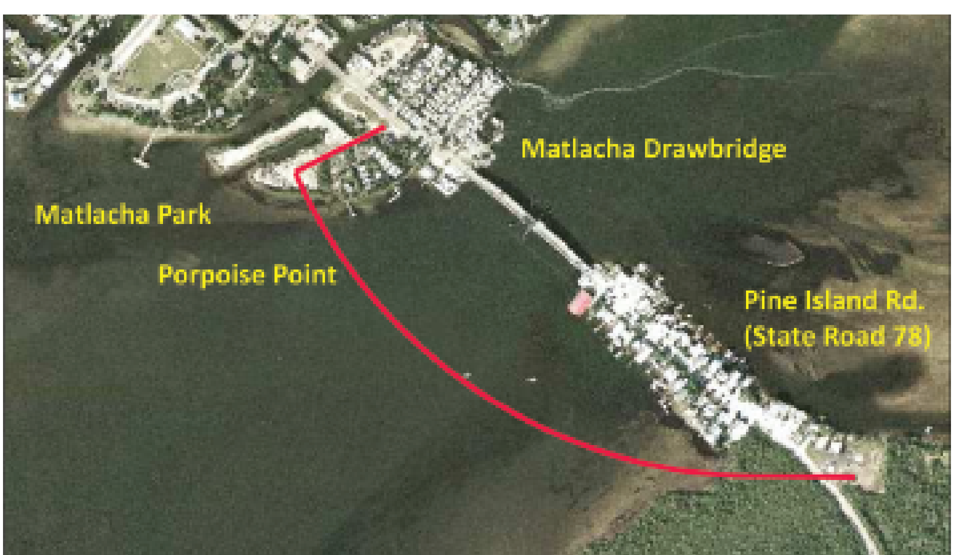

Figure 4 – Alternate Pipe Route 3 Selected

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(FDEP) in early 2006. It was decided that the placement of the water line at this location would not be viable or permittable by the Lee County Department of Transportation (DOT) because of a future county DOT drawbridge expansion.

The drawbridge expansion will include significant construction of bents and seawalls, making it a showstopper for any HDD alignment options within the existing county DOT right-of-way in the vicinity of this bridge. The project team decided to explore alternative pipe routes farther from the drawbridge.

Water Main Route Selection

Because of the significant length and complexity of this HDD project, the design team brought onboard Haley and Aldrich, a firm specializing in underground engineering, directional drilling techniques, and BAT environmental solutions, which would be critical to the success of this project. During the preliminary phase of the project, the design team evaluated three different pipe routes based on feasibility of design and construction, costs, ease of permitting, HDPE fused-pipe string-out, and availability of easements from private landowners. Figures 2 through 4 show the proposed pipe routes originally considered.

Alternate Pipe Route No. 1 had the longest pipe length. It was not selected because of costs and because of the significant mangrove area and tie-in complications south of Pine Island Road. Also, Lee County Parks department discouraged use of Matlacha Park for construction staging.

Although Alternate Pipe Route No. 2 had the shortest pipe length, it was not selected because of difficulty in getting easements from three private landowners on the west side of the bridge.

Alternate Pipe Route No. 3 was selected mainly because of lower projected construction costs than Alternate Pipe Route No.1. Also, the owner of the Porpoise Point peninsula site was willing to negotiate an upland easement with the GPIWA for use of this site as the western drill site.

Design Focused on Reducing Frac-out Potential

Design challenges included the selection of pipe size, entry and exit angles, and determination of pull-back loads anticipated along the bore path. Geotechnical studies were conducted to determine subsurface conditions and the subsequent HDD depth below the Matlacha Pass mud line.

Based on the geotechnical data reports, an annular pressure curve was prepared to minimize drill fluid loss and frac-out potential during drilling operations. This pressure curve was the basis for the protective casing designed to protect the mangrove areas near the upland sites.

Drill fluid loss is defined as the loss of drill fluid from the drill hole and into the geologic formation. Frac-out can result in high-volume loss of bentonite drill fluid, which could migrate upward and harm the pristine waterway and aquatic environment of Matlacha Pass.

The proposed water main would be installed under the state's sovereign submerged lands, mangrove areas, the protected aquatic preserve area, and the Calusa Land Trust area, below the mud line; therefore, an environmental resource permit and authorization to use sovereign submerged lands was required from the FDEP for its construction.

The environmental resource permit application package included a detailed frac-out plan, which outlined methods for controlling drill fluid loss during construction to prevent impacts to wetlands and water quality. The drill fluid loss would be monitored along the drill path by taking actual annular pressure readings and comparing to the design annular pressure.

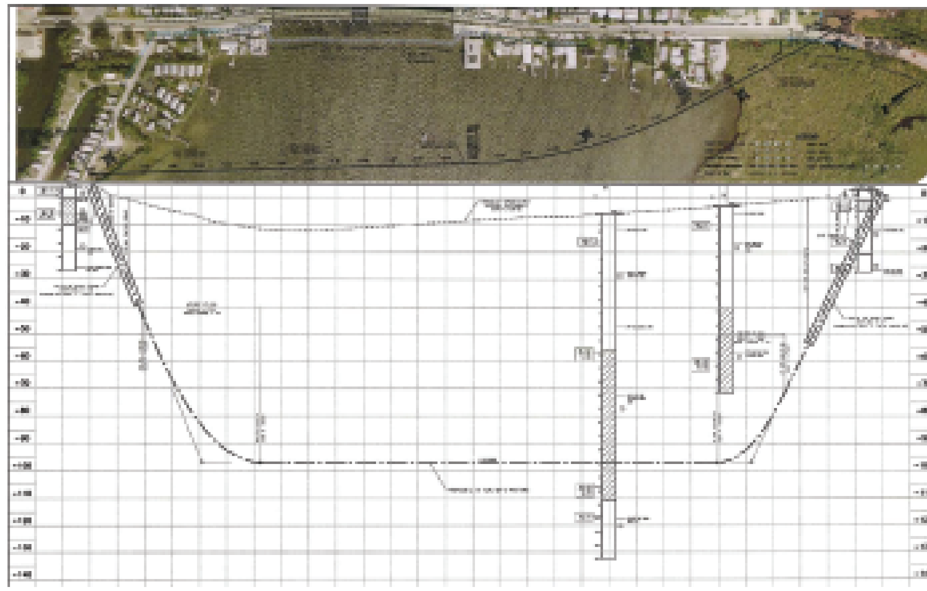

Figure 5 – Drill Path Plan and Profile

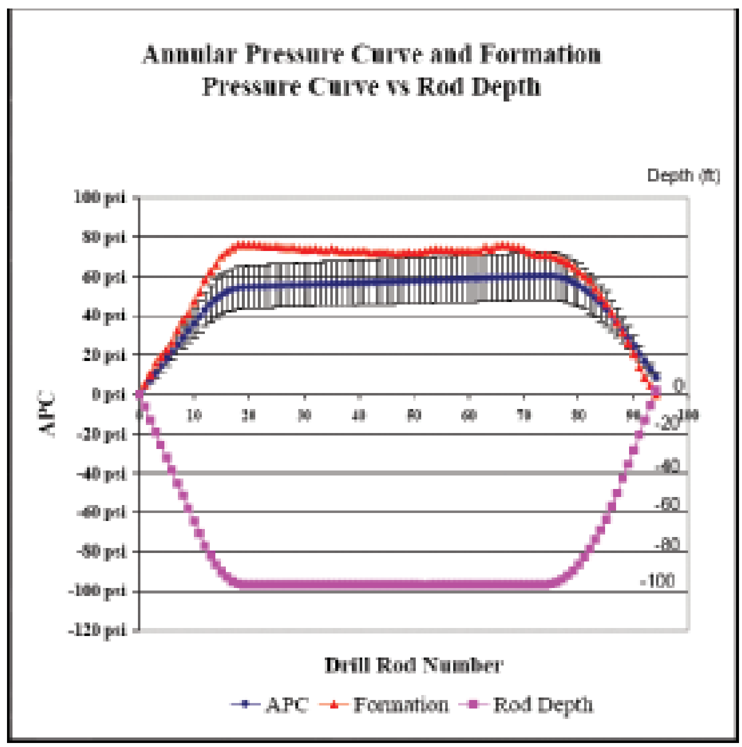

Figure 6 – Drill Fluid Management Curve

Drill Path Design

A summary drill path design is shown in Figure 5. As part of the drill path design, the geotechnical baseline reports were used to develop an annular pressure curve (with tolerances) and a formation confining pressure curve for the geological conditions expected below the mud line. These curves are shown in Figure 6.

Depth of cover of the proposed HDD boring was considered carefully to minimize potential frac-out and environmental risk to the surrounding mangroves and this sensitive waterway crossing from the outset. HDD design considered drilling from either drill site, as well as performing an intersecting drill from both sites, and HDD performance specifications were developed accordingly.

As shown in Figure 5, this significant HDD project encompasses a total length of approximately 2,915 feet and was designed with a depth of cover below the mud line of 97 feet below the Matlacha Pass waterway.

The depth of the drill path was assessed for frac-out potential by analyzing the anticipated annular pressure curve of the drill fluid. To prevent hydraulic fracturing, the depth of the drill path (approximately 50 feet below the majority of the mangroves and 97 feet below the waterway itself) was acceptable, and posed minimal risk of frac-out along most of the drill path trajectory; however, toward the ends of the drill (near the two drill sites at each end), there was insufficient depth of cover and the potential for frac-out of the silty/sandy soil and the mangrove muck layer posed unacceptable risk. To address this problem, the design team incorporated permanent installation of 36-inch steel casing protection at both ends of the drill to contain drill fluids at the shallow drill depths.

The east end of the drill path had insufficient capacity up to a rod distance of 93 feet, or a minimum depth of 19 feet, so the design included installing a 36-inch casing pipe and drilling through the casing pipe with an intersecting drill and BAT steering and tracking elements to virtually prevent frac-out and subsequent drill fluid loss at the shallow drill depths. By applying a safety factor of approximately 3.0, the total length of casing pipe at the east end of the drill was approximately 270 feet.

The west end was more susceptible to hydraulic fracturing because it was further from the drill rig; therefore, more pressure was required to move the drill fluid back to the rig. The problem started to occur at approximately 200 feet from the west end drill site.

Since the west end was not as environmentally sensitive as the east end, a factor of safety of 1.0 was considered sufficient, so the total length of casing pipe at the west end of the drill was approximately 200 feet.

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Differential Pressure on Pipe at 97 foot deep							
	Drill Depth		Product Limit		Max. Design Depth		
					Empty	Full	
Short Term	53.9 psi	<	89.6 psi	<	101.3 ft	>200 ft	OK
Long Term	77.0 psi	>	38.7 psi	>	69.7 ft	316.6 ft	Leave Full

Safe Pull Load (based on pipe capacity)			
(ASTM F 1804-03)			
fy =	0.4	Tensile yield design safety factor @ 73 degrees F	
ft =	0.965	Time under tension design safety factor	
Ty =	3200	Tensile yield strength @ 73 degrees F, psi	
T =	73	Installation Temperature, F	
Pd =	10	Pull duration time, hrs	
Duct	Quantity	Safe Pull Each	Total Capacity
16	1	120,279 lb	120,279 lb
	Total Safe Pull Capacity =		120,279 lb
		1234.92 psi	Allowable Stress
Note:			
1. Safe Pull load not reduced for excessive bend radius (<100*D)			

Ovality from buoyancy for pipe			
d/D =(0.086*(W1-W2)*D^(DR-1)^4)/E*(DR)			
E= modulus of elasticity =	28,200 psi		
W1 = drill fluid weight (psi) =	80.0 pcf	0.05 psi	
W2 = fluid in pipe weight (psi) =	62.4 pcf	0.04 psi	
Allowable deflection for DR =	8.00%		
d/D =	0.02	2.0%	OK

Reissner Effect on ovality by bend radius	
If R(design) > 40*D	
Then ovality in not an issue	
40*D =	58 ft
Min Bend R =	29 feet
R(design) =	800 feet
Not material	

Table 1 – Pine Island Emergency Potable Water Main Replacement Duct Fill, Safe Pull, and Properties

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Pipe Thickness & Safe Pull Load Determination

Although the existing cast-iron water main is 12-inch, the project team decided to install one size larger HDPE pipe (16-inch) because the inside diameter of a 16-inch HDPE DR-9 pipe is hydraulically equivalent to the inside diameter of a 12-inch cast-iron pipe.

The selected pipe material was HDPE for its corrosion resistance. The failure mode for this pipe is buckling, which may occur during construction activities for installing the pipe, short-term conditions; or during operations, long- term conditions.

Buckling is controlled by the stress distribution on the pipe and the pipe properties. HDPE is a plastic that behaves as a visco-elastic material, meaning that the properties are time, temperature, and stress dependent.

Properties over selected time and temperature conditions have been determined by testing within the industry and by outside laboratories. Results are available from the manufacturers. Typically, an operating temperature range is selected and time intervals are selected based on the design condition being evaluated.

For short-term conditions, a typical time interval is 10 hours. For long-term conditions, the modulus and strength are normally reduced by 50 percent to account for creep effects. As the properties reduce with increased temperature, typically we assess only the higher temperature. For this project, we selected a temperature of 73 degrees F.

Short-term loads occur during construction and need to be evaluated to select the pipe strength, which is a combination of material properties and pipe geometry. The pipe geometry has been found to relate to the pipe dimension ratio (DR), which is the pipe outside diameter divided by the wall thickness.

Short-term loads include (1) tensile loads that occur from handling the pipe during welding and pulling into the drill hole and (2) hydrostatic loads that occur from the immersion of the pipe in the drill fluid within the drill hole during the pulling process.

These two loads interact on the performance of the pipe structure in that additional tensile load will reduce buckling capacity of the pipe; therefore, a short-term load assessment includes evaluating the pipe structural pull load that may be needed to install the pipe and the hydrostatic structural load capacity, which occurs on the installed pipe.

Tensile failure causes the pipe to pinch or exceed design ovality. The maximum structural tensile load is called the safe pull-back load. This load can not be exceeded during the installation of the pipe or it will significantly elevate the risk of pipe collapse or tensile failure; therefore, each pipe DR has a maximum load that may be applied for installation.

The calculated pull stress for installation is a function of static and dynamic friction between the pipe and the ground, the size of the drill hole, and the velocity at which the pipe is pulled through the drill fluid that causes hydraulic drag. This is not a simple calculation. The calculated pull load must be less than the structural capacity of the pipe or a lower DR pipe must be selected. The structural buckling capacity of the pipe must be greater than the applied hydrostatic force on the pipe.

Since the pipe is sealed during the pull at one end, the drill fluid in the drill hole does not enter the pipe during the installation process. Additionally, the pipe is relatively impermeable, which allows the pipe wall to act as a membrane. This means that the actual stress acting on the pipe is the difference between the external hydrostatic load resulting from the drill fluid static load and the internal air or fluid pressure applied to the inside of the pipe—differential pressure.

The pipe structure can withstand a design

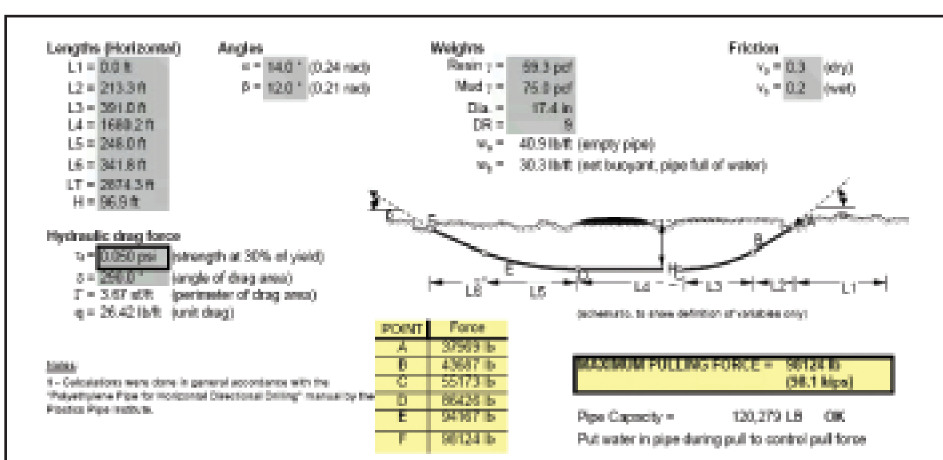

Figure 7 – Anticipated Maximum Pull Load Calculation

differential pressure with a factor of safety without buckling. Because the pipe is in a fluid-filled drill hole, the pressure is considered hydrostatic and uniformly applied; hence, the calculation for buckling is simplified to an unconstrained buckling calculation.

For this project, the drill fluid properties were assumed from past experience and estimated to be 80 pounds per cubic feet (pcf) as a conservative value. The unconstrained buckling capacity can not be exceeded without creating an elevated risk of collapse during the installation process. The externally calculated load is determined by static analysis of the density and depth of the drill fluid in the drill hole. The calculated value must be less than the allowable structural capacity or a lower DR pipe must be used.

Long-term loads on the installed pipe are produced by ground loads on the pipe and by internal pressures within the pipe during operations and maintenance. The structural capacity of the pipe to withstand the external soil load is a function of reduced long-term properties of the pipe in unconstrained buckling. Again, this assessment assumes very conservatively that the buckling mode is unconstrained; thus, lateral resistance from the ground is ignored.

The applied ground load is calculated by total stress analyses at the pipe depth. As the pipe buckling is really a function of differential stress, then the actual critical depth or load is determined for the pipe based on the difference between the external and internal pressures.

Results of the calculations indicated that the short-term analysis caused the controlling conditions for the pipe strength selection (Table 1). The pull force was the most critical, followed by the buckling. If the actual pull force that was measured remained below the structural capacity of the pipe because of a well-prepared hole, then the contractor would not need to add any water until after the pipe was installed.

Although the actual pull-back force (Figure 7) is less than the safe pull-back load, it was recommended that the pipe be full of water to reduce the force sufficiently to install without exceeding the structural capacity of the DR 9 pipe. Because the pull occurs relatively quickly, a contractor is typically provided with this analysis and may select to pull the pipe dry until the pull force approaches the critical value, at which time the contractor will start adding water to reduce the buoyancy and pull force required. The results of the long-term assessment, however, indicated that the pipe must remain full of water to remain at a stress level less than the pipe capacity.

This approach was not expected to be a problem. The pipe could still be dewatered for short periods of time if necessary for maintenance. Short periods of time are generally less than 10 to 20 hours and were dependant on the ground and pipe temperature.

Drill Fluid Loss Monitoring

One of the primary requirements for approval of an environmental resource permit by the FDEP is to manage drill fluid during construction. Drill fluid management involves designing a drill path to confine the fluid under both static and dynamic fluid pressures, developing realistic assumptions regarding down-hole drilling pressures, then conducting field measurements for verification and for input to the driller and tracking personnel about the performance of the drill with respect to the geological conditions encountered.

During the design phase, drill fluid management curves were prepared (Figure 6). During construction, drill fluid loss due to hydraulic fracturing was controlled by keeping drilling pressures below the formation confinement pressures.

HDPE Fused Pipe String-Out Innovations

During the alignment planning phase,

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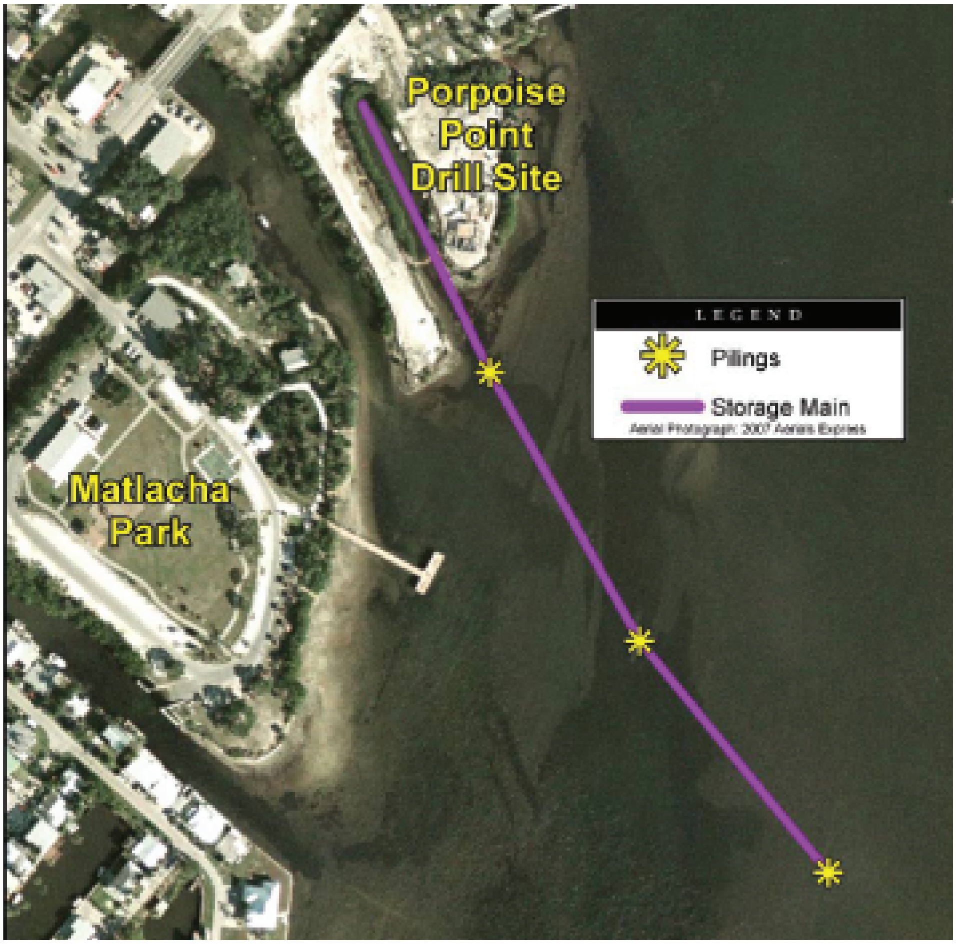

Figure 8 – HDPE Pipe String-out in Open Water

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the water main route was highly influenced by the local geography necessary to support the HDPE pipe fusing, string-out, and staging operations associated with 3,000 feet of HDPE pipe pullback through the bore hole. As indicated in Figure 4, the lack of available road rights-of-way and land for staging 3,000 feet of HDPE fused pipe string-out resulted in the decision early on in the design phase to float and stage the fused pipe string-out into the local waterway.

Floating thousands of feet of 16-inch diameter HDPE pipe in the vicinity of Matlacha Pass, with the high volume of small boat activity and in such a shallow marine environment covered with seagrass, was no small matter. The local FDEP Charlotte Harbor Aquatic Preserve staff and the Coast Guard became involved in developing an innovative HDPE fused pipe string-out storing and staging plan from the beginning of the permitting process.

The fused pipe string-out plan considered storage of six 500-foot sections of floating pipe, capped at the ends, which were stored during the beginning of construction in a local canal near one of the upland drill sites for several weeks. This private 500-foot canal at the western drill site has no boat traffic (this drill site was an undeveloped peninsula) and offers protection from any potential storms or hurricanes, so it was a prime location to stage the floating fused pipe string-out.

Once the HDD borehole was prepared and ready, the concept was to float the fused pipe string-out into three 1,000-foot-long floating cartridges that could be staged in the local waterway for starting the HDPE pipe pullback. During the pullback, two brief HDPE fusing periods would be needed to weld the three fused pipe string-out cartridges into one continuous 3,000-foot water main. The permitting process required advanced approval of this HDPE fused pipe string-out plan.

The project team conducted extensive seagrass research and surveys throughout the planned storage and staging areas, working with the aquatic preserve staff on a mutual understanding that the fused pipe string-out and the HDPE pipe pullback construction activities would not harm the abundant seagrass in this protected waterway. As a result, the design package involved the installation of three temporary pilings within the aquatic preserve for the purpose of storing and staging the 16-inch fused pipe string-out in open water.

The temporary pilings were designed at 500-foot intervals, for a total of 1,000 feet to be used as an anchor for pipe pullback through the borehole (see Figure 8). The team worked with the Coast Guard to develop the navigation lighting requirements for the pilings and the floating pipe string-out to ensure there would be no public safety or navigation hazards.

Upland Easements: Challenge

Because of the large construction area necessary to perform such a major directional drill, planning adequate room for the drill contractor was required up front and early. Securing the availability of rather large upland drill site easements from private landowners took the better part of seven months.

The large size of the HDD rig for drilling the 30-inch diameter borehole and having the pullback capacity for the 3,000 feet of HDPE pipe required at least a DD220 rig, rated for over 200,000 pounds of pullback. This large drill rig is approximately 75 feet in length, and when you consider the construction area needed for the ancillary equipment (storage of the 30 foot-long drill rods, the on-site mud recycling unit, the frac-out tank, etc.), the required temporary construction area for each of the drill sites is well over half an acre.

Constrained by limited road rights-of-way with which to work, negotiation and securing of these temporary construction easements at each end of the drill was a critical element in the success of this project. Furthermore, the western drill site for this project was being developed into a condominium resort community; therefore, adequate space and coordination at this site had to provide for simultaneous construction of not only this project but some of the units in this condo community.

Fast-Track SLERP Permitting

Within weeks of isolating the failed water main in the wake of Hurricane Wilma, the project team engaged the local FDEP, the Lee County Department of Health, and the Lee County DOT to attempt to design, permit, and construct an emergency replacement water main under the Hurricane Emergency Order. Unfortunately, the pending DOT expansion plans for the Matlacha Drawbridge resulted in a much more complex water main replacement with significant sovereign submerged lands aspect, which became a much more significant environmental permitting challenge in these protected waters.

Several pre-application meetings with the local FDEP and aquatic preserve staff were critical to understanding and addressing the various stakeholder concerns with this project. The design was driven by developing a mutual understanding of the FDEP's concerns surrounding potential frac-out, which

Figure 9 – HDPE Fused Pipe String-out

Figure 10 – Pipe Pullback

could result in catastrophic impacts to seagrass and shellfish population in the pass, as well as providing the utmost protection of mangroves and seagrass. For example, the first construction step involved installation of 36-inch casing at a 12-degree down angle (with resultant end of casing depth 50 feet below the mangrove mud/muck layer) to virtually eliminate frac-out potential at the shallow drill depths.

The project team and the permitting agencies acknowledged that although this was an emergency project, protection of the pass and the aquatic preserve was paramount. Meeting all the FDEP requirements, such as seagrass and shellfish surveys and extensive geotechnical surveys, as well as developing a design package that utilized BAT to minimize risk to the environment, were understood by all to be mandatory.

For this reason, an extensive and comprehensive Submerged Lands and Environmental Resources Program (SLERP) permit application package was submitted in early June 2006 to the FDEP and was fast-tracked as much as feasible. By July 31, after revisions to clarify drill fluid monitoring and drilling performance specifications and to ensure that no adverse impacts to seagrass would occur when the three pilings were installed in the open waterway for supporting pipe pullback, the FDEP deemed the permit application package complete.

The FDEP approved the SLERP permit on October 27, 2006. All told, securing this complex and extensive permit in less than five months' duration was truly a historic "fast-track" permitting effort.

Construction Challenges

The construction contract was bid and awarded such that the HDD contractor was on board and ready to start as soon as possible after the SLERP permit was obtained. The contractor, Michels Directional Crossings Inc., rapidly developed the fast-track construction schedule and submitted the drill plan in accordance with the performance specifications. The plan involved two HDD rigs (one at the east end drill site location and one at the west end drill site location) and an intersecting drill through the permanent 36-inch steel casings located at both ends.

The general construction schedule encompassed the following major tasks:

- Pipe ram installation and auger cleaning of both the east end casing and the west end casing.
- HDD pilot bore east end with large HDD rig – pilot bore completed to approximately 2,700 linear feet to "intersection" target location under the pass mudline.
- HDD pilot bore west end with small HDD rig – pilot bore steering and "intersection" of the east drill at the target location under the pass mudline.
- Reaming of drill holes (with both HDD rigs) to properly prepare the hole for HDPE pipe pullback.
- Fusing and staging HDPE pipe string-out at the west end drill site.
- HDPE pipe pullback.
- Tie-ins to existing potable water transmission main at both ends.
- Flushing, pressure testing, bacteriological testing, and clearance prior to placing new transmission main in service.
- Restoration of both drill sites.

Although the east end casing installation progressed without a hitch, a major design and

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construction challenge developed at the west end drill site on Porpoise Point. In order to avoid conflicts with the Porpoise Point landowner's condominium construction plans, the team was forced to change the location of the west end drill location by over 400 feet.

Subsequently, before constructing the west end casing, the engineering team worked with Michel's to revise the drill path design. The design parameters were revised to reflect the new drill "intersection" target location, and the anticipated pipe pullback calculations were redeveloped to confirm that the contractor would be successful with the revised drill design.

Also, the close proximity of the west end casing to a proposed building foundation resulted in additional seismic monitoring of this casing installation during air hammering operations, to confirm that casing installation did not adversely impact the recently constructed piling foundation at the corner of one of the condominiums.

The engineering team worked with the GPIWA to contract a third-party geotechnical/drilling site engineer during construction for risk management; reducing the risk of frac-out was paramount. This full-time site drilling engineer/geotech consultant was hired to help the contractor monitor drill fluid parameters, to react promptly on the owner's behalf to changing drill conditions, and to assist the driller in adjusting drill parameters in accordance with the construction contract's performance specifications.

Several field modifications to the various drill parameters and the drilling operations were implemented through timely consultation with the design team to ensure that the borehole was properly prepared and that no frac-out would occur. These rapid modifications were made without delaying the contractor's production schedule, which was critical to maintaining a stable drill hole under the local conditions and controlling cost.

The design and field engineering program successfully addressed these construction challenges in a timely manner, allowing the contractor to perform the intersecting drill and complete the testing and tie-ins. The new transmission main was placed in service in February 2007, with construction substantially complete in less than four months' total duration, allowing the GPIWA to restore fire protection service and potable water service to its customers east of the Matlacha Drawbridge as quickly as possible.

Although site restoration at the east end site required the GPIWA to perform a Phase 1 Environmental Study in accordance with the temporary easement agreement between this landowner and the association, the west end site restoration avoided conflicts with the condominium construction activities. Restoration of both drill sites was completed to the satisfaction of all the landowners and the GPIWA.

Conclusions

This historic directional drill project met all of the GPIWA's, FDEP's, and other environmental stakeholders' expectations. Here are the results of the final design, which was focused on reduced risk of frac-out and BAT to protect the sensitive waterway:

- The total HDD length of the pipe is approximately 2,900 feet, at a maximum depth of 97 feet below the mud line. This historic intersecting drill, with precise tracking, targeted 36-inch steel casing almost 3,000 feet away.
- Sixteen-inch HDPE SDR 9 pipe was selected to prevent buckling and to achieve equivalent hydraulic capacity of the failed 12-inch cast-iron water main.
- At each end of drill path, casing pipe was installed to prevent frac-out and subsequent drill fluid loss at the shallow drill depths. At the east end of the drill path, approximately 270 feet of 36-inch steel casing pipe (0.75-inch wall thickness) was required. At the west end of the drill path, approximately 200 feet of 36-inch steel casing pipe was required.
- The anticipated pull load for the designed drill path was 97,000 lbs, less than the safe pull load of 120,000 lbs for HDPE pipe of this class.
- Annular pressure curve with tolerances and formation confinement curves were prepared during design. These curves were used by the contractor to track and monitor drill fluid down-hole pressures during all phases of drilling construction. No frac-out occurred, and the contractor met all performance specifications.
- HDD route selection took considerable innovative planning, not only for a viable design to reduce frac-out potential, but for securing large, upland drill site areas and use of the open waterway for storage, fusing, string-out, and staging operations associated with the HDPE pipe pullback.

In conclusion, the GPIWA potable water transmission main was replaced successfully using HDD technology to restore potable water service to the GPIWA's customers. The entire project team delivered this project without any adverse environmental impacts and met all of the stakeholders' expectations.

References

1. ASTM Standard F1962-05, "Standard Guide for Use of Maxi-Horizontal Directional Drilling for Placement of Polyethylene Pipe or Conduit Under Obstacles, Including River Crossings," April 2005
2. Dorwart, Brian, "Risk Managed Design Method," presented at the North American Society for Trenchless Technology (NASTT), March 2006.
3. Hair, John D., "Design and Project Management Considerations Involved with Horizontal Directional Drilling," Presented at American Augers 29th Trenchless Technology Seminar, January 1995.
4. Tierra, Inc, "Report of Geotechnical Services for Matlacha Water Main Replacement – Lee County Florida," April 2006.