

INVERTED SIPHON INSTALLED FROM ALAMEDA TO OAKLAND USING HDD

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ABSTRACT

The East Bay Municipal Utility District (EBMUD), in conjunction with the Port of Oakland and the City of Alameda needed a new inverted siphon beneath the Alameda channel to replace an existing force main. The design was extremely challenging due to the diameter, preferred pipe material, great depths under the channel to avoid future dredging, the proposed length of the channel crossing, and spatial constraints.

Horizontal directional drilling (HDD) was the construction method selected for installing a 30-inch diameter, HDPE inverted siphon. The siphon was successfully completed in November, 2000. Construction aspects of the projects are the primary focus of this paper. The construction activities and complications are discussed for the pilot bore, the multiple reaming passes, and the pull-back operations. Lessons learned during design and construction that may be of interest to others considering similar projects are also described.

Keywords: horizontal directional drilling, HDPE pipe, Alameda Channel, EBMUD, construction management, trenchless technology, trenchless design.

INTRODUCTION

The heavily traveled Alameda channel in the Port of Oakland is scheduled for dredging to increase necessary channel depths. However, the scheduled dredging operations will remove the existing force main from Alameda to Oakland. The sewage currently being conveyed by the force main was re-routed to the south where it connected into an existing EBMUD interceptor that crosses the Alameda Channel through an existing two-barrel inverted siphon. A third barrel was required in order to convey this additional flow.

Figure 1 Alameda Channel



Trenchless techniques were chosen to minimize disruption to the channel traffic and reduce environmental impacts. The feasibility study evaluated horizontal directional drilling (HDD) and microtunneling at pipe diameters ranging from 30 to 48-inches. For HDD operations, HDPE pipe was preferred over steel pipe by the operations and maintenance staff; however, at a 30 to 48-inch flow diameter and depths of over 65 feet the installation presented significant challenges. Microtunneling with reinforced concrete pipe was technically feasible but the higher estimated cost could have led to cancellation of the project. Six combinations of trenchless alternatives, including multiple crossings at various diameters, were evaluated to determine the best solution for the project [1].

At the beginning of the feasibility evaluation, the preferred pipe size was approximately 48-inches (inside diameter) in order to match the capacity of the largest existing siphon barrel. HDPE was selected as the preferred pipe material for the HDD alternatives. However, due to the project depth necessary to maintain appropriate clearance beneath the channel, a pipe diameter pushing the upper bound for HDD construction to date, the length of the HDD pull, and the limitations on manufacturing of large-diameter, thick-walled HDPE, this option presented substantial risk. Microtunneling would have reduced the risk for a 48-inch diameter. However, the cost for the microtunneling option was substantially higher due to the costs of constructing deep shafts.

Due to the costs and risks associated with the construction of a 48-inch diameter HDPE siphon, alternative diameters were analyzed in detail. It was determined that a 30-inch flow diameter

was adequate to carry the additional peak flow of 18.8 cfs or 12 mgd. In addition, a new 30-inch ID siphon would provide redundancy to the existing 30-inch barrel. HDPE pipes of this diameter had been successfully installed with HDD techniques, substantially reducing the perceived risk of the installation.

Based on the cost estimates for installation and the associated risk factors, installing a 30-inch ID HDPE pipe with HDD provided a promising solution for the construction of the new siphon within the budget limits. The design for the project was completed in early 2000 and the construction of the 36-inch OD HDPE siphon was successfully completed in November, 2000.

Siphon Geometry

The following is a short summary of the HDD geometry.

Overall Length	1,250 feet (approx.)
Entrance Angle	18.5 degrees
Exit Angle	20 degrees
Radius	720-foot radius
Depth of Channel	40 feet (approx.)
Depth Below Bottom of Channel	30 feet
Product Pipe	36" OD HDPE (SDR 11)
Reaming Passes	28", 36", 48", and 42" swab
Reaming Direction	Forward Ream
Pullback Time	21 hours

Geotechnical Conditions

A geotechnical investigation was performed by Olivia Chen Consultants, San Francisco, to define the ground conditions beneath and adjacent to the channel. Six borings were drilled on the land, three on each side of the channel. Soil samples were collected from all borings and sent for laboratory testing. Borings on the shore revealed a thin layer of fill, ranging from two to five feet, underlain by "younger Bay Mud." The USCS classification for the younger Bay Mud was highly plastic silt (MH), with some low plasticity clay (CL). The younger Bay Mud was very soft to medium stiff with blow counts ranging from 0 to 6 blows per foot.

In addition, a barge-mounted drill rig was mobilized along the proposed alignment to drill three holes within the channel. Soils encountered beneath the channel were predominately "older Bay Mud," although one boring encountered a lens of sand and clayey sand. The older Bay Mud had a laboratory classification of low plasticity clay (CL). The consistency of the material beneath the channel was stiff to hard. Blow counts beneath the channel ranged from 11 to 56 blows per foot.

A hydrofracture analysis was performed for the directional drilling operations to determine an appropriate depth beneath the channel to guard against hydro-fracture or migration of drilling fluid to the channel. Based on the soil properties determined by laboratory testing on samples taken during the geotechnical investigation, a minimum depth of cover below the channel of 15 feet was established for horizontal directional drilling.

During the geotechnical investigation, historical photos were examined. These photos showed old pile-supported piers. Further investigation revealed that the wooden piles remained on the shoreline but were broken off at the mud line or water surface. Due to this information, the design was adjusted to place the pipeline below the assumed depth of the pile tips.

SIPHON CONSTRUCTION

Table 1. Duration of critical activities

ACTIVITY	DURATION (WORK DAYS)
Mobilization	4 days
Pilot Hole: includes both pilot holes – see text.	5 days
Ream #1	3 days
Ream #2	3 days
Ream #3	5 days
Final Swab and Pullback	2 days (32 hours)
Demobilization	3 days
TOTAL	25 Working Days 28 Calendar Days

Drilling of the pilot bore began on October 16, and the pullback was completed on November 6, 2000. Major construction activities and durations are presented in Table 1. ARB, Inc. was the horizontal directional drilling contractor. For the drilling, a HDD rig with 300,000 pounds of pulling capacity was used. The subsequent sections of this paper address the construction of the siphon, as well as some of the difficulties encountered during construction.

Mobilization

The first equipment arrived at the site on October 12, 2000. The drill rig was located on the east side of the channel in Oakland. The drill operation would progress beneath the Alameda channel to the west, exiting in Alameda. Mobilization required four days. A TruTracker system was

Figure 2 Rig-Side Equipment Layout -- Oakland



used to track the location of the drilling tool during the construction of the pilot hole. A TruTracker coil was placed on the east bank of the channel and the location of the coil was surveyed so that the positions could be entered into the computerized tracking system. The inaccessible channel was navigated using the downhole instrumentation without the

TruTracker system. A 3.5-foot deep entry mud pit was built in order to contain drilling fluid, measuring 6 by 9 feet.

The siphon was designed with an entry angle of 20 degrees to avoid the risks of hitting the tips of piles that were located on the eastern bank of the river. However, ARB elected to reduce the entry angle to 17.5 degrees and move the rig back from the design entry location. ARB was concerned that they might have to increase the angle of the rig during pull-back operations. Since 20 degrees was at the upper end of their capabilities, they would have to employ special measures to elevate the rig if the entry angle was not reduced. Although there was some concern about hitting the piles, ARB was allowed to proceed with the 17.5 degree entry angle.

Pilot Bore

Drilling of the pilot bore began on October 16, 2000. The contractor elected to work 11 hours per day, 6 days per week. A tri-cone roller drill bit with three nozzles was used. ARB elected to close 2 of the nozzles, leaving only one nozzle open for drilling mud injection in the bore. A total of 3 drilling pipes were installed on the first day of drilling. The typical drilling pipe was 30.5 feet long with a 5-inch outside diameter. A small ditch was dug to direct drilling fluid back to the entry pit whenever hydrofracture occurred near the entry.

On the second day of drilling, the contractor installed 19 drill pipes. At the end of the second day, the head of the drill was 797 feet from the entry location, measured horizontally. During the drilling of drill pipe number 6, approximately 155 feet into the bore, the drill head was deflected by a buried object. Although the operator continuously monitored the drill head, the drill head was well beyond the banks of the channel, away from the TruTracker surface coil, and the exact location of the drill head was not known.

On the third day of drilling the contractor began by installing 14 drill pipes, at which point the drill head was near the west bank of the channel. ARB then installed the TruTracker coil on the west side of the channel in Alameda, on the houseboat docks. The contractor measured the location and, based on the TruTracker information, the drill head was 56 feet north of the design alignment. The contractor elected to remove 27 drill pipes or approximately 810 feet of drill pipe in an attempt to drill through the object that caused the deflection in the pilot bore. They then began re-drilling the pilot hole and installed drill pipes 6 through 10. However, the operator felt that there were still problems with the location of the drill head and the contractor removed all of the drill pipes that were in the pilot bore.

On October 19th, the fourth day of drilling, the contractor decided to raise the drill rig to an 18.5 degree entry angle. They began re-drilling the pilot bore and were able to pass the obstruction without any deflection in the alignment. The contractor installed 22 drill pipes, or approximately 660 feet of the second pilot bore.

On October 20th, drill pipes 23 through 28 were installed. The TruTracker coil on the west bank of the channel was used to detect the location of the drill head. The drilling head was found to be 12 feet to the south of the planned alignment. The contractor removed 10 drill pipes to re-drill for position. After re-drilling the drill head was 5.5 feet south of the planned alignment, at 997 feet from the entry point.

The pilot bore was completed on the 21st of October. A total of 41 drill pipes were installed in the pilot bore and the final exit location was approximately 18 inches north of the planned exit location. When the drill head was approximately 120 feet from the hole-out location, inadvertent mud returns were observed in the channel. This was not surprising since the soil on the west side of the channel at the design elevation was extremely soft and did not provide enough resistance to contain pressurized drilling mud. Drilling was stopped in order to take measures to contain future hydrofracture events. Upon completion, adjustments were made to the drilling operations and drilling continued with significantly lower drilling fluid pressures applied at the cutting nozzles of the drill head. One additional area of hydrofracture occurred approximately 90 feet from the hole-out location. The contractor completed the bore and then cleaned the mud from the channel and banks with a vacuum system.

Reaming

The contractor elected to handle the mud cleaning operations from only one location. As a result, they decided to forward ream the bore so that all of the mud processing took place on the east (rig) side of the channel in Oakland. To facilitate the installation of a 36-inch OD pipeline, several reaming passes were made to enlarge the borehole to a 48-inch diameter.

28-inch Reaming Pass. On the first reaming pass, a 28-inch fly cutter was used to enlarge the pilot bore. There was some concern that the reamer might encounter the object that caused the pilot bore to deflect; however the contractor reamed past that location without incident. When the reamer was approximately 300 feet into the bore, drilling mud circulation was lost and

Figure 3 28-inch Fly Cutter



inadvertent returns were observed on the east side of the channel. The contractor elected to pull the drill rods in an attempt to seal the hole and re-establish circulation. The driller believed that the open portion of the fly cutter was plugged with clay, allowing the pressure to build up in the bore and mud to escape to the surface rather than returning to the mud pit. The contractor was able to re-gain circulation and decided to bring the marsh funnel viscosity of the mud down to help facilitate removal of the excavated material. This plan was successful and on the second day of reaming 28 drill pipes (approximately 840 feet) were installed.

The 28-inch pre-reaming bore was completed on the third day of reaming. Like the pilot bore, mud escaped to the surface beneath the channel when the reamer was approaching the west bank of the channel in Alameda. The inadvertent returns occurred during the reaming of drill pipe 35 or approximately 180 feet from the exit location. When the inadvertent returns were noticed, drilling stopped while the contractor contained the drilling mud within the previously built containment area constructed of sand bags. The mud was then removed from the containment area with a vacuum truck. Reaming continued while the mud was controlled by the vacuum operations. When the reamer emerged from the bore it was approximately 75 percent

packed off with soil, allowing only 25 percent of the open area for mud circulation. The contractor pulled drill rods from the Alameda side of the channel to the Oakland side of the channel through the bore to avoid having to truck them from the exit location to the entry location for the second reaming pass.

36-inch Reaming Pass. The second pre-reaming pass was conducted with a combination of a 20-inch barrel reamer followed by a 36-inch fly cutter. The 20-inch barrel was used to keep the reamer centralized in the previously reamed 28-inch bore. Again, forward reaming operations

Figure 4 Second Reaming Pass



took place from the Oakland side of the channel to the Alameda side of the channel. The enlargement of the borehole to 36 inches generated a tremendous volume of mud that contained seashells. These shells would clog the sand cones on the mud plant. As a result, the mud plant was the limiting factor for the speed of the drilling operations. The reaming had to be stopped several times while the seashells were cleaned from the sand cones in the mud plant.

When the reaming operation was on the 5th drill pipe, the torque readings were extremely high and pieces of wood were noted on the mud plant. The reaming assembly had encountered the buried obstruction that caused the deflection in the original pilot bore, forcing the contractor to abandon the original pilot bore and drill a new pilot. Due to the high torque, the reaming operations had to be slowed considerably. It took over 1.5 hours to ream through the buried object, assumed to be a pile.

The 36-inch ream was completed on the third day of reaming. Inadvertent returns were noted at the exit side at the approximate location of the hydrofracture during the drilling of the pilot bore and the first reaming pass. Again the crew was able to contain the drilling mud and remove it from the containment area with a vacuum operation.

48-inch Reaming Pass. The third reaming pass was performed in four days with a 36-inch centralizing barrel reamer followed by a 48-inch fly cutter. Drilling rates were again limited by the capabilities of the mud plant because the shells in the excavated material would clog the plant. As expected, hydrofracture occurred when the reaming pass was on drill pipe 35. During the drilling of pipe 35, drilling operations became difficult. The operator believed that the slurry jets on the fly cutter were clogging but they continued to ream and became stuck on the last drill pipe, when the reamer was approximately 8 feet deep. They believed that they were hitting another obstruction. The contractor attached a smaller fly cutter at the exit point and back

reamed to the obstacle in an attempt to remove it with the smaller fly cutter. When the smaller fly cutter encountered the obstruction during the back ream, large pieces of wood were retrieved from the exit mud pit. The operation was successful and the 48-inch reaming pass was completed.

Swab Pass. Upon completion of the reaming operations, a swab pass was conducted prior to the pullback of the product pipe. The contractor used a 42-inch barrel reamer and forward swabbed

Figure 5 42-inch Barrel Reamer for Swab Pass⁷⁴



from Oakland to Alameda. The swab pass was completed in 8 hours and 20 minutes.

Pull Back

At the completion of the reaming and swabbing operations, the 42-inch barrel reamer was turned 180 degrees in preparation for the pull back. The 42-inch reamer was followed by the swivel, which was connected to the 36-inch HDPE product pipe. A large capacity crane was mobilized to the site to lift the pipe and

facilitate the pull back operations without over-stressing the pipe. The contractor elected to operate on continuous 24-hour shifts for the pull back. The pull-back was started at 5:45 am on November 4, 2000. The pull back was successfully completed in just over 21 hours at 2:47 am on November 5, 2000.

CONCLUSIONS

Several lessons were learned during the design and construction of this challenging project that can be used on future projects to improve the chances of constructing a successful project.

Extensive Pre-Design Evaluation

Because of the complex features of the project, many construction alternatives were examined at the conceptual stage of the engineering evaluation. During the pre-design phase, these alternatives were examined in detail to aid in the development of a design that would meet the needs of the District while remaining within the reasonable limits of the construction techniques. These pre-design alternative evaluations proved to be invaluable in the selection of the pipe diameter and construction methods.

Experienced Site Personnel

Having full-time on-site construction inspection personnel with experience in horizontal directional drilling allowed close tracking of the drilling operations. The construction management team closely monitored drill head location, drilling rates, drilling mud parameters,

difficulties experienced during construction, the occurrences of inadvertent returns, pull back forces, required torque, and other operational parameters. With this information, the Owner was aware of any problems as they developed and was able to participate in timely decisions that were critical to the successful completion of the project. This information also provided a first-line defense against any frivolous claims and provided the Owner with a baseline from which to judge any construction claims.

Containing Inadvertent Returns

Inadvertent returns during the drilling operations were a concern to the District, especially if they occurred beneath the channel. As a result, a detailed geotechnical investigation was performed to characterize the soils that would be encountered during the bore. Based on the information collected during the geotechnical investigations, calculations were performed at the design phase to determine limiting drilling fluid pressures and risk of hydrofracture. Since the risk of hydrofracture was substantial in the young Bay Mud, found primarily beneath the west Alameda bank of the channel, the specifications required the contractor to submit contingency plans for containing inadvertent returns. As a result, the contractor had all necessary equipment on site during the drilling operations. This included vacuum trucks, mud pumps, and other equipment needed to quickly build berms around any drilling mud plumes/ponds and remove the material.

Drill Head Location Information

A downhole TruTracker surface grid system was used to locate the position of the drilling head. However, the TruTracker coil was located only on the banks of the channel. Once the drill head was under the channel, the operator had to rely on the accelerometer pitch readings to calculate the position of the head. However, these calculations were not accurate. As a result, when the drill head was across the channel and within the vicinity of the TruTracker coil on the west bank, the drill head was significantly off of the alignment. As a result, the contractor had to re-drill the majority of the pilot hole. One potential solution would be for the contractor to extend the TruTracker coil out into the water. It is possible to string TruTracker coils across non-navigable bodies of water or to lay coils along the bottom of navigable water bodies. The required accuracy, costs and benefits should be taken into consideration before specifying the installation of a continuous grid. In addition, it should be noted that the achievable survey accuracy for a grid installed beneath water will be less than for a surface grid above water.

REFERENCES

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