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Davenport Ranch, Austin, Texas
Crossing Lake Austin using Horizontal Directional Drilling

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Abstract

The Austin Country Club (ACC) and Davenport Ranch development needed to decommission its independent wastewater treatment facility and connect to the City of Austin's wastewater conveyance system. To support this initiative, the City of Austin developed a Master Plan to build a new Lift Station in the ACC area and discharge the wastewater to the city's Cross Town Tunnel. To implement their plan, the City would need to design and construct a 4,000 foot force main that crossed the ACC golf course and Lake Austin. Concurrently, the City partnered with Austin Energy, the local electrical supplier, to bundle the force mains with a series of electrical conduits, allowing Austin Energy to extend electrical service between the Davenport Ranch development and the Austin Energy transmission system on the other side of Lake Austin. This paper discusses the many challenges addressed during the design and construction phases of the project, ultimately resulting in a successful HDD installation, providing vital new wastewater and electric infrastructure to the residents and businesses surrounding Davenport Ranch.

Introduction and Project Overview: The City of Austin investigated a number of construction methods to install a new 12-inch wastewater force main across Lake Austin and Austin Country Club (golf course), concluding that horizontal directional drilling (HDD) was the most favorable method. HDD is a trenchless construction technique that uses guided drilling to create an arc profile. This technique is most applicable to long distance crossing beneath rivers, lagoons, landfalls, and sensitive or highly urbanized areas. The process involves three main stages: 1) Piloting (drilling of a pilot hole); 2) Reaming (pilot hole enlargement in stages; 3) Pullback (installation of pipe).

From a design perspective, using HDD techniques to install large diameter pipe is more complex than traditional open cut techniques. However, the decision to use HDD must take into account the social costs such as noise and disruption of open cut trenching, measured against the HDD's benefits of reduced environmental stress, improved margins of safety, and eliminating risk to existing facilities. The social and economic benefits clearly justify the additional design cost for this type of solution. However, installing force mains and the electrical lines using HDD techniques created several specific challenges that were resolved during the design and construction phases of the project. This paper discusses both design and construction aspects of the individual project elements concurrently.

The City considered a number of alternative alignments for the new utilities, evaluating a dual 2,000-foot segmental installation, as compared to a single 6,000-foot continuous installation. In the end, the final configuration installed two 2,000 foot long segments using horizontal directional drilling (HDD). Each segment consisted of two 12-inch diameter HDPE force mains (one acting as a redundant service) and six 3-inch diameter electrical conduits, completely encased inside of a single 30-inch steel casing.

Crossing Lake Austin using Horizontal Directional Drilling

***Figure 1** – Davenport Ranch HDD Site: The two combined Horizontal Directional Drilling (HDD) segments (shown in pink) exceed 4,000 feet of subsurface improvements, installed with no disruption to the golf course, Lake Austin, the public boat ramp, or to Loop 360 and the Pennybaker Bridge.*

Segment 1 parallels the southern shoreline of Lake Austin. The pipeline starts at the maintenance area located about 500 feet south of the Lake shoreline and centrally within the golf course property. Along this alignment, the ground elevation varies between 494 feet and 515 feet above mean sea level (msl).

Segment 2 follows a north/south orientation parallel to the Loop 360 Bridge on the eastern side of the highway crossing below Lake Austin. The elevation near the Loop 360 highway boat ramp is approximately 500 feet above msl. Elevation rises sharply on the north side of the Lake, where the highway was cut through a segment of limestone formation. The Lake is approximately 600 feet wide at this location. At the termination point along Loop 360, the elevation is approximately 602 feet above msl.

Segment 2 negotiated nearly 150 feet of elevation change between the entry and exit points passing through the limestone substrate. Entry point for this segment was located within a 50-foot by 70-foot area, just east of the Loop 360 bridge. The exit was approximately 2000 feet north, between the shoulder of Loop 360 and the cliff. Laydown area for this segment was extremely tight and consisted of a 15 foot wide strip of land between the shoulder of Loop 360 and the adjacent cliff.

Developing Project Consensus: While constructing this project was technically feasible with an alignment that placed an open cut trench through the adjacent residential neighborhoods and supporting the force main on the bridge, the drastic impacts of "cut and cover" installation were expected to stir strong feelings of resentment and resistance to the project. Further, the City recognized that there are extensive environmental consequences when installing open cut force mains adjacent to a river bed. Using HDD technology for installation of these lines mitigated these concerns, making it feasible to eliminate the force main alignment through the very vocal residential area and avoiding that pocket of organized resistance for the project. The HDD solution met all the goals of the City and addressed their infrastructure needs without any "human cry" that would have resulted from any undue disturbance to the area.

The success of a previous 24-inch water main HDD crossing beneath Lake Austin in 2000 (also designed by Jacobs) served to increase project confidence for the City as well as local stakeholders. The primary innovation that evolved from the design team's approach to project development focused on the opportunity to combine the electrical crossing in the same casing as the wastewater force mains. Once this idea gained support, the designers maintained communication between the project team and the various City departments to keep the project moving.

Early Planning Identifies Opportunities to Meet Multiple Objectives: In 2001 the City initially designed a crossing that would support the force mains from the Pennybaker Bridge (Loop 360 Bridge). The Texas Department of Transportation (TxDOT) was quick to remind the City that this structure is "the most photographed structure" in Texas, expressing their concern for any solution that may affect aesthetics of that facility. This TxDOT concern was considered in the original open cut design, which proposed a new sidewalk over the existing sidewalk with the force main between the two slabs. This "major" reconstruction caused additional requirements to bring the entrances up to meet ADA standards not involved in the original bridge design. Thus this option quickly became impractical and cost prohibitive. The HDD solution eliminated all these issues, while providing a safe, environmentally sound solution. At the same time, Austin Energy needed redundancy for their electrical service to the Davenport development. Their initial design considered erecting monumental steel towers to span the Lake. The ensuing public concern for the unsightly appearance of towers and right-of-way needs would have been enormous obstacles to overcome. Construction of these utilities also needed to avoid interfering with Lake Austin navigation while minimizing obstruction to the public boat ramp located below the Loop 360 bridge.

***Figure 2** – Lake Austin and Penny Baker Bridge: The City and Austin Energy partnered to install new force mains and electrical conduits to serve the Davenport Ranch development near the picturesque Lake Austin and Penny Baker Bridge.*

By combining the two utilities within a common casing, the project saved literally millions of dollars associated with an aerial electrical crossing and avoided costly, time-consuming negotiation with various agencies and public groups that would be required for either crossing.

Cost Effective Sharing by Compatible Utilities Offers Significant Advantages: Once HDD was selected, the City decided to take advantage of the economies of scale and add a redundant force main into the project. In this way, they could be assured of ample capacity and redundancy should one line ever need to be taken out of service. The City also recognized the potential for bundling the electric conduits within the remaining space within the casing. Once Austin Energy was approached, the solution to both utility's problems for serving Davenport Ranch became obvious.

Although constructing a force main across Lake Austin was unusually well-suited for the HDD method, the City was able to leverage this opportunity to provide cost sharing benefits by teaming with Austin Energy. This project combined multiple users for the crossing, offering fully independent benefits, while substantially reducing the overall cost associated with each entity. Austin Energy entered into a cost sharing agreement with City of Austin's water utility, thereby sharing the $5M construction cost while literally saving millions of dollars associated with spanning Lake Austin with separate aerial tower crossing for the electrical lines.

Innovative Project Packaging: The initial design consisted of the lift station, force mains and the gravity lines as a single construction package. While this package met the intent of holding one contractor responsible for construction, it severely limited the bidding and bonding capabilities of smaller contractors. Also, many HDD contractors did not bid the job (As Prime) due to the lift station component. This resulted in one bid which was cost prohibitive. In response, the team worked aggressively to implement an innovative construction packaging scheme which separated out the lift station, HDD components and open cut gravity line into three packages. Subdivision of this construction provided more opportunities to multiple contractors and resulted in an overall cost reduction of $2M for the complete project. Mears HDD, LLC was the successful contractor for the HDD project (Package 1) with a low bid of $5.2 M. The costs were well within what the City considers "acceptable tolerances", especially in light of the drastic rise in material costs (most notably steel and fuel), during the development of this program.

Managing Pipe Lay-Down and Work Area Constraints: An area west of a triangular shaped plot of land approximately 100 feet by 200 feet along its longest legs was used for beginning the HDD entry for Segment 1. The land surrounding the maintenance area is the open space of the golf course. The force main traversed beneath the golf course and a waterway inlet protruding into the ACC property from Lake Austin, just east of the Highway Loop 360 bridge, and terminate at an existing boat ramp below the Loop 360 bridge. Travis County maintains the boat ramp, while TxDOT owns the Right of Way. The paved area of the boat ramp is roughly 300 feet by 200 feet and is used year-round for launching recreational watercraft.

For HDD installation, a pipe lay-down area that is equal in length to the total installation is most desirable. Stopping during pullback to connect additional pipe greatly increases the risk of pipe becoming stuck in the hole. The need to identify suitable pipe lay-down areas for this project were complicated by the environmentally sensitive Lake Austin shoreline, the heavily traveled Loop 360, and the physical constraints posed by the cliff. Along Segment 1, the vegetated shoreline along Lake Austin, west of the boat ramp provided a good lay-down area. However, the active boat ramp needed to remain open to the public throughout construction. Therefore, the lay-down and pipe assembly area was short by about 200 feet due to difficulties in getting construction easement and a drainage channel separating the boat ramp and the lay-down area. Design and specifications made allowances for the pipe to be assembled in two sections and the final sections were welded during pullback operations.

Figure 3 - *The lay-down area for Segment 1 extended for 2000 feet between the Lake Shore and the vegetated land. An open, grassy area west of the boat ramp extends approximately 1,000 feet along the shoreline of Lake Austin; the land west of this strip is an overgrown vegetated strip consisting of large trees. Due to vegetation and other constraints the width of the lay-down area was limited to 50 feet.*

Lay-down area for Segment 2 was extremely tight and consisted of a 15 foot wide strip of land between the shoulder of Loop 360 and the adjacent Cliff. Concurrent assembly of the Steel Pipe and HDPE pipe was not feasible in this tight area. Hence, the decision was made during construction to pull the steel pipe, followed with the assembly and pull of the HDPE conduits.

Understanding Subsurface Conditions: Preliminary Segment 1 geotechnical data indicated a shallow limestone formation (the Glenrose formation). However, after the initial borings were obtained, the data suggested the top of limestone dropped more than anticipated as the alignment approached the shore of Lake Austin. While the HDD method can negotiate varying amounts of soil and rock interfaces, the drill equipment operates optimally when traveling through a consistent, rather than a mixed, subsurface material. Negotiating undulating or varying soil and rock will wear out HDD drill equipment prematurely. To manage this risk, a second round of borings located close to the alignment was obtained. These boring were located so that they would not provide a pathway for drill mud to break out during construction. The second round of data verified a more variable subsurface condition along the alignment that would consist of fill close to the surface, with an undulating layer of alluvial soils above a limestone formation. Fill at the golf course consisted of poorly compacted silt, clayey silt, clayey sandy silt and clayey silty sand with small to large limestone gravel, cobbles and boulders. Alluvium varied over short distances both vertically and horizontally. The soil/rock interface was found to be highly irregular with the potential to contain gravel, boulders and cobbles. The rock layer consisted of moderately dolomitized fine-grained limestone with a combined quartz-plagioclase content of less than 5 percent. With this data, our team was able to optimize the force main profile to operate within the hydraulic parameters of a lift station that was already in the final stages of design, while providing the HDD contractor information to properly prepare their bid.

A **Geotechnical Baseline Report can be an effective risk management tool for HDD:** The City elected to prepare a geotechnical baseline report to provide bidders a set of baseline conditions that would serve as a common basis for bid development. The GBR was intended to facilitate more accurate bidding without inflating the risks that may not eventuate. The GBR conveyed those baseline values that determined the anticipated conditions to be encountered by the HDD contractor during the course of the installation. The values provided common ground between the City, the City's consultant, and the City's contractor to evaluate conditions encountered and to balance the risks. The GBR provided a list of baseline values of rock and soil. The baseline conditions provided to the contractor were set on the density and compressive strength of the soil and rock. The anticipated construction impacts based on the baseline conditions set were presented in the GBR. From this, the City and contractor were to anticipate soil and rock that are susceptible to frac-out of drilling fluid and that drilling navigation would be negatively affected due to changing soil and rock characteristics.

By basing their bids on uniform information, the contractors were able to manage contingency bid amounts and the City was able to control its exposure to potential claims should subsurface conditions achieve the baseline conditions presented. For example, during construction of Segment 1, the undulating strata of the rock and soil was creating problems as the drill stem was slipping at the top of the rock and was hindered from entering the rock bed during the initial phase of pilot hole. Frac-out of drill mud occurred within 50 to 150 feet of entry location because the existing ground surface sloped at the approximate angle of the drill path resulting in a thin soil layer insufficient to hold down the mud pressures. This problem was addressed by a steeper entry angle drill angle along with a casing pipe. The steeper angle facilitated the entry of the drill bit into the rock, while the casing pipe maintained the recirculation of the drilling fluid at the entry point and eliminated frac-outs. The contractor did not claim a changed condition in part because this potential was identified in the GBR. The contractor was able to implement their contingency plans and mitigate for the frac-out conditions reasonably.

Entry/Exit Elevation Changes: The lake crossing had a 150-foot elevation change creating technically challenging entry and exit points. Our team evaluated all the pull-back stresses on the steel casing and the HDPE pipe taking into consideration the elevation, distances and the geological strata. Design of pipe pullback took into account the bridge height and the entry angle of the pipe, as all pipe had to be pulled below the bridge without damaging the beams.

Bundled Electrical Conduit Require Specialized Grouting: The capabilities of HDD are being challenged and pushed with every new project – challenges that recently would have been considered beyond the technical envelope are now routinely achieved. A combination of factors pushed this project to the edge of HDD's technical limits: the project's length, large diameter, but most importantly, the need for multiple conduits to accommodate the dual-purpose electric service and wastewater conveyance contained inside of a single casing pipe. To address the dispersion of heat generated from the electrical lines, the annular space within the steel casing had to be filled using a grout with a very low thermal resistivity of less than 90^{o} C-cm/W. The grout also had to be designed to travel long distances within limited intestinal spaces. To meet this design restriction, a grout mix with a time of Efflux of 25 seconds or less was designed. Further the grout had to maintain the time of efflux for a duration of more than 4 hours to facilitate pumping. To meet these requirements, extensive testing and investigation was completed during the design phase to develop a grout mix that could meet the thermal and viscosity characteristics, to facilitate grouting from both ends of the HDD casing.

Our discussions with leading grout contractors found no applications where grouting was successfully completed over these distances unless the thermal resistivity limits were relaxed well over that required for our project. We helped the City resolve this challenge by hiring Geotherm (a specialized grout company) to develop a grout that satisfied each of these unique requirements. Our team prepared and experimented with several trial mixes consisting of locally available materials to determine a mix that met the project requirements. The key element of the mix that made this application a success was to use silica flour instead of sand along with other more traditional components of cement, fly ash and polymers to meet all requirements. This project proved that mixes reliant upon traditional sand in lieu of silica flour could not achieve the high pumpability requirements. Further, we realized that mixes with even very small quantities of bentonite (less than one percent), a technique commonly used to improve pumpability, causes significant water to be entrained, and would raise thermal resistivity well beyond our acceptable limit. Also, mixes with fly ash met all the requirements, but set relatively fast and could not maintain the efflux over the longer time durations. In the final design the fly ash was substituted by cement and plasticizers.

The final grout solution has a tremendous benefit to the engineering profession. Prior to developing the new grout design, projects of this complexity were either restricted to less than 1,000 feet or the electric service was de-rated which has costly long-term impacts because of the reduced load-carrying capacity of the electrical line. The combination of this grout mix and HDD expands the technical envelope, vastly increasing the number of HDD applications that can now be considered viable to maximize the efficiency of transmitting electric power. It also opens opportunities for more cost sharing between individual utilities, while reducing overall costs by allowing smaller casings to be used, and providing a tremendous risk reduction impact on ever longer HDD projects. By developing an improved grout mix to facilitate these twin 2,000-foot crossings in Austin, our data and research indicates the grout's flowable characteristics will enable project delivery in the range of 4,000 feet.

Specialized Casing Spacers Assist Bundling and Grouting: Our staff coordinated with a leading casing spacer manufacturer for the casing spacers that would be needed.

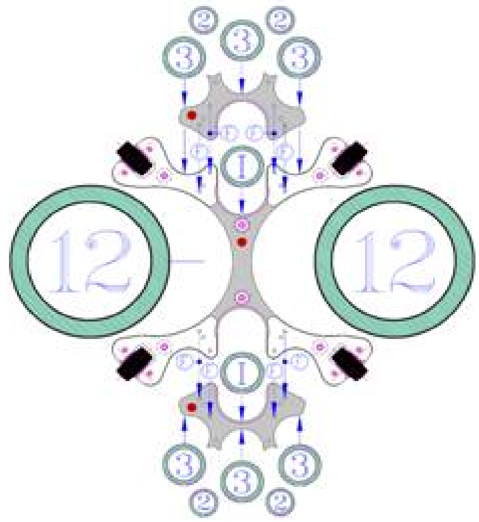

Figure 4 - During construction, the contractor was able to modify the casing spacer design further to better assist with field assembly, to resist frictional forces during pullback, and to prevent damage to the HDPE lines from a cork-screw effects during the pull-back through the steel casing. Also, modifications were necessary to add two additional grout lines.

A full size mock-up of the casing spacer system and carrier pipes provides useful opportunity to adjust grouting procedures before full-scale grouting begins: The contract documents required the contractor to assemble a mock set-up of HDPE bundles, along with casing spaces and grout tubes. This allowed field testing and evaluation of grout designs, procedures, and lab testing before the full-scale grouting operation begins. The mock up (shown in the figure) provided an opportunity to monitor grouting procedures and to identify improvements that otherwise could not be planned in the midst of the full-scale grout operation when every minute is critical toward the success of the grout operation. Upon request the grout mix developed during design was provided to the contractor to develop the field grout mix. A complete mock field test for a 50 foot pipe segment to evaluate feasibility of the casing spacers and grout operation, prior to installation was completed. This test also determined the approximate amount of grout that would be needed for the line segments. Minor changes to the design of spacers were completed to add additional grout tubes and provide back-up tubes if any of the smaller pipes clogged. Also, HDPE pipes were filled with water to avoid any risk of deformation as a result of heat of hydration during setting of grout. After successful mock-up tests the HDPE force mains, electrical conduits and grout tubes were welded and laid out for both the segments.

Figure 5 - Based on the mock up results, grouting operations were done in phases. The first two phases consisted of sealing the center sections of each line segment to create a plug. This was followed by grouting at either ends to completely fill the voids. Batch tests of the grout was collected at each phase to determine the Thermal Resistivity of the mixes and verified that

grout batches met the specified requirements. Pressure and mandrel testing of pipes were completed after the grout was cured and verified the internal diameter of all conduits met the deflection limits specified.

Allowing for Changing HDPE Pipe Characteristics During Assembly: HDPE pipe exposed to direct sunlight had very high expansion. These pipes were contracting during the night hours and created loose bundles. Any minor pipe movement during the HDPE pullback operation had to be avoided. It was critical that pipe bundles and casings do not cork-screw and get stuck inside the 30-inch steel pipe.

Figure 6 *- Bundling our pipes was done in the early morning hours and pipe was pulled inside the casing as the bundles were assembled. A special rack was fabricated to facilitate this operation. Additional tightness was obtained by utilizing a canvas strap to bundle the pipes prior to tightening the steel straps.*

Figure 7 *- A special rack was fabricated to facilitate the pullback operation while maintaining correct separation between the multiple HDPE conduits.*

Flexibility Allows for Contractor Input to Affect Means and Methods: After evaluating the project and the layout space Mears started the set up of the entry pits and the exit areas. A drilling plan was submitted for approval which identified the required labor and equipment.

Figure 8 *- A DD500 (CMS Rig) and DD140 (American Auger Rig) were used for the operations. 2 MCS-750 mud mixing/cleaning systems along with a combination of mud pumps were used for the drilling operations. A ParaTrack2 MGS Guidance System was utilized along with other equipment consisting of back hoes and trucks. The drilling fluid primarily consisted of fresh water and bentonite, with polymers to optimize performance.*

Due to seasonal closing restrictions imposed by golf course, the Segment 1 installation was drilled first. The sequence of construction operations was as follows:

- Set up drill equipment and mud pit within the designated golf course area. Drilling, reaming and pullback of 30-inch steel pipe along Segment 1. Welding and testing operations along the layout space were done concurrently along with the drilling.
- Move drill ring to the boat ramp area and drill north to the exit point for Segment 2. Drilling, reaming and pullback of 30-inch steel pipe along Segment 2. Welding and testing operations along the layout space were done concurrently along with the drilling.
- Assemble and test HDPE bundles for Segment 1 and Segment 2. Complete mock grout test.
- Pull HDPE bundles for Segment 2, followed by Segment 1. Pressure test HDPE bundles and electrical conduits.
- Complete grouting for Segment 2 and Segment 1. A detail grouting and testing sequence was developed to plug the bottom portions of the segments and avoid any major issues during the grouting process.
- Final tie-in, including connections to MH, installation of electrical MH, Air Release MH's and testing was completed.

Construction Scheduling and Sequencing are Vital Management Tools: A detailed schedule was developed with the design and included in the contract documents as there were time restrictions for construction within the golf course. Also, location of the drilling equipment and layout space was pre-determined. The contractor had the option to install the casing along with the HDPE pipe and pull the bundle at one time, or pull the steel casing and then pull the HDPE conduits inside the casing.

The design of the force mains was completed and the project was advertised in July 2005. Bids were opened in September 2005 and the low bidder was Mears HDD, LLC for about \$5.2M. Construction of the project started in January 2006 and was substantially completed in one year. All of the City's project management scheduling was maintained – even in light of the multiple bids this project incorporated to maintain adherence to the City's budget and time schedule.