Directional Drilling the World’s Third Largest Airport

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ABSTRACT

In 2006, Chesapeake Energy and the Dallas-Fort Worth International Airport teamed together to produce natural gas from the Barnett Shale. What resulted was an $80 million fast tracked gas gathering and produced water pipeline project. The project includes 80 miles of gas and waterlines around the perimeter of the airport. One of the more intriguing aspects of the project was the design and construction of 15 miles of pipe installed by Horizontal Directional Drilling (HDD).

The 15 miles of HDD pipelines presented many unique and challenging design and installation methods such as:

- boring between two buildings less than 7 feet apart,
- a 2,600 linear foot HDD on a 1,600 foot radius while paralleling multiple utilities less than 25 feet apart,
- challenges of boring across a major state highway and a developed area without impacting either constraint,
- design and construction of 5 major state highway bores,
- a 2,400 linear foot bore underneath a major airport office building parking lot, and crossing under a taxiway bridge

The purpose of this paper is to present the many different fast tracked HDD design and installation case studies, their constraints and challenges, lessons learned, and the practical design principles used on this project that can be applied to other HDD projects.

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INTRODUCTION

The Chesapeake Energy DFW Gas Gathering Pipeline Project was initiated in the fall of 2006, when Freese and Nichols, Inc. received the request from Chesapeake Energy Corporation to begin a fast track design of over 80 miles of gas gathering and freshwater pipelines at the DFW International Airport. The DFW gas drilling project as a whole includes 52 drill pad sites, 344 gas wells, 40 miles of steel gas pipeline, 40 miles of HDPE saltwater pipelines, 5 miles of freshwater pipelines, nine 12 million gallon frac ponds, and a 5,300 horsepower compressor station. Only the pipeline facilities were designed by Freese and Nichols, while other facilities were designed by either Chesapeake or Nichol and Associates (subcontractor for gas pipelines). Of the 80 total miles of gas gathering and freshwater pipelines, 15 miles was bored by the horizontal directional drill (HDD) method. These 15 miles of HDD pipelines presented many unique and challenging bores that included limited work space constraints, alignment constraints, construction height constraints, depth requirements, and design constraints due to the vast amount of infrastructure that the world’s 3rd largest airport (DFW) presented. The majority of the pipeline used in the DFW gathering system is 24” O.D. steel with a wall thickness of 0.375” and 10” SDR11 HDPE pipe. Many times this project pushed the upper limits on HDD design and construction which allowed for lessons learned and practical design theory that can be applied to any HDD project.

The project went out for bids and ultimately Driver Pipeline based in Dallas was selected. Driver pipeline has constructed HDD’s for about 20 years and their knowledge on this matter was quite helpful throughout the course of the project. This paper will present the more challenging case study bores, constraints and challenges associated with these bores, lessons learned, and describe the many design requirements when engineering an HDD project.

BACKGROUND

The DFW Airport has a vested interest with the Chesapeake Energy Corp. on this project because the DFW Airport receives a percentage of the royalties from the gas that is produced by Chesapeake because DFW owns the rights to the minerals on the airport property. With this being said, Chesapeake’s role with DFW was still the same as any other utility company in that everything that needed to be constructed for this project had to go through eight DFW code departments (planning, environmental, fire, operations, FAA, etc.) during the review process before approval and construction could take place. In many cases, pipeline routes were dictated by the DFW code review process, and since the drill pad locations could not always accommodate pipeline installation, there may have been better alternatives to the routes that were constructed, however future development plans and other factors at the airport effected what areas were available for pipeline installation. This led to pipeline alignments that presented many constraints and concerns which presented the more challenging and unique HDD designs and installations.

Scheduling of this pipeline project and HDD’s were dictated by the drill schedule. A drill pad may have 2 to 10 wells but each well is drilled one at a time.
When drilling of a pad site begins, pipeline construction should be ready if not already underway. This is because natural gas drilling does not wait for pipeline construction to be completed or started to begin drilling. In addition, gas drilling does not stop due to any type of weather activity and at the DFW airport wells have been drilled in world record times. These factors ensure a fast track project where schedules and short construction times are critical. Well drilling for this project was conducted completely independent of pipeline construction, and it was expected that pipeline be run to the pad when the first well was ready to flow gas. The area of greatest concern in a gas gathering project is a WOPL (Waiting on Pipeline). This occurs when a well is ready to produce and flow gas but there is no pipeline run to the pad to deliver it to a sales location. WOPL’s result in millions of dollars lost. At the DFW airport, not one well was ever drilled and completed that did not have pipeline available to flow gas.

So how was the design and construction able to meet these fast tracked drill schedules? The DFW airport pipelines functioned much like a design build project. In the beginning a contractor was selected based upon a unit price bid and their qualifications. Once the contractor was selected, a portion of the pipeline construction drawings were handed over to the contractor to begin. Due to the time it took for the DFW code departments to review the construction drawings for approval, and the ever-changing and short lead time on the drill schedule, it was not feasible for the pipeline team to complete design of the entire 80 miles of pipelines. There was preliminary route planning that had to be done, and some pad site locations were not finalized. In addition, the routes had to have some degree of preliminary planning with DFW so that the review process would go faster. This means construction, final design, and preliminary design of these pipeline routes and bores occurred simultaneously. This help cut time and speed up the project.

GENERAL HDD DISCUSSION

There are several methods used to cross various anomalies when open cut trenching pipe is either impractical or unfeasible. These methods include but are not limited to Horizontal Directional Drilling (HDD), Micro-tunneling, and auger boring. HDD is typically used when dealing with relatively small diameter pipes (<48”) and relatively long spans to cross. There are several different types of HDD rigs, but the basic components are the same. Figure 1 shows a typical directional drilling rig.
HDD’s usually start and end at ground level; the drill enters the ground with a specific entry angle, the drill then turns with a radius bend, and ultimately the drill exits the ground. Performing a HDD requires a drilling rig and a mud pumping system. This first step in performing any HDD is drilling of the pilot hole. A pilot hole is drilled using steel drill pipe (typically 3 to 6 inches in diameter), and the location of the drill head is monitored along all three axes. After the drill head exits a bore, a reamer is attached and pulled back through the pilot hole. Reamers of increasing size are pulled through the hole to incrementally expand it to the desired size. The number of passes with reamers is dependent on soil type and desired hole size. Drilling fluid is pumped into the hole to reduce friction and to prevent the hole from caving in. After the hole is set to the desired diameter, the pipeline to be installed is strung out and welded on the exit side of the drill. The pipe is connected to the drill head and pulled back through the hole. Once the pulling process is started, work will not stop until the process is completed. Contractors generally prefer to pull pipe in one string to reduce start and stops due to welding of multiple strings. Casing pipe was used on the HDPE lines when crossing under existing or future roadways, however, the steel gas line did not use casing due to corrosion concerns. An impressed current cathodic protection system was installed on the steel gas line.

The direction and depth of the drill was monitored and controlled by two methods at the airport. A method known as wireline guidance utilizes two small wires running above ground and a third connected to a probe in a stainless steel collar just behind drill bit. This method was used almost everywhere on the airport. The second method used at DFW is called walk-over guidance, this was used when it was infeasible to use above ground guide wires (only once at DFW airport). The walk-over guidance method is new and utilizes similar technology used in aviation. The drill starts at a known point and a gyroscope on the bit is used to measure direction and speed. Both methods are able to provide location information on the bit in all three planes within +/- 2 feet of accuracy. Both of these methods provide digital data on the drill location in the x, y, and z planes. Figure 2 illustrates pipe being pulled through a drilled casing pipe.

Figure 2 – Pipe Pulling Operations
DESIGN PARAMETERS

When designing a HDD it is essential to look at design parameters to ensure the layout is feasible. This section will describe some basic design parameters as well as specific parameters that were used for this project.

- **Work Spaces** – A HDD requires a work space for the drilling rig and mud pumping system on the entry side of the bore and a pipe stringing area on the exit side of the bore. The work space size used on the entry side for this project was 200’ x 300’ for pipes 24” or greater in diameter and 100’ x 150’ for pipes 20” or less in diameter. Pipe stringing area is determined by the length of the drill and the number of pipe strings required. For our project a drill with a single string of pipe was designated with a 40’ pipe stringing width. For example, a 1200’ bore performed in one string would require a 1200’ x 40’ pipe stringing area, if it were done in two strings a 600’ x 60’ pipe stringing area would suffice.

- **Minimum/Maximum Drill Length** – A common rule of thumb for minimum HDD length is twelve feet for every foot of depth at the deepest point of the drill. For Example a symmetrical drill with a center depth of 20 feet would require 240 feet to the entry and 240 feet to the exit, resulting in a total length of 480 feet. Maximum drill length can differ not only from pipe size but also from site to site and contractor to contractor. Ultimately the maximum length of the bore is controlled by the pulling power of the drill rig being used. This is affected by soil type and contact surface area (pipe size). At DFW airport we were limited to a maximum drill length of 3,500 feet for a 24-inch diameter pipe. Ultimately the maximum drill length is dependent on the pull radius and entry/exit angle.

- **Pipe Bending Radius** – When installing pipelines by HDD it is imperative to prevent pipe bending radii from being too small. This could undermine the structural integrity of the pipe and bend it out of round. The rule of thumb for Steel and Ductile Iron Pipe is 100 times the outside diameter of the pipe in inches while plastic pipe can be bent up to 40 times the outside diameter. For example, a 24” steel pipe would have a minimum bending radius of 2400’.

- **Drill Entry/Exit Angles** – Entry and exit angles for HDD’s are highly dependent on specific contractor capabilities. Entry angles can range from anywhere from 8-15 degrees and exit angles range from 8-10 degrees.

- **Minimum Depth of Cover** – Minimum cover depths should be required when crossing utilities, creeks, and pavement. HDD mud pumping systems produce relatively high pressures typically between 200-250 psi. This causes mud to travel up naturally occurring fissures in soil formations and can cause frac outs. A frac out occurs when drilling mud reaches the surface within the crossing area. Frac outs are relatively common and cannot be forecasted, additional depth can help but certainly does not guarantee a frac out will not occur. When a frac out does occur a dirt berm should be built around the frac out area so drilling mud can be collected and removed. The DFW project required the following depths at various crossings:

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1. Two Lane Roads = 10’
2. Major Highway = 24’
3. Creek = 15’
4. Concrete Drainage Structures = 25’
5. Taxiways = 25’
6. Wetlands = 15’
7. Utilities = 5’
8. Parking Lots = 10’

- Pipe Spacing – Minimum horizontal spacing between pipelines in HDD’s generally is between 15-20 feet. This spacing is required to protect the integrity of the adjacent drill holes.

- Pipe Coatings – The most common steel pipe coating used to protect against the pulling pressures is fusion-bonded epoxy (FBE). Joints are typically protected with a special shrink sleeve or are field coated with epoxy. At DFW an FBE coating was used on all the steel pipelines at the airport excluding bores. At bore locations an ARO coating was used to protect the pipe from surrounding soils when pulling.

- Pipe Tensile Strength – The pipe tensile strength is extremely important in HDD. This is because the pipe is pulled back through the hole and yield strength of the pipe can be a controlling factor. Typically the design number used is 90% of the yield strength. At DFW the majority of the pipe had a 60 ksi yield strength allowing for 54,000 lbs of pull force. Typically this is left up to the contractor because in general they are responsible for the HDD’s they perform.

- Drilling Fluids – Drilling fluid is used as a lubricant and the positive pressure holds the drilling hole open to prevent cave-ins. The amount and type of drilling fluid is dependent on field conditions and equipment being used, and should be determined by the contractor not the engineer. Typically drilling mud is mostly bentonite, which is not harmful to the environment and is stored on site during the drilling process.

- Pros of Directional Drilling –
  1. Good when going deep (eliminates the need for deep bore pits)
  2. Good for long bores
  3. Good for tight areas (can be controlled accurately and precisely)
  4. Does not require large bore pits for boring equipment
  5. Relatively quick construction times
  6. Relatively small disturbance to the ground surface
  7. Becoming a common method

- Cons of Directional Drilling –
  1. Relatively expensive method
  2. Longer than any other method (requires a lot of work space area)
  3. Frac outs can damage property
CASE STUDIES

There were over 120 HDD’s on this pipeline project of which 30 were greater than 1,000 linear feet in length. In order to capture the more intriguing side of these 120 HDD’s, this paper will only discuss a few unique HDD’s. The drills mentioned presented specific challenges. These six drills had to deal with the following issues:

1. Horizontal and Vertical bends simultaneously
2. Close proximity to multiple utilities and tight spaces between roadways.
3. High accuracy requirements to pass between buildings less than 10’ apart.
4. Extreme Length
5. Difficult soil conditions (rock layers, etc.)
6. Passing under concrete drainage channels
7. Passing near concrete bridge piers
8. Coordination effort with rapidly developing areas

Design and Construction of 6 Major HDD crossings

- HDD beneath West Airfield Drive from Pad BZ to BV
  This bore required drilling and pulling a 16-inch steel casing pipe for an HDPE produced water line and a 10-inch steel gas line. Due to specific constraints in this area, such as aircraft operating areas, utilities, and easement width requirements, this bore had to be constructed with a horizontal bend. A radius of 1600’ was used to fall within acceptable limits of the steel casing pipe (D*100). The figure below shows a plan view of the drill.

![Figure 3 – HDD BZ to BV](image_url)
- **HDD beneath Salvage Yard area along East Airfield Drive**
  This bore required drilling and pulling a 16-inch steel casing pipe for an HDPE produced water line and a 24-inch steel gas line. This particular location required two drills that were required to pass between two buildings approximately 10 feet apart. There were a total of 3 unmanned buildings at this location. The produced water line and casing passed between the easternmost and center building while the gas line passed between the westernmost and center building. This was a difficult drill for the contractor due to the tight tolerances required. The figure below illustrates this HDD.

![Figure 4 – HDD Salvage Yard](image)

- **HDD beneath Flight Safety and Taxiway**
  This bore required drilling and pulling a 16-inch steel casing pipe for an HDPE produced water line and a 24-inch steel gas line. This bore began on the north side of the taxiway and ended south of the flight safety building, covering approximately 2,400 feet. This drill was unique because it was necessary to avoid piers 50-60 feet under the taxiway bridge. At the closest point the drill passed approximately 10’ away from the bridge piers. The figure below illustrates this HDD.

![Figure 5 – HDD Flight Safety](image)
- **HDD beneath Verizon Lease**
  This bore required drilling and pulling of a 10-inch HDPE produced water line and a 16-inch steel gas line. The most challenging aspect of this bore was total length which was approximately 3,100 feet. The length and diameter of this drill under the soil conditions present push the limits of the contractor’s capability. The figure below illustrates this HDD.

![Figure 6 – HDD Verizon Lease](image)

- **HDD beneath drainage channel**
  This bore required drilling and pulling of a 10-inch HDPE produced water line and a 16-inch steel gas line. This bore began at the pad and traveled north across the concrete drainage channel. The maximum entry angle is approximately 12 degrees; therefore a specific set back is required to obtain the required depth at the crossing location. This drill was unique because it was difficult to maintain sufficient cover due to the limited space on the exit side of the bore and the slope of the drainage channel. The figure below illustrates this HDD.

![Figure 7 – HDD Drainage Channel](image)
• HDD beneath Highway 114 and Trammel Crow Development

This bore required drilling and pulling a 16-inch steel casing pipe for an HDPE produced water line and a 24-inch steel gas line. This bore was challenging because of coordination issues. The area under construction was installing multiple utilities which caused conflicts with the construction of the HDD. The figure below illustrates this HDD.

![Figure 8 – HDD Highway 114 and Trammel Crow](image)

LESSONS LEARNED

During any project there are lessons that can be learned to apply to future projects. The DFW gathering system was no different; multiple techniques and equipment changes were utilized as experience was gained throughout directional drilling operations.

DFW Airport is known for having poor soil conditions. Part of the reason is because of fill material, the fill at the airport causes soils at the airport to vary greatly even in small areas ranging from rocky conditions to sandy conditions. At DFW early in the project sedimentary rock formations in some locations caused problems. The formations at the airport were layered at an angle rather than perpendicular to the ground line. If the bit didn’t come in at a sharp enough angle the bit would either dig in and bounce off the formation or skim across the bottom or top of the formation. This was a huge problem early in the project and multiple drills had to be started over due to this. Another potential problem is sandy conditions because the hole can collapse on itself when reaming, and finally clay soil conditions can thicken drilling mud and cause problems as well. All of these soil conditions are manageable in directional drilling if they can be located accurately and are consistent, but having a variety of these soils within one drill can cause problems because preparations are more difficult. Geotechnical investigation is the single most valuable asset to ensure a drill will be completed successfully. By investigating soil types and their elevations, HDD operators can avoid potentially poor soil conditions. At the airport cores were rarely drilled, instead in most cases, TxDOT (Texas Department of Transportation) geotechnical data was reviewed to acquire a better idea of what soils would be encountered. Geotechnical information affects not only possible drill direction but also drilling mud viscosity. For example, when drilling through rock a thicker mud viscosity would be used to ensure cuttings are carried out of the hole. At
the beginning of the project, money was wasted on chemicals such as polymers and clay inhibitors, however, as the project went on, less of these chemicals were used and drills were completed faster because the contractor learned how to better deal with the challenging soil conditions. Another part of the drilling process that changed was the type of reamer used. The contractor at the airport designed a reamer specifically for this project and to deal with over-lapping soil and rock formations.

There were very few frac outs during this project; however, one under a concrete drainage channel caused some problems. Even before construction began, the concrete drainage channel was cracked and almost continually carried water. This caused underlying soil to become saturated. Because of limited space the maximum depth that could be obtained under the channel was 35 feet. Typically this would be enough to prevent a frac out from occurring but this drill had steep slopes on either side of the channel bottom causing a pressure spike directly under the channel. The pressure spike buckled the channel bottom and lifted it up approximately four feet. Under ideal conditions a shallower slope would have been taken to relieve and dissipate some of the mud pressure. Another lesson learned from this was to better document conditions before beginning construction. Pictures should have been taken and the concerns about channel failure due to its condition and soil conditions in the area should have been discussed with airport officials before starting construction.

Some of the drills performed near the end of the project pressed the limits and capabilities of the contractor. These drills were performed with 24-inch pipe, they stretched over 3,000 feet, and they were in highly visible locations. To prevent frac outs in these locations operators began monitoring mud back flow. When backflow decreases pressure and volume of mud in the hole increases, this ultimately leads to frac outs. If back flow was stopped, the drill pipe was pulled back out to relieve the pressure and then reinserted. Driver Pipeline did a great job adapting to the challenging conditions at DFW airport and keeping up with the fast paced schedule. By the end of the DFW Gathering System Project many lessons were learned that could be applied to future projects and ultimately make drilling operations run more efficiently.

REFERENCES

ASCE HDD design guideline task committee (2005), “Pipeline Design for Installation by Horizontal Directional Drilling,” American Society of Civil Engineers, Reston, Virginia

