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Can You See It Coming? Examining and Mitigating the Common Causes of HDD Failures

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1. ABSTRACT

At 3:00 p.m. on a Friday afternoon, during the product pipe pullback of a horizontal directional drill, a hydro-fracture occurred within inches of a federal highway. This caused the contractor's personnel to cancel their weekend plans, scramble to bring in maintenance-of-traffic devices, notify the state highway manager and deal with a myriad of other inconveniences and potential financial losses. Utility staff attempted to understand *what* had gone wrong, which revealed a hard truth. We didn't really know what had gone wrong. This left us feeling very lucky the hydro-fracture hadn't actually washed out the highway, but also very exposed to the possibility of a repeat occurrence.

Over the last eight years, horizontal directional drill (HDD) has become increasingly popular on County Utility projects. That time has been marked by an increase in the number, length and complexity of horizontal directional drills. Those projects have experienced many successes; however, there have also been many failures, such as lost drill tools, hydro-fracture, failed drill stems, and other abnormal events. Looking back at a wide variety of HDD projects, we found many of the failures were preceded by signs of impending problems. This made us wonder: Would it be possible to identify those signs in advance of an impending failure and, if so, intervene and mitigate the losses?

This paper will identify commonalities and root causes of many directional drill failures, and will share strategies for preparing, recognizing and addressing those issues so that losses and failures can be reduced.

2. INTRODUCTION

Like many aspects of engineering, good design and construction are based on experienced personnel who have expertise that was developed over time. In many cases, that expertise did not come easily and was shaped by a series of successes and failures. For the purposes of this paper, failure is defined as any part of the HDD that did not meet its intended objective during HDD design or construction, whether on a grand scale or a minor incident. While failure is not a pleasant event, it does offer learning opportunities which can reduce the chances of the same failure happening again.

The following section provides a brief overview of three Sarasota County, Florida projects and their associated failures which provided learning opportunities. The subsequent section expands the discussion beyond the three County projects and includes strategies for preparing, recognizing and addressing those issues. The intent is to focus on failure types and prevention strategies and not the specific projects, which is why the project descriptions were kept relatively generic.

3. HDD FAILURES

Example Project No.1

This project involved replacing a 10-inch water main by constructing a single 2,700-linear-foot subaqueous HDD. The project site was within environmentally sensitive habitat with limited construction access. The majority of the HDD alignment was subaqueous and the horizontal alignment was generally straight.

The primary failure originated from the contractor's decision to drill at a depth that exceeded the deepest geotechnical boring. The original design was for the HDD to have a maximum depth of 40 feet using 1,000-ft. and 1,200-ft. vertical curves. The contractor proposed to increase the entry angle of the drill from 16.5 degrees to 17 degrees and increase the drill rig setback distance to avoid a sea wall identified in the plans. This resulted in a deeper bore, down to 80 feet deep. The maximum geotechnical boring depth was 50 feet, so the contractor did not have geotechnical information for a significant length of the HDD. Although the HDD was successfully completed, the lack of geotechnical information was considered a failure and was cause for considerable concern by all parties involved and represented a significant risk to the successful completion of the project.

A second failure occurred during reaming the pilot hole. A rod was brought on site without first being inspected as required in the specifications. The rod was clogged with cemented bentonite when it was threaded into the drill string. There were five days of downtime to find and remove the failed rod once the clog was discovered. The risk of losing the drill head and GPS steering tool was high due to the prolonged lack of mud flow and setting bentonite. Drilling proceeded following the delay without the loss of drilling tools, but the avoidable oversight caused financial loss and frustration to all parties and put the project at risk of a much bigger failure.

Figure 1. Clogged rod that caused a failure.

Example Project No. 2

This project consisted of 20-inch and 24-inch wastewater force main. The alignment included sections of open cut and HDD. Approximately 6,000 feet were installed by HDD using 24-inch DR-11 high-density polyethylene (HDPE). The longest HDD was 1,500 feet under a canal and roadway.

There were two primary failure types for this project. The first was regarding the drill rig stabilizing outriggers. The existing utilities consisted of asbestos clay pipe (ACP) and clay pipe, which are brittle and problematic if disturbed. Because of the fragile existing utilities, the contractor did not utilize the stabilizing outriggers in most cases, out of concern of damaging these pipes. Therefore, a wrecker truck was used to stabilize the drill rig.

The second failure originated from the lack of geotechnical information to support the contractor's decision to increase the depth of several HDD segments. The HDD design depth was 30 feet deep which matched the depth of the geotechnical borings. The contractor experienced problems stabilizing the bore hole and preventing settlement of the road surface at the design depth. In order to prevent problems on the remaining segments, the contractor requested to use FDOT standards which requires the HDD depth to be at least ten times the bore hole diameter under FDOT right-of-way. Based on the success of the first HDD installed at the deeper FDOT depths, the Contractor requested to deepen the remaining HDDs. The contractor believed the risk of drilling into unknown soils was warranted since denser soils and better bore hole stabilization were encountered at the increased depth. It was unclear if the drilling fluid mix contributed to the bore hole stabilization problems at the shallower depths. Like example project No. 1, the lack of geotechnical information was considered a failure and was cause for considerable concern by all parties.

Example Project No. 3

This project consisted of the installation of 11,500 linear feet of 24-inch water transmission main to provide auxiliary water supply to the County to meet growing demands. Approximately 3,500 linear feet of the project passed through environmentally sensitive lands under a small waterway and a major crossing under an interstate highway. To traverse these obstacles, HDD with HDPE pipe was utilized. To provide an equivalent inside diameter, the line was upsized to a 30-inch SDR-11 pipe.

There were two failure mechanisms on this project. The first occurred during the interstate crossing. The soil under the interstate had a mixed soil interface that included the presence of rock at the design elevation. During construction, the HDD subcontractor had a difficult time with the pilot hole. Several attempts to establish a drill path were made, but the drill head continued to bounce off the rock interface. After numerous unsuccessful passes, the general contractor retained a subsequent driller to evaluate and complete the drill. This contractor changed drill tools; also, elected to steepen the angle of attack and take the drill to a deeper depth to get into a more competent, consistent material. The drill was completed but the forensic drilling operation cost the project over 90 days of delay and cost the original driller and general contractor significantly.

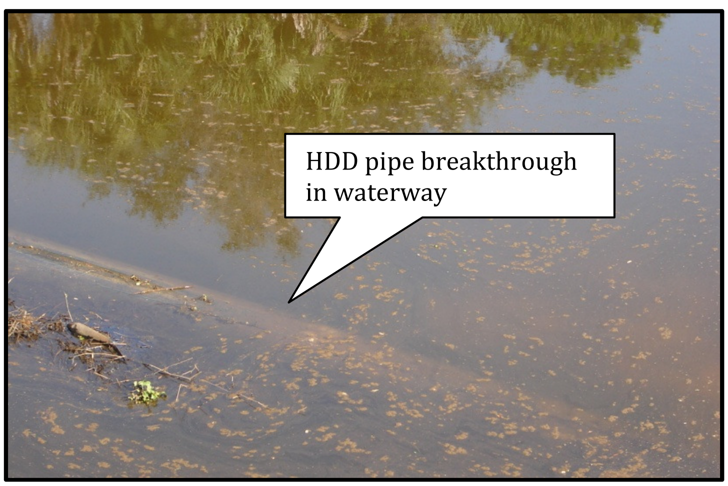

Figure 2. HDD pipe breakthrough in waterway

The second failure occurred because the waterway crossing was too short, making the radius of curvature aggressive. Also, the overburden was shallow and soft. The drill was initially completed, but shortly after installation the pipe was found floating in the waterway after it had broken through the soft soils, as shown in Figure 2. This line was subsequently re-permitted and installed as an open cut with precast ballast and bottom protection at a substantial cost. In addition to these capital losses, the project was delayed for an extended period.

4. POTENTIAL FAILURE CAUSES

In order to identify potential failures before they happen, commonly occurring failure causes must be known. This can be accomplished by evaluating past projects and analyzing what went wrong, as evidenced by the examples that have been included in this paper. While not an exhaustive list by any measure, Table 1 expands the list of HDD failures by introducing several more common failure root causes.

Table 1. Potential HDD Failures

Failure Source	**Cause(s)**
Geotechnical Exploration	Soil borings not deep enough
	Soil borings not frequent enough
	Soil borings located on top of proposed pipe alignment
	Insufficient soil information obtained
Design	Utility/structure conflicts (SUE locates)
	Inadequate staging area
	Staging too close to obstacle
	3D alignment proposed
	Drill calculations not completed
	Drill angle of attack too shallow
	Drill radius too small
	Drill depth at mixed face soil conditions
	Insufficient overburden/cover
	Soft soils
	Improper pipe specified
	Flooded vs. unflooded installation
	Lack of constructability review
Construction	Equipment in disrepair
	Wrong drill rig for the job
	Wrong drill head for soil conditions
	Drill change by contractor
	Improper drilling fluid used
	Hydro-fracture
	Problematic soils causing the contractor to seek better soils

5. FAILURE MITIGATION OPTIONS

Based on the previous discussion, failure causes can be categorized as geotechnical exploration, design or construction based. The following discussion summarizes several considerations that can help mitigate future HDD failures.

Geotechnical Exploration

Based on project examples used in this paper, the most prevalent cause for the failures in Sarasota County projects was related to geotechnical exploration. The following design considerations related to geotechnical exploration may help the County mitigate these types of failures on future projects.

Boring Location

A common error when conducting geotechnical borings to support HDD design is to locate the borings directly on top of the proposed horizontal alignment. Although the borings are required to be grouted, improperly grouted boreholes can create a potential pathway for drilling mud to escape the HDD bore hole. Therefore, it is recommended to offset geotechnical borings approximately 25 feet from the proposed centerline of the drilling alignment, alternating from one side to the other along the drill route. The offset should be increased if there is the potential for a significant change to the horizontal alignment during design.

Boring Depth

Boring at depths exceeding the available geotechnical investigations was a frequent occurrence on Sarasota County HDD projects discussed in this paper. The common failure was not anticipating there may be reasons to increase the HDD depth. Maximum separation from existing improvements and encountering or expecting soils where steering may be difficult are two such reasons bores have been constructed deeper than planned. If a contractor believes soil conditions may make steering difficult, they will want to use larger bend radii to make hitting the steering marks easier. Poorly consolidated soils, where it is challenging to gain traction with the drill tool or where hard interfaces exist are two conditions which can warrant flatter bend radii, and so deeper bores. To the extent possible conservative approaches for conflict avoidance and steering should be considered during design. Conducting drilling calculations using industry-accepted software also reduces this potential. Consider geotechnical information when finalizing design of the bore profile. Obtain additional geotechnical information if necessary. Lastly, consider including language in the specifications that requires contractors to conduct their own geotechnical borings if they propose drilling deeper than what is shown on the plans.

Design Considerations

Boring Information

Once geotechnical information is obtained, it must be evaluated and incorporated into the HDD design. The lack of consideration of the geotechnical information during design appears to have been the root cause of the two failures discussed for Project No. 3. A strategy going forward is to pay extra attention during design when there are varying soil conditions such as soft soil underlain by rock, since this may impact the design entry and exit angle, as well as the drill head used to complete the drill. Another strategy learned from Project No. 3 is to check for pipe breakthrough when 1) the HDD is relatively shallow, 2) the vertical curve is aggressive and 3) the ground water table is high. Other items to consider when evaluating the geotechnical information are the density of the soils, the soil classification and the identification of any rock fractures. If HDD design software is being used, the geotechnical information should be entered into the program to further check the suitability of the soil to support the HDD design.

Drill Geometry

Drill geometry is an important consideration during design. The common failure associated with geometry is a design that is too aggressive for a contractor to install. An aggressive geometry is a design horizontal or vertical alignment that will be difficult for the contractor to install. An overly aggressive geometry increases the potential of the contractor to miss the target exit point and increases the risk of an unsuccessful drill to the owner.

Radius of Curvature

A HDD should be designed with the intent to minimize the difficulty of successfully completing the drill. One aspect related to difficulty is the relationship of horizontal curves to the vertical curves. The overlap of a horizontal curve location with a vertical curve location is called a three-dimensional (3D) curve. 3D curves require the contractor to simultaneously steer in both the horizontal and vertical planes, which substantially increases the difficulty to accurately steer the HDD. A good design strategy is to eliminate or minimize the location of 3D curves if at all possible. If it can't be avoided, it is recommended that the horizontal and vertical curve radius be increased so the curves are more conservative, which gives the contractor room to compensate for any over-steering.

Drill Radius

An appropriate drill radius can mitigate several types of HDD failures. The Second Edition Handbook of PE Pipe, published by the Plastics Pipe Institute (PPI), provides guidance in determining the drill radius based on the pipe material, pipe diameter and drill rod. In most cases, the rod minimum bend radius will govern, but both the pipe and rod minimum bend radius should be checked. In many cases, the minimum radius will be much less than the radius that should be considered during design. A strategy to mitigate failures caused by inappropriate drill radiuses is to establish the minimum radius, then increase the radius as high as the alignment will allow. Radiuses of 1,000 feet are not uncommon for 10-inch HDPE, and 2,000 feet for pipe 24 inches and up. If the radius is suspected to be aggressive, advice from an experienced contractor may provide valuable insight.

Hydro-Fracture

A hydro-fracture is an accidental release of drilling fluids to the ground surface or a water body, and can result in downtime, expense, equipment loss and loss of public confidence. To prevent this, the design activities should include a thorough evaluation of the proposed drill alignment utilizing an industry-accepted drilling software that evaluates soil conditions, overburden and mud pressures. This information can help guide the design process to minimize the potential for hydro-fracture on a project.

However, soil evaluations only look at single points along the drill path, and the potential for hydro-fracture always exists on a project. As such, a hydro-fracture contingency plan should be required on all projects. Based on the County's experience, when evidence of a hydro-fracture occurred, projects with a hydro-fracture contingency plan experienced decreased downtime and associated costs when compared to those without a plan developed in advance. The contingency plan was also found to facilitate acquisition of permits from the Florida Department of Environmental Protection (FDEP), since the plan provided assurances that the County could react quickly to a hydro-fracture and mitigate any potential negative impact to the environment. Contingency plans for hydro-fracture, as well as other plan types such as a bore plan and drilling fluid plan, can significantly minimize the losses associated with these failure types.

Construction Considerations

In addition to the design considerations previously discussed, there are many considerations during construction that can help mitigate HDD failures. The following discussion summarizes two construction considerations that the County has recently experienced.

Rollers vs. Ground

There are two primary failure types of concern when rollers are considered: damage to the pipe by yielding due to excessive force applied by the drill rig or pipe wall surface damage caused by the ground that decreases pipe wall thickness, as shown in Figure 3. If the pull force dictates the need for rollers and rollers are not feasible, then using a thicker wall pipe may be required. These types of issues should be identified early during construction and be coordinated with the contractor so the appropriate pipe is provided.

The decision to use rollers to protect the pipe from damage as it slides over the ground surface depends on the type of ground surface and the ability of the contractor to successfully keep the pipe on the rollers. Given its thick wall and robustness, the use of HDPE pipe is particularly useful in situations when the pipe will be subjected to surface damage. Steps must be taken to protect both the pipe and surface improvements.

Figure 3. HDPE Surface Damage.

Inspection

A common observation by the County on its HDD projects is the need to provide detailed inspection services during HDD installation. Failures related to hydro-fracture, excessive pull back forces and mud management have shown the County the importance of having knowledgeable oversight in the field. When properly trained, an inspector will be able to spot the signs of a potential hydro-fracture such as loss of mud pressure, read the gauges on the drill rig to monitor pull back forces, monitor the rate of reaming and pull back, and spot failures in the drilling fluid plan such as using an excessive amount of mud relative to industry standards. The County is pursuing providing HDD training to its inspectors and strengthening the language in its standard specification to reduce failures that can be mitigated by good inspection techniques.

6. CONCLUSIONS

As HDD installations become increasingly popular and complex on County Utility projects, the need to prepare, recognize and address the issues that can lead to failure will become increasingly important. By reviewing past HDD projects and learning from their success and failures, the County has obtained valuable insight regarding good HDD design and construction practices. The primary question of this paper was "is it possible to identify signs of an impending failure and, if so, intervene and mitigate the losses". Based on the preceding review of past failures on County HDD projects and the identification of potential failure causes, there are several mitigation options that if implemented during design and construction can successfully be used to identify and mitigate failure on future HDD projects.

7. REFERENCES

1. The Plastics Pipe Institute, Inc. – Handbook of PE Pipe, Second Edition
2. HDD Consortium (2004) - Horizontal Directional Drilling Good Practices Guidelines