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GUIDELINES FOR PREVENTING UNDERGROUND UTILITY DAMAGE AS A RESULT OF HORIZONTAL DIRECTIONAL DRILLING

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Abstract

Horizontal directional drilling (HDD) has become the preferred method for installing pipelines and other utilities beneath obstacles that can't be efficiently crossed using an open trench. Initially used primarily in remote locations to place oil and gas pipelines beneath major waterways, HDD has evolved to the point that it is now used to install a wide variety of underground utilities in locations that include residential developments and congested urban areas. The widespread acceptance of HDD can be partially attributed to advances in technology that have significantly improved the accuracy of the HDD installation method. However, considering that greater accuracy makes it possible to utilize HDD in closer proximity to potential obstructions, the possibility that existing underground utilities could be damaged as a result of HDD operations remains a serious concern.

Over the years, HDD industry standards have increasingly focused on reducing the potential for damage to existing utilities. While these efforts have yielded obvious benefits in the area of damage prevention, current practices with regard to locating existing utilities in advance of HDD operations could be improved. The objective of this paper is to present guidelines that will reduce the potential for damage to existing utilities during HDD operations. Development of new tools and techniques to complement these guidelines and further improve damage prevention practices is also addressed.

1. INTRODUCTION

Horizontal directional drilling (HDD) has become the preferred method for installing pipelines and other utilities beneath obstacles that can't be efficiently crossed using an open trench. Initially used primarily in remote locations to place oil and gas pipelines beneath major waterways, HDD has evolved to the point that it is now used to install a wide variety of underground utilities in locations that include residential developments and congested urban areas. The widespread acceptance of HDD can be partially attributed to advances in technology that have significantly improved the accuracy of the HDD installation method. However, considering that greater accuracy makes it possible to utilize HDD in closer proximity to potential obstructions, the possibility that existing underground utilities could be damaged as a result of HDD operations remains a serious concern.

Over the years, HDD industry standards have increasingly focused on reducing the potential for damage to existing utilities. While these efforts have yielded obvious benefits in the area of damage prevention, current practices with regard to locating existing utilities in advance of HDD operations could be improved. The objective of this paper is to present guidelines that will reduce the potential for damage to existing utilities during HDD operations. Development of new tools and techniques to complement these guidelines and further improve damage prevention practices is also addressed.

2. CAUSES OF UNDERGROUND UTILITY DAMAGE

In order to effectively reduce the potential for utility damage resulting from HDD operations, it's important to understand exactly why damage occurs. In many cases, the cause of the damage may seem to be obvious, but further analysis often reveals underlying issues that are largely to blame. In order to prevent similar damage scenarios in the future, these underlying issues must be determined and addressed. For example, it's well known that damage can occur if an underground utility is struck by an HDD contractor's bit or reaming tool. However, considering that a reputable HDD contractor would never intentionally drill into an existing utility, there must be a more obscure reason that the utility strike occurred. When the root cause of the damage is addressed, the potential for damage is reduced significantly. In general, damage to existing utilities as a result of HDD operations can be attributed to one of the following three fundamental issues.

1. An existing utility was encountered in a location where it wasn't expected, either because it wasn't positively located or it wasn't known to exist.

2. The contractor's downhole tools, drill string, or pull section weren't where they were believed to be.

3. The subsurface material surrounding an existing utility was affected by HDD operations, in turn causing damage to the utility.

In the following sections, these fundamental issues are further examined.

2.1 Failure to Positively Locate a Known Utility

Utility damage resulting from HDD operations is commonly caused by an underground utility being encountered in a location where it wasn't expected. If an underground utility is known to exist but its anticipated location is inaccurate, it's reasonable to assume that it wasn't positively located. Positively locating an existing utility involves exposing the utility at critical locations so it can be visually confirmed and its position can be accurately determined. This is especially important with regard to an HDD installation as obstructions along the drilled path are seldom evident during construction. The only way to make sure that the drilled path will maintain an acceptable separation distance from existing utilities is to know exactly where the utilities are located. As long as this can be achieved and the utility locations are accurately indicated on the HDD design drawing, the potential for damaging an existing utility during HDD operations will be reduced significantly.

Unfortunately, it's not always possible to positively locate every existing utility that may be susceptible to damage. A prime example is provided by an HDD installation in close proximity to an existing utility that was also installed by HDD. HDD crossings are often placed at depths that exceed the capabilities of surface-based locating techniques or beneath obstacles that can impede or prevent location from the surface. In such cases, unusually conservative design criteria may be warranted in order to reduce the risk of damage. Recommended practices are addressed in Section 3.5.

2.2 Utility Not Known to Exist

Encountering an underground utility that isn't known to exist is a serious concern with regard to the use of HDD as there is currently no reliable means to determine the location of an existing utility while drilling. A skilled downhole surveyor may be alerted to the presence of an unknown utility by an unexplained increase in magnetic interference during pilot hole drilling. However, existing technology doesn't allow the location of magnetic anomalies to be determined with confidence. Additionally, detection is only possible if the existing utility either transmits an electric current or is composed of ferrous material. Nonmetallic utilities that don't involve current flow typically can't be detected at all. This is a serious problem that merits further research. Development of tools or techniques that can reliably detect existing underground utilities while HDD operations are in progress is addressed in Section 4.

With regard to this issue, it's important to understand the distinction between utilities that simply haven't been located and utilities that are truly unanticipated. For example, most inhabitable buildings are served by a variety of underground utilities installed at locatable depths. However, some of these utilities may not be identified in response to a one-call. While it would be beneficial if the one-call process would ensure identification of all existing utilities in a specific area, the fact that certain utilities are not identified doesn't necessarily mean that they're not known to exist.

An example of damage that results from failure to locate utilities that often could have been anticipated is provided by what is referred to in the trenchless industry as a *cross-bore*. A cross-bore is an intersection of two underground utilities that typically occurs when the newer utility is installed using a trenchless installation method such as HDD. Cross-bores that involve natural gas lines placed through sanitary sewers are of particular concern as they often go unnoticed, presenting an ongoing risk that the gas line could be severed by a sewer cleaning tool causing an explosion.[1] The severity of the cross-bore problem is demonstrated by reports from hundreds of miles of inspection projects which found between two and three cross-bores per mile of sewer main and laterals inspected.[2]

2.3 Pilot Hole Inaccuracy

Pilot hole inaccuracy can result from several sources including the accuracy limitations of the locating system being used, magnetic interference, accumulated calculation error, and human error. These potential sources of inaccuracy and their impact on the accuracy of the resulting pilot hole data are addressed in the following sections.

2.3.1 Locating System Inaccuracy

As with any measurement instrument, all of the systems used to determine the location of an HDD pilot hole contain some degree of inherent inaccuracy. The accuracy limitations of HDD locating systems are typically stated in the manufacturer's specifications and, in most cases, are based on ideal conditions (i.e. a properly calibrated system with no outside sources of interference). As a result, the manufacturer's stated accuracy should be considered to be the best accuracy achievable, even if better accuracy has been realized on occasion. Comparison of the position error that could result from common HDD locating systems is complicated by the fact that the accuracy of surface-based systems is primarily a function of depth while the accuracy of downhole systems is primarily a function of drilled length. The following tables provide an indication of the maximum position error that could be expected for common HDD locating systems based solely on the approximate stated accuracy for each type of system. However, in reviewing this information, it should be noted that it is general in nature. Some manufacturers may claim better accuracy than what is presented in the following tables. If the accuracy of a specific system is needed, the manufacturer's literature should be consulted. It's also important to note that when a surface monitoring system is used in conjunction with a magnetic steering tool, surface monitoring data can typically be used to correct and/or verify the data obtained by the steering tool.[3]

Table 1. Maximum Position Error of Surface-Based HDD Locating Systems

System	Approximate Stated Accuracy[4],[5],[6]	Maximum Position Error at 20-foot (6.1 m) Depth		Maximum Position Error at 50-foot (15.2 m) Depth	
		Elevation	Offset (right)	Elevation	Offset (right)
Walkover Locator	± 5% of depth	±1.0 foot (±0.30 m)	±1.0 foot (±0.30 m)	± 2.5 feet (±0.76 m)	± 2.5 feet (±0.76 m)
Surface Monitoring System	± 2% of depth	± 0.4 feet (±0.12 m)	± 0.4 feet (±0.12 m)	± 1.0 foot (±0.30 m)	± 1.0 foot (±0.30 m)

Table 2. Maximum Position Error of Downhole HDD Locating Systems*

System	Approximate Stated Accuracy[7],[8]	Maximum Position Error at 500-foot (152.4 m) Length		Maximum Position Error at 2,000-foot (609.6 m) Length	
		Elevation	Offset (right)	Elevation	Offset (right)
Magnetic Steering Tool	± 0.1° in inclination ± 0.3° in azimuth	±0.9 feet (±0.27 m)	± 2.6 feet (±0.79 m)	± 3.5 feet (±1.07 m)	± 10.5 feet (±3.20 m)
Gyroscopic Steering Tool	± 0.02° in inclination ± 0.04° in azimuth	± 0.2 feet (±0.06 m)	± 0.4 feet (±0.12 m)	± 0.7 feet (±0.21 m)	± 1.4 feet (±0.43 m)

* Determined based on geometric analysis over a typical HDD angular range

2.3.2 Magnetic Interference

Locating systems that obtain information using magnetic fields are subject to inaccuracy as a result of magnetic interference. In essence, magnetic interference is any distortion of the magnetic field being interpreted by the HDD locating system as a result of a magnetic anomaly in the vicinity of the drilled path. Common sources of interference include adjacent pipelines, metallic structures, power lines (both above and below ground), buried cables, cathodic protection systems, and magnetic minerals in the ground.

Walkover locators, magnetic steering tools, and surface monitoring systems can all be affected by magnetic interference to some degree, although each of these system are affected differently. The effects of magnetic interference on a walkover system include erratic signal strength, depth and position inaccuracy, and a loss of data.[9] Interference can have a significant impact on the accuracy of the azimuth readings obtained by a magnetic steering tool, in turn affecting the accuracy of the calculated *offset*, or *right*, coordinate. Surface monitoring systems are employed specifically to eliminate the effects of magnetic interference and, in most cases, they successfully achieve this goal. However, in a magnetically corrupt environment, the accuracy of the data obtained by a surface monitoring system can also be affected.[10]

2.3.3 Accumulated Calculation Error

Pilot hole locating methods that require calculating the position of the steering tool based on angular readings are subject to inaccuracy as a result of accumulated calculation error. This error affects both magnetic and gyroscopic steering tools and it results from two primary sources: the *dead reckoning* nature of downhole locating methods and *driller's bias*.

Dead reckoning originated as a nautical term used to describe a method of navigation in which the position of a ship could be calculated based on its known course and travel distance. Using this method, errors in measurement tend to be compounded as the accuracy of each new position is dependent upon the accuracy of the previous position. Navigation of an HDD pilot hole using a downhole steering tool is based on the same principles and involves a similar compounding of errors.

Driller's bias refers to the fact that the accuracy of pilot hole calculations can be influenced by the way the pilot hole is drilled. Pilot hole calculation methods typically take into account only the angular values measured at the end of each joint. Assumptions with regard to how the angular change was distributed over the length of the joint are then applied in order to project the pilot hole's position. However, if the point at which the driller achieves the desired angular change for each joint differs from the assumptions that are applied by the calculation method being used, the actual location of the pilot hole will differ slightly from the calculated location. As the length of the pilot hole increases, inaccuracy resulting from driller's bias can become significant.

2.3.4 Human Error

While the previously described sources of error have the potential to result in significant inaccuracy with regard to the location of the pilot hole, human error can be equally detrimental. However, human error is completely preventable whereas other types of error may not be. Utility owners, design engineers, and HDD contractors all have the potential to make errors that could ultimately result in an existing utility being damaged. As a result, quality assurance is essential during all phases of an HDD project.

Utility owners and design engineers must be conscious of the fact that the accuracy of the pilot hole is directly dependent on the accuracy of the entry and exit point locations that are staked in the field.[11] If either of these points are unknowingly staked incorrectly, the drilled path won't actually be where it's believed to be. The elevation of the entry point is especially critical as it affects every subsequent elevation in the pilot hole survey. It's also important to obtain accurate survey information during the design phase as the topographic survey forms the basis for the design. A bust in the survey has the potential to reduce the separation distance between the drilled path and existing utilities.

The HDD contractor has a potential to introduce human error prior to commencing pilot hole operations if the crossing is not set up in accordance with the design drawing. An inaccurately surveyed surface monitoring wire and failure to ensure that the locating equipment has been calibrated in accordance with the manufacturer's recommendations can also be sources of preventable error. Once the pilot hole begins, erroneous measurements and basic data entry errors have the potential to result in pilot hole inaccuracy.

2.4 Reamer Migration

Current technology in the HDD industry allows for drilling a pilot hole along a designed path within certain tolerances, therefore the coordinates associated with an HDD design typically govern the location of the pilot hole as opposed to the utility that will ultimately be installed. This has been a source of confusion in the underground utility industry as utility owners often don't understand that the HDD contractor has little control over the location of the utility being installed once the pilot hole is completed. Experience has shown that reaming operations tend to make the borehole progressively deeper with each pass due to the weight of the reaming tools that are used to enlarge the hole. How much deeper the hole will become depends on the properties of the subsurface material along the drilled path and the number of reaming passes that are conducted. Smaller diameter holes and holes placed through competent rock may remain reasonably centered about the pilot hole whereas large diameter holes placed through soft soils may end up being substantially deeper. As increasingly larger diameter reaming tools are used and the weight of those tools forces them deeper, the cross-section of the reamed hole will tend to become somewhat egg shaped.[12] As a result, if an HDD crossing is to be installed directly above an existing underground utility, the potential for downward migration of reaming tools must be considered.

The potential of the reamed hole to migrate upwards, commonly referred to as *reamer migration*, is a debated topic in the HDD industry. In the nearly 40 years that HDD installations have been performed, there have been very few documented instances of reaming tools migrating a significant distance above the confines of the theoretical reamed hole that is centered about the pilot hole. Nonetheless, practices that may increase the potential for a reamer to *walk* should be avoided as a precaution. These include reaming without the use of a tail string[13], push reaming (i.e. advancing a reamer away from the rig using only the rig's thrust), and failure to use appropriate centralizers when reaming rock holes.

2.5 Pull Section Migration

Migration of the pull section out of the reamed hole either during or after pullback is extremely uncommon due to the fact that HDD crossings are typically placed through undisturbed soils at depths that provide sufficient overburden support to restrain the installed pipe. However, pull section migration has been known to occur in certain circumstances; specifically, when buoyant pipe is placed through extremely soft soils with very little depth of cover. If the overburden is soft and its shear strength is low enough, it's possible for a buoyant pull section to simply float to the surface, potentially damaging overlying underground utilities in the process. However, this typically isn't a concern for an HDD installation that is designed in accordance with standard HDD industry practice. Recommendations with regard to HDD design criteria can be found in Chapter 4 of *Installation of Pipelines by Horizontal Directional Drilling, an Engineering Design Guide*.[14]

2.6 Indirect Damage

The potential for indirect damage to existing utilities as a result of HDD operations is commonly overlooked. However, it's important to be aware that an underground utility doesn't necessarily have to be contacted by a drill bit or reaming tool in order to be damaged. Indirect damage to existing utilities is similar to the damage that HDD operations can inflict on roads, even though an appreciable depth of cover is maintained. It is an accepted fact that HDD has the potential to cause heaving and settlement of the ground surface, occasionally resulting in buckling of pavement, gradual surface subsidence, or rapid sink hole development. Therefore, it stands to reason that utilities beneath the ground surface could be damaged in a similar fashion.

While it's possible that an existing utility could be damaged due to uplift of the surrounding soils, indirect damage is more likely to be caused by settlement. The most probable damage scenario involves unintentional removal of the soil beneath an existing utility causing a portion of that utility to be unsupported. When this occurs, utilities that have little spanning capacity are prone to failure. Utilities with unrestrained joints, such as sanitary sewers and storm sewers, are particularly susceptible to damage as the joints can separate if the supporting soil is removed. As a result, placement of an HDD crossing beneath these types of utilities may warrant increased depth of cover.

Unintentional removal of the soil that supports an existing utility can occur for several reasons. When a crossing is placed through loose, cohesionless soils such as sand and gravel, the soil overlying the reamed hole may simply fall in, eventually creating a void that extends to an overlying utility. Crossings that involve a significant elevation differential are susceptible to the formation of sink holes due to the fact that drilling fluid can't be maintained in the portion of the hole that lies above the lower HDD endpoint. Placement of a crossing through soft overburden soils and into bedrock frequently results in settlement occurring within the overburden portion of the hole due to the extended duration that's required to ream the rock portion. In this case, the probability that settlement will occur increases with both crossing length and diameter. Finally, removal of the soils that support an existing utility can be caused by an unanticipated subsurface condition. As an example, penetration of an artesian aquifer can cause groundwater and saturated fine soils to flow into the reamed hole. A steady inflow of silt or sand from around the drilled path can eventually result in the formation of a subsurface void.

Indirect damage to existing utilities can best be prevented by maintaining an adequate separation distance between existing utilities and the drilled path. Unfortunately, it can be difficult to know how much separation is adequate to prevent damage. As a result, judgment is often required. Recommendations with regard to separation from existing utilities are presented in Section 3.5.

3. GUIDELINES FOR PREVENTING UTILITY DAMAGE DUE TO HDD OPERATIONS

In order to minimize the possibility that an existing underground utility will be damaged as a result of HDD construction operations, there are four basic requirements that must be satisfied.

1. The utility must be known to exist.
2. The location of the existing utility must be determined.
3. The HDD crossing must be designed to provide adequate separation from the existing utility.
4. The HDD crossing must be constructed in accordance with the design.

If any of these requirements aren't satisfied, there will be an elevated risk that the existing utility could be damaged.

Both the owner of the utility being installed and the contractor who performs the HDD installation have an interest in making sure that these four requirements are satisfied. Traditionally, the utility owner takes responsibility for design of the crossing since it's difficult to solicit bids from multiple contractors on an equal basis without providing a design. Also, the owner is most familiar with the applicable design constraints and often must submit design information to permitting agencies prior to selecting a contractor. However, owners of existing utilities don't usually take responsibility for positively locating existing utilities in the vicinity of a proposed HDD installation. When shown on the owner's drawings, underground utility locations are often based only on available records and visible surface features such as manholes and valves. Confirmation of utility locations is usually left to the contractor and is generally performed just prior to construction. This can result in conflicts that necessitate last minute modifications to the crossing design, often requiring compromise with regard to separation from existing utilities. This, in turn, increases the potential that existing utilities could be damaged.

An alternative approach is for existing utility locations to be confirmed by the owner during the design phase so the design can be based on accurate information. In essence, this is the approach that's described in the American Society of Civil Engineers' *Standard Guideline for the Collection and Depiction of Existing Subsurface Utility Data*.[15] Briefly, this ASCE Standard presents a system for classifying the quality of the underground utility information that is shown on design drawings. Although this standard does allow some flexibility with regard to the quality of the utility information that is provided by the owner, it clearly advocates owner responsibility for obtaining reliable information during the design phase. This approach is generally unpopular with utility owners due the perception that it will add both cost and time to the design process[16]; however, it does offer certain benefits with regard to damage prevention. The primary benefit is that conflicts with existing utilities could be avoided during the construction phase, eliminating the need for last-minute design modifications that may reduce the separation distance between existing utilities and the drilled path.

Regardless of the approach that is taken, it's imperative that existing underground utilities in the vicinity of a proposed HDD installation are located prior to starting construction. Locating of existing utilities is addressed in the remainder of this section along with recommendations relative to documentation, design criteria, and construction quality assurance.

3.1 Existing Utility Research

If an underground utility isn't known to exist, it's impossible to make an effort to avoid it. As a result, research to determine all of the existing utilities that could potentially be affected by an HDD installation is a critical element with regard to damage prevention. This research effort should typically involve two primary components: a review of available records and an investigation of the site.

Records of existing utilities are often available from a variety of sources including utility owners, state and local government agencies, one-call notification centers, and property owners. The information that may be provided by these sources includes as-built or design drawings from previous projects, underground utility mapping maintained by public or private entities, alignment sheets, plats, tax maps, and field notes. Easement information obtained during the right-of-way acquisition phase of a project can also serve as a starting point for determining the existence of underground utilities. In many cases, these sources will identify most of the underground utilities that may be encountered by an HDD installation.

This review of available records should typically be followed by an investigation of the site to search for surface indications of existing underground utilities. This provides preliminary confirmation of the information obtained from available records and may also reveal the presence of utilities that were not previously identified. The most common surface indications of underground utilities include marker posts, vent pipes, manholes, catch basins, fire hydrants, valve boxes, transformers, hand holes, clean outs, and meters. Less obvious indications include surface depressions or paving repairs along underground utility ditch lines and utility poles that may tie in to underground services.

In reviewing the information obtained from available records and site investigation, it's important to determine not only the presence and approximate location of existing utilities, but also their diameters, materials, jointing methods, and the services that they provide wherever possible. The information that is obtained from existing utility research often makes it possible to select a preliminary alignment that will largely avoid nearby existing utilities. However, because of the possibility of inaccurate information, reliance solely upon available records should not be considered sufficient for construction.[17] The locations of any existing utilities that are at risk of damage from HDD operations should ultimately be confirmed.

3.2 Locating Existing Utilities

The importance of locating underground utilities that could potentially be impacted by HDD operations cannot be overstated. In the underground utility industry, the term *locating* can be taken to mean one of two things. The first is determination of an existing utility's approximate location through the use of surface-based locating methods and marking the approximate horizontal position of the utility on the ground surface.[18] Some surface-based locating methods can also provide the utility's approximate depth. In their *Standard Guideline for the Collection and Depiction of Existing Subsurface Utility Data*, the ASCE refers to this definition as *designating* rather than locating. The second definition that can be attributed to the term locating is exposing and recording the precise horizontal and vertical location of an existing utility.[19] This is often referred to as *positively locating*. In order to prevent damage as a result of HDD operations, both types of locating are typically required.

3.2.1 One-Call Notification

Prior to conducting any form of excavation, it's generally necessary to contact the local *one-call notification center*. This is typically the first step in the underground utility location process. In the United States, one-call notification can be accomplished by dialing 811, which routes the call to the appropriate local call center. The call center then contacts those companies who have underground utilities in the area and the utility owners dispatch locating crews to mark the approximate locations of their underground utilities on the ground.

The one-call process provides a relatively simple way to identify and locate the underground utilities in a specific area.[20] However, it does have several limitations. First, not every underground utility is a member of the one-call network, thus the need for research as described in Section 3.1. Second, utility locations that are marked on the ground are not necessarily exact. Typically, a buffer zone must be maintained to either side of the locate marks to account for possible inaccuracy. Third, depths of existing utilities typically aren't provided in response to a one-call. Finally, one-call notification may not be available during the design phase in some areas. Due to these limitations, one-call notification should serve only as a starting point for more thorough locating efforts.

3.2.2 Surface-Based Underground Utility Locating Methods

Before an underground utility can be positively located, someone has to determine where to dig for it. In some cases, the information that's obtained during the one-call process is sufficient for excavating purposes. However, considering the potential inaccuracy of one-call marks along with the fact that one-call locates don't typically provide any depth information, it can be beneficial to confirm the locations of underground utilities prior to excavation. This can be accomplished using any number of available surface-based underground utility locating methods. Some of these methods can also be used to scan large areas for unknown utilities.

While there are many surface-based locating methods, the most common methods involve the use of pipe and cable locators, metal detectors, and ground penetrating radar. Pipe and cable locators can be used to determine the approximate horizontal and vertical locations of both metallic and non-metallic utilities that either have current flowing through them or have been installed with a tracer wire. Non-metallic utilities without a tracer wire can often be detected if a transmitter or metallic conductor can be placed inside the utility. Metal detectors are necessary for finding shallow manhole lids, valve box covers, etc. Ground penetrating radar (GPR) can be used to detect and locate both metallic and non-metallic utilities, although its effectiveness is highly dependent upon soil conditions as well as the depth and diameter of the utilities being located. In general, GPR doesn't work well in clay soils and is best suited to locating medium to large diameter utilities within about 6 feet (1.8 m) of the surface.[21] Nonetheless, GPR can be a useful tool, especially with regard to detecting relatively shallow utilities that aren't known to exist.

Although other locating methods aren't nearly as common as the methods described above, there are a number of surface-based locating methods that can be used. Many of these methods are described in the appendices to the ASCE's *Standard Guideline for the Collection and Depiction of Existing Subsurface Utility Data*.[22]

3.2.3 Confirmation of Existing Utility Locations

After the existing underground utilities in the vicinity of a proposed HDD installation have been identified and their approximate locations have been determined, any utilities that are at risk of damage from HDD operations should be positively located. This requires a certain amount of judgment as there are a lot of considerations that go into determining which utilities may be at risk. As a general rule, every underground utility that will either be crossed by the drilled path or could possibly be within 10 feet (3 m) of the drilled path at any point should be positively located. In determining which utilities may fall within 10 feet (3 m), it's important to remember that the drilled path won't necessarily be the same as the design. Typically, the HDD contractor is given tolerances that define how far the actual drilled path can deviate from the designed path. Therefore, if the specified tolerances allow the drilled path to be up to 5 feet (1.5 m) right or left of the designed alignment, any utilities that are less than 15 feet (4.6 m) from the designed alignment could potentially be within 10 feet (3 m) of the drilled path. In some situations, it may be prudent to positively locate utilities that are anticipated to be more than 10 feet (3 m) from the drilled path, especially if the approximate location of an existing utility is not particularly reliable. Other examples include HDD installations that will require large diameter reaming passes and those with lengths or depths that could result in excessive pilot hole inaccuracy.

As previously addressed, positively locating an underground utility requires exposing the utility at critical locations so it can be visually confirmed and its position can be accurately determined. The preferred method for exposing an underground utility is non-destructive vacuum excavation[23], which produces a relatively small test hole that extends from the surface to the utility. Vacuum excavation uses either high pressure air or water to loosen the soil over an underground utility and is typically limited to a depth of around 20 feet (6 m).[24] As the soil is loosened, it is simultaneously removed from the excavation with a vacuum hose and stored in a holding tank for subsequent disposal or use as backfill. Hand digging is also a commonly accepted method for positively locating underground utilities. However, in addition to being both labor intensive and time consuming, hand digging involves a risk of utility damage and injury to excavating personnel. As a result, hand digging should be performed with caution.

In years past, probe rods were frequently used to determine the horizontal and vertical location of underground utilities. However, since probing doesn't allow for visual confirmation, the information that it provides cannot be considered to be a positive location. Nonetheless, if probing is allowed by the utility owner, it can serve as an efficient means to pinpoint a utility's location prior to exposing the utility by either vacuum excavation or hand digging. Mechanized excavation equipment such as a backhoe generally shouldn't be used to expose underground utilities for locating purposes as the risk of damage is simply too great.

3.3 Unlocatable Existing Utilities

Methods exist to locate underground utilities installed at traditional cut & cover depths, but utilities installed by HDD often can't be positively located as a result of either their depth or having been placed beneath an obstacle that prevents access from the surface. As a result, design engineers and HDD contractors are often forced to rely on as-built information provided by the owner of the utility, assuming that as-built data exists and can be found. Unfortunately, as-built documentation produced for HDD installations often doesn't accurately describe the location of the installed pipe or conduit.[25] Therefore, it's important to review as-built information with a critical eye and take steps to reduce the risk of damaging utilities that cannot be positively located.

3.3.1 Review of As-Built Data

In most cases, HDD as-built data is provided by the contractor who installs the crossing with no independent verification of its accuracy. Some HDD contractors make a concerted effort to deliver as-built information that is as accurate as possible. At the other end of the spectrum are contractors who deliver minimal documentation while making absolutely no effort to ensure that it's accurate. The rest tend to fall somewhere in between. Considering the variability that exists with regard to HDD as-built documentation, anyone planning an HDD installation in close proximity to a utility that was installed by HDD should be familiar with common sources of as-builting inaccuracy. Issues that can result in inaccuracy are addressed below.

- **The as-built reflects the location of the pilot hole rather than the installed utility.** This is true of most HDD as-builts and, in some cases, the location of the installed utility can differ substantially from that of the pilot hole. This is an important point to bear in mind if an existing HDD installation must be crossed.

- **The as-built information was generated from pilot hole survey data that was not corrected to account for accumulated error.** This is most obvious when the as-built indicates that the pilot hole exited a significant distance above or below the ground surface. Failure to correct accumulated error with respect to the drilled path's alignment usually isn't apparent unless the actual location of the exit point is known.

- **The locations and elevations of the actual entry and exit points were not confirmed.** It's commonly assumed that the pilot hole entered the ground at the entry stake and that the stake was in the correct location. However, it's not unusual for one or both of the HDD endpoints to be staked incorrectly.

- **The as-built data is not referenced to control that can be reestablished.** At a minimum, the endpoints of the reference line to which the as-built data is referenced must be preserved, otherwise the as-built coordinates are essentially nothing more than a collection of points in space. This is common on as-built drawings produced by HDD contractors.

- **Differences between directional (calculated) pilot hole survey data and surface monitoring data were not resolved.** This can lead to confusion with regard to which set of data is believed to more accurately represent the location of the pilot hole. On the other hand, being provided with both sets of data does provide a basis for evaluating accuracy.

- **Drawings noted as HDD as-builts are actually nothing more than the crossing design.** This is usually fairly obvious to anyone with experience in the HDD industry.

A thorough review of the pilot hole documentation may reveal some of these issues and, in some cases, will provide an indication of the as-built data's accuracy. If the HDD contractor's raw data is available, it may also be beneficial to reconstruct the pilot hole survey so that the resulting information can be compared against the as-built data that was provided.

3.3.2 Location of Accessible Portions

If there is uncertainty with regard to the location of a completed HDD installation's actual entry and exit points, surface-based utility locating methods and vacuum excavation can be used to positively locate the shallow portions of the installed utility near the HDD endpoints. This information can then be plotted in both plan and profile and compared against the HDD as-built drawing as a means of evaluating the accuracy of the as-built data. If the information obtained on both ends of the crossing matches up well with the as-built data that was provided when the crossing was installed, this may provide some degree of reassurance with regard to the intermediate portions of the HDD installation that cannot be positively located.

3.3.3 Centerline Mapping using In-Line Inspection Tools

In-line inspection tools that incorporate inertial navigation systems are capable of determining the location of existing underground utilities with a reasonable degree of accuracy, often without taking the utility out of operation. When an underground utility cannot be positively located, the information obtained by such a tool can significantly reduce uncertainty with regard to the utility's location. Inspection tools with mapping capabilities typically rely on information obtained from gyroscopes, accelerometers, and other motion sensing devices to generate continuous three-dimensional coordinates that describe the utility's centerline. Accuracy is primarily a function of the distance between points at which the utility's position has been surveyed and, depending on the system that is used, generally ranges from 0.025%[26] to 0.25%[27] of the distance between known points. For a 2,000-foot (609.6 m) HDD crossing that can be positively located at both ends, this equates to a maximum position error ranging from 0.5 feet (0.15 m) to 5 feet (1.5 m) at the middle of the segment.

3.4 Documentation of Existing Utilities

Once the locations of existing underground utilities in the vicinity of a proposed HDD installation have been determined, they should be accurately presented on a plan & profile drawing along with the HDD crossing design and other pertinent information. This makes it possible to see how the crossing design relates to both existing underground utilities and major obstacles such as waterways and roads. As a general rule, all existing utilities and prominent manmade or topographic features within 25 feet (7.6 m) of the proposed HDD alignment should be shown in the plan view of the design drawing. In some cases, it may be beneficial to show existing utilities and prominent features located a greater distance from the proposed centerline, but 25 feet (7.6 m) should serve as an absolute minimum. Positively located utilities should be tied in by survey while the source of utility locations determined by other means should be appropriately noted. The type of utility and its outside diameter should also be indicated wherever possible.

In the profile view, elevations should be provided for any existing utilities that will either be crossed by, or are within 10 feet (3 m) of, the proposed HDD alignment at any point. Accurate existing grade elevations along the proposed HDD alignment are also essential as the surveyed grade typically serves as the basis for the HDD design. Ideally, all survey data should be referenced to publicly maintained coordinate systems and datums so it can be accurately reestablished if necessary.

The importance of providing the HDD contractor with a plan & profile drawing that presents the crossing design, the results of site-specific topographic and geotechnical surveys, and the locations of existing underground utilities is often overlooked. While it's possible to produce a simple HDD design drawing prior to starting construction using commercially available software, it's important to understand that it's not the drawing itself that is of benefit with regard to damage prevention, but rather the information that must be obtained in order to produce that drawing.

3.5 Design Criteria

As important as it is to locate existing utilities that could potentially be impacted by an HDD installation, simply knowing where underground utilities are located does not prevent damage. Damage prevention ultimately requires maintaining an adequate separation distance between underground utilities and the drilled path. This can best be accomplished by incorporating design criteria that has been proven effective with regard to minimizing utility damage during HDD operations.

As a general rule, the designed drilled path should provide no less than 10 feet (3 m) of separation from all existing underground utilities. This distance corresponds with the common requirement in HDD technical specifications to expose underground utilities that are located within 10 feet (3 m) of the designed drilled path. While necessary at times for damage prevention purposes, extensive exposure of underground utilities is generally undesirable as one of the primary benefits of HDD is avoidance of excavation between the drilled segment endpoints. Excavation of an existing utility carries its own risk of damage and often requires that the utility is supported by some means. The use of vacuum excavation to pothole existing utilities at specified intervals is not much more appealing as an open pothole along the drilled alignment can easily become a flow path for drilling fluid.

While a separation distance of 10 feet (3 m) should serve as an absolute minimum, it may be necessary to increase this distance in certain situations. Bearing in mind that the designed drilled path represents the theoretical centerline of the pilot hole, larger diameter crossings may require a greater separation distance so that adequate clearance will be maintained once the hole is reamed. Crossings of utilities with little spanning capability, such as sanitary sewers and storm sewers with unrestrained joints, may also require additional separation in order to reduce the potential for indirect damage. Finally, increased separation may be necessary when the soils along the drilled path are potentially unstable, especially when the duration of reaming operations is expected to be excessive.

When an HDD crossing must be installed in close proximity to an underground utility that cannot be positively located, it's important to ascertain the level of uncertainty that exists with regard to the approximate location of the existing utility. This can often be accomplished by conducting a review of available information as described in Section 3.3. Once the level of uncertainty has been determined, the separation distance provided by the design should be increased to account for that uncertainty. In such situations, conservative design criteria is strongly recommended.

3.6 Construction Quality Assurance

Assuming that all existing utilities in the vicinity of the proposed drilled path have been positively located and that the crossing design provides adequate separation from those utilities, the final requirement with regard to preventing utility damage is to ensure that the crossing is constructed in accordance with the design. This can best be accomplished by using knowledgeable inspection personnel to monitor the HDD contractor's operations on behalf of the owner. An HDD inspector should have a basic understanding of the pilot hole locating system being used by the contractor along with the ability interpret its readings. Pilot hole information should be independently analyzed by the inspector and plotted on a joint-by-joint basis in order to confirm that both the position and curvature of the pilot hole are within the specified tolerances. As long as clearance from existing utilities was considered in establishing the allowable tolerances, this will also provide confirmation that the designer's intended separation distances were maintained. If a portion of the pilot hole is determined to be unacceptable, the problem should be addressed with the contractor while the pilot hole is being drilled so that remedial action can be taken promptly. Failure to address problems at the time they occur can ultimately result in an HDD installation being accepted despite the fact that it doesn't conform to the specified requirements.

4. DEVELOPMENT OF TOOLS AND TECHNIQUES TO DETECT UTILITIES WHILE DRILLING

The guidelines that are presented in this report have the potential to significantly reduce damage to underground utilities as a result of HDD operations. However, their effectiveness generally relies on knowing that an underground utility exists and having the ability to determine its location with reasonable certainty. While a thorough research effort should reveal the existence of most underground utilities, it is inevitable that unexpected utilities will occasionally be encountered during HDD operations. This poses a substantial risk of damage to existing utilities and a threat to the safety of those in the immediate vicinity of HDD construction operations. As a result, there is a need for tools or techniques that can reliably detect existing underground utilities while HDD operations are in progress. Development of such tools or techniques has been proposed as the next phase of this research effort.

Over the past decade, there have been efforts by both industry organizations and private companies to develop technologies that can detect underground obstacles while drilling. These efforts have resulted in both patents and the development of prototypes, some of which may soon be available as commercial products for use in the HDD industry. The technologies that have been evaluated include ground penetrating radar (GPR), differential soil impedance, acoustic-based detection, and electromagnetic detection. Research conducted to date has identified certain advantages and disadvantages with each of the technologies being evaluated.

Although it's probable that an obstacle detection system will ultimately be made available as a result of ongoing efforts by other organizations, additional efforts should be encouraged in the interest of innovation. The plan that has been proposed as part of this effort involves teaming with the developer of a commonly used downhole survey system to develop a tool that can reliably detect underground utilities during HDD operations. By involving someone who has specific expertise in the development of electronic tools for use in the HDD industry, it is envisioned that an effective solution can be developed.

REFERENCES

1 Bradley Kramer, "Cross-Bores Out in the Open", *Trenchless Technology*, vol. 16, no. 6, June 2007, page 27.

2 Mark Bruce, "Preventing and Eliminating Cross Bores – Increasing Safety and Reducing Risk, Cross Bore Safety Association.

3 Manual of Practice No. 108, *Pipeline Design for Installation by Horizontal Directional Drilling* (Reston, VA: American Society of Civil Engineers, 2005), page 49.

4 *ParaTrack2 Survey and Tracking System Specifications*, Vector Magnetics LLC, Accessed Feb. 24, 2011, http://www.vectormagnetics.com/Specifications_hdd.htm.

5 *TruTracker*, Sharewell LP, Accessed Feb. 24, 2011, http://www.sharewell.com/pdf/toolsandequipmentpdf_3.pdf.

6 *DigiTrak F5 Directional Drilling Locating System* (Kent, WA: Digital Control Incorporated, October 2010).

7 *Directional Crossing Survey Standards* (Dallas: Directional Crossing Contractors Association, 1998), page 5.

8 *Drillguide GST*, Brownline B.V., Accessed Feb. 24, 2011, http://www.drillguide.com/html_site/drillguidegst.asp.

9 Siggi Finnsson, "Interference & What Can Be Done About It", *Trenchless Technology*, vol. 15, no. 12, December 2007, page 56.

10 *Sharewell Learning Center*, "5.7.2.3 Dealing with TruTracker Interference", Sharewell LP, Accessed Feb. 24, 2011, http://www.sharewell.com/learningcenter/index.php?option=com_content&task=view&id=165&Itemid=44.

11 *Installation of Pipelines by Horizontal Directional Drilling, An Engineering Design Guide* (Arlington, VA: Pipeline Research Council International, Inc., 2008), page 57.

12 Manual of Practice No. 108, *Pipeline Design for Installation by Horizontal Directional Drilling*, page 49.

13 *Directional Crossing Survey Standards*, page 5.

14 *Installation of Pipelines by Horizontal Directional Drilling, An Engineering Design Guide*, pages 17-19.

15 CI/ASCE 38-02, *Standard Guideline for the Collection and Depiction of Existing Subsurface Utility Data* (Reston, VA: American Society of Civil Engineers, 2003).

16 *Damage Prevention Project, Final Report* (Kansas City, MO: Mid-America Regional Council, December 2003), page 23.

17 Manual of Practice No. 108, *Pipeline Design for Installation by Horizontal Directional Drilling*, page 6.

18 CI/ASCE 38-02, *Standard Guideline for the Collection and Depiction of Existing Subsurface Utility Data*, page 2.

19 CI/ASCE 38-02, *Standard Guideline for the Collection and Depiction of Existing Subsurface Utility Data*, page 2.

20 Manual of Practice No. 108, *Pipeline Design for Installation by Horizontal Directional Drilling*, page 6.

21 CI/ASCE 38-02, *Standard Guideline for the Collection and Depiction of Existing Subsurface Utility Data*, pages 15-16.

22 CI/ASCE 38-02, *Standard Guideline for the Collection and Depiction of Existing Subsurface Utility Data*, pages 14-18.

23 *Kansas City Metro Damage Prevention Report, Potholing Practice* (Kansas City, MO: Mid-America Regional Council, December 2003), page 33.

24 Manual of Practice No. 108, *Pipeline Design for Installation by Horizontal Directional Drilling*, page 7.

25 Barb Cooper, "The Hole Truth, Hydro Excavation Systems Provide Precise, Safe Utility Location", *Utility Contractor*, vol. 33, no. 4, April 2009, page 28.

26 Stein Wendel, Rolf Hugo Kirkivk, Stuart Clouston, Jaroslaw Czyz, *Pipeline Out of Straightness and Depth of Burial Measurement Using an Inertial Geometry Intelligent Pig* (Houston, TX, BJ Services Company), page 5.

27 Mark A. Smith, *Unique Autonomous Pipeline Mapping System: An Overview* (Pittsburgh, PA: Geospatial Corporation), page 6.