Guidelines for Successful Directional Crossing Survey Standards

The accuracy of the placement of directional crossings is important for public safety. Those involved with directional crossings should be knowledgeable about methods to locate existing underground utilities, survey tool selection, survey tool operation, and calculation methods. The directional contractor is often asked to install a new crossing in proximity to a previously drilled installation.The engineer and contractor should be able to interpret all available data so the new installation can be accomplished safely and without damage to existing utilities.

Preconstruction Design - Figure Locating Locating Existing Utilities
The planning stages for any successful directional crossing project are critical.The preliminary investigation of the project should include a comprehensive utility compilation to properly plan the proposed drilling alignment.The accuracy of the initial survey of the existing underground utilities is the basis of the subsequent accuracy of the installation. In extreme cases, property damage, injury and loss of life can occur from installations undertaken with inadequate information.

The emerging field of Subsurface Utility Engineering (SUE) is providing better methods to map underground utilities. The site conditions dictate the level of effort and expense required to determine the accurate location of existing underground utilities. Initially, the designer compiles a utility compilation plan from the owner's records and facility maps.

During the preliminary design phase the depth prior the designer traces the existing utilities using electronic technologies to determine the surface location and presence of below ground facilities. At critical locations, and at the intersection of the proposed alignment with existing facilities, nondestructive air vacuum excavation is utilized to confirm the exact location and depth of existing utilities. Details of available methods follow:

Locating provides a good estimate of the depth prior to exposing the utility.

Pipe Locators: The use of a pipe and cable locator provides a good estimate of the depth prior to exposing the utility.Typically, pipe and cable locators use electromagnetic location.When an electric current flows along a metal line, an electromagnetic field is created and radiates from the line. The signal is detected using a pipe and cable locator.Without current flow, location cannot be determined. Nonmetallic objects (such a plastic or PVC pipe) cannot conduct electronic flow and should be located using other methods.

Signals placed on a line by a transmitter produce current flow, generating an identifiable signal. When selecting a signal frequency, it is important to know that higher frequencies couple to lines easier than low frequencies. Higher frequencies tend to radiate outward more than lower frequencies and therefore have the tendency to "bleed over" and couple on to other lines in the vicinity causing the potential for false locates. Lower frequencies usually travel further down the line than higher frequencies.

Some transmitters have adjustable power outputs. Higher outputs can increase the signal strength and cause the signal to travel farther down the line. Higher signal strengths can also increase the potential for "bleed over." Higher power settings can impact the ability to isolate individual lines. Passive signals are electromagnetic signals that are on the line "naturally." Power and CATV coaxial cable lines can produce a detectable signal if there is current flow. Extreme caution should be exercised when working in the vicinity of buried power lines. A power line can have, but not produce, a detectable signal because current is not flowing. Depth estimates from passive signals are not reliable and should be discounted.

Ground Penetrating Radar (GPR): GPR detects buried objects by transmitting a radio wave into the ground and the reflected wave is recorded with a receiver. A computer is used to record the results and software interprets the data. GPR surveys are very useful in obtaining geological data and subsurface anomalies. Although it is capable of locating pipelines, it does not distinguish between facilities. When utilizing GPR, soil, groundwater and surface, conditions should be examined to decipher the expected results and applicability to the project. Site conditions should be analyzed in the design stage of the survey as they can affect GPR frequency. Antenna arrangement and subsurface strata will be critical.

Ground penetrating radar detects buried objects by transmitting a radio wave into the ground and the reflected wave is recorded with a receiver.

Seismic Survey: Seismic methods are simiIar to GPR, substituting pressure waves for electromagnetic waves. Seismic surveys are generally used in less-congested areas but can provide data from deeper installations.

Nondestructive Air/Hydro Vacuum Excavation: Electronic subsurface detection has a precision that can be ambiguous and varies depending on local interference and site conditions. Although confidence in electronic locating has increased when a number of various locating technologies are used together, actually exposing a facility using nondestructive air or hydro-vacuum excavation is the preferred method. The confirmed location of a utility is precisely located by conventional land survey. Truck-mounted air- and hydro-vacuum excavation systems utilize high-pressure air or water to loosen the soil from around a utility. A vacuum hose extracts the debris from the exploration hole into a holding tank and the material is replaced when the utility is exposed and measured. Vacuum systems vary greatly in design but have become widely accepted by many facility owners as the safest way to uncover utilities.

Vacuum excavation is generally limited to depths of 20 feet. For facilities below that level, more emphasis is placed on electronic detection devices. On very deep installations, the designer may have to rely on the accurate documentation from the previous installation and the thoroughness of the post-construction survey for accurate information.

Prior to groundbreaking, a One-Call request should be made to have the facilities marked. This service should be utilized to ensure all the facilities are accurately depicted on the design plans and any conflicts are resolved before drilling. AII of the data gathered from available records-from the line tracing investigation and the exploration hole services - should be combined in the design document.

Drilling Survey Equipment & Methods

There are several tools available that allow the drilling crew to make a determination of the drill string position as the pilot hole is drilled.The drilling crew uses the data to drill in accordance with a pre-approved alignment and profile and to make course changes. Some of the equipment in use is:

Surface Location Systems: Walkover tracking systems are generally less expensive than other types of surveying methods. These systems are comprised of an electronic transmitter near the bit that is used to track the downhole assembly using a walkover receiver. The transmitter-also referred to as a beacon or sonde-transmits an electromagnetic signal used to estimate the position of the downhole tool. The tracking receiver displays the signal strength. The higher the signal strength, the closer the receiver is to the transmitter.

Most transmitters also have orientation sensors. They are pitch (inclination), roll, and, in some cases, left/right deviation. Information from the sensors is displayed on the receiver and used to make steering decisions.The receiver is used to estimate the depth from the receiver to the transmitter. It is very important that the operator follows the manufacturer's recommended calibration procedures to help ensure accurate depth measurement.

Plan Pipes

Index	Pipe	Away	Lateral	Depth	Pitch	L/R
1	10.0	9.7	0.0	-12.7	-28%	0ºR
2	20.0	19.3	0.0	-2.7	-28%	0ºR
3	30.0	28.9	0.0	-10.8	-28%	0ºR
4	40.0	38.8	0.0	-13.7	-22%	0ºR
5	50.0	48.8	0.0	-10.0	-10%	0ºR
6	60.0	58.8	0.0	-10.0	0%	0ºR
7	70.0	68.8	0.0	-10.0	0%	0ºR
8	80.0	78.8	0.0	-10.0	0%	0ºR
9	90.0	88.8	0.0	-10.0	0%	0ºR
10	100.0	98.8	0.0	-14.3	0%	0ºR
11	110.0	108.8	0.0	-13.3	0%	0ºR
12	120.0	118.8	0.0	-11.2	0%	0ºR
13	130.0	128.8	0.0	-10.6	10%	0ºR
14	140.0	138.7	0.0	-11.0	21%	0ºR
15	150.0	148.3	0.0	-8.5	28%	0ºR
16	160.0	158.0	0.0	-3.8	28%	0ºR
17	170.0	167.6	0.0	-0.1	28%	0ºR
Punch Out	175.0	168	0.0	0.0	28%	0ºR

Surface location systems are used for bores that are usually less than 70 feet deep.The transmitters use batteries, and the time required to complete the bore is a criteria for selection. Road and creek crossings can often be accomplished using surface location systems. However, remote steering capabilities are typically limited to distances of 50 feet.

Borepath planning and mapping systems are available with some surface location systems. They are capable of recording depths of the downhole tool at specific intervals from the drill with the ability to produce a survey or as-built map of the pilot bore.

Magnetic SteeringTool: The magnetic steering tool is the industry standard for long, deep crossings.The magnetic steer ing tool allows the drill crew to calculate the position of the bore at any time during the drilling. Drilling corrections are made so the bore complies with the crossing specifications.

The magnetic steering tool uses a rugged tri-axis magnetometer to determine the tool position relative to the earth's local magnetic field. The magnetometer is an electric compass. A tri-axis accelerometer package is used to determine the tool position relative to the earth's axis.The accelerometer is an electronic level.Together, the data output from the instruments are mathematically transformed to yield the tool attitude.The attitude includes the inclination of the steering tool, the direction of the inclination of the steering tool and the tool face, and reference of the tool body position relative to the borepath.

Each successive set of measurements is used to calculate the incremental position of the bore along its designed path. The incremental position calculations are added at each point and the actual borepath can be plotted.These tools have a nominal accuracy of +/- 0.1 of a degree of inclination, +/- 0.3 or better of a degree of azimuth.

Magnetic steering tools are often used in conjunction with the Tru-Tracker system. The Tru-Tracker system consists of an electric cable positioned on the surface over the borehole.The cable position is surveyed and selectively energized, producing a local magnetic field of known intensity and location.The magnetic steering tool is sensitive to this induced magnetic field and proprietary software is used to refine the steering tool and borehole position during the drilling.

Gyroscopic: A less commonly used system incorporates gyroscopes. Gyroscopes maintain a fixed-orientation and are not affected by magnetic interference. However, gyroscopes used while drilling are small to fit inside the drill string. Small gyroscopes have reduced accuracy and increased drift. Specialist operators are also required.

Selection of the tools described above is based on site specificifications and cost considerations. Generally, the surface location systems are the least expensive but can only be used on smaller crossings. The magnetic steering tool is used on most large installations where depth of the drill can accommodate separation from existing utilities and magnetic interference can be identified and quantified.

Construction - Equipment Standards and Setup

The steering tool and any back-up tool selected for the project should have a recent shop calibration to ensure they are within the manufacturer's specified tolerances. An on-site roll calibration check should also be carried out prior to every project. This roll check can be done in conjunction with the probe shoot-in process to determine the course direction.

The steering tool is placed on the ground-in an area of magnetic interference-along the drill alignment and information is recorded as the tool is rolled at equal tool orientations within a circle. For roll checks, a minimum of eight points should be checked. On shoot-ins, four points are adequate. Alternate shoot-ins should be performed in various locations along the drill path to check for magnetic changes, and to confirm the course direction. If possible, the shoot-in should be performed with the steering tool housed in the nonmagnetic drilling assembly. All data received during the check should be recorded and available for comparison during drilling operations.

Where Tru-Tracker can be used at the beginning of the pilot hole, the course azimuth can be verified and adjusted as needed.Tru-Tracker surveys and any direction changes must be recorded.

An incorrect pilot hole exit can occur because of magnetic interference, improper azimuth determination, tool malfunction, or operator error. However, a missed punchout can be used to establish the correct course azimuth. The actual punch-out location and orientation is compared to the calculated location and a redrill plan is prepared.The drill string is retracted to a point where it is determined to be within specification and then that section of the pilot hole is redrilled.

The survey data represents the position of the pilot hole. Subsequent reaming operations may alter the location of the drilled hole. For instance, in soft soils, reaming tends to somewhat straighten the drilled hole since the reamer is being pulled in tension. It is considered a good construction practice that reaming always be conducted with a full string of drill pipe in the hole in order to reduce the possibility of straying, or "walking", from the accepted pilot hole location.

Post-lnstallation Survey

When working in a congested utility corridor, it is recommended that a post-installation survey be performed.The use of a post-installation survey should be specified by the engineer in the scope of work. This will ensure the new installation is not affecting existing utilities and will not be damaged by future installations.

It is not uncommon to have a discrepancy between calculated positions and the actual drill exit point.This generally occurs when there are long sections of the drill alignment where the Tru-Tracker cannot be used to confirm the position of the drill.
The methods available for post-installation survey are:

Gyroscope: The accuracy of gyroscopes increases with the size of the tool.The best method of the post-installation survey is to pull a gyroscope through the product pipeline.The gyroscope should be centered in the pipeline in order to give more meaningful results. Several runs of the gyroscope should be performed to confirm repeatability and give the results more credibility.

Piezometers: Often, it is only necessary to know pipeline depth. This is the case in sewers where high-spots can trap corrosive gas during the life of the line. The piezometer is a device that accurately measures hydrostatic pressure inside the pipeline.Again, the piezometer should be centered in the pipeline and several runs should be performed to confirm repeatability.

Other: As in locating utilities before the installation, using pipe locators, GPR or seismic can also be used but will be generally less effective for deeper installations.

As-Built Calculations and Documentation

The as-built drawings are compiled at the end of the project and retained by the owner for future reference. The plot of the drill is based on raw data generated during construction, together with any changes in the design survey. Data from post-installation surveys are also incorporated when available.

The assumptions of the as-built preparer are recorded in the as-built record. For instance, there may be occurrences causing raw data to be unrepresentative and there may be discrepancies between the downhole tool and Tru-Tracker information. This may force the preparer to make certain assumptions for closure. Similar discrepancies between pilot hole survey data and post-installation survey data need to be reconciled. Lastly, there are different geometric methods for calculating the position of the utility that may lead to variances.

Therefore, the as-built package should contain more than a ground survey or planimetric drawing that plots the coordinates of the new installation. It is recommended that the package should also include the following data:

Tool Information: Information regarding the actual tools used on the project should be archived. This information should identify the tool manufacturer and serial number and the tool's most recent shop calibration record.

Field Operation Records: The tool operator's report should include details of the pre-drilling field calibration and the raw data record from the survey tool and the TruTracker. The location of Tru-Tracker coils should also be included. Lastly, the coordinates of any punch-outs prior to acceptance should be provided.

As-Built Preparation: The preparer should provide a brief report indicating how the raw data was interpreted and which data (survey tool,Tru-Tracker, and/or post-installation survey) was used. Any changes from the initial construction survey should be noted. The report should include a statement and explanation of the calculation method used.

The as-built should also provide a graphical or pictorial map showing the location of the new installation using land survey practices and procedures. This document should determine the geodetic position of the new pipe, which is reproducible by subsequent surveys. The survey should attempt to meet or exceed the Federal Geodetic Control Commission (FGCC) or the Federal Highway Administration (FHWA) Third Order Construction Control Surveys or a relevant equivalent. Land surveys based on State Plane Coordinate Systems (SPCS) are more desirable but, arbitrary ground surveys will be acceptable with the use of proper practices and procedures-such as spikes, markers and metallic discs-referenced on the as-built so as to facilitate retracement of the survey by others.

All of this information can be used in subsequent verification of the location of the new utility or to ascertain its proximity to future installations.

Summary/Conclusions

Directional crossings are increasingly being installed in congested utility corridors and close to previously drilled installations. The as-built analysis is a mixture of sophisticated data gathered in the field and interpreted by those experienced with the directional crossing method.

The safety of the new installation, existing utilities, and future installations depends on the reasonable interpretation of as-built locations. Utility owners, engineers, and directional contractors involved in the design and construction of directional installations must thoroughly understand the operation and limitations of the survey tools and the information that is provided after construction.

These standards were prepared by the Survey Standards Committee of the Directional Crossing Contracors Association (DCCA). The standards were adopted by the Association on Oct. 12, 1998. The members of the DCCA Survey Standards Committee are:

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