THE DIGITRAK ECLIPSE LOCATING SYSTEM: A FLEXIBLE AND INNOVATIVE APPROACH TO MEETING TODAY'S HDD LOCATING CHALLENGES.

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ABSTRACT

During the recent downturn in the Horizontal Directional Drilling (HDD) market, equipment manufacturers focused on research and have introduced a number of innovations. Nowhere has this been more evident than amongst manufacturers of HDD locating systems. In particular, the documentation of an increasing number of parameters concerning the drilling process has been a focus of development. Additionally, the capability to successfully carry out a wide range of project specifications with the same locating system has been made a priority.

This paper will describe the DigiTrak®Eclipse® locating system's various features and will use short project summaries as examples. Particular emphasis will be placed on gravity sewer installations; project mapping and documentation; down hole drilling fluid pressure; load monitoring and documentation; and magnetic guidance system operations.

It is the intent of the author to demonstrate the level to which modern locating systems have risen and to help educate project planners and owners about some of the various HDD projects successfully undertaken in recent years.

INTRODUCTION

It is prudent at the outset to establish the terminology that will be used in this discussion.

- Transmitter: A transmitting device placed inside a housing at the front of the drill string
- Receiver: A handheld locating device used to locate the position of the transmitter
- Remote Display: A remote readout on the drilling machine
- Locator: The person tasked with locating the transmitter by using the receiver
- Operator: The person sitting at the controls of the drilling machine

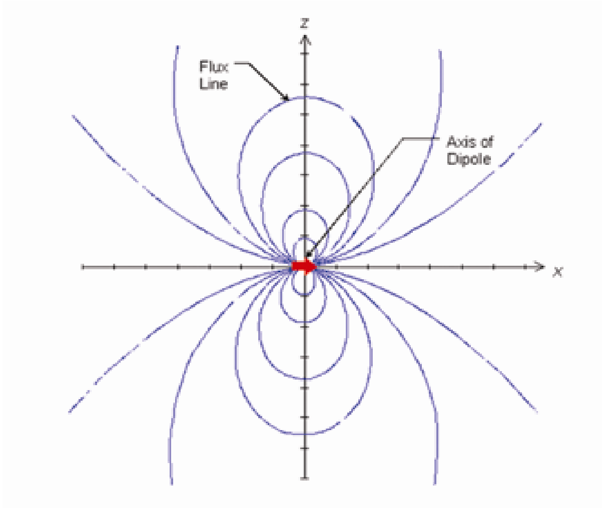

Figure 1. Di-Pole Magnetic Field

An HDD transmitter emits a di-pole magnetic field (figure 1) as well as data which is picked up by a receiver and turned into usable locating information. This information is then used to make steering decisions allowing the drilling team to direct the drill head along a predetermined path. The basis for the technology however has not changed. The object is still to accurately locate a transmitter, buried below ground, often in the presence of multiple types of interference. Not only is it important to locate the transmitter, but its direction and a host of other data such as orientation and inclination needs to be efficiently transferred to the receiver. From the locator standpoint, all this needs to be achieved in a simple and effective manner in order to insure an efficient operation as possible. It is also important that the locating system be able to handle a wide variety of projects requiring different technical capabilities. This then, is the task that manufacturers of locating systems have before them.

PROPERTIES OF DI-POLE MAGNETIC FIELD

Digital Control Incorporated (DCI) introduced its first locating system in 1992 called the DigiTrak® Drillhead Monitor. This system brought to the market a number of technical innovations, the foremost of which was the patented orthogonal antenna arrangement. This was a significant departure from the traditional HDD receivers which up to this point had been designed to find maximum signal strength which is found directly over the transmitter. In the orthogonal configuration the magnetic signal receiving antennas are able use the properties of the magnetic field to identify three distinct characteristics of the magnetic field. These are the forward locate point, the rear locate point and the locate line as shown in figure 2.

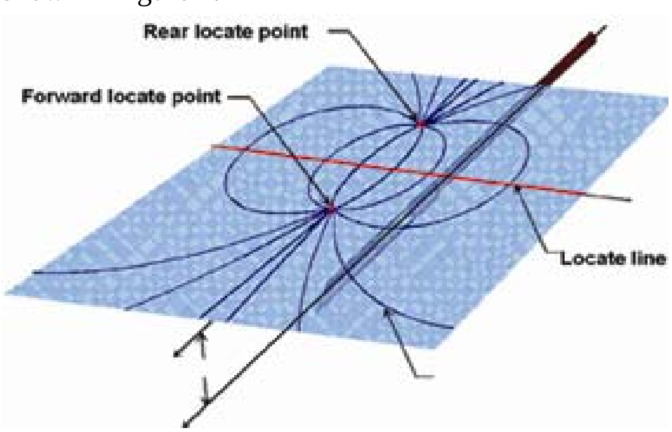

Figure 2. Locate Points and Locate Line

The forward and rear locate points as the names indicate are found in front of and behind the transmitter which are directly above the transmitter axis or stated differently, they define the transmitter axis. The locate points are found where the flux lines are vertical. When the transmitter is level, these are equidistant from the center of the transmitter antenna and the distance between the locate points is 1.4 times the transmitter depth.

The locate line intersects the transmitter axis at a right angle over the center of the transmitter antenna and is found where the flux lines are horizontal.

There are a number of benefits that arise from the orthogonal antenna configuration. First and foremost is the ability to use the forward and rear locate points to very accurately establish the direction (heading) of the transmitter. Since the forward locate point is a projection of the transmitter's heading, any direction changes are magnified allowing the locator to very quickly see the change and steering corrections can be made before the drill head gets too far of

course. The locate points are especially important when the bore path design calls for a curve. By monitoring the locate points, it is easy to see how much the drill head is turning and thereby accurately control the curvature. The locate line identifies the transmitter position along the bore path. This is used to accurately determine the location of the transmitter after its axis using the locate points is known. Since the locate line extends at a right angle to the transmitter axis (as far as the signal extends) the transmitters position can be located off to the side. This is called off-track guidance and is very useful when obstructions or interference prohibit over the transmitter locating.
The original DigiTrak design allowed the locator to find the locate points through a series of 3 or so right angled turns where a plus or minus indication on the receiver would tell the locator which way to move the receiver. The receiver had 3 numerical displays and no graphical information was available. By following a simple rule, the receiver would always guide the locator to one of the locate points. This is a highly accurate method but new users sometimes found the procedure confusing. It was however state of the art when originally brought to market.

DIGITRAK® ECLIPSE® DESIGN PHILOSOPHY

As the HDD market grew and matured the need for more sophisticated locating systems became apparent. Digital Control Inc. embarked upon the design of radically different design. The primary criteria were the following:

- Interference rejection
- A highly accurate locating system
- Technical innovation
- Intuitive user interface and ease of use
- Multiple capabilities, a sort of “one size fits all” approach

Considerable time and effort was devoted to determine the optimum operating frequency of the system. DCI engineers used a spectrum analyzer to map the interference spectrum. Interference frequency data was gathered from a large number of areas where HDD is typically used. Some examples included traffic signal loops, railway tracks, electrical transformers and power lines. Based on this investigation, the frequency band near 12 kHz was found to be relatively free of interfering signal. Therefore 12 kHz was chosen as the primary operating frequency for the Eclipse system.

Figure 3. DigiTrak Eclipse locating system

The biggest technical innovation was the introduction of a three dimensional signal antenna. This leads to a number of benefits for the locator as far as ease of use is concerned. Primary of which is the concept of “Ball in the box” locating display. The Eclipse system also introduced some sophisticated locating options which will be described in more detail later on. More importantly, the 3-D signal antenna configuration allows the receiver to accurately read the magnetic dipole signal for increased locating accuracy.
The system is configured much like today’s computers employing a menu system which allows the locator to easily access the many functions the system offers. This makes training easier and also allows the user to confidently operate the various aspects of the locating system. The Eclipse system is the

platform upon which most future developments will be based and this is where much of the engineering effort is being focused.

SYSTEM SPECIFICATION AND CAPABILITIES

The Eclipse system design has focused on making the basic platform very flexible, allowing for added capabilities in the form of upgrades in terms of hardware, operating software or sometimes both. What follows is a short description of the capabilities of the system.

Transmitters

When used as a walk over locating system there are four different transmitters that can be used with the Eclipse locating system. Each one of these is sewer grade, that is, the pitch or inclination is measured in 0.1% or 0.1 degree increments. The Berea OH, sanitary sewer project case history demonstrates the capabilities of the system for installing gravity sewers. The clock or drill head roll orientation is measured in 24 clock positions, allowing for more an accurate than is common, steering control.
The standard transmitter has a depth range of 15 m (50 ft) and transmits the locating signal on the Eclipse base frequency of 12 kHz. The dual frequency transmitter functions in two modes; in the dual frequency mode in transmits simultaneously at 12 kHz as well as a much lower 1.5 kHz frequency for a depth of 15 m (50 ft). This lower frequency signal is specifically intended to combat interference from rebar and other metallic objects along the drill path. In the single frequency mode it transmits only at 12 kHz but to a depth of 21 m (70 ft). The third Eclipse transmitter is a shorter range transmitter, smaller in size, and is intended for smaller machines employing much smaller drill heads. This transmitter transmits to a depth of 5 m (16 ft) at 12 kHz only. The fourth transmitter is a wire line transmitter running at the 12 kHz frequency which as the name implies is powered by an above ground power source, most often the drill machine battery, through a wire that runs on the inside of the drill pipe. The same wire is used to transmit roll and pitch data back to the remote display. Only one wire is required since the drill stem acts as the return or ground path. This wire line transmitter is often used on larger and deeper crossings where battery life or depths are an issue. It can also be advantageous in areas of higher interference because of its stronger signal and the fact that the roll/pitch signal is hardwired to the surface.

Locating method

Due to the three dimensional antenna design it is possible to display the transmitter or locate position in real time. This means that the locator is able to watch the locate point, or more appropriately its graphical representation, move as the drill head moves through the ground. Figure 4 shows the main locating screen of the Eclipse system. The "Target" is the graphical representation of the locate point. At the center of the display is an icon representing the receiver itself or alternately the position of the locator holding the receiver. In figure 4 the faintest target (the one the red line is pointing to) indicates that the locate point is out in front and off to the left of the locator. By moving the receiver in that same direction the ball can be seen traveling along the path taken. Remember, in this case the target (locate point) is stationary and the moving ball represents the movement of the locator. Once the target has been placed in the receiver icon at the center of the display the locate point has been found. The locator now has very accurately determined the direction of the

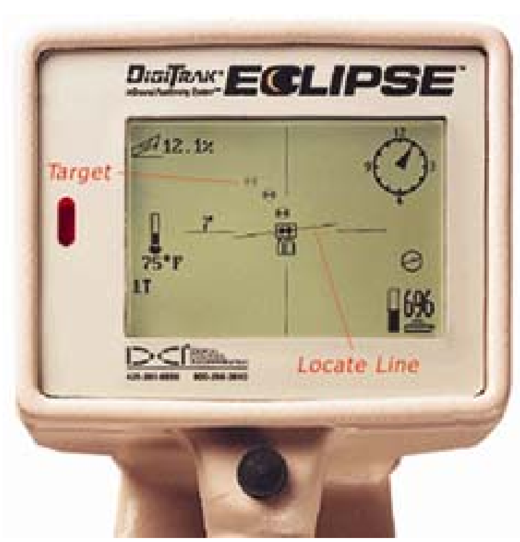

Figure 4. Eclipse receiver locating screen

transmitter and hence the drill head. The figure also shows the locating line, which represents the center of the transmitter or drill head, overlapping the target. This is for illustration purposes only since the receiver can obviously not be over the locate point and drill head at the same time. By lining the locate line up with the horizontal cross hairs in the display and using the locate point as a guide, the receiver is then being held directly above and in line with the head. Now, a depth reading can be taken.

A second and very efficient means of locating with the Eclipse is to place it on the intended bore path, represented by the vertical cross hairs and watch the target move as the drill head advances through the ground. As long as the target moves along the vertical crosshairs, the drill head is on line. Any small deviation is immediately seen by the target moving off the cross hairs and appropriate correction can be taken before the drill head goes off course.

Target Steering

In situations where walk over locating is not feasible or practical, for example when crossing a busy roadway, target steering is a locating method that can be used. As an example, assume that a 10 m (33 ft) wide road has to be crossed and that the bore plan calls for a depth of 3.5 m (11.5 ft) on the far side of the road. The 3.5 m (11.5 ft) depth can then be programmed into the Eclipse receiver as a target depth, and the receiver can be placed on the far side of the road. The horizontal angle of the receiver is of importance since the steering information will guide the drill head directly below and at a right angle to the receiver. With the receiver programmed for a target depth and placed on the far side of the road, figure 5 depicts the view of the remote that the operator on the drilling machine will have. The drill head is 6.2 m (20.3 ft) behind the Eclipse receiver as indicated by the horizontal distance display. The drill head is calculated to be 1.4 m (4.5 ft) below the plane of the receiver. The steering indicator shows that the current drill head position is little bit above and somewhat further to the left of the target represented by the center of the cross hairs. The object is to steer the tool so the steering indicator moves to the center of the cross hairs. The proper steering command for this is to bring the head down and to the right. Experienced drillers know that this is about 4 o'clock. The point on the steering indicator mirrors the clock orientation of the drill head so by rotating the head until the point is aimed at the center, the proper steering can be done. In addition, the pitch reading is continuously updated so that the drill head inclination can be maintained during drilling. In this fashion, the roadway in our example can be crossed without risking injury to the locator or having to divert traffic.

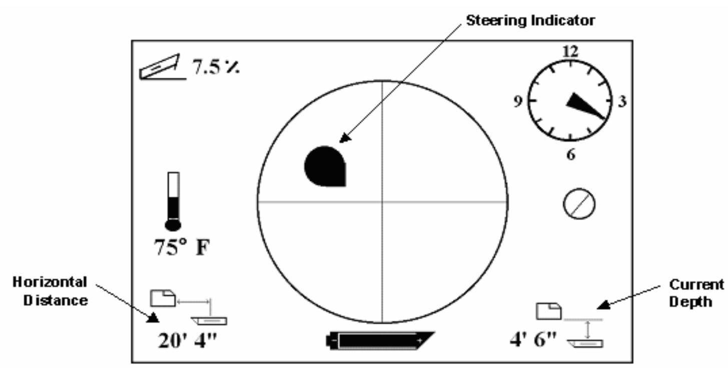

Figure 5. Eclipse remote target steering screen

Data logging

This is the capability of storing pertinent drilling parameters in the Eclipse receiver memory and then downloading this information to a computer to create what is often referred to as an as-built of the installation. When the Eclipse receiver is in DataLog mode and placed on the front locate point, the pitch, depth, transmitter temperature and battery status data are logged. This process is repeated once per rod, or more often, as long as the distance between data points is constant. The Eclipse receiver has enough memory to store 25 separate bores, each consisting of 250 data points before any data has to be downloaded. Once the data has been downloaded a bore profile including topography and a report of the drilling data (rod by rod) can be printed out. Additionally, the placement of utilities crossed or any other pertinent landmarks can be added to the graph for more detail. The bore profile is calculated using the recorded pitch data and assumes the starting elevation to be 0. By comparing the calculated depth with the recorded depth from the Eclipse receiver, topographical information is derived. As an example, if the calculated depth is greater than the measured and recorded depth using the receiver, this would indicate a depression or a trough on the surface. A comprehensive report on the bore profile and drilling data is the final product resulting from the use of the DataLog feature. The Verizon FTTP project story later in this paper will illustrate the use of this feature as well as the use of the Eclipse receiver on a typical fiber optic project.

Magnetic Guidance or Steering Tool System

The DigiTrak Eclipse Short Steering Tool (SST™) is a magnetic guidance wire line system designed to work with the Eclipse walk over locating system. The SST transmitter provides the industry standard guidance tool information, namely roll in 360 distinct increments, inclination in either 0.1 percent or degree increments and compass heading, often referred to as yaw angle, in 0.1 degree increments. This information is sent back the same wire that powers the transmitter. The transmitter is only 24" in length, which allows for a smaller turn radius than the conventionally much longer wire line transmitters. Another important departure from the traditional systems is the fact that the SST can be tracked with the Eclipse receiver which means that the commonly used DC wire grid is not required. The Eclipse walkover locating capability allows for an independent verification of the tool's position where walk over locating is possible down to a depth of about 20 m (65 ft).

Figure 6 shows a view of the bore as it appears on the laptop during the pilot bore process. The screen displays much more detailed information but for the sake of clarity, this has been omitted. The upper portion shows the profile and the lower is the top view of the bore showing left/right deviation. The bore plan and the topography survey information have been preloaded into the SST software. In the figure the bore is about halfway completed. The software allows the drilling crew to monitor the progress and make corrective decisions if required. The Eclipse remote when operated in SST mode displays the roll, inclination, compass heading (yaw) and the deviation (if any) from the reference yaw are displayed. Reference yaw is defined as the establish heading of the bore plan. As the tool deviates from this heading, the remote will display a

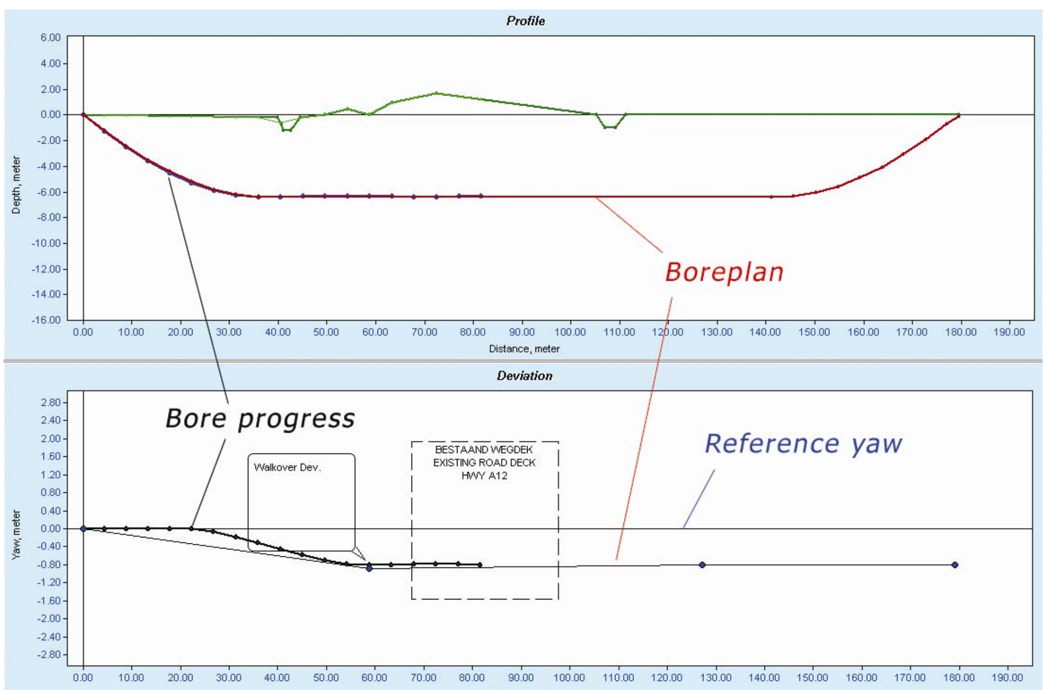

Figure 6. View of SST software on laptop during bore.

left/right deviation in degrees indicating how much off course the tool is. A case history later on describes the A-12 highway crossing near Driebergen in the Netherlands using the SST system.

Down-hole fluid pressure and tension monitoring

TensiTrak™ is a fluid pressure and tension monitoring device for the back reaming process. The TensiTrak monitor is installed between the product pipe and the reamer. It transmits in real time tension data and drilling fluid pressure of the annular space. It can read pressure up to 689.5 kPa (100 psi) in 6.9 kPa increments and loads up to 356 kN (80,000 lbs) depending on the model in 67 N (15 lb) increments. It also transmits a depth signal that allows the progress of the installation to be tracked if required. The pressure and tension data is collected every 4 seconds is and stored in the Eclipse receiver for later downloading but is also displayed on the screen and sent in real time back to the machine operator who monitors both and can take any required corrective action so as not to exceed the planned or established values. A short case history of a project completed in Rome, NY is included later on in this paper as an illustration of the TensiTrak monitor.

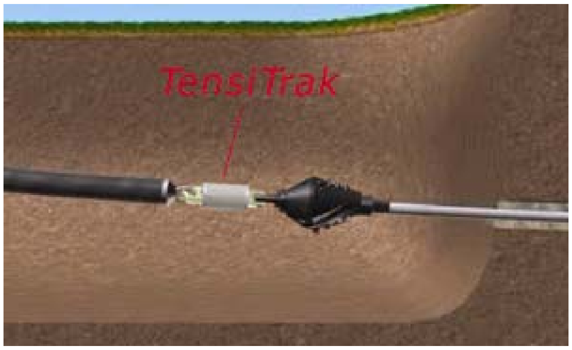

Figure 7. The TensiTrak monitoring system

SANITARY SEWER PROJECT IN BEREA, OHIO

In November 2003, Precision Directional Boring (PDB) was hired as a subcontractor to directionally drill a sanitary sewer project in Berea, Ohio using a DitchWitch® JT 2720 directional drilling machine. The project consisted of installing 122 m (400 ft) of 305 mm (12”) CertainTeed Certa-Lok C-900 PVC pipe with a fall of 0.75%. Ground conditions consisted of fairly uniform hard clay. One of the most challenging aspects of this project was that at the first manhole the invert depth of the pipe was planned at 11.6 m (38 ft) while the last manhole the invert depth was 12.5 m (41 ft). Based on the demanding specifications, PDB decided to use their Eclipse locating system with the dual frequency transmitter.
Along with the Eclipse system a process called Arrow Bore was used, which calls for placing relief hole tubes every 9 m (30 ft) which allows for checking of the line and grade on a regular basis. In order to reach the first manhole depth, the machine had to be set back 61 m (200 ft) requiring PDB to rely solely on the locating system to keep the bore on line and to reach the desired depth before verification at the first relief tube. According to Willard Roth, President of PDB, the front and rear locate feature and depth accuracy of the Eclipse system enabled them to hit the first target precisely on line and depth. The same was true for all thirteen of the relief tubes. In every case the pilot bore was dead on target. Due to the exacting nature of this installation the pilot bore took about 4 days to complete. The entire installation was completed in 3 weeks. After


Figure 8. The drill ready to launch the pilot bore

installation, the pipe was inspected and the invert was found to be only 12 mm (0.5") off of the planned depth at the first manhole and about 50 mm (2") at the final manhole. This was more than acceptable to the project engineer.

VERIZON FTTP PROJECT IN SOUTH LAKE, TEXAS

Dakota Directional out of Ennis, Texas is a contractor working on a large FTTP (Fiber To The Premise) project for the Verizon telephone company. On January 18, 2005 they set up to do a fairly typical bore on this project using their Vermeer® D16x20 drilling machine. The project was to install a 90m (290 ft) of 50 mm (2") HDPE conduit at a depth of 0.9 m (3 ft) for a fiber optic line in a residential area. The bore was drilled at an upward slope generally following the surface where the elevation at the end of the bore was about 1.9 m (6.2 ft) higher than at the entry point. Ground conditions consisted of loam, some clay and a rocky section at the beginning of the bore. With the dual frequency Eclipse transmitter running in dual frequency mode the Eclipse DataLog feature was used to document the bore. Figure 9 shows the bore profile after downloading from the Eclipse receiver on the computer using the Eclipse DataLog software.

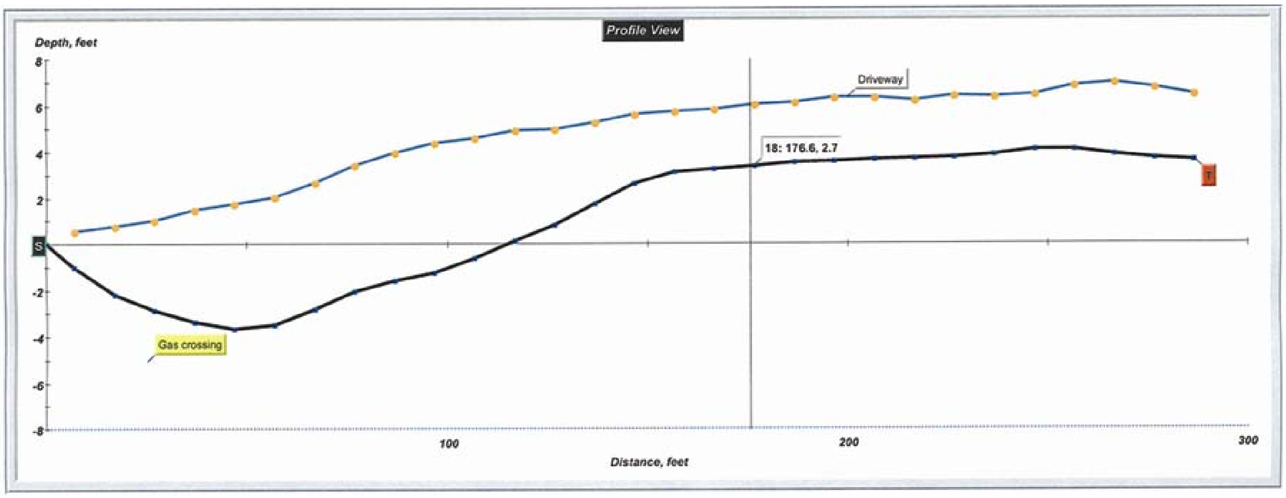

Figure 9. Drill profile report using the Eclipse DataLog Software.

Drilling started in the morning and about 8 m (27 ft) from the starting pit a gas line at 1.8 m (6 ft) had to be crossed. Due to rocky conditions at the outset of the bore, the bore path was changed to get beneath the rocky section. As a result the bore path ended up being about 60 cm (2 ft) deeper than planned for the first 10 rods or so. This brought the bore closer to the gas pipe than originally anticipated but the changed path was nonetheless deemed acceptable and the bore continued. Once out of the rocky section, the progress and steering continued without any problems. The 90 m (290 ft) pilot bore was finished in about 90 minutes including some delays due to the steering problems at the outset. The pullback was completed just before noon allowing the crew to set up and complete a second very similar bore in the afternoon.

A-12 Highway crossing near Driebergen, Netherlands

Van de Beek BV is an accomplished HDD contracting firm located in Neerinjen in the Netherlands. Following is the account of such bore completed in February 2005 using their Vermeer® D50x100 machine and the Eclipse SST system. The project called for installing 2 x 160 mm (6.3 in) and 3 x 125 mm (4.9 in) conduits underneath the A-12 highway for the Enecon utility company. Total length of the bore was planned at 180 m (590 ft) at a maximum depth of 6.4 m (21 ft). Ground conditions consisted of fairly uniform, sandy clay. Figure 10 shows the computer SST software screen with the completed bore. The bore plan called for a about a 40 m (130 ft) straight section and a gentle turn to the left and then straight again for the remainder. While excavating the entry pit an unmarked power line was discovered on the left side of the pit, and with trees on the right side of the pit the machine could not be repositioned.

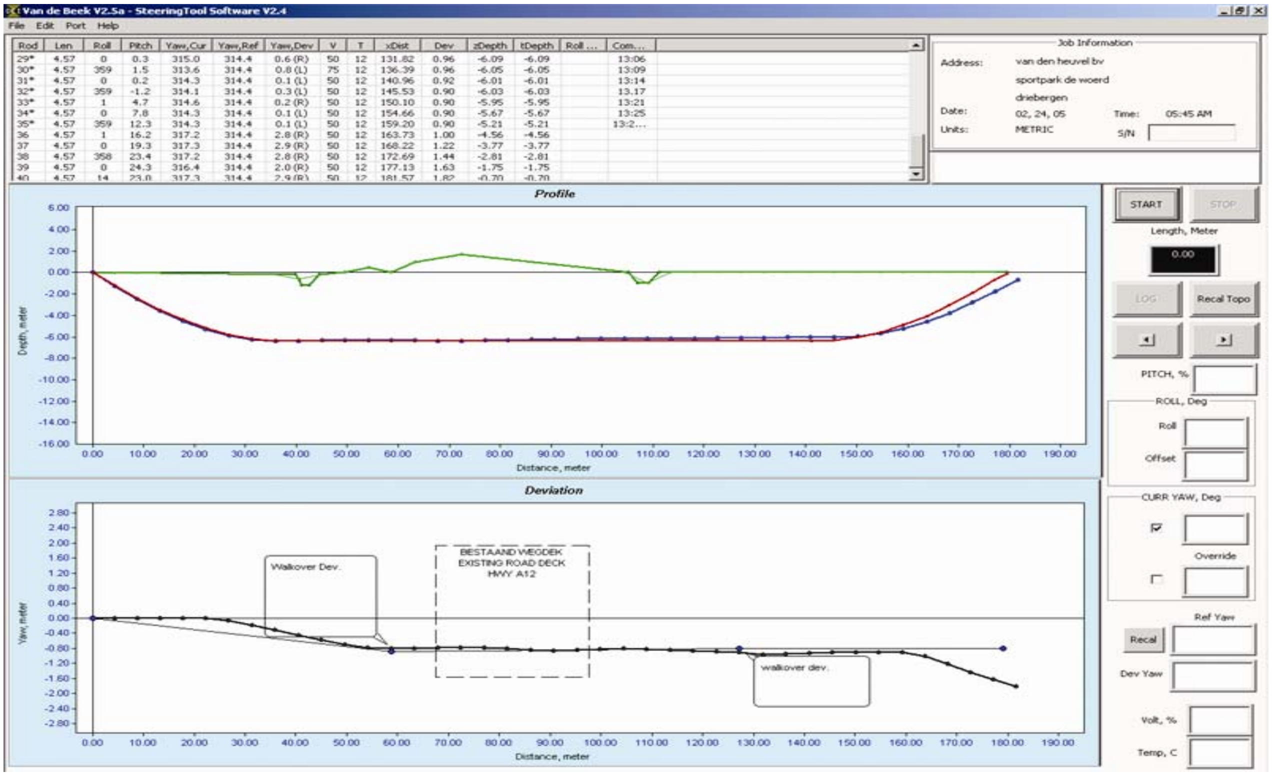

Figure 10. Eclipse SST main screen showing the A-12 highway crossing.

A new reference yaw heading to the left of the power line was established and using the walkover capability, the bore started. After about 20 m (65 ft) a right hand turn was started and again using the Eclipse receiver the tool housing was guided on to the original heading. The new bore path reached the originally planned path at about the 55 m (180 ft) mark. While crossing under the 6 lane highway, the magnetic heading information was used to maintain course. Once across the highway, the magnetic heading was verified with the Eclipse receiver. Another power line was discovered at the exit end which diverted the bore path about 1 m (3.3 ft) to the right of the planned exit point. The final meters were drilled and tracked using the walkover method. The pilot bore was completed in 6 hours and all 5 conduits bundled together were installed in 2 hours which included pre reaming.

TensiTrak test project in Rome, NY

In September 2003 a test bore took place in Rome, NY intended to test the tension load and drilling fluid pressure capabilities of the TensiTrak system. The bore in question was 140 m (460 ft) long and with a maximum depth of 4.3 m (14 ft) and included pulling back a 150 mm (6 in) HDPE pipe. Ground conditions ranged from fine to silty sand. The drilling fluid test consisted of starting with a typical drilling fluid mixture for these conditions (75 second) and about half way through the bore, the drilling fluid was changed to a thicker fluid (153 second) while observing the results. Towards the end of the bore, a Baroid product called AQUA-CLEAR™ PFD was added. This is a Phosphate-Free Dispersant which primarily affects the drilling fluid viscosity by acting as a thinning agent. The tension and fluid pressure data was logged and Figure 11 shows the results as displayed in the TensiTrak software. The tension load continued to rise almost linearly through out the bore ending at about 15.5 kN (3,500 lb) while the pressure data ran between 41.4 and 55.2 kPa (6 – 8 psi). At data point 1500 the drill pipe was pushed back a bit and the tension load went to 0 as expected.

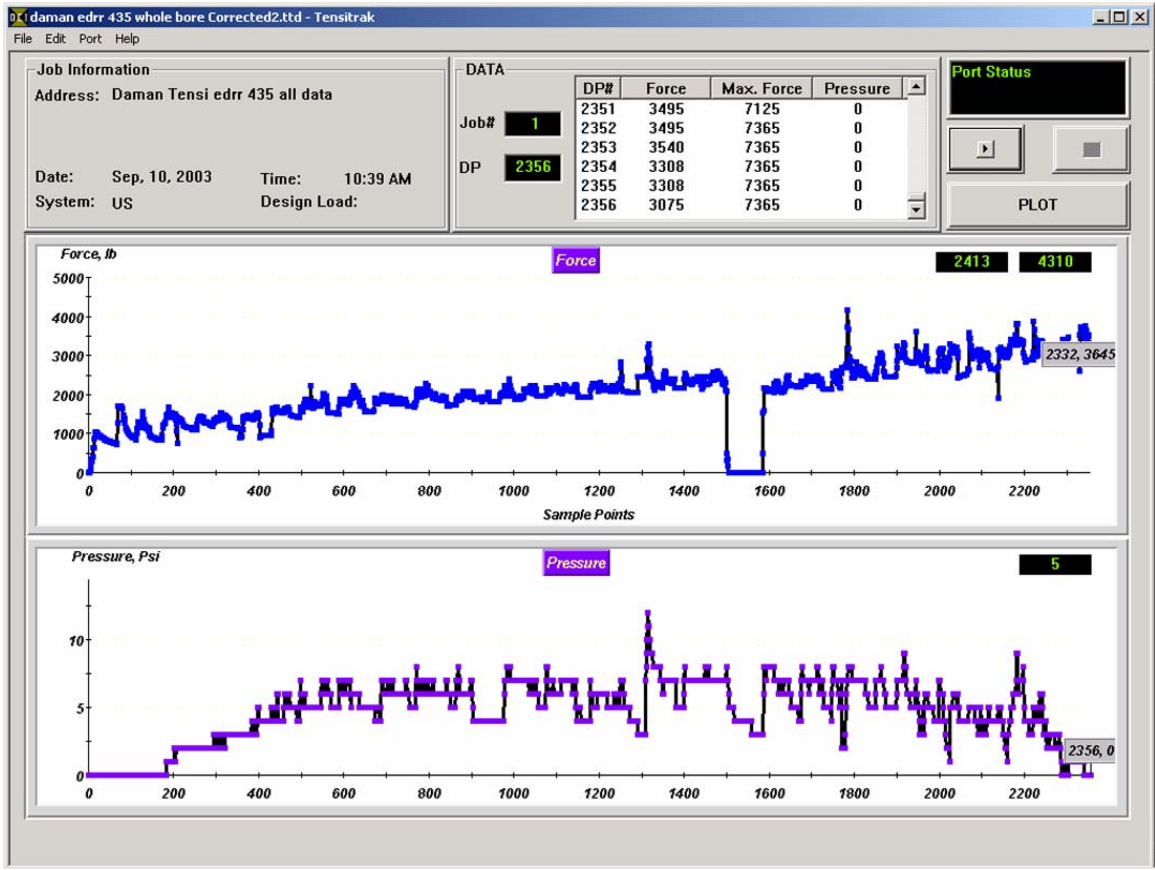

Figure 11. Drilling fluid pressure and tension load data from Rome project.

A pressure spike of 83 kPa (12 psi) which occurred at data point 1300 is where the thicker drilling fluid had been mixed and pumping started. This higher pressure quickly declined to a level slightly higher than it was before. The thinning agent was introduced at data point 2242. Two minutes after the addition, the pressure reading dropped to 13.8 kPa (2 psi) and after another 5 minutes stabilized at 6.9 kPa (2 psi). The readings on both the tension load and drilling fluid pressure behaved as one would have expected indicating a proper function of the TensiTrak.

Summary

The DigiTrak Eclipse locating system has been designed to be very user friendly and simple to use. At the same time it is very accurate and fast. This leads to a short learning curve allowing locators quick proficiency in its use. A second and very important consideration is the flexibility which allows the same locating system to be used on a multitude of differing projects. By using the same locating system for most if not all of their diverse work, an HDD contractor can have greater confidence to attempt more complex projects that they will invariably encounter.