HDD Training

HDD Equipment and Tooling

Mark Miller, PE
Jon Robison, PE

GeoEngineers

HDD Drill Rigs

Horizontal Directional Drilling (HDD) drill rigs come in various shapes and sizes. The small drill rigs are usually capable of pull forces ranging from 5,000 – 100,000 pounds. These rigs are typically track mounted and fairly self contained with on-board power units, mud pumps, operator controls and pipe loading systems. Their small operational footprint makes them ideal for short small-diameter installations because they require much less workspace for construction. Typically these drills use 10 – 15-foot long joints of drill pipe.

The mid-sized drill rigs are typically capable of pull forces ranging from 100,000 – 400,000 pounds. Like the small rigs, these are generally track mounted but some contractors have drills in this class that are trailer mounted. With these rigs, some may have integrated power units, pipe loading systems, mud pumps, or on-board operator control cabs, others do not. These rigs typically use drill pipe joints ranging from 15 to 31 feet in length.

The largest HDD drill rigs are capable of pull forces up to about 1.5 million pounds. These rigs are almost always constructed on a semi-trailer chassis and all of the ancillary equipment and operator controls are separate pieces of equipment. These rigs use 31-foot long joints of drill pipe.

HDD Drill Rigs

A 10-inch xylene pipeline in Tennessee.

A 56-inch gas pipeline in Trinidad.

The size of a drill rig required for a particular project will depend on several factors. The length and diameter of the pipeline installation will have the largest affect on the required installation force. Large diameter installations can require very high pull forces if buoyancy control is not utilized during pullback. When analyzing the estimated installation forces, several buoyancy conditions should be evaluated using different drilling fluid weights downhole and with and without buoyancy control during pullback, so a suitably sized drill rig can be selected.

The subsurface conditions, drilling fluid properties and contractor means and methods can also significantly influence the required installation force. These factors cannot be accurately modeled or predicted and can lead to pull forces much greater than estimated and may lead to a failed installation regardless of the drill rig size.

GeoEngineers

HDD Drill Pipe

Joints of Range 2 drill pipes (~31 feet long)

The drill pipe joints used for HDD vary in length, and depend on the size of the drill rig they will be used with. The most common joint lengths are 10, 15, 20 and 31 feet. Drill pipe is a critical component of the downhole tooling because it is subjected to substantial wear and tear during drilling operations. The threaded tool joint connections at each end are most prone for wear and tear. The tube section of each joint is also prone for wear, especially in rock installations and crossings with significant gravel content.

Each joint of drill pipe should be inspected prior to arrival on site and the HDD contractor should submit the inspection records to prove that the inspection was performed. Each joint of drill pipe should meet the requirements of the API RP7G-2 (moderate or critical service) or TH Hill DS-1 Category 2 or 3.

Drill pipe inspection is important so that worn or damaged drill pipe is not utilized. Downhole drill pipe failures can lead to costly and time consuming setbacks.

HDD Drill Bits

A tungsten carbide insert (TCI) tri-cone drill bit for medium hard rock formations.

A duckbill style drill bit used for soil formations.

Drill bits used for the pilot hole are typically of two different styles. The most common drill bit used for larger installations are tri-cone drill bits like those used in many other forms of downhole drilling. Tri-cone drill bits can be used in any soil formation with a jetting assembly or in rock formations in conjunction with a mud motor. The cutters on the bit come in many different styles appropriate for different drilling conditions. When used in rock, the hours on the bit should be recorded.

Duckbill drill bits are often seen with smaller diameter installations. These drill bits are suitable for all soils that range from soft to hard. These bits tend to steer very well in all soil conditions and since they have no moving parts are less prone to wear.

HDD Drill Bits

All drill bits have drilling fluid jets that face forward in order to cool and lubricate the bit. While jetting through soil formations, the drilling fluid flowing from the jets erodes the formation in front of the bit so that it can be advanced while holding the orientation steady (no rotation) which allows steering corrections to be made.

The jets in the bit can be changed out for jets with larger or smaller openings to suit the subsurface conditions. Tri-cone bits typically have three jets while duckbill bits have up to two jets.

The jets can be individually plugged prior to use in order to direct more drilling fluid in a preferred direction. This can help with steering corrections during pilot hole operations.

A milled-tooth tri-cone drill bit for soil and soft rock formations. Notice the white bands on the joints of drill pipe. They indicate that they have been inspected.

GeoEngineers

Pilot Hole Tools – Jetting Assemblies

The components of a Bottom Hole Assembly (BHA) for soil crossings. The drill bit and jetting assembly on the left and the non-magnetic drill collar (monel) on the right.

In general terms, the pilot hole is advanced with a Bottom Hole Assembly (BHA) consisting of a drill bit attached to either a jetting assembly (soil) or a mud motor (rock). The jetting assembly or mud motor is attached to a non-magnetic drill collar (monel) that houses the downhole steering probe.

Directional control is achieved by a slight bend (1° - 3°) in the jetting assembly or mud motor. Steering corrections and curves are achieved by orienting the bend in the desired direction of travel while advancing the BHA without rotation of the drill string. In soils, the drilling fluid pumped out of jets in the bit cuts the formation allowing advancement. In rock formations, the mud motor turns the bit, which cuts the rock and allows advancement without having to rotate the entire drill string.

Straight drilling is achieved by advancing the BHA with rotation in both soils and rock.

GeoEngineers

Pilot Hole Tools – Jetting Assemblies

The photographs on the left show Bottom Hole Assemblies (BHAs) made up with jetting assemblies for soil crossings. Note the slight angle in the first few feet of the BHA. This allows the BHA to be steered by orienting the bend in the direction of intended advancement. A roll sensor in the steering probe installed in the monel allows the driller to determine the orientation of the bend.

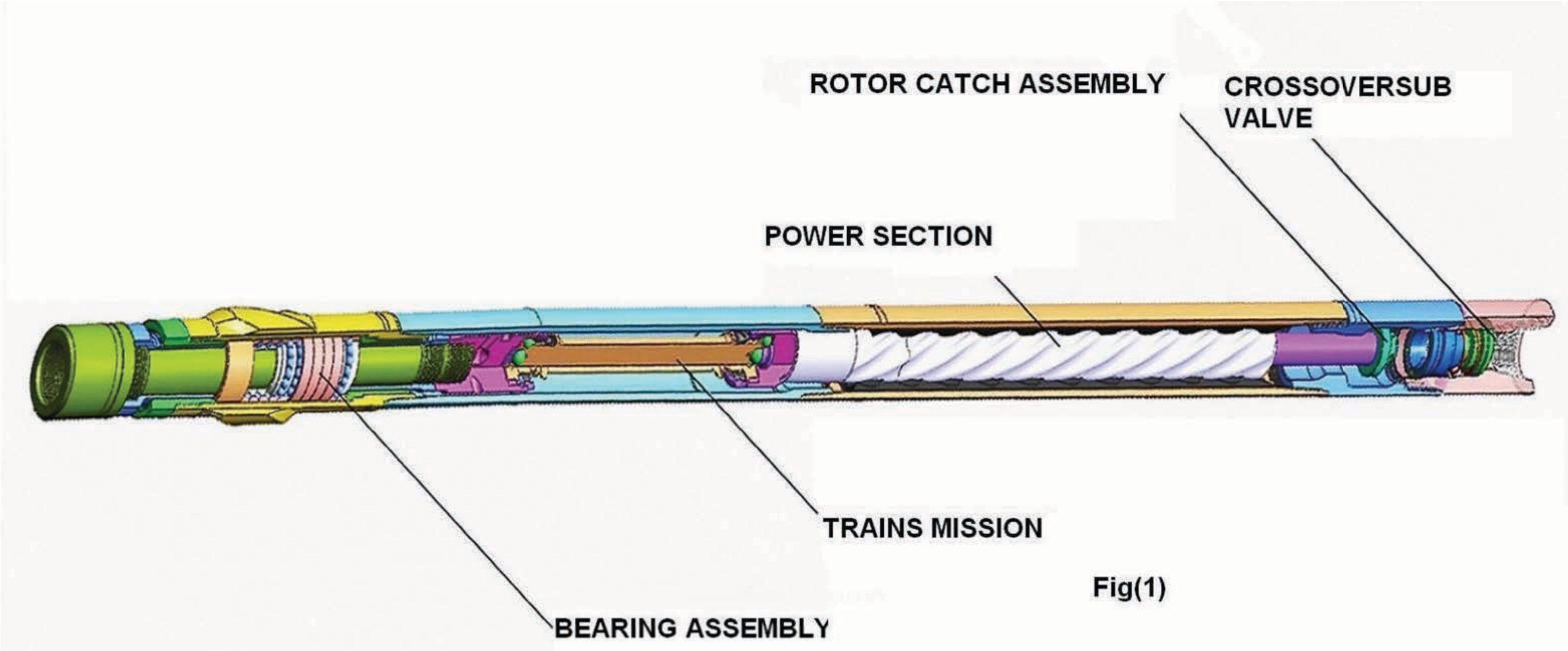
The angle and length of the jetting assembly (a.k.a. bent sub) can be varied to provide more or less steering bias to suit different soil conditions.

The top photograph shows an annular pressure sub immediately behind the jetting assembly. The annular pressure sub has a port in the side, which allows the monitoring of the downhole annular pressures during pilot hole operations. You can see the small pressure port in the annular pressure sub.

The bottom photograph shows the entire BHA made up and loaded onto the drill rig. With jetting assemblies, the distance from the bit to the steering probe located in the monel is relatively short (6 – 8 feet) which allows the pilot hole surveyor to see the affect of steering corrections over a relatively short distance.

GeoEngineers

Pilot Hole Tools – Mud Motors



These photographs show positive displacement mud motors used to drill pilot hole through rock formations. Drilling fluid is pumped downhole through the drill string and mud motor which rotates the drill bit at the front. Mud motors have a slight bend in the leading portion to provide a steering bias like that of jetting assemblies. Most mud motors have a fixed degree of bend while some have adjustable housings to vary the steering bias prior to use.

GeoEngineers

Pilot Hole Tools – Mud Motors

Mud motors have internal stators and lobes that along with the volume of drilling fluid pumped downhole dictate the power output of the motor. Large mud motors typically require a minimum drilling fluid flow rate of about 300 gallons per minute to provide adequate power.

The downhole steering probe is located in the monel behind the mud motor. When using a mud motor, the length of the mud motor creates a larger distance between the drill bit and the steering probe. This distance it typically greater than 20 feet. This distance makes it more difficult for the pilot hole surveyor to see the affects of steering corrections over short drilled distances as opposed to when using jetting assemblies.

A Bottom Hole Assembly with a positive displacement mud motor.

GeoEngineers

Reaming Tools – Soil Installations

After completion of the pilot hole the hole usually needs to be reamed to a larger diameter to accommodate the pipeline to be installed. For larger diameter installations, the hole is reamed in incremental steps to the final diameter.

Ring style flycutters are one type of reamer for soil installations and are typically of a simple design with no moving parts. Many HDD contractors fabricate their own flycutters. Ring style flycutters usually have radial arms with teeth that in conjunction with drilling fluid jets in the tool help cut through the soil. Some of these tools have an outer ring connecting the arms while some don't.

In highly plastic clays, the interior portion of the flycutter can become plugged with large chunks of clay that can later fall out and restrict the hole.

Reaming Tools – Soil Installations

Some HDD contractors use beavertail style flycutters like the one shown at the left. These types of tools are seen more often in smaller diameter installations but can be utilized in soils for any hole diameter.

The beavertail style flycutter is shaped somewhat like a mixing beater and seems to work well in highly plastic clay soils because it helps to break down larger clay cuttings into small fragments which are less prone to sticking together and eventually restricting the hole.

Don't be surprised to see many different styles of flycutters.

GeoEngineers

Reaming Tools – Hole Openers

Hole openers are used for HDD installations in rock. The hole openers shown on the left are sometimes referred to as split-bit hole openers because the cutters (cones) are mounted on individual arms attached to the body of the tool. The cutters rotate on a spindle and ball bearings, which are a part of the arms.

The bearings inside each cone are prone to wear which requires that the hours of use and/or revolutions be logged for each hole opener used. If the bearings in a cone fail, the cone may lock up and stop rotating or the cone may come off of the spindle. One factor in bearing failure is the pull force applied to the tool. If too much pull force is applied to the tool, the bearings can experience premature failure.

The hole opener in the top photo has centralizer arms that centralize the tool in the smaller hole in front of the reamer. In addition to centralizing the tool in the hole, the centralizer arms can help to trap a cutter if the bearings fail and it falls off of the arm. The hole opener in the bottom photo does not have centralizer arms.

Reaming Tools – Barrel Reamers

Barrel reamers are barrel shaped tools that are used primarily for swab passes after the hole is reamed to it's final diameter. Barrel reamers are not really used to ream or enlarge the hole. The job of the barrel reamer is to swab the hole prior to pullback operations. They help breakup any cuttings that have accumulated in the hole.

Barrel reamers are cylindrical in shape with tapered ends. Cutting teeth and drilling fluid jets are typically welded to the front and rear of the tool so that obstructions in the hole can be cleared out.

Barrel reamers can come in sizes ranging from around 12 inches to over 50 inches.

These types of tools are not typically used in rock installations because they lack the ability of break up rock fragments that may have accumulated in the hole.

Barrel reamer used for swab passes.

GeoEngineers

Pullback Assemblies

A pullback assembly used for HDD installations in rock. A pullback assembly for a soil installation would typically include a barrel reamer instead of a hole opener as shown above.

Prior to the beginning of pullback operations, a reinforced pullhead is welded to the leading end of the product pipe. A swivel connection (secured by the lifting strap in the photo) is made between the pullhead and the downhole drill pipe string. Typically, a reamer is included in the pullback assembly between the drill pipe string and the swivel to allow additional fluid to be pumped into the hole during pullback. The swivel allows the transfer of the pull load to the product pipe while reducing the transfer of rotation and torsion stresses to the product pipe.

The swivel should be pull rated to handle the pull force that can be applied by the drill rig. Often times the threaded connections within the pullback assembly are secured with steel bars welded across the tool joint connections. The pin in the shackle attaching the swivel to the pullhead should also be tack welded to prevent it from unscrewing during pullback.

GeoEngineers

Pullback Operations - Rollers

During pullback operations the product pipe pull sections needs to be supported and able to move freely to help reduce the pull force required to install the pipe.

The photos at left show different styles of stationary rollers that are used to support the pull section off of the ground and reduce resistance to movement. Rollers come in varies sizes and styles depending on the size of pipe to be installed.

The spacing of the rollers will depend on the size of the pipe being installed. The rollers should be designed to carry the weight of the pipe.

GEOENGINEERS

Pullback Operations – Roller Cradles

Roller cradles are used in conjunction with sidebooms and excavators to support the pull section. When used with sidebooms and excavators, the roller cradles are capable of supporting the pipe well above the ground. The pull section must be supported above the ground such that it naturally bends over and lines up with the hole. The break over part of the pull section (peak of the supported pipe) is called the overbend.

Roller cradles are made in several sizes to accommodate any diameter installation.

The lower photograph to the right shows a sideboom and crane outfitted with roller cradles to support the overbend of the pull section during pullback operations.

Specialty Tools – Pneumatic Hammers

Pneumatic hammers are sometimes used to assist the pullback process if the pull forces during installation become high or the pipe becomes stuck. Ideally, if the hole is adequately prepared prior to pullback, a pneumatic hammer should not be needed. The HDD contractor should be required to gain approval from the Company prior to the use of a hammer.

The current circumstances should be evaluated prior to approving the use of a pneumatic hammer. If a hammer is needed to continue the installation, it is likely that some kind of obstruction is causing the problem. In these situations, the risk of damage to the pipe or pipe coating is high. Depending on the length of pipe yet to be installed and subsurface materials, the use of a hammer may be warranted.

If the pipe becomes stuck during pullback, it is more appropriate to use the hammer to extract the pipe so that the hole can be reconditioned before reattempting the installation.

GeoEngineers

Specialty Tools – Buoyancy Control

Large diameter pipelines are buoyant in the drilling fluid filled hole during pullback operations. In practice, HDD contractors typically don't utilize buoyancy control for installations less than 24-inches in diameter. The use of buoyancy control can substantially reduce the pull forces required to install the pull section.

Buoyancy control for HDD installations usually consists of adding water to the product pipe pull section during pullback operations. The top photograph on the left shows an HDPE fill line being installed in the pull section prior to the start of pullback. The fill line is used to pump water from the trailing end of the pull section to the leading end of the pull section at the pull head. When adding water to control buoyancy, the volume of water pumped into the pipe should be monitored and recorded.

Alternatively, HDPE pipes may be installed into the pull section and the remaining annular space in the pipe can be filled with water or the pipes themselves can be filled. By carefully selecting the size of the internal pipes, the total buoyancy of the pull section can be fined tuned to a near-neutral buoyancy condition. While this is the most precise way to control buoyancy, it's rarely used because of the extra time and expense to implement.

Drilling Fluid Management

During HDD operations, large volumes of drilling fluid are often generated that need to be properly managed. In the early days of HDD, drilling fluid recycling (cleaning) systems were not common like today. At the time, drilling fluid was pumped to large pits where drilled cuttings were allowed to settle out so it could be reused. This was not an efficient process and resulted in a lot of wasted drilling fluid.

When planning a project, the disposal of the drilling fluid and cuttings needs to be considered. An efficient drilling fluid recycling system can greatly reduce the volume of drilling fluid that has to be disposed of.

Drilling fluid and cuttings contained in large open pits.

Drilling Fluid Management

Modern drilling fluid recycling systems can be very efficient at removing drilled cuttings from the drilling fluid if well maintained and set up properly. The more efficient the system, the longer the drilling fluid can be recirculated downhole before it needs to be disposed of because the weight of the fluid becomes too high.

The solids laden drilling fluid returns that surface at either the entry or exit point during HDD operations need to be “cleaned” prior to being pumped back downhole.

Most drilling fluid recycling systems consist of a mixing unit for mixing fresh drilling fluid and a two or three stage cleaning system. A three stage cleaning system consists of a scalper shaker which separates out the largest particles, a desander which filters out the sand size particles and a desilter which filters out the silt and clay size particles. Once the drilling fluid has passed through each stage of the cleaning system, it can be pumped back downhole.

Screens in the shaker beds can be changed to adjust the opening size depending on the materials being removed from the hole. The cuttings are usually collected in bins adjacent the cleaning system where they can be loaded into trucks for offsite disposal.

Downhole Survey Tools

Modern downhole survey tools are relatively compact and provide much more accurate surveys than the systems first used in the HDD industry. The photographs on the right show examples of the modern steering probes that use the Earth's gravitational and magnetic fields to determine the inclination and azimuth (compass) direction of the BHA. An insulated copper wireline inside the drill pipe string is used to take readings from the steering probe. The wireline leads from the probe to an interface box in the drill cab that is connected to the pilot hole surveyor's laptop computer. The wireline is extended with an additional section of wire each time a joint of drill pipe is added to the drill rig.

One complication with the steering probe is that the azimuth reading from the tool is prone to being influenced by outside magnetics. These can include buried steel elements, cathodic protection systems, vehicle and vessel traffic and other factors. The survey data needs to be evaluated to determine when outside magnetic interference is influencing the survey data.

Corrupted survey data can be problematic if secondary survey systems either are not used or cannot be installed along portions of the HDD alignment.

Secondary Survey Systems

Secondary pilot hole survey systems were developed to increase the accuracy of the downhole survey systems that are susceptible to magnetic interference.

The most common secondary system consists of an insulated copper wire laid on the ground surface along the HDD alignment. The wire is installed in a large loop with one side of the loop either along the HDD alignment or offset to one side. The other side of the loop is offset to the other side of the HDD alignment. By placing an electric current through the wire, a magnetic field is generated that the downhole survey probe uses to calculated its position relative to the wire. Some of these systems use DC current (TruTrack systems) while the ParaTrack system uses AC current. A secondary survey system allows for more accurate horizontal survey when the azimuth from the steering probe is corrupted by outside magnetics.

The ParaTrack system can also use a solenoid as shown in the bottom photo on the left. The solenoid is used to generate an artificial magnetic field without having to string a wire on the ground surface. The solenoid often gives a less accurate location relative to a wire installed on the surface but can be used in situations were a wire cannot be used.

Pilot Hole Survey

With the use of downhole survey tools and secondary survey systems, the accuracy of the survey is very good and allows for relatively tight tolerances. This is especially helpful now that HDD installations are being completed in areas congested with existing utilities and tight ROW limitations. The photos to the left show a Bottom Hole Assembly exiting the ground in very close proximity to the designed exit point.

Because of the accuracy of these systems and the ability to record the data for as-built purposes, we do not recommend that walk-over locator systems be used for the installation of high pressure petroleum pipelines. The accuracy of walk-over locating systems can equal that of downhole survey systems but many times there is no record of the data after completion of the pilot hole.

GeoEngineers

Other Pilot Hole Tools

The top photo to the left shows a gyroscopic steering tool. The inclination and azimuth of the BHA are calculated through the use of fiber-optic gyroscopes rather than the Earth's gravitational and magnetic fields. Because of this, the azimuth is not susceptible to corruption by stray magnetics like the more traditional downhole survey tools. The use of a secondary survey coil wire installed along the alignment is not utilized with this system but this capability is rumored to be forthcoming.

The bottom photo to the left shows an annular pressure tool. The tool is a short sub adapter that is installed on the front of the monel in the Bottom Hole Assembly. A pressure port in the side of the tool allows the downhole steering probe in the monel to sense the annular pressure in the hole. This way, the annular pressure can be continuously monitored and recorded if necessary. This capability is useful to compare the downhole pressures with those estimated from a hydraulic fracture analysis. If downhole pressures are substantially higher than estimated, it may indicated a restriction in the hole. In this way, the HDD contractor may take measures to clear the restriction before inadvertent drilling fluid returns (frac outs) occur.