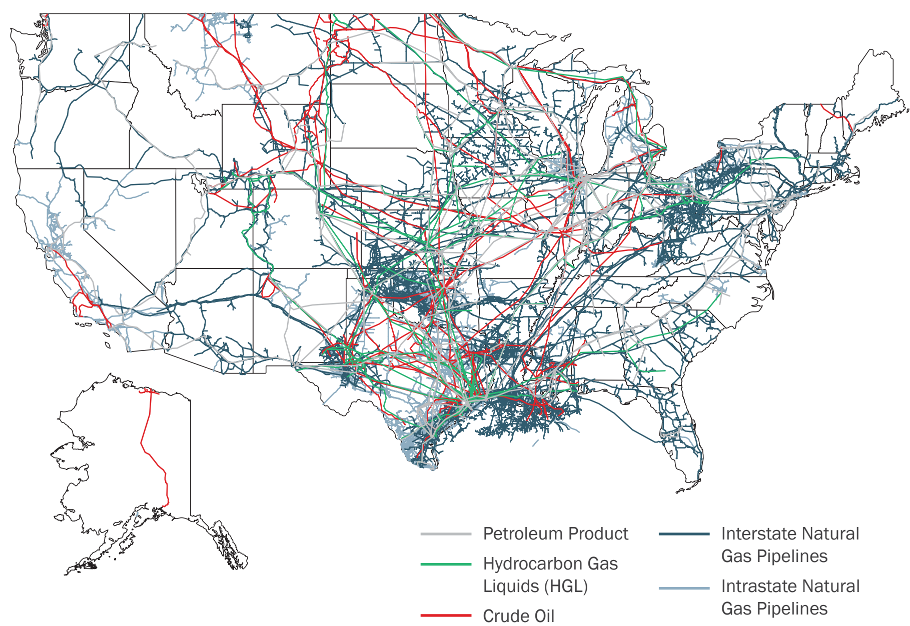
Pipelines: A CRUCIAL PIECE OF MODERN INFRASTRUCTURE

Pipelines are the arteries carrying the lifeblood of the world's energy, utility, and industrial networks. In the United States alone, more than 2.7 million miles (4,345,229 km) of pipelines[1] carry natural gas, crude oil, water and other products used in manufacturing and industrial processes and everyday life. Pipelines are a cornerstone of our modern society's infrastructure. While transporting liquids and gasses by any method will always carry some risk to human health and the environment, pipelines have proved to be significantly safer, more reliable, and more economical than competing transportation methods[2] such as rail or tanker trucks.

Constructing and installing the pipelines that make up our vast energy network is often challenging. Laying pipeline in an empty field may not be difficult, but pipelines must also cross obstacles such as rivers, highways, and densely developed areas where digging surface trenches is difficult or impossible. To install pipelines efficiently and safely in areas with surface obstacles, professionals don't dig trenches at all—they use *trenchless technology*. One effective and common trenchless approach is known as horizontal directional drilling (HDD). In this document, we'll learn about HDD and how this construction technique helps reduce risk in pipeline infrastructure.



SOURCE: U.S. ENERGY INFORMATION ADMINISTRATION

What is Horizontal Directional Drilling?

Traditional open cut pipeline installation (digging a trench and laying the pipe in it) can be very challenging when a pipeline must cross under obstacles. Instead of a surface trench, the HDD approach involves drilling a horizontal hole beneath obstacles and pulling the pipeline through the hole.

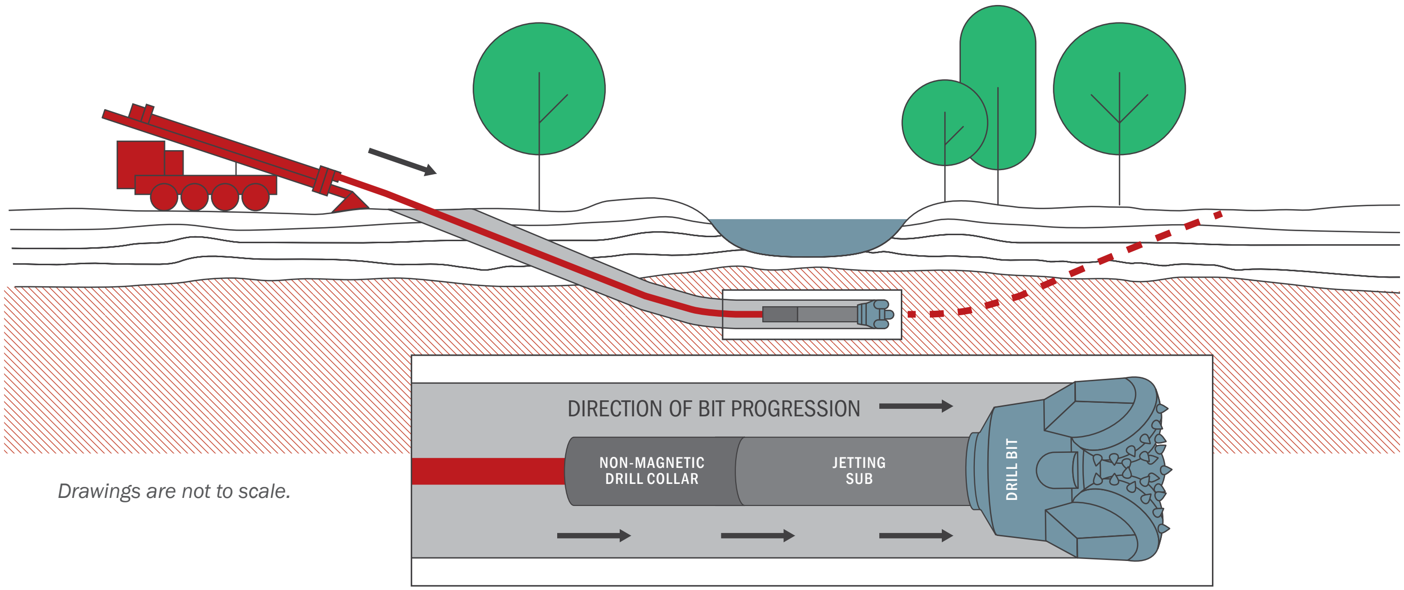
To complete an HDD installation, specialized HDD construction contractors attach steerable drill bits, reamers, tracking and monitoring devices and other tools to the end of a drill pipe string, then slowly drill a hole underneath an obstacle from one side to the other along a path that has been carefully evaluated, permitted, and designed by engineers and scientists. HDD contractors can avoid subsurface obstacles and follow an established path by steering the drill bit both horizontally and vertically while drilling the initial small-diameter pilot hole. This allows them to aim for a precise exit point before reaming the hole to a larger diameter and pulling the pipeline into place.

Although HDD is a valuable pipeline installation approach in many scenarios, there are limitations and considerations. Long-term maintenance on HDD pipeline installations can be more expensive and complex because the pipeline is deeper and less accessible than it would be in a shallow trench. Physical and technical realities can significantly alter the risks of any HDD project. Topographic features, subsurface characteristics, permitting specifications, and timeline requirements can all determine the feasibility of an HDD. Like all construction, HDD does carry risks, and a site evaluation by a professional engineer is recommended to understand the advantages or disadvantages for any given project before deciding on a pipeline installation approach. See page XX for a detailed analysis of the risks and benefits of HDD.

THE BOTTOM LINE

HDD is a useful construction technique that involves installing pipelines without digging a trench from the ground surface, which reduces impact to the natural environment. But HDD is not always appropriate or possible, and installations may fail or cause disturbance if undertaken without enough preparation and study. During the design process, the construction risks associated with the installation should be evaluated and reduced by thoughtful design and sometimes special construction procedures.

HDD ALLOWS PIPELINES TO BE INSTALLED BENEATH SURFACE OBSTACLES LIKE RIVERS OR ROADS.



Drawings are not to scale.

PILOT HOLE

REAMING AND SWABBING

PULLBACK

CLICK TO INTERACT

01

PILOT HOLE

Contractors drill a small diameter (6-12”) pilot hole, carefully monitoring and steering the drill bit to closely follow the designed alignment below the obstacle.

The HDD Process

There are three basic steps to install a pipeline by HDD: drilling the pilot hole, reaming (enlarging the hole), and pulling the pipeline into the reamed hole.

There are many checks and balances during the process to help mitigate risk, such as having an HDD inspector or pipeline owner’s representative on site to observe construction activities and compliance with engineering specifications and permit requirements. These representatives can confirm and document contractor adherence to project plans, specifications, regulatory requirements, and help the contractor and owner make decisions based on real-time data.

PILOT HOLE

Drilling the pilot hole is the first stage of the HDD construction process. During this critical step, a drill crew advances a small-diameter drill bit and pipe assembly horizontally underground, drilling a hole along a specified path according to the engineered design. The pilot hole starts small, usually between 6 and 12 inches in diameter (15 to 30 cm).

To help the drill bit cut through soil and rock, the contractor pumps drilling fluid through the drill pipe string. The fluid exits the drill string through jet nozzles in the bit, lubricating and cooling it. The drilling fluid also suspends and carries the soil and rock cuttings from the hole back to the surface through the annular space (annulus) between the drill pipe string and the wall of the hole.

THE PILOT HOLE ENTRY PIT AT AN HDD SITE

Different conditions (for example, soil or rock) require slightly different approaches and tools. Engineers design for the subsurface conditions as they were known or interpreted during the design phase, and contractors determine the types of tooling that might be required before construction begins.

HDD contractors track the path of the pilot hole using a downhole steering probe that measures the location of the drill bit in relation to the designed path. Pilot hole surveyors can carefully track the drilling progress of the pilot hole with the steering probe to help make steering corrections to match the design.

Drilling Deeper: Drilling Fluids

Drilling fluid is a key part of the HDD processes. HDD contractors use this nontoxic fluid to drill through soil and rock. It is very similar to drilling fluid used to drill drinking water wells. Drilling fluid is 96 to 97 percent water with a mixture of 3 to 4 percent naturally-occurring bentonite clay (sodium montmorillonite) and small amounts of biodegradable polymers. Contractors take precautions and comply with applicable environmental regulations, but small amounts of drilling fluid released into the soil is not considered a significant environmental threat.

Fresh drilling fluid is about 1.5 times denser than water, weighing about 9 pounds per gallon (1,040 kilograms per cubic meter), and it is chemically benign. The function of drilling fluid is to:

- Maintain the drilled hole's stability.
- Clean, cool and lubricate the tooling used during the HDD.
- Suspend and carry cuttings to the surface.

Observations made during pilot hole operations provide real-time information to the HDD construction contractor that can be compared to the initial subsurface characterization report that geologists or geotechnical engineers prepare in advance of the project. These observations may confirm that proper tools, drilling techniques, and drilling fluid properties have been selected. The information obtained during pilot hole operations includes the pilot hole survey data from the steering probe, the effectiveness of steering patterns, rates of penetration, rotary drill string torque, loss of drilling fluid into the subsurface, and visual assessments of removed cuttings.

REAMING AND SWABBING

The hole-opening (reaming) process typically begins after the pilot hole is complete and the path is accepted by the owner to meet the project requirements. A reaming tool is used to enlarge the pilot hole to a diameter that will accommodate the pipeline, sometimes requiring multiple reaming passes with progressively larger reaming tools. Two types of reaming tools are most often used to enlarge the pilot hole. Fly cutters are used for most soil formations, and rock hole opening tools are used for very dense soil or rock formations.

The reaming tools are typically attached to the drill pipe string after it has emerged from the ground at the exit point. The reamer can then be rotated and either pulled back through the hole toward the drill rig on the entry side of the crossing, or advanced from the drill rig to the exit side of the crossing. To keep the reamer cool and clean, contractors pump drilling fluid down the hole through the drill string. The fluid exits the reaming tool through nozzles, helping carry the cuttings back to the surface through the annulus. As the reamer is pulled back toward the drill rig, a string of drill pipe is added behind the tool (tail string) to maintain a continuous section of drill pipe in the hole. The diameter of each reaming pass increases in incremental steps until the desired diameter is reached—typically 12 inches (30 cm) larger than the pipeline for diameters equal to or greater than 24 inches (61 cm), or 1.5 times larger than the pipeline for diameters less than 24 inches.

After the reaming passes are completed, the HDD construction contractor typically completes a swab pass, which generally consists of a barrel reamer or hole opener being pulled through the hole. HDD professionals use swab passes to check the stability of the hole, help remove excess cuttings, provide fresh drilling fluid immediately prior to pullback, and help confirm the hole is in a condition to receive the pipeline. After completing one or more acceptable swab passes, contractors typically move on to the pullback phase.

A BUNDLED PULLBACK ASSEMBLY WITH BARREL REAMER

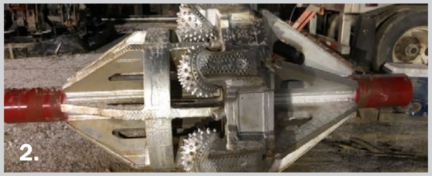
PULLBACK

The last step in a successful installation is pulling the pipeline into the enlarged hole (pullback operations). If the diameter of the product or carrier pipe is greater than 24 inches (61 cm), the HDD contractor may consider using a technique known as buoyancy control. By pumping a fluid (typically water) into the pipeline during pullback, contractors can reduce the positive buoyancy and reduce installation forces—essentially weighing down the pipe to prevent it from floating in the drilling fluid.

Prior to the beginning of pullback operations, a reinforced pull head is welded to the leading end of the pipeline. This piece of hardware is strong enough to withstand the forces generated while pulling the pipeline into the hole with the drill rig. A swivel connection and reamer are included between the pull head and the downhole drill pipe string. The swivel helps transfer the pull load to the pipeline while reducing the transfer of drill string rotation. The reamer allows additional fluid to be pumped into the hole and helps clear potential obstructions during pullback.

During pullback, a combination of roller stands and pipe-handling equipment (cranes, side booms, and excavators) typically supports the product pipeline. In addition to support, this equipment protects the pipeline by directing it into the hole at the correct angle while preventing excessive bending and tension during pullback. After the pipeline is pulled into place, the installed pipe is typically tested, cleaned, and welded to the trenched portion of the pipeline on each side of the HDD to complete the segment.

Drilling Deeper: HDD Tools and Their Functions



1. **Drill Bit:** Attached to the lead portion of the drill string during pilot hole operations. Accompanied by a downhole steering probe for subsurface location and navigation.
2. **Reamer:** A rotary cutting tool included in a drill string. Used to enlarge the size of a pilot or reamed hole and during swab and pullback operations.
3. **Mill Tooth Reamer:** A style of reamer with open blades used to ream holes in hard ground or soft rock formations.
4. **Barrel Reamer:** A barrel shaped reamer with limited cutting capacity. It is commonly use during swab passes and pullback.
5. **Hole Opener:** A style of reamer with rolling cutters, used to enlarge holes in hard rock and soil formations.

THE BOTTOM LINE

Installing a pipeline via HDD consists of three main steps. First, contractors drill a smaller pilot hole, carefully monitoring the position and steering the drill pipe string to achieve the designed alignment and profile. Next, the hole is enlarged by reaming it out with progressively larger diameter cutting tools. Finally, the pipeline is pulled back through the hole, cleaned, and tested for integrity. Most oil and gas HDD installations use high strength steel pipe, ranging in diameter from a few inches to 60 inches (152.4 cm) and lengths from a few hundred feet to well over one mile.

Understanding an HDD Project Site

STEP 1: SITE INVESTIGATION

HDD pipeline installation typically begins with months or years of site investigations and planning before a project ever reaches the construction phase. The first step toward designing an HDD is investigating the proposed installation site and characterizing the topography, subsurface materials, environmentally sensitive areas, and structures there.

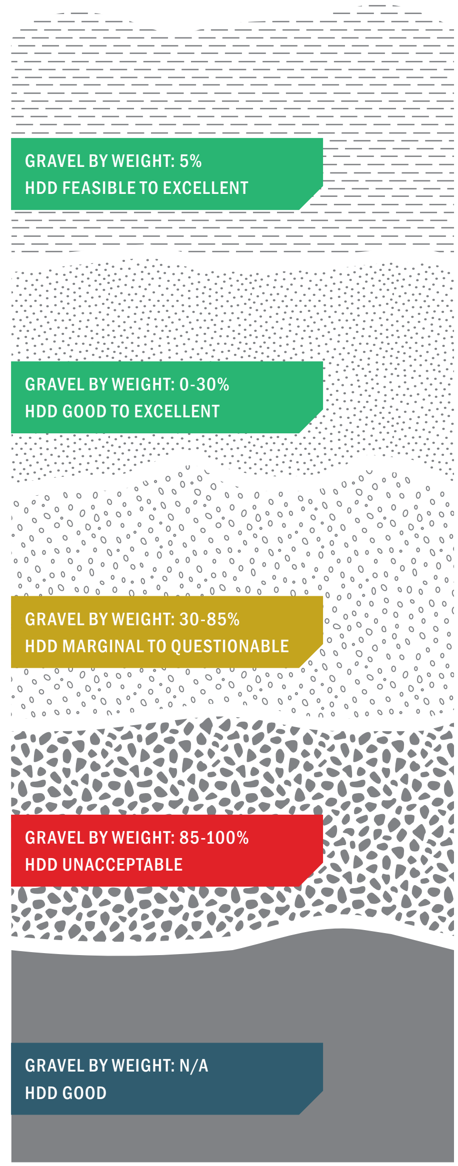
HDD design engineers use a variety of technical approaches to learn about a site, and each can provide unique insights. Topographic surveys along the proposed *HDD alignment* and within the entry and exit workspaces help designers plan the route around geographic or structural limitations on the surface. Existing roadways, railroads, utilities, buildings, and other structures both above and below the surface must be identified and considered in the overall design. When an HDD must cross beneath a waterway, engineers typically perform *bathymetric surveys* of the river bottom.

A GEOTECHNICAL DRILL RIG AT A SITE INVESTIGATION

Drilling Deeper: Geotechnical Borings

Depending on the judgment of the geotechnical engineer, borings may be spaced approximately every 500 to 1,000 feet (150 to 300 meters) and offset from the proposed HDD alignment by a minimum of 25 feet (8 meters) and a maximum of 100 feet (30 meters), when possible. The number and location of the borings is generally based on site-specific conditions and practical economic limits. The borings typically extend below the anticipated depth of the pilot hole a minimum of 20 feet (6 meters).

HDD Feasibility in Various Types of Soil and Rock



CLAY OR SOFT SOIL

Steering in soft soil layers may be difficult and there can be hydraulic fracture potential if the soil is too soft. Proper tooling needed when clay is dense and sticky.

SANDY SOIL

Low risk of fluid loss or hydraulic fracture.

GRAVELY SOIL

Increased gravel content can cause steering challenges in dense areas, and fluid characteristics are important to avoid formation loss.

GRAVEL OR COBBLED ROCK

Drill penetration is very difficult or impossible, and dense gravel (or larger cobble) should always be avoided.

ROCK

Weathered rock can offer good HDD characteristics, but requires more time, heavier tooling and equipment will wear more rapidly. HDD is less feasible in areas where rock formations are interspersed with softer soils.

A LAB WORKER PERFORMING A SOIL TEST

To understand conditions below the surface, HDD designers rely on *geotechnical engineering* investigations. Geotechnical drill crews drill vertically into the ground at pre-determined locations along the HDD alignment, extracting samples of the soil and rock that lie beneath. In general, HDD projects require at least two borings (sometimes many more), and they must extend deep enough to sample material beneath the estimated depth of the HDD. Depending on the specifics of each project, engineers may perform additional investigations to better define the subsurface conditions. These can include geophysical methods such as electrical resistivity, seismic, or ground-penetrating radar surveys.

LAB WORK AND CHARACTERIZATION

After soil or rock samples are collected in the field, they are transported to a geotechnical laboratory where they are classified and tested for strength. Common tests include soil-moisture content, grain-size analyses for classification, shear strength, hardness, and abrasiveness.

HDD designers take the results from the site investigation and integrate them with the original pipeline route and conceptual HDD design to evaluate its feasibility and finalize it before proceeding to the construction phase.

STEP 2: EVALUATING GEOTECHNICAL DATA ON SOIL CONDITIONS

After the site investigation is completed and engineers have their subsurface soil and rock data, they can evaluate construction risks associated with the geotechnical conditions.

HDD can be used in a wide range of subsurface conditions. Each type of geologic formation presents its own set of characteristics that need to be considered during the design and construction phases of an HDD project. In general, the two categories of subsurface materials are soils and rock, with each category consisting of a wide range of different materials. In some cases, an HDD may need to penetrate through both soils and rock.

Soils: Generally considered easily drillable for HDD installations, but gravels can make drilled holes unstable and prone to drilling-fluid loss. Larger granular soils such as cobbles and boulders can also be problematic. See the illustration on page 6 for descriptions of various soil types. In general, low shear strength soils have a higher risk of *hydraulic fracture* and *inadvertent drilling fluid returns*.

Rock: Also typically considered drillable, but more robust tooling specifically designed for rock formations is required. Installations in rock require significantly more time to complete than installations in soil. Existing fractures in rock can also cause hole instabilities and drilling fluid loss while the abrasiveness of the rock can accelerate tool wear.

THE BOTTOM LINE

Before construction on an HDD project can begin, engineers and contractors must have a detailed understanding of the site conditions. Depending on the site, a project team uses a combination of investigative techniques to gather data. Geotechnical investigations characterize the subsurface materials at the site by taking samples of soil and rock along the pipeline's path and characterizing it in a lab. Civil surveys define surface and subsurface infrastructure. Geophysical investigations use technologies like ground-penetrating radar on the surface to map subsurface features. Environmental investigations identify natural and cultural resources at the site so HDD professionals can abide by applicable regulations. Engineers analyze data from these investigations to make technical recommendations and evaluate construction risks.

THE ENTRY PIT WORKSPACE AT AN HDD SITE

Designing an HDD

Armed with site-specific geotechnical and survey data, engineers move to the design phase. HDD installations are significant civil infrastructure projects with potential risk to the environment and public if the pipeline is damaged during installation. Engineers consider a wide range of geometric and technical parameters and can reduce risk through careful design and planning. The design engineer of record should be identified on the project plans and accompanying contract documents.

ENTRY AND EXIT SITES

The HDD's entry and exit workspaces are critical to an installation's success. First, designers must consider the physical constraints of the workspace. They look for a site with a minimum of utilities, roadways, railroads, overhead power lines, and other structures that could interfere with the installation. The proximity of schools, neighborhoods, and businesses can also affect the selection of a site. Construction noise can be problematic for adjacent landowners and may require mitigation techniques such as temporary sound barriers.

Drilling Deeper: Radius of Curvature

HDD designers establish a minimum allowable radius of curvature for the pilot hole so the pipeline can be pulled through without exceeding stress limits and jeopardizing its integrity. Under generally-accepted industry standards, the design radius in feet for the entry and exit vertical curves is typically 100 times the product pipe diameter in inches (for example, 20-inch diameter pipe x 100 = 2,000 foot design radius). Depending on the proposed operating conditions, pipe specification, and geometric considerations, the design radii for the horizontal and vertical curves may vary from this standard.

Sites should also be accessible to the contractor's heavy HDD equipment. Weight limitations of nearby bridges, the height of overhead lines, and other factors can make site access more difficult. Sometimes site improvements, such as clearing and grading, may be required within the workspaces and along the access routes. In some cases, construction teams use temporary timber mats to provide additional support for heavy equipment and reduce ground disturbance.

HDD DESIGN GEOMETRY

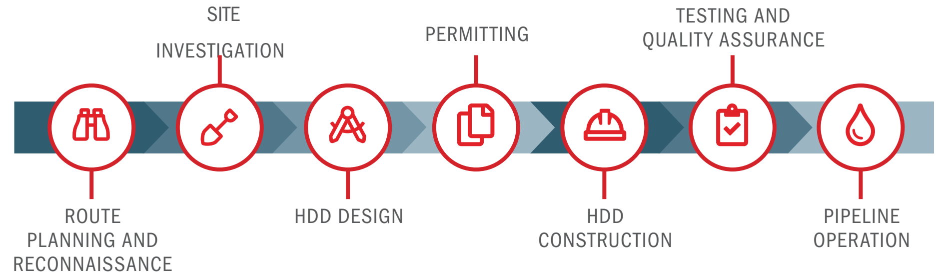
The geometry of an HDD installation refers to the planned underground path of the drilled hole and pipeline. Engineers consider physical site features, the proposed HDD alignment, subsurface conditions, potential obstacles, and sensitive environmental features before calculating a geometric profile for the pipeline. At a minimum, engineers evaluate the following items while conducting the site visit and reviewing the conceptual HDD design.

- The vertical separation between the lowest elevation of the obstacle being crossed (i.e., a river) and the HDD profile.
- The vertical and horizontal separation between the HDD path and existing pipelines, utilities, roads, railroads, and other structures.
- When crossing a water body, engineers consider the width and depth, but also the potential for bank migration and scour during the design life of the crossing.
- The existing topography and its variation in the area of the HDD; particularly with respect to the depth of cover of the proposed HDD and risks of inadvertent drilling fluid surface release during construction.
- Rock outcroppings, gravel, or boulders visible along the proposed HDD alignment or within the immediate area may hint at possible subsurface conditions.

As a general rule, the design engineers attempt to keep the geometry of the HDD alignment and profile as simple as possible to reduce the risk of complications during HDD operations.

If a horizontal curve in the alignment is required, engineers try to design straight tangents between curved segments to reduce stress on the pipeline and make it easier to complete the pilot hole within acceptable tolerances. Combined radius curves—where the profile is simultaneously curving in both the horizontal and vertical planes—are undesirable from a construction and pipe-stress perspective but are sometimes necessary and not uncommon. Each HDD profile is designed to achieve the shortest possible length (given the entry and exit angles selected) while maintaining the necessary depth. The pipeline's depth is based on site-specific obstacles and subsurface conditions and the required radius of curvature for the particular pipeline diameter being installed.

Typical HDD Project



PIPELINE PROPERTIES

The diameter and type of pipeline requiring installation will also have an impact on the design. Different pipelines will have different stress and bending radius tolerances. A steel pipeline can be damaged during installation if pushed beyond its mechanical limits—leading to additional reaming and swab passes, pipe replacement or reinstallation.

Pipe requirements for HDD differ from open-cut pipelines due to loads and stresses that act on the pipe during pullback operations. Pipe properties must be suitable for both installation and operation.

THE BOTTOM LINE

Many factors influence HDD design. Generally, a well-designed HDD is as simple and efficient as possible, considering the conditions. Where possible, it should contain gradual curves and pass through stable geologic formations. Engineers also consider the long-term stresses that will affect the pipeline, the route's proximity to the surface and potential geologic hazards. Risks during HDD installation can be significantly reduced when all these factors are carefully considered in the design phase.

HDD Risks

As with any construction activity, there are a number of risks to be considered when preparing to install pipeline by HDD. Many of the risks mentioned below are interrelated. Designers should assess risk and potential mitigation options on a broad basis—considering multiple risks, mitigations, and their impacts collectively.

DRILLING FLUID CIRCULATION LOSS

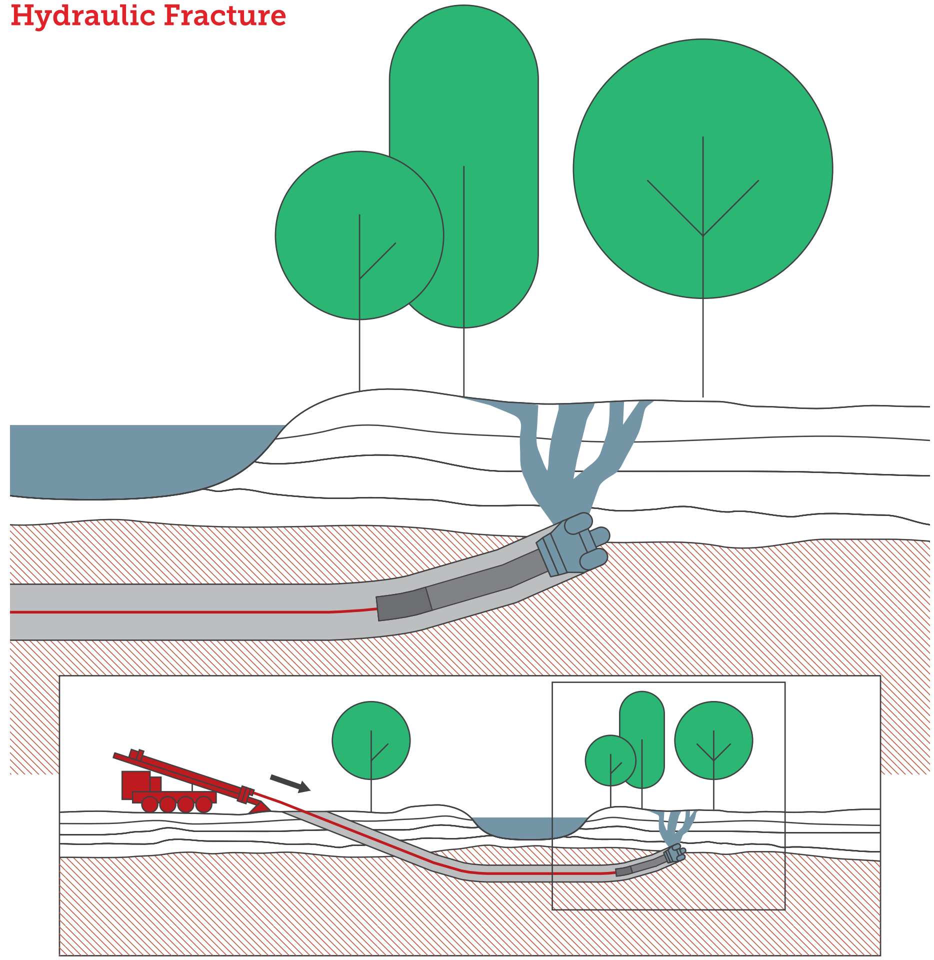
Ideally, drilling fluid flows through the annulus of the drilled hole back to containment pits at the entry or exit points, where it then passes through a cleaning system to remove solids (cuttings) before being reused. In some cases, however, drilling fluid can escape the HDD hole and leak into the surrounding formation. In extreme cases drilling fluid can reach the ground surface, a phenomenon known as inadvertent drilling fluid return.

Formational drilling fluid losses typically occur when drilling fluid flows through porous soil surrounding the HDD profile, or within fractures or voids in rock masses. Silty sands, silts, clays and competent rock typically have a low susceptibility to formational drilling fluid losses. Coarse sand and gravel units with low percentages of silt and clay or rock with abundant fractures, voids, or bedding planes have a moderate to high susceptibility for drilling fluid loss.

In some cases, drilling fluid is lost because of hydraulic fracture. Hydraulic fracture occurs when the drilling fluid pressure exceeds the strength of the surrounding material to contain it. The risk of hydraulic fracture is greatest when the drill path passes through relatively weak (low shear strength) soils. Very loose to loose sands and soft to medium-stiff silts and clays typically have a higher hydraulic fracture potential. Stronger soils, such as medium dense to very dense sands and very stiff to hard silts and clays generally have a low to moderate hydraulic fracture potential.

Properly managing drilling fluid flow and composition by employing industry best practices during the drilling process can reduce drilling fluid loss in the formation and lower the risk of hydraulic fracture.

Hydraulic Fracture



Drawing is not to scale.

INADVERTENT DRILLING FLUID RETURNS

Inadvertent drilling fluid returns occur when drilling fluid flows into the formation and eventually emerges at the ground surface or in any other undesired location such as wetlands, utility trenches, basements, roads, railroads, or water bodies. Inadvertent returns, whether as a result of formational drilling fluid loss or hydraulic fracture, have the potential to release relatively large volumes of drilling fluid over a short period of time, particularly if the high-pressure drilling fluid pumps are not immediately disengaged.

Drilling fluid spilled onto the ground surface can create a considerable mess. If released into a water body, the drilling fluid increases the turbidity (cloudiness) of the water, which can impact some aquatic species if the release is substantial. During construction, contractor personnel will walk the HDD alignment to monitor for the release of drilling fluid to the surface. Responsible HDD teams typically develop contingency and mitigation plans for the construction phase, should a surface release occur.

In practice, inadvertent drilling fluid returns typically occur close to the entry and exit points where the soil cover is thin, and the shear strength of the near-surface soils is often lower. Inadvertent drilling fluid returns can also occur at locations along a drill path where there are low shear strength soils, where the thickness of soil cover is thin or along pre-existing fractures or voids. Other locations where inadvertent drilling fluid returns can occur include geotechnical exploratory boring locations or along the edges of existing subsurface structures such as basements, piles, or utility poles.

PIPELINE DAMAGE DURING PULLBACK

Pipelines can be damaged in a variety of ways during installation. If the pipeline is damaged, it must be pulled back out of the hole and repaired or replaced. Prior to attempting to re-install the pipeline, contractors and the HDD design team re-evaluate the hole to determine the possible cause of the damage and mitigation measures to prevent pipe damage during the second attempt.

DAMAGE MECHANISMS

- The hole may contain sections with a radius of curvature so small that the pipeline cannot conform to the resulting geometry during pullback—causing the pipe to become stuck. This may be due to the nature of the subsurface materials, original pilot hole geometry, or reaming practices utilized by the HDD contractor.
- If buoyancy-control measures are not used during the pullback process, increased friction between the pipeline and formation could lead to an increase in the pulling load. The pipe and protective coatings could be damaged if excessive pull force is applied.
- Cuttings may accumulate in the hole and unstable sections can contain gravel or cobbles. These obstructions can significantly increase pull forces during pullback, increasing the risk of pipe and/or coating damage.
- The reamed hole may be offset (non-concentric) from surface casing that is sometimes used to stabilize overburdened soil and provide other benefits. The pipe can then contact the casing at its end, causing mechanical damage to the pipe coating and potentially the pipe material.
- The pipe and/or coatings can also be damaged as a result of improper handling of the pipe during installation. Contractors develop lift plans prior to pullback to define how the pipe will be supported and what equipment will be necessary to facilitate installation.

HOLE INSTABILITY

The stability of the hole during HDD operations typically depends on the type and composition of the formation, hole diameter, drilling fluid properties, groundwater conditions, and the HDD geometry. Holes drilled or reamed through loose soil formations, soil formations with significant gravel content, and rock formations with poor rock mass quality are prone to instability.

If there is a significant elevation difference between the entry and exit points, the drilling fluid elevation in the hole will tend to equalize to the lower of the two points once the pilot hole is completed. Because a portion of the hole is then situated above the drilling fluid equilibrium elevation, this creates a “dry” section within the hole, which can increase the risk of instability and other problems during construction operations.

- In soil formations, this instability can contribute to collapse of the hole, eventually leading to ground-surface settlement and the potential formation of sinkholes along the HDD alignment. Tooling may also become stuck downhole, and the product pipe may get damaged or stuck during installation.
- In rock formations, dry hole sections are generally more stable and less prone to collapse than in soil formations.
- Groundwater influx into the dry hole section can cause hole instability in soil formations and the groundwater dilutes the drilling fluid, reducing its effectiveness.
- Elevation differential can also lead to hole-flush risk, as fluid can be backed up into the dry hole section if the hole collapses or cuttings plug the hole. In a hole-flush event, the fluid backs up to the point where the plug no longer holds, and the fluid and cuttings rapidly exit (or flush) out the low side of the crossing.

POOR CUTTINGS REMOVAL

An important aspect of the HDD process is removing cuttings from the drilled hole. If soil and rock cuttings are not adequately removed from the annulus of the hole, it increases the risks to a successful installation. When cuttings build up in the annulus, rotary torque on the drill string will typically increase along with tooling wear and the risk of stuck tooling. The risk of inadvertent returns increases, and the risk of hole flushing increases if significant elevation difference exists between entry and exit. At worst, tooling may be lost downhole and/or the pipeline itself could become lodged during pullback. Larger gradation soils (gravels, cobbles and boulders) are particularly prone to poor cuttings removal because they are often too unstable to be effectively cut and broken down into smaller pieces that can be carried out of the hole by the drilling fluid.

STEERING DIFFICULTIES AND PILOT HOLE ALIGNMENT RISKS

Several factors may lead to steering difficulties and poor hole geometry. Formations with highly variable strength and density characteristics can make it difficult to develop a reliable steering pattern during pilot-hole operations. Where the HDD passes through soil deposits with significant cobble and boulder content or a distinct soil/bedrock contact, the tooling tends to deflect away from the harder zones and towards softer zones. These deflections can lead to poor hole geometry or tight (low radius of curvature) zones through which it is difficult to pull the product pipe.

THIS EXPOSED SECTION OF PIPELINE IS POTENTIALLY VULNERABLE TO GEOLOGIC HAZARDS.

GEOLOGIC HAZARDS: LANDSLIDES, RIVER SCOUR AND MIGRATION

HDD professionals stay alert for geologic hazards that may increase risks during installation. These hazards primarily include landslides, river scour, and river migration. Unless designers identify and evaluate these hazards early during the design phase, the pipeline may be exposed, damaged or ruptured during its design life. HDD professionals may complete additional borings, geophysical surveys, geologic site reconnaissance and geologic desktop analyses to better understand and mitigate hazards.

- Landslides can present a significant risk to any pipeline installation within a potential slide mass. A landslide along a pipeline alignment can expose or even rupture the pipeline. Geologic maps, site reconnaissance, 3D surface mapping (LiDAR), and geotechnical investigations can help identify potential landslide hazards.
- River scour and migration can expose a pipeline to the flow of a watercourse if it is not installed deep enough below the scour depth or outside of the *channel migration* zone over the lifetime of the pipeline. Exposure can lead to damage and ruptures if debris in the channel impacts or gets caught on the exposed pipe. Geologic studies, site reconnaissance, and historic aerial photography can help identify these hazards.

Mitigating HDD Risks

It is never possible to completely avoid risk, but each of the issues discussed in the previous section can be mitigated, or made less likely, if precautions are taken. HDD engineers and contractors can often minimize potential risks by simply following industry best practices. The sections below summarize techniques and strategies to reduce risk and bring an HDD installation to a successful completion.

TARGET HIGH-SHEAR-STRENGTH SOILS

By designing an HDD profile that goes through *high-shear strength* (more stable) soil or competent bedrock, engineers can reduce the risk of hydraulic fracture and inadvertent drilling fluid release, hole instabilities, and pipeline damage during pullback.

Paying careful attention to the subsurface features of the site can also reduce the risk of damaging the pipeline during pullback. The design geometry should, to the extent possible, always avoid formations where hole stability is a concern. Transitions from weak to strong formations can cause pipeline alignment issues during pullback, especially when encountered at shallow angles. Engineers can reduce the risk of instability by avoiding lengths of dry hole through soil formations and gravelly/cobbly soils and carefully managing any transitions between weaker and stronger formations.

MANAGE ANNULAR DRILLING FLUID PRESSURES

Carefully managing downhole annular drilling-fluid pressures can reduce the risk of hydraulic fracture. During pilot hole operations, high annular drilling-fluid pressures (which may lead to hydraulic fracture and inadvertent returns) can be caused by insufficient removal of cuttings, hole collapse, or excessive penetration rates. Contractors monitor annular pressures with a downhole annular pressure tool during the pilot-hole process.

If the contractor operates with inadequate pump output rates, less than ideal drilling fluid properties, or excessive rates of penetration, the annulus may become blocked by drill cuttings that fall out of suspension in the drilling fluid. If the accumulation creates a blockage downhole, the annulus may become over-pressurized, leading to hydraulic fracturing and potential inadvertent drilling fluid returns.

CAREFULLY MANAGING DOWNHOLE ANNULAR DILLING-FLUID PRESSURES CAN REDUCE THE RISK OF HYDRAULIC FRACTURE.

COBBLES AND DEBRIS ARE CLEARED FROM A HOLE DURING A SWAB PASS.

LARGER-DIAMETER CASING CAN BE USED TO SUPPORT THE HOLE DURING CONSTRUCTION.

Maintaining drilling fluid returns to one or both of the pits at the ends of the crossing is the primary way to promote good cuttings removal and mitigate the risks caused by the accumulation of cuttings in the hole. The contractor may need to pump fluid at higher flow rates or make multiple passes through a problematic area to help clear cuttings and move them to the surface for disposal. This can be a delicate balance, and contractors use a number of factors to determine pump and penetration rates that reduce the risk of hydraulic fracture and inadvertent drilling fluid returns. It should be noted that when drilling through weak soils, it may not be possible to maintain annular pressures low enough to prevent hydraulic fracture.

CLEAR OBSTACLES WITH SWAB PASSES

Obstacles can accumulate in the hole for a variety of reasons, including hole instabilities, excessive rates of penetration, inadequate drilling fluid flow rates, and improper drilling fluid management. To clear potential obstacles and reduce the risk of damage to the pipeline during pullback or blockage of drilling fluid returns, the contractor may make a series of swab passes. To maintain drilling fluid returns during pilot hole and reaming operations, contractors can partially withdraw the downhole tooling to help clear any downhole obstructions, such as accumulations of cuttings and other loose debris.

Contractors typically complete one or more swab passes through the entire length of the hole before pullback operations to evaluate the condition of the hole, remove accumulated cuttings, and clear any obstructions resulting from unstable portions of the hole.

USE OF TEMPORARY CASING

HDD contractors sometimes use temporary surface casing of various diameters in specific ways to support the hole during construction and help mitigate drilling fluid loss, drilling fluid surface release, hole collapse, and surface subsidence. Small-diameter temporary casing is removed before reaming the hole and installing the final product pipeline while large-diameter temporary casing is left in place until after the pipeline has been installed and then removed prior to the final testing of the pipe.

When hole instability is a concern on the entry side, the contractor may choose to install a temporary large-diameter (24 inches or more) casing to support the formation through the upper soil zones. Casing is typically welded together during installation. As sections are added, the casing will continue to be advanced to a depth necessary to maintain hole stability. The large-diameter casing is left in place during the reaming and swab passes then typically extracted before or after the pullback process. Large-diameter casing is limited to the entry and exit tangents of the drill profile because is not able to conform to the curved portions of the HDD profile. The greatest benefit from the casing is in providing hole stability through the tangent sections during the entire HDD process. This approach is most common in soft or loose soil where the drill path is shallow, and gravel or cobbles are anticipated. If hole stability is a concern on both sides of the crossing, large-diameter casing can be installed on the exit side of the crossing as well, but a pilot hole intersect will have to be completed.

Temporary small-diameter casing has uses as well but must typically be removed prior to reaming the hole. By advancing small-diameter (12 to 16 inches) steel pipe casing over the drill string during pilot hole operations, contractors can reduce the risk of inadvertent drilling fluid returns near either end of the HDD. Small-diameter casing can provide support when drilling into soft and loose soils. The casing prevents erosion of the surrounding formations and can act as a *reaction mass* to improve the transfer of axial loads through the downhole drill pipe string to the drill bit. Casing is pushed over the drill pipe string in 15 to 40 foot sections and welded together during installation unless threaded casing is used. Drilling fluid is often pumped down the casing during installation to help lubricate the outside of the casing and facilitate installation—however, a cautious approach is generally taken because inadvertent drilling fluid returns may occur.

Small-diameter casing is easier to maneuver within an HDD workspace than large-diameter casing and can be installed on most HDD construction sites without the use of specialized equipment. Also, small diameter casing can be installed along curved portions of the HDD profile using the drill pipe string as a guide, when required, unlike large-diameter casing. The small-diameter casing is typically extracted before or during the hole opening process by the drill rig and/or supplementary equipment onsite.

DESIGN USING LARGER RADII OF CURVATURE

A larger radius of curvature is typically used where the subsurface conditions suggest that steering the pilot hole within acceptable tolerances will be difficult. This allows the contractor more freedom while drilling the pilot hole and increases the chance that the pilot hole geometry will allow the pipeline to pass through unimpeded during pullback.

UTILIZE BUOYANCY CONTROL

Utilizing a technique called buoyancy control for larger-diameter installations can reduce forces acting on the pipe, reducing the risk of damage to the pipeline during pullback. Pumping a fluid (typically water) into the pipeline during pullback reduces these forces by preventing the pipeline from floating in the drilling fluid.

REAM THE HOLE TO A LARGER DIAMETER

Poor hole geometry—or an irregularly shaped hole—can cause damage to the pipeline and difficulties during pullback and put more stress on the pipe and downhole tools. These risks can be reduced by simply reaming the hole to a larger diameter than typically required. This allows more annular space for the pipeline to conform to the shape of the hole during pullback operations and can often reduce pullback forces. However, the size of the hole must be balanced with the risk of instability and inadvertent drilling fluid returns.

PERFORM EXHAUSTIVE GEOTECHNICAL INVESTIGATIONS

The key to reducing risk from geologic hazards is straightforward—identify them and avoid them. HDD profiles can then be designed below any anticipated or existing slide planes, where no earth movement is anticipated even if a landslide were to occur. Geotechnical engineers and geologists estimate the slide plane depth using site investigation methods and sophisticated software applications.

River scour can be avoided by evaluating factors like historic flows during flood events, channel morphology, and channel composition. The results of the analysis provide an estimate for the depth of potential scour that that the river might experience at the crossing site so that the HDD profile can be designed below that depth. Similarly, engineers and scientists estimate the potential for channel migration by looking at channel morphology, local geology, peak flows, and aerial photography. Once the potential for a river's lateral migration is determined, the HDD can be designed far enough outside of the channel migration zone that the pipeline will not be exposed during its lifetime.

CONTINGENCY PLANNING

Regulatory agencies typically require contingency plans for inadvertent drilling fluid returns for all large HDD projects and most smaller pipeline installations. These plans include monitoring protocols for detecting inadvertent drilling fluid returns should they occur, containment, collection, and clean-up procedures for areas impacted by drilling fluid, and they may outline alternative drilling or installation methods that could help prevent inadvertent returns.

THE BOTTOM LINE

Although there are risks inherent in the installation of a pipeline via HDD, risks can be greatly reduced if an experienced designer adequately investigates the site, designs the HDD profile with risk-mitigation in mind, and the contractor implements appropriate mitigation measures during construction. Each of the risks outlined in detail in the last section can be reduced with careful preparation and construction techniques.

Regulations and Testing for Constructed Oil and Gas Pipelines

Every HDD project adheres to established regulations and safety testing for the pipeline industry. In many cases, engineers and contractors go above and beyond minimum regulations through industry best practices and careful procedures outlined in this document. Doing so helps protect the professionals working on the project and the public at large.

Pipeline operational safety requirements are mandated by governmental regulations outlined within the Code of Federal Regulations (CFR) in the United States, and laws administered by the National Energy Board (NEB) in Canada. In both countries, regulations are administered by many governmental organizations depending on the location and features of the pipeline project. These standards govern operational safety during an HDD or other pipeline installation, as well as long-term requirements and recommendations over the life of the pipeline. Pipelines are inspected before being put into service and then regularly maintained and inspected once operational.

PRE- AND POST-INSTALLATION HYDROSTATIC (PRESSURE) TESTING AND IN-LINE INSPECTION (ILI) RUNS

During construction, a percentage of all pipeline welds completed during fabrication are nondestructively tested to ensure their structural integrity, either through x-ray or ultrasonic methods. After construction is completed and before use, workers often perform an in-line inspection tool run and hydrostatic test. The in-line inspection tool detects geometric flaws and metal loss within the pipeline. The hydrostatic test fills the pipeline with water, which is then pressurized above its intended operating pressure to test the pipeline's integrity.

HYDROSTATIC TESTS ARE PERFORMED AFTER CONSTRUCTION TO TEST A PIPELINE'S INTEGRITY.

HDD installations are complex, and owners and operators will often require additional testing and in-line inspection. For example, regardless of the percentage of mainline welds (welds located in accessible sections of the pipeline) tested during construction, most owners and operators test 100 percent of welds within HDD segments. They may also require additional hydrostatic tests, and many HDD installations receive both pre- and post-installation testing.

After the pipeline is operational, the owner conducts in-line inspections and/or hydrostatic tests regularly according to federal requirements.

COATING AND CATHODIC PROTECTION

Operators responsible for the long-term integrity of pipelines typically have a corrosion-control plan. Corrosion can cause metal loss within portions of the pipeline, which reduces the amount of material available to withstand operational stresses and can result in the eventual failure of the pipeline. Coating and cathodic protection are two common forms of corrosion control.

Coating refers to an external corrosion resistant covering applied to the pipeline's parent metal. The coating is often a form of epoxy (applied to pipeline segments at the mill) that securely bond to the pipeline through sophisticated heat or electric processes. Owners and operators typically require additional coating on HDD pipeline installations to withstand abrasion during installation. This extra abrasion-resistant overlay (ARO) coating, applied on top of the mill epoxy, resists abrasion, and impact damage.

Cathodic protection is designed to protect portions of the pipeline that may experience coating loss. Cathodic protection is a process of applying an *impressed electrical current* along the pipeline alignment. The low voltage current travels along the parent metal and is discharged into the ground through a sacrificial anode or cluster of anodes, commonly known as a ground or anode bed. This causes the anode to corrode instead of the pipeline.

PERIODIC PEDESTRIAN, FLYOVER INSPECTIONS

In addition to the methods previously described, most pipeline owners and operators also have very robust pedestrian and aerial inspection protocols. Inspectors physically walk or fly along the pipeline right-of-way at specific intervals throughout the year. These teams are typically looking for visual indications of a pipeline failure or release, in addition to encroachment or other potentially hazardous activities such as third parties working within or adjacent to the right-of-way without a "cleared" utility locate ticket, or geologic hazards such as landslides or pipeline exposures.

All of these methods of testing, inspecting and regulating pipelines (especially those installed with HDD) work together to address the risks that regulators and history have identified. This, in turn, protects pipeline owners and their employees, the general public and environment.

WORKERS VISUALLY INSPECT A PIPELINE AS IT IS PULLED INTO PLACE.

THE BOTTOM LINE

Federal, state and local regulating agencies oversee rigorous safety standards for HDD projects and pipelines in general. These standards help protect the professionals working on the project and the public at large. Techniques like hydrostatic pressure tests and in-line inspection (evaluating the condition of the pipe) help verify an HDD segment's integrity before it is commissioned for use. Once in use, pipeline owners and operators regularly inspect pipelines for signs of corrosion, failure, geologic hazards and other risks.

HDD Permitting and Regulations

HDD requires rigorous permitting and regulation—many federal, state/provincial and local regulators oversee and issue permits for pipeline projects. The specific regulatory agency depends on the project location and other characteristics.

U.S. FEDERAL

- U.S. Army Corps of Engineers
- Federal Energy Commission
- U.S. Fish and Wildlife Service
- Bureau of Indian Affairs
- National Park Service
- Bureau of Land Management
- National Transportation Safety Board
- U.S. Department of Transportation Pipelines and Hazardous Materials Safety Administration
- Federal Highway Administration

CANADIAN FEDERAL

- National Energy Board
- Department of Fisheries and Oceans
- Transport Canada

STATE/PROVINCIAL

- Department of Natural Resources
- State Fish and Wildlife Agencies
- State Park Service
- Office of State Lands
- State Department of Environmental Quality
- State Historic Preservation Office
- Gas Safety Offices
- Provincial Historic Resources Management and Archaeology Branch
- State Coastal Zones
- State Department of Transportation

LOCAL

- County/Parish/Municipal District Permit Offices
- County/Parish/Municipal District Coastal Zones

Drilling Deeper: History of HDD

Early attempts at horizontal drilling began in the 1960s on the West Coast of the United States. Contractors at the time had no proven method of steering the drill bit, making these first drilling experiments more guesswork than science.


MARTIN CHERRINGTON, CIRCA 1980

Martin Cherrington of Titan Contractors was a pioneer in the new field of horizontal drilling. Throughout the 1960s, he experimented with ways of controlling the length of the drill. Cherrington noticed that certain types of drilling tools would naturally climb up to the surface during drilling. With a lot of trial and error, Cherrington learned to predict this tendency, giving him the ability to control the length of a crossing by varying the angle of entry and type of drill bit. Although this discovery gave engineers a degree of vertical control, horizontal steering was still impossible.


CHERRINGTON'S FIRST HDD RIG BUILT FOR A RIVER CROSSING, EARLY 1970S

By 1971, Cherrington became the first to import downhole survey methods and drilling techniques from the oil exploration industry to horizontal drilling. Horizontal directional drilling (HDD) was born. New drilling firms expanded quickly, and by the 1980s and 90s a number of competing HDD firms dominated the industry.

Technological advances grew with the evolving HDD industry. Hydraulically powered drill rigs improved safety and efficiency. Advanced downhole survey probes enabled contractors and engineers to quickly and more accurately determine the path of the pilot hole. Better tools made it possible to drill through most types of soil and rock. Today, HDD is one of a growing number of trenchless techniques for pipeline installation and a critical contributor to our global energy infrastructure.

Photos copyright Trenchless Technology Magazine, used with permission

Advantages and Limitations of HDD

HDD is an important tool in pipeline construction because the technique typically reduces ground surface impacts by eliminating trenching or open cut installations. HDD engineers and contractors use specialized equipment to understand and mitigate risks associated with HDD. However, as with any subsurface construction method, unknown or unforeseen conditions may be encountered.

HDD is not appropriate for every design situation and geotechnical condition. Owners and engineers thoroughly and thoughtfully evaluate each proposed HDD during the design phase to limit these risks as much as possible. If an HDD installation is not feasible, an alternate construction method must be used.

When carefully investigated and designed by professionals, HDD installations are critical to the overall development and safety of the North America's pipeline network. HDD is often less expensive than rerouting a pipeline around surface obstacles and provides greater long-term protection from geohazards than competing solutions. Trenchless technology, and HDD specifically, will continue to play an important role in coming decades as energy networks grow to meet increasing demands.

HDD RISKS / APPLICABLE MITIGATION TECHNIQUES

HDD RISKS	DESIGN DRILL PATHS TARGETING HIGH-SHEAR-STRENGTH SOILS.	MANAGE ANNULAR DRILLING FLUID PRESSURES.	CLEAR HOLE OBSTACLES WITH SWAB PASSES.	REINFORCE HOLE WITH TEMPORARY STEEL CASING NEAR ENTRY/ EXIT POINTS.	DESIGN PROFILE WITH A LARGER RADII OF CURVATURE IN SUBSURFACE REGIONS WHERE STEERING WILL BE DIFFICULT.	UTILIZE BUOYANCY CONTROL FOR LARGER DIAMETER INSTALLATIONS TO REDUCE INSTALLATION FORCES.	REAM THE HOLE TO A LARGER DIAMETER THAN REQUIRED TO ALLOW MORE ANNULAR SPACE.	CAREFUL GEOTECHNICAL INVESTIGATIONS TO IDENTIFY HAZARDS.
Hydraulic Fracture and Inadvertent Drilling Fluid Returns	●	●	●	●				●
Pipeline Damage During Pullback	●		●	●	●	●	●	●
Hole Instability	●		●	●			●	●
Poor Cuttings Removal		●	●	●			●	●
Errors in Pilot Hole Alignment				●	●		●	●
Geologic Hazards	●							●

Appendix

REFERENCES

1. GAO.gov. (2019). CRITICAL INFRASTRUCTURE PROTECTION Actions Needed to Address Significant Weaknesses in TSA's Pipeline Security Program Management. [online] Available at: https://www.gao.gov/assets/700/696122.pdf [Accessed 24 Jul. 2019].

2. Green, K. and Jackson, T. (2019). Safety in the Transport of Oil and Gas. [online] Fraserinstitute.org. Available at: https://www.fraserinstitute.org/sites/default/files/safety-in-the-transportation-of-oil-and-gas-pipelines-or-rail-rev2.pdf [Accessed 24 Jul. 2019].

DEFINITIONS

Trenchless Technology: A type of subsurface construction work that requires few or no continuous trenches. Often used to install utilities beneath surface obstacles.

Reamer: A rotary cutting tool included within a drill string. Used to enlarge the size of a previously drilled or reamed hole.

Pilot Hole: A smaller initial hole drilled to follow the designed alignment and profile, used to guide following passes as the hole is enlarged.

Drilling Fluid: A viscous fluid composed mostly of non-toxic bentonite, injected into the hole to lubricate and cool the downhole tools and carry rock and soil cuttings back out of the hole.

Annulus: An annulus is the area between two concentric objects. In drilling, it refers to the area where drilling fluid can flow between the hole wall or casing and the drill pipe.

Drill Pipe String: The sections of drill pipe that are connected to collectively drill and ream the hole.

Downhole Steering Probe: An HDD tool that sends real-time positioning data from downhole to engineers on the surface so they can monitor and steer the drill bit. Typically located 6 to 30 feet behind the drill bit.

Buoyancy Control: A method of reducing stress on a pipeline during pullback by partially filling pipe with clean water, reducing the buoyancy of the pipeline in drilling fluid.

HDD Alignment: This refers to the specific route planned for a section of pipeline when viewed from the top-down, including entry and exit points of an HDD and the horizontal turns required to get from one to the other.

HDD Profile: The specific route planned for a section of pipeline when viewed from the side, including entry and exit points of an HDD and the vertical curves required to get from one to the other beneath any surface obstacles.

Bathymetric Surveys: Any of a number of methods used to measure the depth and underwater topographic features of a body of water.

Geotechnical Engineering: A branch of civil engineering focused on the structural properties of earth materials like soil and rock, and how these materials interact with manmade structures.

High-Shear Strength: Describes a material resistant to sliding structural failure along a plane that is parallel to the direction of the force. Desirable feature of soil and rock formations when installing pipeline via HDD.

Channel Migration: The natural shifting of river or stream channels over time.

Impressed Electrical Current: An impressed current cathodic protection system (ICCP), is a type of cathodic protection that uses anodes connected to a DC power source to send electrical current through a metal pipeline. This protects the metal from corrosion by making it the cathode of an electrochemical cell.

Cuttings: Rock, earth and other material that is dislodged and removed during drilling.

Product or Carrier Pipe: The permanent pipeline being installed during an HDD project, which will transport an industrial or energy product such as oil, natural gas or water. Conventionally, pipelines carrying liquid are called product pipe, and pipelines carrying gas are called carrier pipe.

Geologic Formation: A local grouping of rock strata or soil with similar lithology and other characteristics.

Hydraulic Fracture: Caused when drilling fluid pressure exceeds the strength of the surrounding soil or rock to contain it. Drilling fluid can fracture the surrounding formation and even migrate to the surface in some cases.

Inadvertent Drilling Fluid Returns: Describes drilling fluid that emerges at the ground surface or in any other undesired location such as wetlands, utility trenches, basements, roads, railroads or water bodies. Often caused by hydraulic fracture.

Formational Fluid Loss: Describes drilling fluid lost through porous spaces in the soil or rock surrounding an HDD hole.

Reaction Mass: A mass against which a system operates in order to produce a force or acceleration.

AMERICAN PETROLEUM INSTITUTE (API)
1220 L Street NW | Washington, DC 20005 | USA
Phone: 202-682-8000 www.api.org

This document was developed by API with the assistance of industry consultants:

GeoEngineers
ADIT Engineering
J.D.Hair&Associates,Inc. Consulting Engineers