HORIZONTAL DIRECTIONAL DRILLING WITH DUCTILE IRON PIPE

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By Richard W. Bonds, P.E.
DIPRA Research and Technical Director

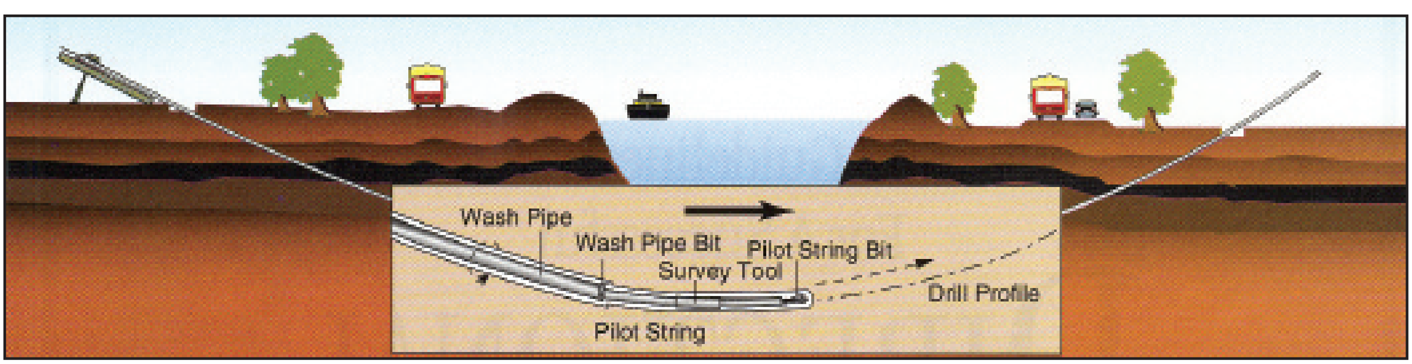
Introduction

Horizontal Directional Drilling (HDD) is a trenchless methodology that provides an installation alternative that can offer a number of benefits over traditional open-cut. HDD can be implemented with very little disruption to surface activities, requires less working space, and may be performed more quickly than open-cut methods. Also, it can simplify or eliminate certain permitting processes. This type of installation of municipal underground infrastructure systems has seen a dramatic increase in recent years. Although there are currently no national standards regarding HDD installations for any pipe material, HDD pipeline installations are becoming more and more common and may be the fastest growing trenchless construction method today. They can be used to install new pipelines or replace existing ones.

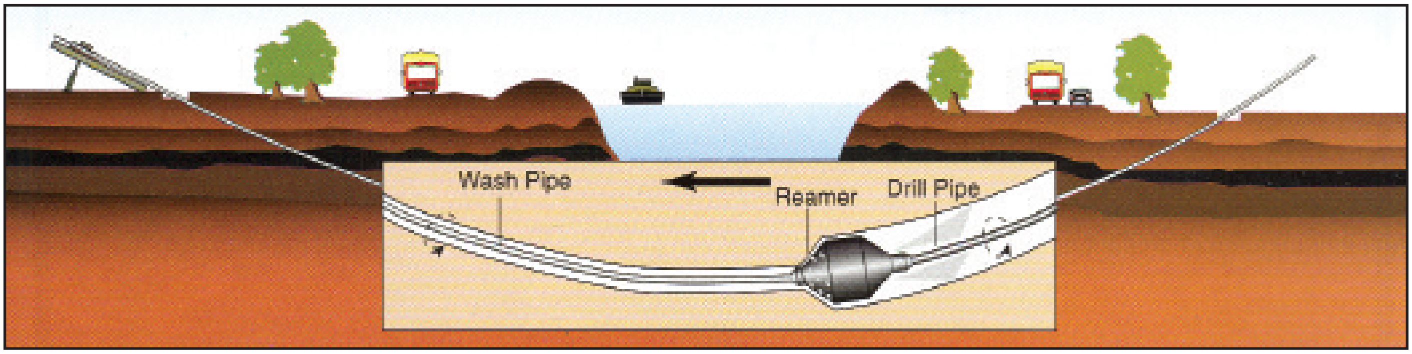
Procedure

HDD is a trenchless construction method that involves drilling a small pilot hole, using technology that allows the drill to be steered and tracked from the surface. The pilot bore is launched from the surface at an angle between 8 and 20 degrees to the horizontal, and transitions to horizontal as the required depth is reached. A bore path of very gradual curvature or near-straight alignment is normally followed to minimize friction and to stay within the allowable joint deflection and the allowable curve radius for the pipe. This minimizes the chance of getting the pipeline "hung up" in the soil or damaging the pipe.

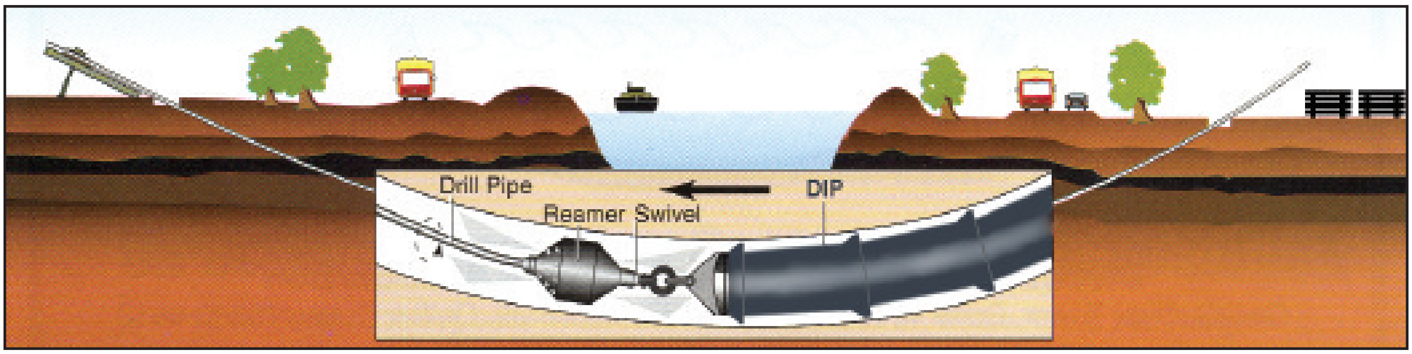
The pilot hole is enlarged (usually approximately 1.5 times the largest outside diameter of the new pipe) by pulling back increasingly larger reamers, or reaming heads, from the pipe insertion point to the rig side. To achieve the appropriate bore path size it may be necessary to perform several reaming operations. Generally, all reaming procedures prior to the actual product installation are referred to as pre-reams, and the final ream to which the product pipe is attached is referred to as the back ream. After the pre-reams, the pulling head and connecting product pipe are attached to the reamer using a swivel, a device that isolates the product pipe from the rotation of the HDD drill pipe. The product pipe is then pulled behind the final reamer back through the horizontal directional drill path to the exit pit on the rig side.



PILOT HOLE



PRE-REAMING



Schematics are courtesy of the Directional Crossing Contractors Association

PULL-BACK

Drilling Mud

"Drilling mud" is normally utilized to lubricate the cutting head during the drilling operation and stabilize the reamed bore path prior to and during pull-back. The "drilling mud" usually consists of a mixture of fresh water and bentonite clay; however, other materials—such as polymers—are sometimes used. Bentonite is a naturally occurring clay mineral that forms a mud when mixed with water. Drilling fluids are characterized by their viscosity, gel strength, filtration, fluid loss, fluid density, pH, and lubricity. The principal functions of drilling fluids used in HDD are:[1]

1. Transporting drill cuttings to the surface by suspending and carrying them in a slurry that flows in the annulus between the bore wall and the drill/product pipe.
2. Cleaning build-up on drill bits or reamer cutters by directing fluid streams at the cutters.
3. Cooling the downhole tools and electronic equipment.
4. Lubricating to reduce the friction between the drill pipe/product and the bore wall.
5. Stabilizing the bore path, especially in loose or soft soils, by building a low-permeability filter cake and exerting a positive hydrostatic pressure against the bore path wall. The filter cake and positive hydrostatic pressure reduce obstruction of the bore path and prevent formation fluids (i.e., groundwater) from flowing into the bore, or drilling fluids from exiting the bore path into the formation (loss of circulation).
6. Providing hydraulic power to downhole mud motors.

For HDD, the proper drilling fluid mixture and delivery pressure is heavily dependent upon the type of soil encountered. It must be formulated for the anticipated geological conditions. For simplicity, soil conditions may be defined as either a coarse soil (sand and gravel) or a fine soil (clay, silt, and shale). In general, for coarse soils bentonite should be used, while for fine soils polymers (possibly added to a bentonite base) are recommended.[1]

HDD Entrance Pit and Drilling Mud Recycling Pump

Installation Methods for HDD of Ductile Iron Pipe

Actual installation of the pipe in an HDD application involves maintaining an unobstructed bore path that the pipe is pulled through as smoothly and quickly as possible. HDD installations with Ductile Iron pipe have an advantage over other pipe materials since the installation can be readily accomplished by either the cartridge method, unique to segmented pipe like Ductile Iron pipe, or an assembled-line method where pipes are pre-assembled on an adjacent right of way, then pulled in as a single unit.

Cartridge Method

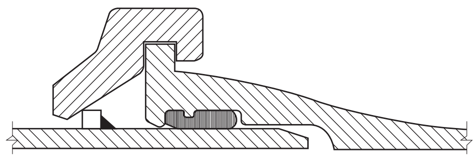
The cartridge method involves connecting the joints during installation, one at a time, and is preferred in locations where rights of way (ROWs) or easements are limited. Ductile Iron pipe restrained joint systems can be quickly assembled as the drill string is retracted. During pull-back the joint assembly normally requires little more time than it takes to disassemble the drill stem sections and store them on the rack. This installation method requires significantly less space or right-of-way requirements than the assembled-line method.

Assembled-Line Method

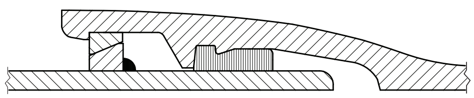
The assembled-line method involves stringing out the connected pipe on the ground prior to pull-back. With this method it is necessary to have substantial space available to pre-string the pipe above ground (generally on rollers) in direct alignment with the end of the drill path. This is normally the only option for welded-steel and fused-joint polyethylene pipe due to the significant time required to position and properly weld or fuse individual pipe sections.

Joint Applications and Deflections

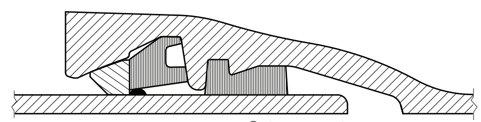
Flexible restrained joints are the key to successful installations of Ductile Iron pipe by HDD. These joints result in good distribution of thrust or pulling force around the bell and barrel and afford greater pulling forces than other pipe options. They also have a liberal allowable joint deflection with simultaneous joint restraint and are quickly and easily assembled for "cartridge" installations where there are limited easements or ROWs. Ductile Iron pipe manufacturers have proprietary flexible restrained joints that they recommend for HDD applications. Contact the individual pipe manufacturers for their recommended joint and related maximum deflections. A few joints that are recommended for HDD installations are shown below.



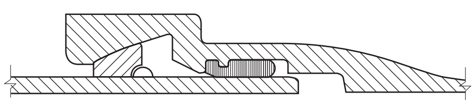
Super-Lock® (6"-30")



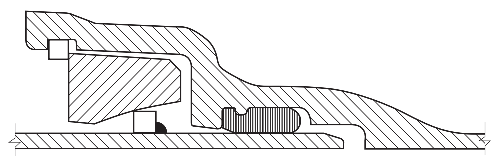
Flex-Ring® (4"-12")



Flex-Ring® (14"-42")



TR FLEX® (4"-24")



SNAP-LOK™ (6"-48")

Gripping push-on joint gaskets that utilize stainless-steel teeth locking segments are not recommended for HDD installations. Joint deflections or relative rotation between two pipe sections during installation with these types of restrained joint gaskets could result in leakage or possible joint separation.

Radius Pulls

The preparation site and drill path have to be designed so that the manufacturers' allowable deflection for the Ductile Iron pipe joints are not exceeded when the pipe is pulled into position. When crossing a body of water, for example, HDD pulling operations can be, in a sense, safer for the installation of Ductile Iron pipe restrained joint systems than restrained joint with similar deflection capability installed in a land/subaqueous open-cut installation. Contractors cannot as readily over-deflect (or damage with applied bending moments) the joints in the HDD pulling operation. The normally close-fitting horizontal directional drilling bore path effectively restricts lateral movement of the joints and pipes. Unlike welded or fused-pipe strings, the restrained joints of Ductile Iron pipes applied to horizontal directional drilling are flexible (in effect, they are hinges). By conforming to a properly designed radius of curvature of a Ductile Iron pipe bore path, the applied pulling load creates little or no added tensile stress on the Ductile Iron pipe walls due to bending moment. In other words, with Ductile Iron pipe the primary design concern relative to pulling the pipe through a properly designed radius of curvature is basically just the pulling load encountered, including any impact effects, if applicable.[2]

It is appropriate to note that some pipe manufacturers might caution against extremely long radius curved pulls and alternatively recommend that radius turns be made with several straight pulls to eliminate the possibility of over-deflecting the joint and exceeding the maximum pulling force.

Minimum Allowable Radius of Curve

Maximum Allowable Joint Deflection (degrees)	Minimum Allowable Radius of Curve For 18-Foot Pipe (feet)	Minimum Allowable Radius of Curve For 20-Foot Pipe (feet)
3.00	340	380
3.25	317	352
3.50	295	330
3.75	275	305
4.00	258	285
4.25	243	270
4.50	229	255
4.75	217	241
5.00	205	230

Pipe Bore Path Friction

Case histories have given indications "that pulling loads were less for Ductile Iron pipe than they typically were for similar size HDPE pipe."[3] One reason for this is that the bulk density of empty Ductile Iron pipe is normally closer to that of the soil/fluid slurry than it is with lighter pipe materials. Therefore, there may often be very little normal force from gravity or bouyancy to result in increased friction against the walls of the bore hole as the pipe is pulled back.[4]

In HDD installations, restrained joint pipe bells can be oriented to minimize friction of the bell in pulling through the bore hole. This allows the drilling fluid and excavated material to flow easily over the smooth contour of the bells. With low-profile, internal-ring joint designs this is normally the spigot-forward orientation, but this varies by joint design, and pipe manufacturers should be consulted.

Pulling Force Capability

Today some HDD machines are capable of generating tremendous pulling forces. The pipe joint must be capable of withstanding these forces. Ductile Iron pipe manufacturers have proprietary restrained joints with substantial strength that they recommend for HDD applications. Contact the individual pipe manufacturers for their recommended maximum allowable pulling force.

Pulling Heads

After the pre-reaming operation(s) has been completed, a swivel connector is attached between the final reamer and the pulling head. The pulling head is then attached to the spigot end of the first piece of pipe. There are many different pulling head designs. Pulling heads may be fabricated by the installer or obtained from some pipe manufacturers.

Corrosion Control

If the native soil or drilling mud is considered corrosive to Ductile Iron pipe, corrosion protection is warranted. Numerous HDD installations and inspections have proved that Ductile Iron pipe can be successfully installed when encased in polyethylene material that meets the ANSI/AWWA C105/A21.5 standard.

With some minor modifications, the "Alternate Method A for Wet Trench Conditions" as specified in ANSI/AWWA C105/A21.5 should be utilized for applying polyethylene encasement to Ductile Iron pipe for HDD installations.

The initial piece of pipe will require that the polyethylene tube be securely attached to the pipe barrel with several circumferential wraps of tape for approximately one foot from the end. The tape should be applied directly to both the polyethylene and metal barrel of the pipe. This will ensure that any tendency for drilling fluid or cuttings to get under the polyethylene tube will be minimized. When applying the polyethylene encasement to the assembled joint, the polyethylene overlap should always have the forward pipe's polyethylene tube overlap the next pipe's polyethylene. Again, this is to ensure that drilling fluid and cuttings are not forced under the polyethylene tube during the pull-back. To secure the polyethylene at the joint area a plastic tie strap or tape should be snugly installed/circumferentially wrapped on each side of the joint.

DIPRA has inspected the polyethylene encasement installed using this procedure and found excellent results. The full circumferential wraps of tape around the barrel of the pipe at two-foot intervals permit any trapped air to escape at the joint overlap area as the hydrostatic pressure of the drilling fluid applies a uniform pressure around the pipe. An alternative fastening method would be to continuously spiral wrap with tape on about one-foot centers around the exterior of the polyethylene-encased Ductile Iron pipe.

Horizontal directional drill installations of Ductile Iron pipe generally originate at a prepared assembly area immediately adjacent to the pipe pull-back entry pit. This allows for the polyethylene-encased pipe to immediately enter the slick, lubricating drilling fluid without being dragged on rough ground that could damage the encasement.

Conclusion

Successful HDD installations have firmly established restrained flexible joint Ductile Iron pipe as a viable, and in many instances superior, trenchless pipe option. The advantages of using restrained flexible joint Ductile Iron pipe for HDD installations include:[4]

1. Standard pressure capabilities up to 350 psi (greater upon special request).
2. Great material strength for handling pull-back and external dead and live loading.
3. Better distribution of thrust or pulling forces around the bell and barrel.
4. Greater allowable pulling forces than other pipe options.
5. Generous allowable joint deflections.
6. Quick, easy joint assembly.
7. "Cartridge" installation option for limited easements or ROWs.
8. Can be located from surface with commonly used locators.
9. Performance capabilities are not impacted by elevated temperatures.
10. Material strength that does not creep or decrease with time.
11. Pipe wall is impermeable to volatile hydrocarbons, minimizing the potential of water system contamination in the present or future.
12. No significant residual bending stresses remain in the pipe after the pull-back that could adversely affect future serviceability, including tapping.
13. No significant "recoil" and minimal pipe movement due to thermal expansion.
14. Eliminates potential for shearing of tapped lateral outlets due to thermal expansion and contraction.

With the increasing demand for water and wastewater infrastructure and a movement to reduce the social/economic impact on ratepayers that is often associated with open-cut construction, trenchless installation using HDD will certainly play an increasing role. For these installations, public works personnel and contractors have the option of installing superior Ductile Iron pipe and in so doing, **making the right decision.**

References

1. Ariaratnam, Samuel T., "Evaluation of the Annular Space Region in Horizontal Directional Drilling Installations," Arizona State University.

2. Conner, Randy, "Horizontal Directional Drilling with Ductile Iron Pipe," ASCE Pipeline Division Specialty Conference: Pipelines in the Constructed Environments, San Diego, California, 1998.

3. Carnes, Singh, and Carpenter, "Trenchless Solutions Utilizing Ductile Iron Pipe," 2002 AWWA National Conference, New Orleans, Louisiana, June 2002.

4. Ariaratnam, Mistler, and Carpenter, "Installation of Municipal Underground Infrastructure Systems Using Horizontal Directional Drilling and Ductile Iron Pipe."

DIPRA MEMBER COMPANIES

American Cast Iron Pipe Company
P.O. Box 2727
Birmingham, Alabama 35202-2727

Atlantic States Cast Iron Pipe Company
183 Sitgreaves Street
Phillipsburg, New Jersey 08865-3000

Canada Pipe Company, Ltd.
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Clow Water Systems Company
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