Planners need good grasp of trenchless construction—Part 1

Decision to specify horizontal directional drilling of a crossing requires structured feasibility investigation

J. D. Hair, J.D. Hair & Associates, Inc., Tulsa, Oklahoma

Pipe line operators and contractors must understand the capabilities of horizontal directional drilling (HDD) before they can evaluate whether or not a proposed drilled crossing is technically and economically feasible.

While HDD is a proven installation method throughout the world, owners need to work through a structured set of decisions to determine the technique's suitability for a particular application.

Three standards may be used to assess the feasibility of HDD for a given crossing. These feasibility standards are:

- Technical
- Contractual
- Economic.

First, a crossing is technically feasible if it can be installed using existing tools and techniques regardless of uncertainties surrounding installation cost.

Second, a crossing is contractually feasible if the installation cost can be accurately estimated in advance, allowing contractors to submit lump-sum bids.

Third, HDD is economically feasible if installation cost is less than the cost of an equivalent construction method.

Technical feasibility. For an HDD installation, one of two conditions must be achieved downhole. Either an open hole must be cut into the subsurface material that allows a pipe string to be pulled back through the hole, or the soil properties must be modified to behave in a fluid manner, allowing pipe to be pulled back. Whether either of these conditions can be achieved depends primarily on subsurface soil conditions.

The open hole condition is similar to that achieved in a typical oil well. A cylindrical hole is cut in the subsurface. During the cutting, drilling fluid flows to the surface in the annulus between the pipe and the hole wall. The drilling fluid transports drilled spoil to the surface. This process generally is applicable to rock and cohesive soils. It also may apply to some sandy or silty soils, depending on the density of the material, the specific makeup of the coarse fraction, and the binding or structural capacity of the fine fraction.

Loose, cohesionless soils probably will not support an open hole over a long horizontally drilled length. However, this does not prevent pipe line installation. The mechanical agitation of the reaming tool, coupled with the injection of bentonitic drilling fluid, will decrease the loose soil's shear strength. If the resulting shear strength is low enough, the soil will behave in a fluid manner, allowing pipe to be pulled back. Fluid behavior of loose sands, commonly called quicksand, is defined by geotechnical engineers as liquefaction.

If either an open hole or fluid condition can be achieved downhole and the stresses imposed on the pipe and tooling are not excessive, HDD installation is technically feasible. The technical feasibility of a proposed HDD installation can be predicted by comparing it to past installations in three basic parameters:

- Drilled length
- Pipe diameter
- Subsurface soil material.

The three parameters work in combination to limit what can be achieved. HDD installations that define the state-of-the-art in length and diameter as of 1994 are shown in Table 1.

Table 1. State-of-the-art horizontal directional drilling installations as of 1994

Location	Length	Diameter	Soil material	Date
Wormley Creek Yorktown, Virginia	5,850 ft (1,783 m)	10 in. (DN 250)	Alluvial	1994
SB Elizabeth River Norfolk, Virginia	2,160 ft (658 m)	48 in. (DN 1200)	Alluvial	1993

Length and diameter are limited primarily by capacity of existing tools and drill pipe. Present technology involves thrusting pipe from the surface to advance a pilot hole. The flexibility of relatively slender drill pipe does not allow an unlimited amount of thrust to be applied. Directional control diminishes over long lengths. Present technology also involves rotating pipe at the surface to rotate

Table 2. HDD technical feasibility assessment guidelines

Earth material type	Gravel % by weight	HDD feasibility
Very soft to hard strength, possibly slickensided, clay.	N/A	Good to excellent. Plugging of the annulus surrounding the drill stem during pilot hole drilling may produce inadvertent drilling fluid returns through slickensides. Penetration of strong clay surrounded by considerably weaker or looser soils may result in the pilot bit "skipping" along the interface. Pilot hole steering difficulties are likely during passage through very soft layers.
Very loose to very dense sand with or without gravel traces.	0 to 30	Good to excellent. Gravel may cause slight steering problems. Some steering imprecision may also result during passage through very loose material.
Very loose to very dense gravelly sand.	30 to 50	Marginally acceptable. Drilling fluid characteristics and handling are critical to success. Pilot hole steering may be imprecise.
Very loose to very dense sandy gravel.	50 to 85	Questionable. Horizontal penetration for any appreciable distance will be extremely difficult regardless of drilling fluid quality. Pilot hole steering may be imprecise.
Very loose to very dense gravel.	85 to 100	Unacceptable. With present technology and experience, horizontal penetration, especially in the denser strata, is almost impossible. Such materials must be avoided or penetrated at a steep angle.
Rock.	N/A	Excellent to unacceptable. Softer or partially weathered materials offer HDD performance akin to that of hard-strength clay. Technology is available to drill through more competent rock, especially in the weaker horizontal plane. Penetrating solid rock after passing through soil may be difficult due to the bit's tendency to "skip" along the lower hard surface. If in "rounded" cobble form, competent rock is virtually impossible to drill.

reamers downhole. Drill pipe capacity to transmit torsion is limited. Installing a 48-in. pipe typically requires completing a 60-in. reaming pass. While development of new tools and techniques that increase load-bearing and energy transmission capacities of drill pipe is possible, economic factors come into play. The market has not been defined for HDD pipe installation over longer lengths or larger diameters than those presented in Table 1.

While length, diameter and subsurface soil material work in combination to limit the technical feasibility of an HDD installation, technical feasibility primarily is limited by subsurface soil material. Two material characteristics prevent establishing either an open hole, or fluid condition. These are large grain content, such as gravel and cobbles, and excessive rock strength and hardness.

Soil consisting principally of coarse-grained material seriously restricts HDD feasibility. Coarse material cannot be readily fluidized by the drilling fluid. Neither is it stable enough to be cut and removed in a drilling fluid stream through an open hole as is the case in a crossing drilled in competent rock.

A boulder or cluster of cobbles will remain in the drilled path and present an obstruction to a bit, reamer or pipe line. They must be mechanically displaced during hole enlargement. Displacement may be radially outward into voids formed by the entrainment of finer-grained materials such as sand and smaller components. However, naturally dense, high-gravel-percentage soils contain little entrainable material. Voids developed in these soils may be insufficient to permit passage by larger-diameter reamers or pipe. Coarse material also may migrate to low spots on the drilled path, forming impenetrable blocks.

Exceptionally strong and hard rock will hamper all phases of an HDD project. Experience has shown competent rock with unconfined compressive strengths exceeding 12,000 psi and Mohs Scale of Hardness factors ranging somewhat above 7 can be negotiated with today's technology. However, entry of such materials at depth usually is difficult. The directional drilling string tends to deflect rather than penetrate. Conversely, poor-quality rock, extensively fractured or jointed, can present the same problems as coarse, granular deposits.

Two of the most significant crossings installed in rock to date were completed in 1991. The longest, at about 3,000 ft (914 m), was installed beneath the Niagara River near Niagara Falls, New York. This 30-in. (DN 750) crossing was placed through soft shale. The second installation in harder rock was completed in 1991 beneath the Housatonic River near Shelton, Connecticut. This 24-in. (DN 600) line penetrated about 1,200 ft (366 m) of hard, fine-grained schist in a total horizontally drilled length of about 1,732 ft (528 m).

General guidelines for assessing the technical feasibility of prospective HDD installations based on soil material type and gravel percent by weight are presented in Table 2.

Engineering judgment based on practical experience must be applied when using the guidelines in Table 2. Knowledge of subsurface conditions will be based on extrapolating measured properties from discrete soil borings generally taken by contractors not involved in HDD construction. A crossing may be placed in competent rock beneath a river. Nevertheless, overburden soils will probably have to be penetrated before the rock stratum is entered. A crossing in the lower Mississippi River flood plain may encounter clays, silts, sands and gravels of varying relative densities in a relatively short distance. Only the general character of the subsurface material will be known in advance.

Contractual feasibility. Once the technical feasibility of a prospective HDD installation has been established, its contractual feasibility can be assessed.

This assessment is accomplished the same way as technical feasibility, by comparing it to past installations. If the crossing falls near the limits of the state-of-the-art in any basic parameter—length, diameter or soil conditions—contractors may view it as too risky to undertake for a fixed, lump sum price. However, determining contractual feasibility is subjective and will vary for individual contractors based on experience and commercial situation. In today's market for HDD services, most technically feasible crossings will be bid on a lump sum basis by at least one contractor. For state-of-the-art crossings, it is not unusual to receive only one lump sum bid or to receive lump sum bids that are high. If contractual feasibility is questionable, the benefits of a day-work contract or an alternate construction method should be considered.

Economic feasibility. Determining the economic feasibility of a prospective HDD installation is a fairly straightforward exercise involving comparison of the estimated HDD cost with the estimated cost of an alternate installation method.

If the HDD estimate is less, it is economically feasible. When making the comparison, it is important for designers to estimate the cost of equivalent designs and to include all costs associated with each method. For example, it would not be valid to compare the cost of a pipe line river crossing installed by open excavation with 3-ft cover against the cost of a drilled installation providing 25-ft cover without including some adjustment in the excavated estimate to account for possible future remedial work brought on by the relatively shallow 3-ft cover. Restoration costs and the costs associated with environmental impact for each method must also be included.

Next month—The author describes factors included in a Lotus spreadsheet routine for estimating the contractor's costs for specialized horizontal directional drilling services.

ACKNOWLEDGMENT

This article is based on a portion of a report, "Installation of Pipe Lines by Horizontal Directional Drilling; An Engineering Design Guide," furnished to PRC *I*nternational (PRC*I*) by J.D. Hair & Associates, Inc., in fulfillment of PRC*I* project PR-227-9424. PRC*I* (formerly the Pipeline Research Committee) was organized in response to the need to sponsor and direct basic, developmental and applied research aimed at optimizing all technical aspects of the natural gas transmission industry and its related activities. The opinions, findings and conclusions expressed are those of the author and not necessarily those of AGA or PRC*I*. A copy of the complete report is available from PRC*I*.

BIBLIOGRAPHY

"Drilling fluids in pipe line installation by horizontal directional drilling," prepared for the Offshore and Onshore Design Applications Supervisory Committee of the Pipeline Research Committee at the American Gas Association, Oct. 31, 1994.