RIVER CROSSINGS

Subsurface soils affect horizontally drilled river-crossing design

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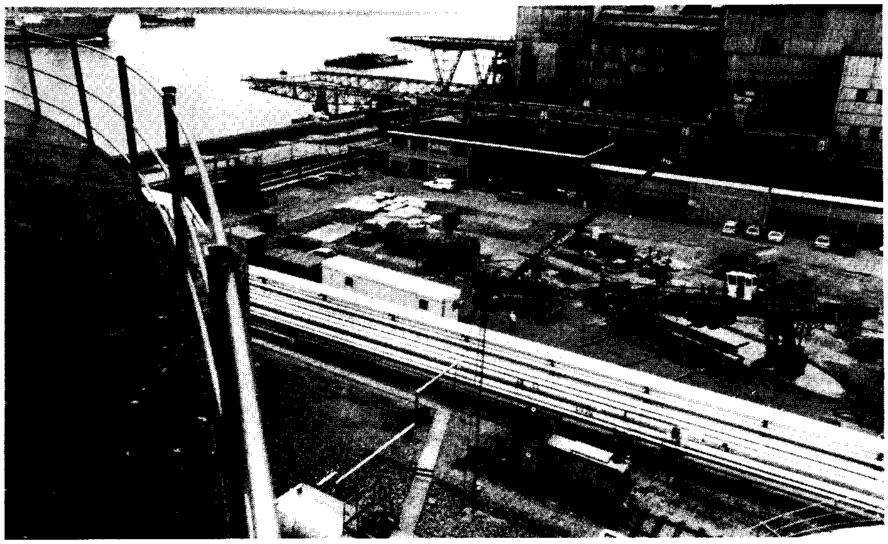


Slant configuration of a horizontal drilling rig is evident in this drilled river-crossing project on

Successful horizontally drilled pipeline river crossings depend on adequate knowledge of subsurface conditions at the location and on sufficient flexibility in crossing geometry being afforded by the method (OGJ, Apr. 25, p. 48, and May 2, p. 88).

This is the first of two articles which review directionally controlled horizontal-drilling techniques for pipeline installation and recommend improvements in techniques for investigating, designing, and executing such drilled crossings.

The first article examines the installation process and how its advantages and limitations affect crossing design.

Technological outgrowth. The directionally controlled horizontal-drilling process in use today to install pipelines beneath rivers is an outgrowth of the technology and methods developed for drilling directional oil wells. The principal difference is in orientation.

A pilot hole drilled for a river-crossing installation is very similar to an oil well, only horizontal. Of course, this is a crucial difference.

A typical horizontal drilling spread is shown in Fig. 1. The components of the spread are similar to those employed in drilling an oil well with the exception that, instead of a vertical mast and traveling block, the rig has an inclined ramp with a mobile carriage that provides rotation, tension, and thrust.

Horizontal drilling was first employed in the installation of a pipeline river crossing in 1971 by Pacific Gas & Electric Co. on a 4-in. (10-cm) crossing of the Pajaro River near Watsonville, Calif. The drilled length of this crossing was approximately 600 ft (183 m).

Although this application was successful, use of the technique was limited to small diameter, short crossings until the late 1970s when it had developed so that it could be applied economically over a wide range of diameters and drilled lengths.

In the period between 1971 and 1979, a total of only 36 crossings were installed by horizontal drilling with applications limited to the U.S.

In the 7 years that followed this period, more than 175 installations were completed with operations extending to South America, Europe, and Asia. As of the summer of 1988, more than 400 installations had been completed with roughly 100 installations taking place each year.

The technique has been principally utilized in the petroleum industry on cross-country pipeline transmission systems but is gaining acceptance for municipal water and sewer lines and submarine power and telecommunications crossings.

Two stages. The process employed in the majority of horizontally drilled river crossings is a two-stage process.

The first consists of drilling a small-diameter pilot hole along a designed directional profile.

The second involves enlarging this pilot hole to a diameter which will accommodate the pipeline, or conduit, and pulling it back into the enlarged hole.

Pilot-hole directional capability is accomplished with a small diameter, typically less than 3-in. (7.6 cm), nonrotating drillstring with an angular offset or a deflection shoe at the leading edge.

This offset creates a steering bias in its direction and plane. If a change in direction is required, the drillstring is rotated so that the direction of bias is the same as the desired change in direction.

Mechanical cutting action is provided by a downhole mud motor. Drilling can also be achieved by hydraulic cutting action with a jet nozzle. A typical mud motor assembly is shown in Fig. 2.

The actual path of the pilot hole (Fig. 3) is monitored during drilling by periodic readings of the inclination and azimuth of the leading edge.

These readings, in conjunction with measurements of the distance drilled since the last survey, are used to calculate the horizontal and vertical coordinates of the leading edge relative to the initial entry point on the surface.

Survey readings are taken by a downhole survey system which is placed directly behind the leading edge. It senses its orientation relative to the earth's magnetic field as well as the orientation of the steering bias and transmits this information to the surface where it is interpreted.

Typically, position measurements are taken every joint (30 ft, 9.1 m) and plotted against a design-profile drawing. If unacceptable deviations are shown, the drillstring is withdrawn over the unacceptable length and the pilot hole redrilled to acceptable limits.

Periodically during pilot-hole drilling, a larger diameter wash pipe is rotated concentrically over the nonrotating drillstring (Fig. 3).

This washover pipe prevents sticking of the smaller nonrotating string and allows its drilling bias to be freely oriented. It also maintains the pilot hole if it becomes necessary to withdraw the steerable string.

When both the steerable string and the washover pipe penetrate the surface of the river bank opposite the horizontal drill rig, the pilot hole is complete.

The steerable string is then withdrawn leaving the washover pipe beneath the river along the designed profile.

Ream, pull back. Enlarging the pilot hole is accomplished with either prereaming passes prior to pipe pull back or simultaneously during pull back.

For prereaming, reaming tools are attached to the washover pipe at the exit point. The reamers are then rotated and drawn to the drilling rig thus enlarging the pilot hole. Drill pipe is added behind the reamers as they progress toward the drill rig.

This ensures that a string of pipe is always maintained in the drilled hole.

For smaller-diameter lines (typically 20-in., 51 cm, or less), prereaming passes are omitted, and the final installation pass is undertaken upon completion of the pilot hole. In this case, the prefabricated pipeline pull section is attached behind the remaining assembly instead of more drill pipe and follows the reamers beneath the river to the drill rig.

A swivel is utilized to connect the pull section to the leading reamers and wash pipe to reduce torsional stress imposed on the pipeline. The decision whether to preream is based heavily on soil conditions and is not made until after the pilot hole has been completed and data obtained during its drilling reviewed.

Pipeline pull-section fabrication and handling during installation typically do not differ significantly from a cut-and-cover installation.

Pull sections are fabricated in one continuous length, if possible, to avoid shutdown periods during pull-back for tie-in welds and are supported during installation in such a manner that axial loads imposed on the line as it enters the drilled hole are held to a minimum.

Soil behavior. The behavior of the soil downhole during installation of a pipeline river crossing by directionally controlled horizontal drilling has not been completely defined. As with any subsurface construction method, it is difficult to predict and inconsistent.

The procedure being applied today has been developed by contractors using trial-and-error methods with emphasis on results rather than theory.

Basically, two conceptual models can be applied: open-hole structural behavior and fluid structural behavior. These two concepts emphasize the pull-back stage of operations because it is the most critical where most problems are experienced.

- Under open-hole-structure conditions, reaming operations actually produce an open hole filled with drilling fluid. The principal cutting action is mechanical.

Mud flow from the reamers to the surface is possible with associated transportation of cuttings. Mud-flow rates are designed to provide a velocity in the open hole which will maintain cuttings in suspension.

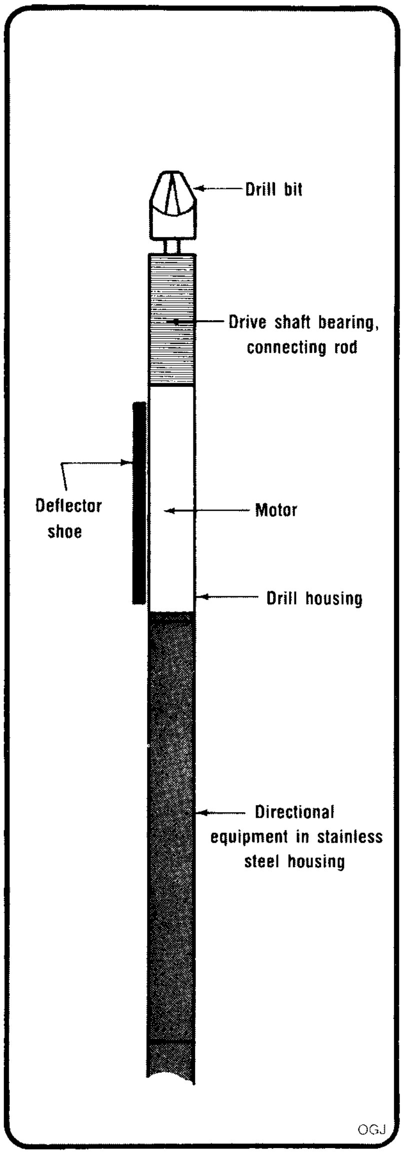
Reamer progress is set at a value which will produce a volume of cuttings to balance the volume capable of being transported by the drilling-mud flow. Practices and procedures similar to those used in drilling vertical oil wells can be applied.

- In the fluid-structure model, reaming operations do not produce a structurally sound open hole. Rather, injection of drilling mud downhole fluidizes the soil structure allowing the pipeline to be pulled through it. The principal cutting action is hydraulic.

Mud flow from the reamers to the surface is not maintained. Mud-flow rates are designed to provide a positive pressure downhole and reamer progress is maximized to complete installation while the soil is still in its disturbed fluid state.

Fig. 2

Directional drillstring



This procedure can be viewed as similar to jetting a pile into place.

Cohesive soils will generally behave with the characteristics of an open-hole structure. It is possible to ream a large structurally competent hole which will stay open over a reasonable time period. Although reamer progress may be difficult due to balling up of material, clays are considered to be an ideal material for horizontally drilled pipeline installation.

Cohesionless soils will generally behave in a fluid manner. However, if the material is sufficiently dense, it can exhibit structurally sound properties.

Grain size and grading are also critical to the behavior of cohesionless soils during reaming operations. As grain size increases, the soil appears to breakdown more readily and form a fluid with the drilling mud.

As grain size passes into the gravel and cobble ranges, maintaining the fluid structure becomes more difficult with installation problems occurring.

Rock structures will behave with open-hole characteristics.

Unfortunately, soils encountered in river beds rarely fall into one of these categories. Most will be alluvial deposits and cohesionless in nature.

Combinations of all soil types can be expected, however, and contractors must prepare to react to changing or unforeseen conditions.

Process limitations. As of June, the longest crossing installed using horizontal drilling lies beneath the St. Lawrence River near Trois Rivieres, Quebec. This project involved approximately 6,000 ft (1830 m) of 8-in. (20-cm) line and was completed in 1983.

The largest diameter is 42-in. (107 cm) over a length of approximately 1,750 ft (530 m). This was completed in 1985 beneath the Panaro River in northern Italy.

Installation lengths of approximately 4,000 ft (1,219 m) involving diameters of 30 in. (77 cm) or less are fairly routine.

Installations of 40-in. (103 cm) pipelines over lengths less than 2,000 ft (610 m) have also been accomplished with regularity. These limits will embrace most economic pipeline applications.

The primary factor limiting the application of directionally controlled horizontal drilling techniques is adverse subsurface conditions.

Installations through strata which contain significant amounts of gravel or larger granular material are very difficult to execute. This is particularly true where random boulders or lenses of cobbles are present.

These large-grain materials cannot be suspended in drilling mud and therefore will not behave as a fluid. Nor are they usually in a structure which will allow them to be mechanically cut with cuttings removed by mud circulation.

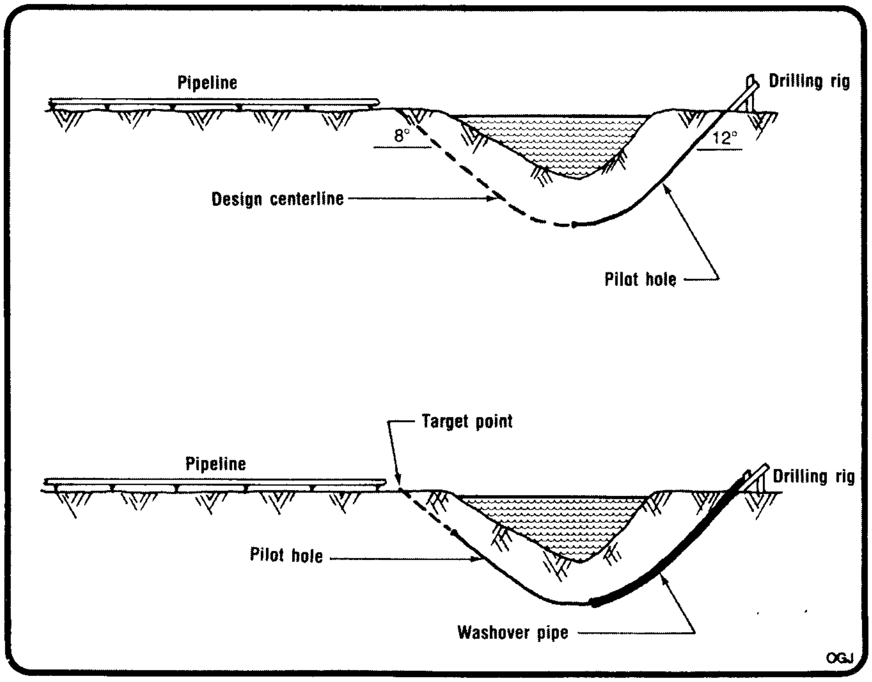
Instead, they tend to become lodged in and around the reaming assembly or pull section and prevent successful pull-back installation.

The presence of rock formations also presents problems for horizontal drillers.

Although installations have been successfully completed in rock, as rock strength increases, so does the mechanical effort required to cut it and the limits of readily available drill

Pilot-hole path

Fig. 3



pipe and remaining tools are exceeded. This problem is magnified when the reaming assembly has been designed for alluvial deposits or when rock strength is inconsistent.

Construction effects. Pipe installed by directionally controlled horizontal drilling will be subjected to tension and external pressure during installation.

Theoretically, neither of these loads will be particularly severe, but their presence should be borne in mind during selection of pipe for the river crossing. The exterior of the pipe should be as smooth as possible and externally upset joints should be avoided.

Welded steel is typically the preferred material for horizontally drilled river crossings. Since most are also in pressurized service, the grade of steel and wall thickness determined by internal-pressure design requirements exceed those necessary to withstand temporary construction stresses.

Experience in the petroleum industry indicates that steel pipe can be protected from external corrosion by a combination of coatings and cathodic protection.

If the crossing will be used to transmit material which subjects the pipe to internal corrosion, internal coating can also be applied. Another solution to this problem is to use a polyethylene liner within an outer steel casing.

It is also possible to install polyethylene pipe alone in a drilled crossing. If this option is selected, however, external collapse pressure due to installation and hydrostatic head should be carefully analyzed. This is particularly critical for larger diameters.

Because of the typical minimum depth of undisturbed cover (15 ft, 4.6 m) involved with a drilled crossing, external weight coating is not required for flotation resistance.

Drilled path geometry. Designing a drilled profile is a fairly straightforward exercise in geometry.

A typical profile will consist of tangents connecting two natural sagbends.

Radiuses of curvature for the bends are calculated using the following formulas:

$$R = 100(d)$$

or

$$R = \frac{E(r)}{SMYS(f)(12)}$$

where:

R = Radius of curvature of circular sagbends, ft
E = Modulus of elasticity for steel
r = Outside radius of pipe, in.
SMYS = Specified minimum yield strength of pipe steel, psi
d = Nominal diameter of the pipe, in.
f = Allowable bending stress factor

The first formula is based on experience and sets the radius at a value which will generally prevent binding or undue loads from occurring during installation.

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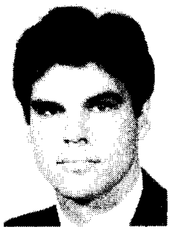

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The second formula calculates bending stress in the extreme fibers of the pipe to ensure that allowable limits are not exceeded.

The maximum value for radius calculated by either of the formulas is the value used in designing the drilled profile.

Other variable parameters which must then be set are the deepest point on the profile (PI elevation), the relative location of the entry and exit points (drilled length), and the entry and exit angles.

Once these values are assigned, the remaining positions on the profile can be calculated with simple trigonometry and standard circular-curve relationships.

The profile is then plotted on a cross-section survey of the river and reviewed to see if all design constraints are satisfied.

Typically, a minimum depth of cover of 15 ft (4.6 m) should be maintained in design of drilled profiles to provide a margin of safety against downhole "blowout."

Entry angles should be held to between 8 and 20° with horizontal. These limits are due chiefly to equipment limitations.

Exit angles should be designed to allow easy breakover support. That is, the exit angle should not be so steep that the pull section must be severely elevated in order to guide it into the drilled hole. ▪