PIPELINE LANDFALL CONSTRUCTION BY HORIZONTAL DRILLING

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ABSTRACT

The segment of an offshore pipeline where the transition is made from standard offshore laying procedures to standard on land laying procedures represents a difficult and costly construction problem. This problem is compounded by the arctic environment where conditions such as ice scour, extreme weather and intense environmental concern greatly increase costs of conventional construction techniques. A solution to this problem which promises significant economical advantages and minimal environmental impact is the application of the directionally controlled, horizontal drilling technique. This technique has been used throughout the world in construction of pipeline river crossings and landfalls in more temperate environments. Presented in this paper is a description of today's state-of-the-art in horizontal drilling and an extrapolation of these capabilities to the arctic application. Techniques developed and experience gained in related applications such as tunneling and mining are described and integrated into the proposed construction procedure.

INTRODUCTION

Consideration of horizontal drilling for the installation of pipeline landfalls in the arctic is not a new concept. However, over the past four years, since 1980, significant advances in the state-of-the-art of horizontal drilling technology have been made. Additionally, the state-of-the-art in the related techniques of mine shaft raise boring and small diameter tunneling has also been advanced in recent years. The objective of this paper is to describe these advances and illustrate how they are relative to the specific problem in hand, that of landing a pipeline in the arctic.

The detailed design of arctic landfalls is not dis-

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cussed. It is accepted that deep burial beneath undisturbed cover holds significant advantages for the system's owner. (2) Specific economic advantages relative to other construction techniques are also not reviewed. However, experience with similar applications in existing oil production facilities on an international scale has generally shown horizontal drilling to be economical. (4)

HORIZONTAL DRILLING STATE-OF-THE-ART

As of the fall of 1984, approximately 150 pipeline installations totaling about 240,000 ft (73,200m) had been completed using horizontal drilling techniques. The maximum diameter installed is 40 in (1016mm) and the maximum length installed is approximately 6,000 ft (1830m).

The method is particularly suited to installations where deep burial is required beneath obstacles which make excavation very difficult or costly. An example of this is the Mississippi River. Dramatic changes in bottom elevation from season to season or with course changes in the river make maintenance of a buried crossing very difficult. Additionally, water depths approaching 100 ft (30.5m) limit dredging equipment to a very few long ladder, high volume hydraulic dredges.

The first pipeline crossing installed beneath the Mississippi by horizontal drilling was completed in the fall of 1980. This was a 24 in (610mm) welded steel line approximately 4,200 ft (1281m) long. The completed line had a minimum of 40 ft (12.2m) of undisturbed cover beneath the river channel. Since that time, thirteen pipeline crossings have been constructed under the Mississippi with all but two installed by horizontal drilling.

The process presently employed in installing pipelines by horizontal drilling is a two stage process. The first stage consists of drilling a small diameter pilot hole following a designed profile as closely as possible. This is accomplished using a specially designed horizontal drill rig in conjunction with directionally controlled downhole drilling tools.

The course of the pilot hole is determined by taking periodic readings of the inclination and azimuth of the drill head. 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 drill head relative to the initial entry point on the surface.

Directional control is accomplished through the use of a nonrotating drill string with an angular offset at the leading edge which creates a steering bias in its direction.
and plane. If a change in direction is required, the drill string is simply rotated so that the direction of bias is the same as the desired change in direction. A downhole positive displacement mud motor rotates the drill bit to provide mechanical cutting action.

After completion of the pilot hole, the reaming and pulling back phase of operations begins. For larger diameter lines, this consists of pulling successively larger diameter reaming tools through the pilot hole until a hole diameter is achieved which is suitable for installation of the pipeline. This diameter will be larger than the outside diameter of the product pipeline allowing the pipeline to be suspended in drilling mud and permitting easy movement of the pull section during installation.

These pre-reaming passes are accomplished by attaching specially designed reaming tools to the pilot hole drill string at the exit point. The reamers are then rotated and drawn to the drilling rig enlarging the pilot hole as they go. Drill pipe is added behind the reamers as they progress toward the drill rig. This assures that a string of pipe is always maintained in the drilled hole. For smaller diameter lines, pre-reaming passes are omitted and the final installation pass is undertaken upon completion of the pilot hole.

The final installation pass is similar to the pre-reaming passes with the exception that the reamers are followed by the actual product pipeline instead of additional wash pipe. A swivel is utilized to connect the pipeline pull section to the leading reamers and wash pipe to prevent any torsional stress from reaching the pipeline.

RELATED TECHNIQUES

As yet the technical limits of the horizontal drilling technique previously described have not been defined. Applications which are economically feasible rarely extend past 4,500 ft (1373m) in drilled length or 36 in (914mm) in outside diameter and, because of the nature of the obstacles to be crossed, generally penetrate soft alluvial or marine deposits.

Experience which is useful in evaluating the technical feasibility of the horizontal drilling method for application in the arctic can be gained, nonetheless, from related construction techniques utilized outside the petroleum pipeline industry. Two of these techniques which merit examination are raise drilling in mine shaft construction and small bore tunnelling.
RAISE DRILLING

Raise drilling is a method for excavating vertical or inclined mine shafts using a two phase process similar to the horizontal drilling process previously described but without the directional control capacity.

First a pilot hole is rotary drilled by the boring machine from the surface down to the underground mine level workings. A large reaming head then is attached to the drill string, replacing the pilot bit assembly. The raise drilling or backreaming phase involves upward boring by the reaming head which is rotated and forced against the rock by hydraulic cylinders used to withdraw the drill string. Rotation torque and speed are imparted to the head through the drill string by an electric motor. The rock cuttings fall to the bottom of the shaft for mechanical removal through the mine workings.

This technique has been utilized in the mining industry in the United States since 1962. It is widely accepted throughout the world with roughly 300 machines operating in 25 countries.

The diameters of shafts generally constructed by this method range from 2.3 ft (0.7m) to 21 ft (6.4m) and may extend over lengths up to 3000 ft (914m). Although most raises are constructed vertically, raises have been drilled at angles as low as 55° from horizontal. The substrata through which raises are drilled range from soft to hard rock which is often overlain by looser sediments. (1) Machines are manufactured which are capable of providing 1,000,000 lb (454,000kg) of upward thrust with up to 211,000 ft-lbs (29,217kg-m) of continuous boring torque. (3)

An illustration of what has been accomplished using this method is provided by considering a specific example. In mid 1978 two 20.3 ft (6.2m) shafts were raise bored through 230 ft (70.2m) of sedimentary rock by the Monterey Coal Company in Southwestern Illinois. The shafts were cut upward with a staged boring head requiring about 400,000 lb (181,000kg) of upward thrust. Boring rates averaged approximately 2 ft (0.6m) per hour with a maximum of 10 ft (3m) per hour attained in the softer rock. (3)

Another mining technique which is closely related to raise drilling is box hole drilling. This technique is used in mining applications where a machine cannot be set up on the surface or upper level to pull a boring head through a previously drilled pilot hole. Instead, the full size head is thrust and rotated away from the machine located at the lower level cutting the hole in a single phase, one pass operation. Once again cuttings fall to the bottom of the hole and are removed by mechanical means. Two concepts are used to provide rotating torque to the cutting head. Some
machines rotate the drill pipe as in raise drilling while others employ either electric or hydraulic drive systems located directly behind the cutting head.(1)

**SMALL BORE TUNNELING**

Tunneling techniques have been extensively used in mining and civil projects for many years. Many different methods have been developed over several generations and have been applied with success.

A tunneling technique which is of considerable interest for its small bore capabilities in soft and discontinuous soils and its method of spoil removal is the Mechanical Type Earth Pressure Counter-Balanced Bentonite Shield System.

This system is a boring/jacking system utilizing a lead boring section with a full face rotating cutter followed by a segmented tunnel liner. As the lead section advances, lining segments are added to the rear and thrust into place using hydraulic jacks located in a pit at the initial point of the tunnel.

Bentonite mud is pumped to the cutting face from the surface and serves to "float" the cutting face as it advances and to transport soil cuttings. The mud/cuttings slurry is returned to the surface by a pump located downhole in the boring section. Rotation of the cutting face is accomplished by an electric motor located downhole which receives its power from a generator on the surface. Steering is provided by hydraulic jacks which adjust the alignment and inclination of the initial segment of the boring section.

This system has been used to construct tunnels over a wide range of diameters, up to 10 ft (3m) and as small as 1 ft (0.3m). Operation in larger diameters is by men stationed in the boring section. Smaller diameters, however, are controlled remotely through the use of a television system to monitor an instrumentation panel downhole. Equipment is manufactured which has the capability to bore through clays, silts, sands, gravels and strata containing boulders to as large as 20 in (500mm).

Application of this technique is worldwide in scope generally on utility projects in urban areas where congestion or manmade obstacles prevent standard cut and cover construction. One such project recently executed in the U.S. was a 48 in (1219mm) water pipe installed beneath an interstate highway and railroad right-of-way in Southern Florida. The line was placed in a 72 in (1829mm) casing which was installed by a remote controlled slurry mole over a distance of 615 ft (188m). Construction was accomplished in 104 hours of working time spread over a two week period.
PROPOSED ARCTIC APPLICATION

The technique envisioned for application in the arctic would have the following capabilities:

1. The ability to install a pipeline along a curved path (surface to seafloor).

2. The ability to install welded steel pipe with an outside diameter of 48 in (1219mm) or less over a horizontal distance of 5,000 ft (1525m) or less.

3. The ability to install pipe in all types of subsoils found in the arctic coastal zones. These are expected to include cohesive soils, granular soils ranging to cobbles and boulders, rock formations and particularly permafrost.

Installation of the pipe along a curved path can be accomplished using the directionally controlled horizontal drilling techniques described previously.

Past experience with drilled river crossings has indicated that a pilot hole length of 5,000 ft (1525m) is within the state-of-the-art of today's technology. Because of the high northern location of the probable jobsites, a new downhole survey system utilizing a method other than magnetic deviation for steering the drill head would need to be utilized. Preliminary development work has been done on a tool which would determine drill head location downhole using sonic methods. Additionally, tools employing gyroscopes could also be developed. The theoretical basis for these concepts is sound; however, the economic stimulus for their commercial development does not exist in today's horizontal drilling market and therefore they are not presently available.

Two construction procedures are proposed to accomplish the task of installing a 48 in (1219mm) diameter pipeline over a 5,000 ft (1525m) distance in the arctic.

The first would differ only slightly from the method now in use that has been described earlier. Past experience with raise boring techniques employed in drilling mine ventilation shafts gives a clear indication that it is possible, given suitable soil conditions and properly designed tools, to open a hole much greater in diameter than 48-inch by pulling a reaming tool through a pilot hole.

For the procedure envisioned, a mud system for removing cuttings would be employed similar to that used in drilling conventional landfalls. Bentonite mud would be pumped down the interior of the drill string and exhaust through the cutter lubricating and cooling the cutting edges and carrying away soil cuttings. The mud would flow around the annu-
lus of the pull string being installed and provide lubrication.

This technique does, however, contain significant drawbacks. Considerable expense will be involved in fabricating and handling the landfall pull section offshore. Additionally, drilling fluids will not be recirculated and will be discharged along with cuttings on the sea floor representing a probable environmental concern.

A second procedure proposed to eliminate these drawbacks is the "forward thrust" technique. This technique is not a staged technique using a small diameter pilot hole to establish directional control and then installing the carrier pipe by reaming and pulling. Rather, pipe installation is accomplished in one pass through the use of a large diameter steerable drilling head which is followed as it advances by the product pipeline.

This technique was favored in the early stages of development of horizontal drilling for large diameter pipeline installation but has been used only twice -- the first time on a 30 in (762mm) crossing of Greens Bayou and the second on a 40 in (1016mm) crossing of the Houston Ship Channel. Both crossings were located in Houston, Texas with drilled lengths of 751 ft (229m) and 1700 ft (519m) respectively.

The key to forward thrust is the large diameter, steerable drilling head. This head functions very much like the small bore tunneling machines described earlier. Hole is made by a rotating cutting face. Drilling fluid is pumped through nozzles on the cutting face and serves to lubricate and cool the face and remove cuttings. Exhausted fluid containing soil cuttings is pumped back to the surface for recirculation or disposal by a slurry pump in the cutting head.

Directional control is accomplished using adjustable rams located around the circumference of the drill head. Downhole surveying would be continuous using a gyroscopic or sonic system.

Power, drilling fluid and communications would all be supplied to the drilling head through lines extending down the interior of the carrier pipe from the surface. Power could be transmitted from primary sources on the surface by electric means as in the small bore tunneling machines.

The problems posed by the pull-back method are eliminated using forward thrust. Since all activities associated with construction of the landfall take place on the shore, no expensive offshore operations need be considered. Also, no path will be opened to the sea floor until construction is complete and therefore discharge of drilling fluid will be minimized. It will, of course, be necessary to recover
the drilling head once it exits on the sea floor.

A problem posed by this technique is how to follow the drilling head with the carrier pipeline. Joint by joint connection is time consuming and awkward especially when considering that additional utility connections must also be made with each joint.

This problem can be solved by prefabricating the carrier pipe in one or more installation sections thus eliminating as much as possible connections during drilling. It would be necessary to align the sections over the rig ramp and down through a thrusting mechanism into the hole. Utilities would be provided on movable skids which would follow each section as it was installed.

**CONCLUSION**

Installation of pipelines by horizontal drilling has had a major impact on the design and construction of pipelines in crossing major obstacles such as rivers or surf zones. This technique was developed by taking proven tools and techniques from fields outside of pipeline construction, combining them into a workable system and modifying and adding to this system based on experience to produce an efficient workable construction process for application in temperate climates.

An opportunity exists to follow a similar path to aid in the development of offshore resources in the arctic. Experience in horizontal drilling to date gives a strong indication that application of the technique can be successful in the arctic given the capability limits proposed in this paper. Lack of specific experience under arctic conditions can be compensated for by considering experience derived from similar techniques under similar conditions.

Therefore, the following preliminary conclusions can be drawn:

1. A small diameter curved pilot hole can be drilled over distances as long as 5,000 ft (1525 m).
2. A pilot hole can be reamed to a diameter of 60 in (1524 mm) or less in competent rock or permafrost by pulling a reaming tool through it.
3. A remotely controlled steerable drilling head can be built which can bore through discontinuous granular deposits and/or competent rock cutting a hole with a diameter of 60 in (1524 mm) or less.
4. A welded steel section of pipe 48 in (1219 mm) or less in diameter can be either thrust or drawn into a curved
hole cut by one or both of the methods described above over a distance of 5,000 ft (1525 m).

These conclusions are termed preliminary because the detailed analysis and design required to confirm them is beyond the scope of this paper. They are presented, instead, to serve as justification for the effort and expense involved in such a confirmation.

More effort needs to be directed to the examination and analysis of related techniques including, and in addition to, those presented here. The results of such a study should then be forged into a more specific process design which can be compared against competing techniques on an economic as well as technical basis.

An effort such as this can best be undertaken by a combination of talent drawn from construction contractors, equipment manufacturers and resource development companies. In this way, adequate knowledge and financial resources can be devoted in an objective manner to accomplish the task.

APPENDIX - REFERENCES


