DIRECT PIPE AS AN ALTERNATIVE TO HDD, METHOD AND CASE STUDIES

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ABSTRACT

This paper provides an overview of the multiple case histories of the Direct Pipe technology worldwide. Thereby illustrating the benefits for the owner, engineer and contractor in comparison to HDD in permeable soil conditions.

The Direct Pipe method has been first used in 2007 at the Rhine river crossing in Worms, Germany. Since then, more than 18 crossings have been installed in Europe and the US with great success. The longest installation so far had a total length of 4,600ft (1,400m) and a pipeline diameter of 48". The peak performance during that installation was 756ft (232m) per day (24hrs).

Since its inception Direct Pipe has been adopted for the installation of over 30 crossings in numerous European countries and further afield such as America, Canada and Thailand.

To date all attempted installations have been successful.

The largest pipeline currently installed is a 56" steel pipe in Preston, England with a total length of 2,820ft, serving as casing pipe for a post installed 36" potable water pipeline (HDPE).

The combination of the well established Microtunneling technique with the Pipe Thruster technology makes it ideal for difficult (permeable) soil conditions which pose a certain risk for frack-outs using the HDD method, and this paper intends to highlight the benefits from operational, construction programme and risk mitigation aspects.

KEYWORDS

Pipeline Installation, Geology, Safety, Environment, Innovation

1 INTRODUCTION

In pipe and pipeline construction, safe passageways through sensitive areas are a matter of course and only rarely a major challenge. But in every project the question is which of the available construction methods is the most economical and less risky from an engineering point of view.

Apart from characteristics such as the pipeline diameter and drive length, the choice of a suitable method mainly depends on other project-specific parameters like geological, environmental and other boundary conditions.

The Direct Pipe method opens up new application options by combining the benefits of the well established microtunneling technology and the HDD. The key innovation is the Pipe Thruster which grips the pipeline circumferentially and pushes it into the ground. This means that the pre-fabricated pipeline can be installed in the ground simultaneously with the excavation process, thus permanently supporting the bore hole.

The Direct Pipe method, which was developed in the scope of a research project sponsored by the German Federal Ministry of Education and Research (BMBF), was successfully deployed for the first time in 2007 for a Rhine crossing in Worms. Since then, the individual process components have been continuously improved and adapted to reflect increasing requirements. Beginning of 2014 36 projects with a total of more than 18 kilometers of laid pipeline have been realized in Europe and the USA. The pipeline diameters vary between 30" (Outer Diameter: OD=762 mm) and 56" (OD=1,422 mm) with a maximum drive length of 4,600ft (1,400m).

The new established process is characterized by the fact that it is suitable for direct laying of larger diameter product pipes. In specific project conditions, Direct Pipe offers benefits compared with older established installation methods, and is thus a useful alternative.

The following pages provide an introduction to the machine technology and design parameters. Based on reference projects, a differentiation between Direct Pipe and the alternative methods, Horizontal Directional Drilling (HDD) and Pipe Jacking / Microtunnelling follows.

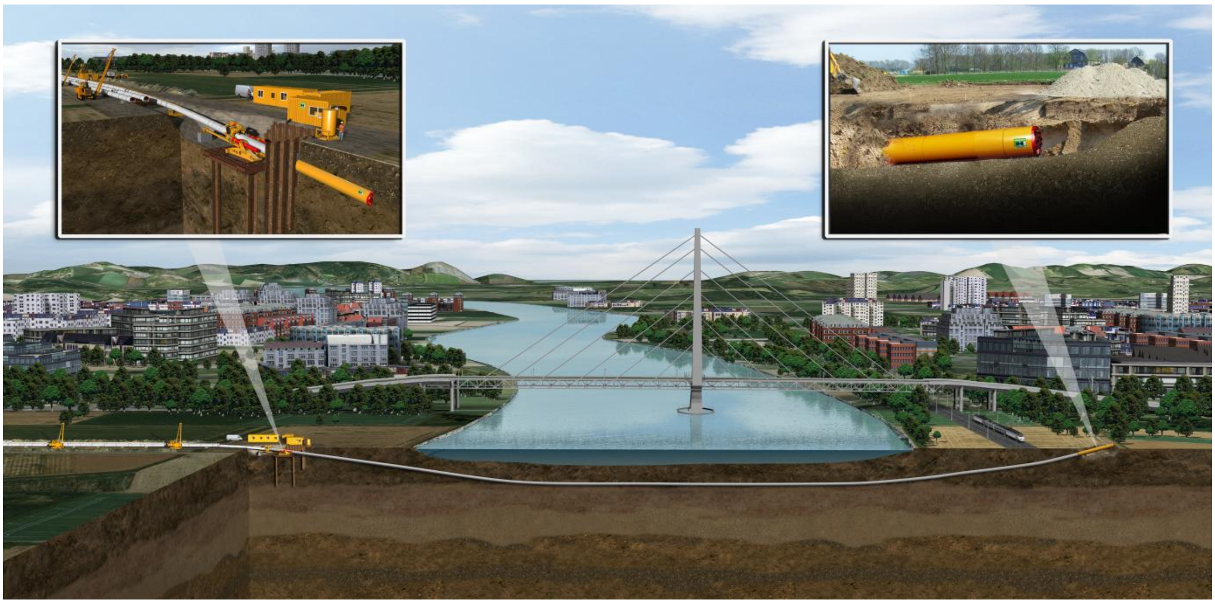

Figure 1: River crossing using the Direct Pipe method from left to right

2 MAIN COMPONENTS

2.1 DIRECT PIPE MACHINE

The slurry supported Direct Pipe machine works roughly in a similar way like a conventional slurry supported microtunnelling machine (AVN), but differs in length. To allow for a curved movement of the machine and the trailing pipeline in the curved path, the machine is equipped with two backup pipes. The fact that all of the joints in the individual backup pipes are articulated and connected by tension rods, ensures optimum steering capability of the machine. An additional benefit is that the machine together with the pipeline can be retracted, in the case it is needed, with the aid of the Pipe Thruster.

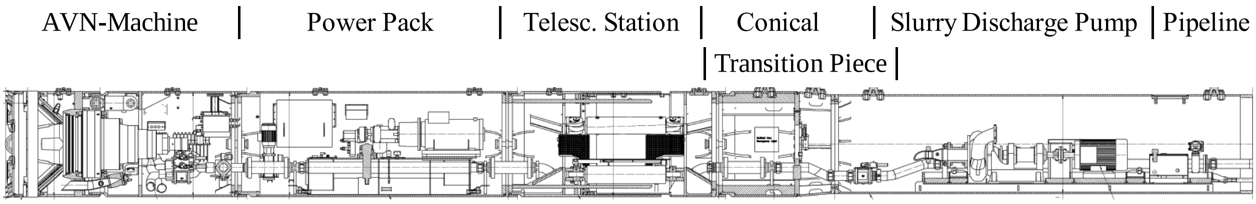

Figure 2: Longitudinal section through a Direct Pipe machine (AVN1000XC for a 48” pipeline)

The scope of project planning, includes the machine's cutterhead, which is adjusted to the geological conditions. In case boulders or rock are anticipated along the route, disc cutters can be deployed in addition to the cutting knives. Disc cutters crush the rock ahead of the machine until the fragments are small enough to pass through the cutting wheel openings and enter into the crusher chamber which is also called excavation chamber.

With the cone crusher inside the crusher chamber a wide geological range can be handled from coarse gravel, cobbles and boulders to hard rock. The crusher basically uses the same principle as a coffee grinder. Stones are ground until they pass through the predetermined openings on the inner cone of the excavation chamber, the last stage where the maximum grain size before entering into the slurry lines is limited. This prevents blockages in the following slurry lines.

With pipe diameter of 40" (OD=1,016mm) an greater, Direct Pipe machines are equipped with an integrated Power Pack. The unit generates the hydraulic pressure required to rotate the cutterhead and power the steering cylinders. It is located in the backup pipe behind the cutterhead and the steering cylinders. The advantage of generating energy locally in this way is that longer drive lengths can be achieved. However, due to the lack of space, smaller machines with a pipe diameters of 28"- 38" (OD= 711-965mm) cannot be equipped with a Power Pack. They need to be driven by hydraulic lines from a power pack on the surface. The hydraulic losses resulting from a therewith necessary hydraulic supply through pipes and hoses from the control container on the surface limit the drive length to approx. 1,000ft. (300m).

A telescopic station can be assembled between the backup pipe with the power pack and the conical transition piece connecting the pipeline with the micromachine. Thereby it is possible to thrust the machine forward independently from the pipeline, e.g. after a longer period of standstill where frictional forces tend to be higher. Additionally, there is more control of excavating obstacles such as e.g. boulders or rock formations. In contrast to the telescopic station deployed in Pipe Jacking with concrete pipes, the telescopic cylinders on the Direct Pipe machine can act in both directions. If it becomes necessary to withdraw the machine with the pipeline, the frictional forces between the ground and the machine can be handled by the telescopic cylinders and the friction between the ground and the pipeline by the Pipe Thruster. This can be useful if the machine is "locked" in the ground. The telescopic station thus acts as a safety tool which can be deployed under certain conditions.

The transition piece onto which the pipeline is welded has a conical shape. It reduces the larger diameter of the machine to the smaller pipeline diameter. The conical transition piece contains a backwards facing bentonite lubritacation ring from which the main volume of bentonite lubricant is pumped into the annulus. The whole operation is volume controlled in order to make sure that the annulus is not over pressurized. The built in rear bulkhead seals off the machine from the pipeline and the intrinsic slurry lines.

2.2 PUSH UNIT PIPE THRUSTER

The Pipe Thruster was originally designed as an auxiliary assist tool for the pipe pull-in with the HDD method (installed on the pipe-side). The Pipe Thruster's applications are as follows:

- Pushing or pulling pipelines into the excavated open bore holes (e.g. created by HDD) or existing tunnels. This has already been implemented in several projects worldwide. The maximum length of a pipe pushed in like this is currently at 13,000ft (4,000m).
- Pulling out previously laid steel pipes from the ground. This is also established in the USA and Europe.
- Direct Pipe method for laying pipelines (with coating if needed). Thus far, 35 projects have been successfully completed. Chapter 4 briefly describes some of them.

Figure 3: The Pipe Thruster HK500PT exhibited at the Hannover Fair in 2006 clamping a 48" steel pipe.

The maximum pipeline diameter that the biggest Pipe Thruster version can clamp is 60" (OD=1,524 mm). The clamping unit is mainly adapted by changing the clamping inserts to match the pipeline diameter. It was designed to avoid damaging the coating of the product pipes, such as gas or oil pipelines. In extensive tests at the Herrenknecht workshop in Germany, it was demonstrated in cooperation with various gas suppliers that no damage is caused to the coating. PE (polyethylene), PP (polypropylene) and Glasfibre Reinforced Plastic (GRP on PE) coated pipes were tested at full clamping force of the clamping unit and at full thrust force. The contact surface between the pipe and the clamping inserts is covered with hot-vulcanized rubber. It is designed to be large enough to minimize the pressure (3.5 N/mm²) and shear forces (1.2 N/mm²) on the coating.

Table 1: Characteristics of the three different Pipe Thruster models

Pipe Thruster Models	**HK300PT**	**HK500PT**	**HK750PT**
Max. push and pull force (in kN / tons)	3,000 / 300	5,000 / 500	7,500 / 750
Clamping diameter (in inches = ")	Max. 36	Max. 48	Max. 60
Attack angle (in °)	0 to 15		
Weight (in tons)	40	53	78

3 ACCESSORIES AND SET UP AT CONSTRUCTION SITE

3.1 LAUNCH AND TARGET PITS

By using the Direct Pipe method, the drilling route is typically a curve from the surface of the terrain, underneath the obstacle (river) to be drilled under, to the opposite surface, like in HDD. The benefit here is the simplicity of the required launch and target pits. The Pipe Thruster can either be set up and anchored in a shallow launch pit, or right on the surface.

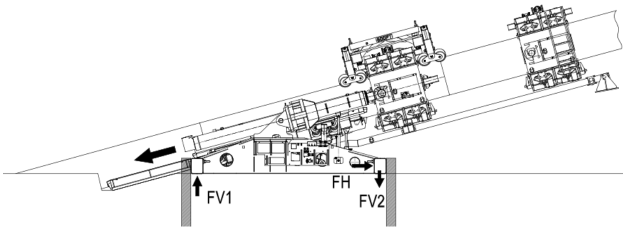

Figure 4: Force components to be anchored on pushing the pipe with the Pipe Thruster

The machine connected to the pipeline is set up at the required entrance angle in front of the launch seal. The overbend of the outlaid pipeline is held in place with side booms or roller supports as well as launch tracks with rollers on the surface. The horizontal and vertical forces to be anchored depend on the entrance angle and the maximum push or pull force to be applied. The forces can, for example, be held by an anchoring frame and sheet piling or foundation piles with a depth sufficient for the geology. The following table shows the values for the resulting forces with a corresponding entrance angle.

Table 2: Vertical and horizontal forces for three Pipe Thruster models - computed for maximum push and pull force in corresponding entrance angles (figures in kN)

Launch angle	HK 300 PT			HK 500 PT			HK 750 PT		
	FV1	FV2	FH	FV1	FV2	FH	FV1	FV2	FH
0°	986	986	3000	1532	1532	5000	2998	2298	7500
1°	1020	967	3000	1577	1490	4999	2366	2235	7499
5°	1153	891	2989	1751	1315	4981	2627	1973	7471
7°	1217	852	2978	1835	1226	4963	2753	1839	7444
10°	1311	790	2954	1957	1089	4924	2935	1633	7386
12°	1372	748	2934	2035	996	4891	3053	1493	7336
15°	1459	683	2898	2148	854	4830	3222	1280	7244

Similar to Microtunnelling with concrete pipes, penetration of groundwater, soil, slurry or lubricating bentonite out of the annulus into the launch pit must be prevented by the use of a launch seal. The overcut is sealed with a neoprene rubber. To be able to compensate for movements in the pipeline, the launch seal for Direct Pipe comprises of two steel structures which are supported by a U-shaped Neoprene rubber to allow for relative movement. Guide rollers on the front part of the seal ensure the required clearance between the pipeline coating and the structure of the seal. To ensure the best possible sealing effect, the launch seal is mounted to the pit wall at the selected entrance angle. The soil coverage over the launch seal should be at least one or two times the machine diameter.

Figure 5: Direct Pipe Launch Seal

3.2 OPERATION CONTAINER

All of the process components involved in drilling and lying, such as the machine, the Pipe Thruster, pumps and navigation systems are remotely controlled from the control container. The important functions and measured values are visualized for the machine operator on multiple displays located in the control cabin. One screen displays e.g. the navigation system, another one the pictures from the cameras built inside the machine. The control container is installed next to the launch pit. The hydraulic power supply to the Pipe Thruster is provided by a power unit built into the container.

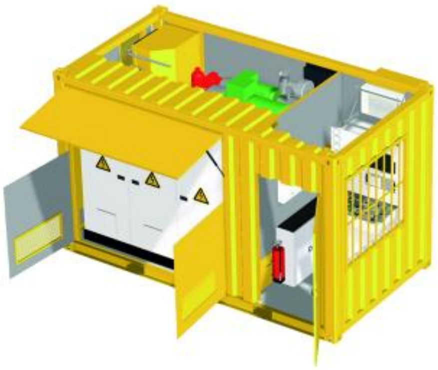

Figure 5: The control container

Figure 6: Machine operator's workplace

3.3 NAVIGATION SYSTEM

To allow the machine to drill precisely along the required route, and thus lay the pipeline exactly at the desired location, a suitable surveying system is needed to locate the machine. The horizontal position is determined by a fibre-optic gyroscope. The latest generation of gyroscopes measures continuously, thus removing the need for interruptions, as previously dictated by the mechanical gyroscope. The vertical position is determined by an electronic hydraulic water level, a simple and proven system. The navigation system is accurate within a few centimeters (in some cases even only a few millimeters).

Before drilling begins, the coordinates for the route (start and/or end points) are entered in the surveying software. The machine operator sees a visualization of where the machine is located compared to the target route during drilling. By extending the three steering cylinders appropriately, the steering head can be articulated. The machine moves in the desired direction, with the entire pipeline following.

3.4 PREPARATION OF THE PIPELINE

The pipeline is laid out at the predetermined launch angle so that it can be easily moved in the direction of the launch pit when drilling starts. Depending on local conditions and the launch angle, it is supported either by rollers or side booms.

Figure 7: Pipeline (48") laid out on roller supports in the direction of the launch pit.

The feed and discharge lines are connected from the machine through the whole pipeline to the separation unit on the surface. All lines are placed on steel hangers which are equipped with rubber coated rollers for easy assembly and disassembly. None of the service lines are thereby touching the pipe wall and therefore there is no risk of damaging the coating from inside. At the end of the pipeline flexible hoses for the slurry and the bentonite lubrication are laid next to the pipeline and connected to the separation plant which is half way back to the shaft. The power and data cables are installed on top of the pipe and connected to the control container.

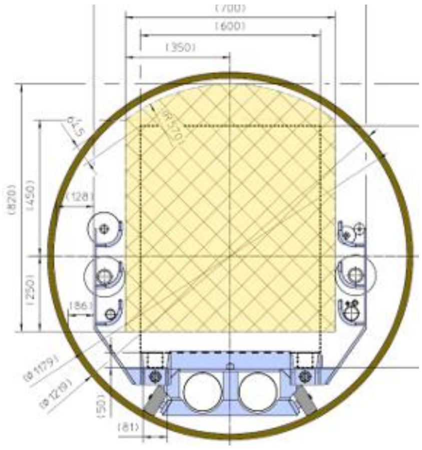

Figure 8 and 9: View into and cross-section of a 48" pipeline with supply lines placed on movable support structures

4 PROJECT CASE STUDIES

4.1 PROJECTS TO DATE

To date 35 projects have been completed using the Direct Pipe method with a total of approximately 18km of pipeline installed. Case studies of selected projects are given below.

4.2 PILOT PROJECT 2007 IN WORMS, GERMANY

The development of the Direct Pipe method was supported by the Germany's Federal Ministry of Education and Research (BMBF). The pilot project was successfully completed in Worms in 2007. A 464 m, (1522 ft) 48" steel pipe was laid under the river Rhine (48” casing pipe for various lines). The reasons for choosing this method were the partly difficult geology (sands, gravels, cobbles) on the one hand and the confined space conditions on the exit side on the other hand. In addition it was impossible to lay out the pipe in a single section on either bank of the river, thus making HDD extremely difficult.

The crossing was completed in 13 days with only five days of microtunneling. The remaining days were needed for pipe extension. The limited easement area only allowed for pipe strings of 90m. The fact that the machine including the pipeline was thrust into the small target pit in Worms with a thrust force of just 80 tons (500to Pipe Thruster installed) has shown the enormous capabilities of the new system and laid the foundation for further installations.

4.3 48" GAS PIPELINES IN THE NETHERLANDS

The first gas pipe job in the Netherlands opened the market outside Germany. In the years 2010 and 2011, a total of six projects were realized. Drive length between 1,200ft and 4,600ft, thereby crossing rivers, rail tracks and archeological sites were part of the 310miles (500km) North-South route which distributes gas in a 48” pipeline throughout Holland.

One example is the 1,800ft (540m) crossing below the very deep Hartelkanaal in Rotterdam. It was required to install the pipeline at a depth of 100ft (30m) below the surface. The limited space available on both sides of the crossing, resulted in steep launch and exit angles of 10° and 12°. The pipeline was split up into 10 pipe sections of each 177ft (54m) which have been installed within 2 weeks. The Dutch Society for Trenchless Tunneling "NSTT" awarded the client and the construction company the No-Dig Prize 2010 for the successful use of the innovative system.

Another remarkable project was the installation of a 4,600ft (1,400m) 48" gas pipeline on the same pipeline project. It has been chosen as test to evaluate the capacity of the Direct Pipe system. It is currently the record in terms of drive length. The pipeline was laid out in three pipe sections of 1,640ft (500m) each. With two pipe changes, the thrust duration from launch to arrival of the machine at the target was just 16 days. The maximum advance rate in 24 hours was 760ft (232m).

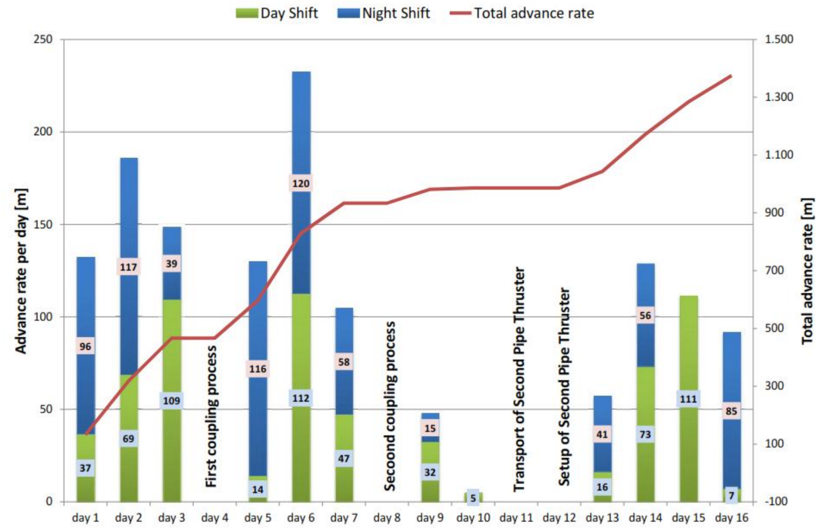

Figure 13: Advance rates in laying a 4,600ft (1,400m) gas pipeline (48") in sand

The 16 days included setting up a second Pipe Thruster (HK500PT), which was installed after advancing approx. 3,000ft (900m). The thrust force of 500 tons was insufficient at approx. the 3,000ft mark. After installing the second Pipe Thruster, the remaining pipe section was pushed into the target pit within just four days by the two Pipe Thrusters. This is equivalent (with an effective working period of 11 days) with an average advance rate of around 410ft (125m) per day.

Figure 14: Two HK500PT Pipe Thrusters in line laying a 4,600ft (1,400m) 48" gas pipeline

4.4 42" CASING PIPE INSTALLED IN NEW YORK

In May 2011 Empire Pipeline Inc., a subsidiary of National Fuel Gas Company received approval to build a natural gas pipeline in Steuben County (N.Y.) and Tioga County (P.A.) with a connection to Empire´s existing network at the northern end of the project. The new, 15-mile pipeline will bring further supplies of domestic, clean-burning natural gas from locally produced Marcellus Shale and Trenton-Black River gas wells to consumers in this region and beyond. This Tioga County Extension Project demanded installation of a new 24-inch pipeline on a length of 15 miles. One challenging section on this route was the crossing of State Highway 382 and the adjacent river in Corning, N.Y.

On a length of 2,900 feet the pipeline was installed by Michels Directional Crossings Inc. using the HDD method. To excavate through the initial layer of cobbles and gravels, where HDD is not suited, the construction company decided to install a 420ft (130m) long 42" casing pipe by the use of the Direct Pipe system. An AVN800 Direct Pipe machine with a Pipe Thruster HK750PT installed the casing within 5 days, with an entry angle of 11°.

Figure 16 and 17: Pipe Thruster HK750PT anchored on the surface with deployed machine AVN800A and 42" pipeline

4.5 AQUASHICOLA AND WETLANDS CROSSING

Laney Directional Drilling out of Houston utilized the Direct Pipe technology in 2013 on the 'Aquashicola Creek and Wetlands Crossing' in Monroe County Pennsylvania. It is a segment of the Williams Northeast Supply Link project and represents the longest Direct Pipe installation in North America to date, with a total installation length of 1,358ft (410 m).

One of the primary reasons why Direct Pipe had been chosen over HDD is the minimum frac-out risk of Direct Pipe. The Aquashicola Creek flows through a valley with steep ridges on either side. An HDD design would have been significantly longer and most importantly sufficiently deeper than Direct Pipe in order to have enough safety against hydraulic fractures and inadvertent returns within the permeable soil conditions under the river bed. The subsurface conditions included rock, shale with layers of gravel and cobbles. Especially the gravel and cobbles posed an additional challenge for the alternative HDD method. An average of 4ft per hour had been achieved in the challenging soil conditions. A special launch pipe configuration has been chosen by the contractor to minimize installation time of the equipment.

The pipeline has been split in 2 sections and could be installed on roller supports. The topography benefited the stinging of the pipeline close to the surface.

Figure 18 and 19: HK 750PT installed on the launch side in front of the launch pipe – pipe layout section with service lines.

The project was completed on 21st of June in time and budget and laid the foundation for Laney Directional Drilling to use the technology on future projects in North America.

4.6 DEBUT IN CANADA FOR THE BEAVER RIVER CROSSING

Sept. 2013 Michels Canada Co. completed the first unground pipeline installation in Canada using the Direct Pipe method. The project was part of the Inter Pipeline Cold Lake and Polaris Expansion Program and involved the installation of 1,122 ft (342 m) of a 42-inch pipe across the Beaver River near Bonnyville, Alberta.

Michels Canada is a wholly owned subsidiary of Michels Corporation who has already used the Technology in the U.S. in previous years.

The Direct Pipe method was selected for the Beaver River project to accommodate geotechnical and routing challenges as well as the specific environmental and cultural sensitivities associated with this particular watershed. The project was located in a rural area about 12.4 miles (20km) north east of Bonnyville, Alberta.

Michels decided to use a 750to Pipe Thruster (HK750PT) together with a 42” Direct Pipe machine. The installation had an entry angle of 4 degrees and an exit angle of 8 degrees. The depth of cover under the Beaver River bed was 16.4 ft (5 m).

The owner Inter Pipeline Ltd., together with the design engineer Complete Crossings Solutions and Michels Canada Co. began preliminary design on the oil pipeline crossing almost a year before it started. In early August, crews and equipment were mobilized and set-up was completed within two weeks of arrival. The entire project was supported by the mainline pipeline contractor which prepared the entry and exit locations and pipe sections.

Michels finished the crossing on Labor Day weekend and was off the site mid-September.

Figure 20: Side booms supporting during pipe extension

4.7 56” CASING PIPE FOR WASTEWATER CASING PIPE IN ENGLAND

The Direct Pipe method has been chosen as alternative to an EPBM (2,8m ID) which had been trapped after only 70m. In order to maintain the same hydraulic capacity a twin tube with each 56” in diameter have been chosen. Due to the anticipated galcial deposits, the use of the HDD method was assessed to be too difficult and too risky. The 850m long alignment led through constantly changing layers of clay, sands, gravel and also cobbles and bolders had to be excavated in the galcial deposits.From a shared launch pit, the two parallel 56" pipelines (OD=1,422 mm) were laid at a distance of just 3.5 m (11.5ft) . The two pipes acted as a casing for two waste water lines (DN900) which had been installed later. In contrast to most of the projects realized previously, whose target pits were near to the surface, the machine had to be recovered from a 15 m deep target shaft. The navigation system deployed (gyroscope and water leveling system) allowed for precise steering of the machine up to only a few mm into the seal installed in the reception shaft. Drive progress averaged 20m a day with a new UK pipe-jacking record of 72m in a single 12 hour shift.

Figure 21: Direct Pipe Equipment set up in the launch pit in front of the launch seal (HK750PT with AVN1200TB) with 56” pipeline.

5 BENEFITS COMPARED WITH OTHER TRENCHLESS METHODS

The benefits which have been discussed throughout the paper are briefly summarized in the following Figure.

COMPARED TO HDD	COMPARED TO MICROTUNNELLING
1. One-step pipe installation (no reaming steps necessary)	1. One-step pipe installation (no bigger casing pipe necessary) → high speed
2. Smaller borehole diameter (overcut not 1/3 of pipe-Ø but only approx. 10 cm in diameter)	2. Smaller borehole diameter (due to 1.) → less ground to move and dump
3. Permanent borehole support → reduced geological risk	3. Pullback option in case of obstacles → reduced geological risk
4. Access from only one side needed → ideal for Sea Outfalls & narrow cond.	4. Drilling from surface to surface → Simple pit construction on both sides
5. Laying off in pipe sections not risky	
6. Lower mud pressure and mud volume → reduced environmental risk	
7. Less overburden needed → advantage for client for later accessibility	
8. Discontinuous working schedule possible → in event of foreseen or unforeseen stops no risk of loss of borehole	

Figure 22: Direct Pipe vs. HDD and Direct Pipe vs. Microtunneling

6 CONCLUSION AND OUTLOOK

The first 35 projects have shown, that Direct Pipe achieves fast pipe installation performance. This makes the method an alternative to HDD and microtunnelling in terms of both installation safety and economics. The drives completed so far show the feasibility of increasingly long distances, given the right geology, which are only restricted by the smaller defined diameters of the product pipes and thus the limited accessibility of the machine for cutting tool changes. With the records of 4,600ft (1,400m) length of a 48” pipeline and the largest diameter of 56” installed by Direct Pipe, it was possible to set another milestone in innovative pipeline construction. Improved installation safety in difficult terrain - compared with HDD – and the economic benefits compared with standard Microtunnelling, makes the method very competitive. Direct Pipe is at its best when installing pipe through mixed soil conditions or unconsolidated rock formations non-conducive to HDD, or when performing installations with minimum cover. Since the equipment is only required on one side of the crossing, Direct Pipe can be ideal in applications with restricted areas on the exit side.