APPLICATION OF TRENCHLESS TECHNOLOGIES IN LATIN AMERICA: DEMAND AND PERSPECTIVE

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1. ABSTRACT

Services laid underground are indispensable for supplying the growing world population with water, oil, gas and electricity, for removing wastewater and to provide functioning telephone and communications networks. No-Dig technology is in a constant process of gaining importance due to rising ecological and economical awareness and restricted conditions on the surface. It can be used in all geological and hydrological ground conditions. During the recent years, the limits of trenchless applications have been permanently shifted. This lead to higher and stronger project requirements which had to be answered by new technologies or by further development of existing methods. New installation technologies, like Direct Pipe® for pipelines, have even been derived from proven methods.

Based on experience and engineering resources, pipe jacked tunneling projects can nowadays be carried out on growing drive lengths (>1,000m), higher groundwater pressures, or with challenging curved alignments. If the project requires, even with retractable machine concepts or subsea machine recovery.

This paper shows different trenchless technologies with their application fields such as water, sewage and cable tunnel construction. Furthermore, it will present international case studies proving the recent achievements in the industry with their potential for Latin America.

2. INTRODUCTION

Trenchless technologies are becoming more and more important to a wide range of application fields. With a growing world population and increasing urbanization, volumes of sewage are rising especially in large cities and require larger capacities in sewage transport and treatment. The systems that were built decades ago need to be modernized, extended or replaced to ensure efficient and sustainable wastewater management. Innovative tunnelling and shaft sinking methods prove out their benefits, especially in challenging conditions, e.g. in great depth or under groundwater pressure.

In the field of water supply, tunnels for water networks and transfer have to be built. Furthermore, trenchless methods are used, when water intake installations for desalination plants have to be installed out to the Sea. Special technological features make it possible to excavate a tunnel under the seabed and to recover the machine offshore. This technology is also used for cooling water intakes for coastal power plants and sewage outfalls.

With increasing demand for energy worldwide, hydroelectric power has gained importance during the recent years, particularly as a source of clean energy. New power plants of every size sprout up everywhere and the renovation of many existing schemes is under consideration. Long distance horizontal, inclined or declined tunnels also with pressure resistance linings are part of these schemes to manage the water transfer and its discharge needed for power generation. Different alternative technologies for excavation and lining have to be considered to choose the most economic, project-specific solution. In addition, the majority of hydropower projects is located in remote mountainous regions or environmentally sensitive areas, thus creating challenges with regards to access and logistics.

In pipeline construction, occurring surface and sub-surface obstacles such as waterways, roads and underground installations or environmentally sensitive areas have to be crossed. These obstacles require specialized construction techniques with minimum environmental impact. In the planning stage of a pipeline crossing project, all surrounding conditions have to be analyzed to find the safest and most cost-efficient method to be deployed. Besides technologies made especially for the pipeline industry, e.g. HDD, there is a growing number of alternative pipeline installation methods, which partly come from the tunneling industry. Whereas some of the technologies install the product pipeline directly into the borehole (e.g. HDD, Direct Pipe®, Pipe Express®), others install casings in which the pipeline is pulled-in in a further step, e.g. by a Pipe Thruster.

3. TRENCHLESS TECHNOLOGIES OVERVIEW

	Pipe Jacking trenchless	Segment Lining trenchless	Direct Pipe® trenchless	Pipe Express® Semi-trenchless	HDD trenchless
Diameter [mm]	ID 250-4000	ID 2300-4000	ID 711-1500	ID 900-1500	ID 250-1500
Pipe material	Steel Concrete GRP/Hobas Clay pipe	Concrete segments Combisegments (incl. Inliner) Rib & Lagging	Steel (Plastic)	Steel Concrete Plastic (HDPE)	Steel Plastic (HDPE) Cast iron
Max. drive length *dep. On Ø	Ø 250mm: 100 m Ø3000mm: 1.5 km	Ø 2000mm: 2 km Ø 3000mm: 8 km	Ø up to 38": 300m Ø up to 60": 1,4km	40" – 60": 1000m	Ø up to 20": 4km Ø up to 60": 1,7km

Table 1 Trenchless Technologies overview

3.1. Pipe Jacking

Pipe jacking is a method of constructing tunnels and underground pipelines. Pipes are jacked by hydraulic jacking cylinders from a launch shaft into the ground to a reception shaft. Thereby simultaneously the excavation of the ground material at the face and the conveyance of the muck are effected. The jacking station has to be installed in the launch shaft and adjusted in direction, height and pitch. Then, the tunnelling machine has to be arranged in the jacking station and the jacking cylinders are extended. The tunnelling machine is pushed into the ground and at the same time the rotating cutting wheel of the machine excavates the ground material. The advance stops, when the maximum stroke of the jacking cylinders is reached. The cylinders are retracted and a new pipe is to be installed in the jacking station. Then the jacking cylinders extend anew. This cycle has to be repeated until the tunnelling machine runs into the reception shaft. There the machine has to be recovered. The remote-controlled microtunnelling machines are operated from a control panel in a container which is located on surface next to the launch shaft. This is an advantage regarding safety regulations, because no staff has to work in the tunnel during construction. The position of the remote-controlled machine is monitored by a guidance system. Today, the developed tunnelling technique enables the realization of long distance advances, also in difficult ground conditions. The following tunnelling equipment and features reduce friction and jacking forces.

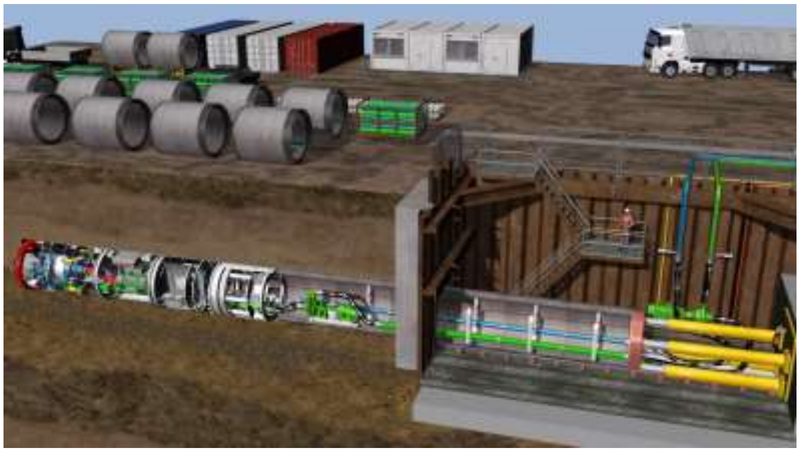

Figure 1 Schematic view of an AVN/slurry machine jobsite installation for Pipe Jacking

3.2. Segment Lining

Segment lining is a tunnel construction method used mainly for longer drive lengths, drives with multiple curves and larger tunnel inner diameters. The tunnel is constructed of rings which in turn are comprised of individual segments. For large diameter tunnels, segments facilitate the handling of the tunnel lining substantially in comparison, for instance, to individual pipes, which, depending on the location, can pose logistical challenges over ID4000.
The tunnel lining is assembled in the protected rear section of the TBM called the tailskin. After one complete ring is installed, thrust cylinders in the TBM thrust module push against the installed ring moving the TBM forward for the next excavation cycle. Depending on the type of TBM the excavated material is transported to the surface by rail-bound locomotive system with muck cars, tunnel belt conveyor, slurry fluid transport system or rubber wheeled multi service vehicle (MSV).

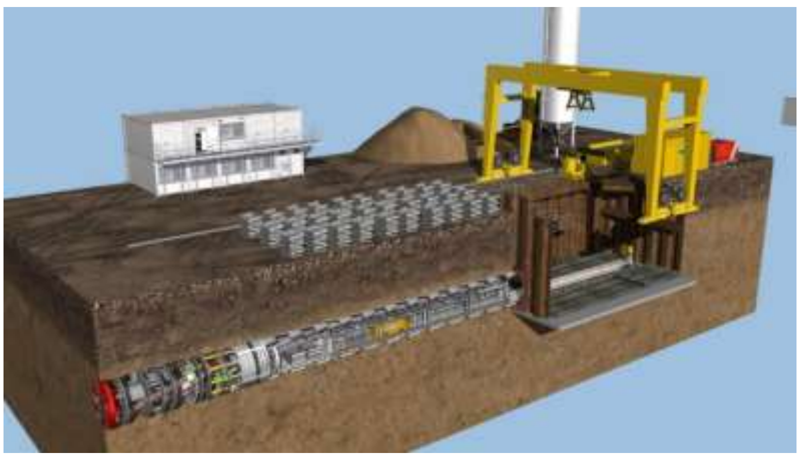

Figure 2 Schematic view of an EPB machine jobsite installation for Segment Lining

3.3. Direct Pipe

The Direct Pipe®-method for trenchless installation of prefabricated steel pipelines combines microtunnelling technology of excavation with a thrust unit, the so-called Pipe Thruster. Direct Pipe® incorporates the advantages of microtunnelling which enable application in difficult ground conditions, while reducing risks to a minimum.This opens up new application potentials.

Figure 3 Schematic view of a Direct Pipe River crossing

3.4. Pipe Express

The latest major development is the so called Pipe Express® Method; a semi-trenchless technology to install pipelines without the need for open trenches. This is an economic and also environmentally friendly solution, since the space requirements along the pipeline is reduced by 70%. This means that typical surface preparation requests for the Right Of Way (like cutting trees etc.) will be reduced down to only 30% of the conventional pipe laying method. The Pipe Express® Method also combines the excavation technology of a full face microtunnelling machine with the Herrenknecht Pipe Thruster which pushes the pipeline with the machine ahead.

Figure 4 Schematic view of Pipe Express principle

3.5. Horizontal Directional Drilling

In the HDD method, pipelines are laid in three stages.
First, a pilot drill is carried out from the launch point, using rotating drilling rods. The excavated material is transported to the surface by the drilling fluid which also gives the chisel extra drive. In the second phase, the retraction of the drilling pipeline, the excavating diameter is gradually enlarged with a reamer. In most cases, the borehole is supported by a bentonite suspension which at the same time serves as the transport medium for the excavated material. Finally, the pipeline is installed by pullback of the pipeline. This method is suitable for diameters of up to 56 inches (approx. 1.5 meters) and for lengths of up to around 3,000 meters, depending on the diameter. Drilling in less stable geologies, such as gravel, is not always possible because, unlike in the pipe jacking or segmental lining methods, the drill hole is not immediately stabilized.

Figure 5 Schematic view of HDD

3.6. Pipe Jacking and Segment Lining machine types

Figure 6 Overview of tunnelling machine types

Within this process of chosing the best-suited machine technology for a tunnelling project, the detailed analysis of the geotechnical report is the most important decisive factor. According to geology and requested diameter the following machine types are available for pipe jacking and segment lining.

AVN / AVND (Slurry / Mixshield) TBM
AVN machines are allrounders for safe tunnelling in the diameter range of 0.4 to around 4 meters. The slurry-supported excavation concept, where the excavated ground is transported to the surface by a slurry circuit, makes it possible to use these machines in all kinds of ground conditions, ranging from silt to clay soils and further to gravel and rock. Depending on the diameter, this is possible both in pipe jacking and for segmental lining. In soft soils and mixed geologies, standard or mixed ground cutterheads are used, while a rock cutterhead with disc cutters is used for tunnelling in stable rock formations. A cone-shaped crusher inside the excavation chamber crumbles stones and other obstructions to a conveyable grain size while tunnelling and advancing.

Partial Face Machines (MH/MHSM)
Partial-face excavation machines are an economically interesting solution in homogeneous and almost stable grounds with little or no groundwater. This tunnelling technology can be easily adapted to changing geological conditions both in loose soils and in hard rock due to its strikingly simple design. TBMs with partial-face excavation can excavate the soil with two different cutting tools. In loose soils, the excavator has proved its great value, roadheader booms are used in harder rock with uniaxial compressive strengths from up to 80 mega Pascal. Both boom technologies allow quick and easy replacement of the worn tools. The excavated material is transported by belt conveyors or chain conveyors to the conveying system in the back.

EPB (Earth Pressure Balanced) TBM
For soft, cohesive soils tunnel boring machines with earth pressure support are a preferred option. So-called Earth Pressure Balance Shields (EPB) turn the excavated material into a soil paste that is used as pliable, plastic support medium. This makes it possible to balance the pressure conditions at the tunnel face, avoids uncontrolled inflow of soil into the machine and creates the conditions for rapid tunnelling with minimum settlement. Transport of the excavated soil is done by a screw conveyor, belt and muck skip or via a muck pump system.

Single Shield / Double Shield TBM

Single Shield TBMs are designed for tunnelling through rock and other stable, non-groundwater-bearing soils. Due to the typical tunnelling methods with segmental lining or pipe jacking, high tunnelling performances can also be achieved in instable rock formations. When tunnelling with a Single Shield TBM, a rotating cutterhead equipped with disc cutters is pressed against the tunnel face with a pressure of up to tonnes per disc. Due to the rolling movement of the discs, the rock to be excavated is broken down to small pieces, so-called chips. Water jets can cool the cutting tools and reduce dust formation. Buckets installed at the cutterhead take up the excavated material. Thanks to gravity, it slides to the center of the machine through integrated muck chutes while the cutterhead rotates and then falls through the funnel-shaped muck ring onto the machine belt. At the end of the machine belt, the rock chips are passed on to belt conveyors or transport vehicles and removed from the tunnel. Double Shield TBMs are also called telescopic shields. In stable rock, the machine is braced radially against the tunnel with the gripper shoes. This means that the front shield can be advanced independently of the gripper shield using the main thrust cylinders.

Gripper TBM

Gripper TBMs have proven to be efficient solutions for fast mechanized tunnelling in hard rock on many occasions. Due to the process, rock support method without segments, medium- to high rock strengths are a requirement for high advance rates. In more fractured geological formations, various systems for immediate rock support behind the cutterhead are installed at the TBM directly. The rock cutting process of a Gripper TBM is the same as for the Single Shield TBM described above.

3.6. Tunnelled outfall projects

Tunnelling machines to be used for Sea Outfalls are equipped with an additional recovery module, consisting of a steel can with bulkhead to close the machine and hydraulic cylinders to separate tunnel and machine. The supply of hydraulic oil for these cylinders is done by divers and connected from the outside skin of the recovery module. After complete installation of the tunnel, the seaside end of the pipeline is mostly closed with a bulkhead equipped with a valve.

Figure 7 Tunnelling under seabed and preparation of machine recovery

In most cases the tunneling equipment has to be recovered and lifted up to the surface. Therefore, the jacking machine is equipped with lifting eyes on its upper side. There are two ways to lift the tunnelling machine:

1. A barge with a crane is moored at the position from which the jacking machine shall be recovered. To be more independent from the sea, a jack-up platform with crane can be installed which is able to lift higher weights than a floating barge. The crane is connected to the lifting eyes of the jacking machine by means of a spreader beam. The connection has to be carried out with the help of divers. The jacking machine is lifted to surface by the crane.

2. Another possibility to lift the machine from seabed to water surface is the application of airbags. These are fixed by divers to the lifting eyes of the machine. A compressor installed on a ship or barge on the surface inflates the number of airbags needed to lift the weight of the machine. Water level fluctuations caused by ebb and flood may be considered to reduce the lifting height. The barge or a ship transports the jacking machine to the next harbour, where it can be taken out of the water by a high-capacity crane.

Figure 8 recovery of tunnelling machine via airbags, lifting by crane in harbor

4. APPLICATION FIELDS OF TRENCHLESS TECHNOLOGIES

4.1. Sewage: Interceptor Norte Río Medellín, Colombia

The Medellín River runs right through the heart of the city of the same name in Colombia. Much of the sewage generated in the second largest economic center in the country is discharged untreated into the river and negatively affects not only the water but also the quality of life of local residents. For a clean future, therefore, the project "Medellín River Sanitation Program" is being carried out to clean up the Medellín River: a large-scale restoration project as part of which a new sewage treatment plant is being built in the neighboring municipality of Bello. Around 120 tonnes of contaminants which are transported by sewage from industry, commerce and households will be treated there daily in future. The burden on the Medellín River will thus be significantly reduced and 95 percent of the sewage discharged into the river, purified.

For the implementation of the new treatment plant sewage collectors and corresponding connecting channels had to be bored. Three Herrenknecht AVN Machines were used for this purpose in the complex project, which ran through subsoil containing groundwater and involved 27 drives with lengths ranging between 200 and 750 meters. Excavation of the tunnel with a total length of over 8 kilometers began in August 2012 in Moravia, a suburb of Medellín. The second AVN Machine began its work in October in the municipality of Bello. Toward the end of the project, the third AVN Machine with a diameter of 2,425 millimeters was used for smaller water collectors. Section by section the geology allrounders progressed with their tunnelling with overburdens of 3.3 to 21 meters. In doing so they successfully and without causing interferences crossed under both railway and metro lines, i.e., important avenues of passenger and cargo traffic, as well as the Medellín River itself. The top performances were 30 meters per day and 108 meters per week.

Figure 9 Medellin Jobsite

In October 2015 the last of the Herrenknecht machines reached its destination. With the commissioning of the new sewage treatment plant the sewage from more than three million people in the area can be purified and discharged clean into the river: an important step for the revitalization of the river and the region along its banks

Figure 10 AVN 600 in operation in San Jose, Costa Rica

4.2. Water: Aguas del Parana, Argentina

"It is one of the country's most important infrastructure projects from the past 50 years" said President of Argentina, Cristina Fernández de Kirchner. She was talking about the construction of the "Juan Manuel de Rosas" water treatment plant in Tigre on the northern edge of Buenos Aires' metropolitan area. The plant and an extensive pipeline network will supply around three million people with 1.2 million cubic meters of water per day.

Two Herrenknecht EPB Shields have been drilling the nearly 15 kilometer long tunnel that drains the water from the Paraná River and feeds it into the processing plant. The two machines set to work at depths of down to 20 meters from a common starting shaft in April and October 2011. The Earth Pressure Balance Shield "Liliana" is driving in the direction of the treatment plant, while "Cristina " is making her way towards the river. The excavated tunnel is lined with segments that are produced in a factory that was planned and equipped with the complete mould system by Herrenknecht Formwork. Then, in August and September 2013, the big success for the teams and the machines: breakthrough for the two Herrenknecht EPB Shields after best performances of up to 26.6 meters per day and 28.8. meters per week.

Figure 11 2 x EPB3600, OD 4390 in Herrenknecht factory, Schwanau, Germany

4.3. Hydropower: Gripper TBM, Rio Vermelho Project, Brazil

The use of tunnelling machines to install the needed transmission lines for small hydropower projects in remote regions is more and more gaining importance. For different small hydropower plants supplied by Rio Vermelho, South of Brazil, Herrenknecht AG has designed a compact Gripper-TBM (Ø 2850mm) to install 6 tunnels with a total length of 7,7km. A dam construction and a total of 6 small hydropower plants with 2 – 8.5 MW are installed at each tunnel. The first tunnel with 775m length has been built with 0.4% slope and will serve a 3.1 MW hydropower plant with a production of electrical energy of 1.268 MWh per month. With flow rates of up to 6m/s and 55% of allowed utilized water capacity per year the plant will be supply additional electric power to the public network. The design of the Gripper-TBM allows a very flexible use for different types of hydropower tunnels of different length and slope. Its compact design simplifies handling and logistics on the jobsite. The TBM can be mounted even under restricted space conditions. Its retractable design enables recovery of the machine when there is no space available for machine recovery on the target side. Cost and time investment for installation, operation, maintenance and disassembly has been reduced to a minimum to increase overall cost effectiveness of the small hydropower plant. As the tunnels are installed through rock, there is no additional tunnel lining necessary.
To manage slopes of up to 5%, tunnel logistics are handled by two Multi-Service-Vehicles, delivered by Techni-Metal Systems, a Herrenknecht subisidiary company. These vehicles in very “slim” design can flexibly handle slopes of up to 8% (in general even up to 16% is possible), where railmounted systems cannot be used anymore.

After completion of the first tunnel in July 2015 at Rio Vermelho, the construction company KM26 - Caldeiraria e Madeireira LTD plans to use the TBM on five further hydropower projects with lengths up to 3km and curved alignments with 300m curve radius. Designed by Tamarindo Engineering, each project has to be approved by competent environmental authorities to assure a maximum of environmental protection.

Figure 12 Assembly of the Gripper-TBM (Ø 2850mm) at the starting point of the first tunnel and view in tunnel

4.4. HDD: Val d`Astico Hydropower Pipeline, Italy

In the northern Italian province of Vicenza, a project was initiated for water-powered generation of renewable energy. The installed 920m long pipeline forms part of a project for the generation of hydroelectric power. The aim was to use the collected mixed water from the Asiago plateau and the Astico valley to power a turbine to generate electricity.

An altitude difference of 450 meters had to be negotiated during a drilling stretch of almost one kilometer in order to lay an 8-inch stainless steel pipeline. This is an impressive performance in view of the demanding construction site installation with tight space constraints and complex geological conditions. Herrenknecht’s HDD technology mastered rock and limestone with compressive strengths of up to 160 megapascal, as well as many unexpected cavities and gaps.

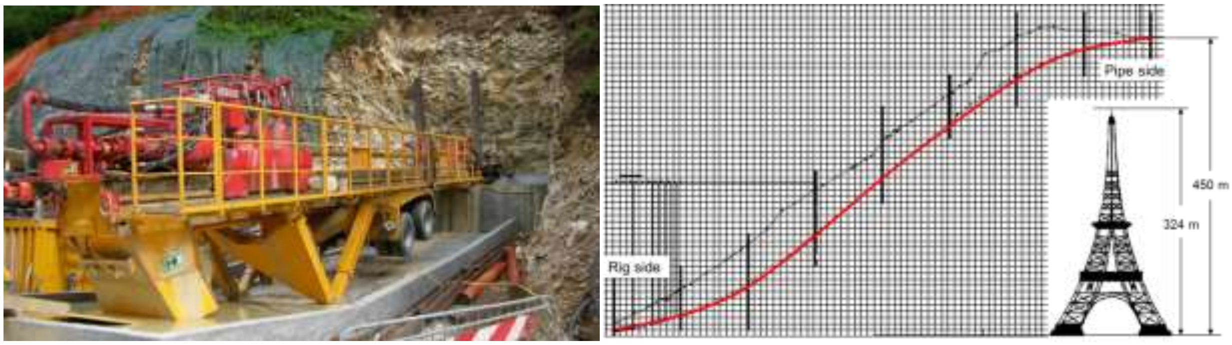

Figure 13 HDD Rig installed for 8° entry angle to drill 775m upwards