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XXL Pipe Jacking: Technological aspects of large-diameter and long-distance drives

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ABSTRACT: Pipe-jacked tunnels are considered for a large variety of applications from water and sewage, cable ducts to pipeline construction. In most cases, Slurry MTBMs are used to carry out these projects. Continuous further development of pipe jacking technology are vital to overcome feasibility limits and to meet increased project requirements.

As tightened safety regulations increasingly limit the options of segment lining in diameters below 4 m, pipe jacking has partially taken over. During the last decades, a growing number of large-diameter and long-distance pipe jacking projects has been completed. Experienced contractors successfully use the technological capacity of MTBM equipment. Continuous further development of technological features for pipe jacking is key to overcome feasibility limits and to meet increased project requirements. The overall aim is to provide clients and contractors with safe and economical solutions for successful projects. International milestone projects and latest innovations will be shared in this presentation.

1 INTRODUCTION

The main focus of contemporary underground tunnel construction is to complete tunneling structures safely and within the given time and cost frame. This is of particular interest for clients, project owners and the nominated contractors. Successfully executed projects help to gain trust and acceptance of large-scale projects among the population and to convince planning authorities of the opportunities and the benefits of mechanized tunneling.

As safety aspects in mechanized tunneling have gained more and more importance and safety standards have been consequently improved, requested space and accessibility in small-diameter segment lining projects leads to an increasing minimum diameter for such projects. As a result, pipe jacking has partly replaced small-diameter segment lining, which leads to longer drives and larger diameters in pipe jacking. Experienced contractors execute pipe jacking works with tight curves, multi-curved or inclined alignments, even under high groundwater pressures or with low overburden and related high settlement risk.

2 LONG-DISTANCE PIPE JACKING

From a technical point of view, long-distance pipe jacking can be an alternative to small diameter segment lining. Detailed investigation and project planning as well as the use of latest technological features and contractors´ experience are essential for project success. Long-distance pipe jacking usually requires accessibility for maintenance operations and disassembly measures after tunneling, even with remote-controlled equipment. As a result, long distance pipe jacks in general have a minimum inner diameter of 2,000mm. Besides the respective design of the tunneling machine and the cutting wheel according to the defined soil conditions to be expected along the

tunneling alignment, the main concern of long-distance pipe jacking is the limitation of the jacking forces.

2.1 *The role of bentonite lubrication*

In pipe jacking the control of the friction between the pipe and the surrounding ground is a key factor for project success. Besides the contractor´s experience and other important measures like the use of interjacking stations, special attention is paid to bentonite lubrication. The longer the drive or the larger the diameter, the more the focus is on lubrication. Uncontrolled distribution of bentonite along the tunnel route or tearing of the lubrication film can lead to significant increase in jacking forces. In order to ensure continuous lubrication throughout the tunnel alignment, the volume-controlled bentonite lubrication system has been developed. The automated system offers a high level of bentonite control and automation to overcome the limitations of conventional systems. Easy handling and smart, partly automated setting of the relevant parameters assist the machine operator and avoid variations caused by personnel changes or uncontrolled pumping of bentonite.

In a first step, the volume-controlled bentonite system automatically regulates the initial injection in the area close behind the machine, where the annular gap is created. The bentonite fills the annular gap, provides support and simultaneously lubricates the pipe. The subsequent injection maintains the lubricant film that has been established. Both steps are described in Figure 1. The visualization in the control container shows the volume of injected bentonite in every meter of tunnel along the alignment. The system provides unprecedented situation control, no matter if it is used in classic or volume-controlled mode. When running in volume-controlled mode the system automatically distributes the bentonite along the tunnel axis according to the needs of the prevailing project conditions.

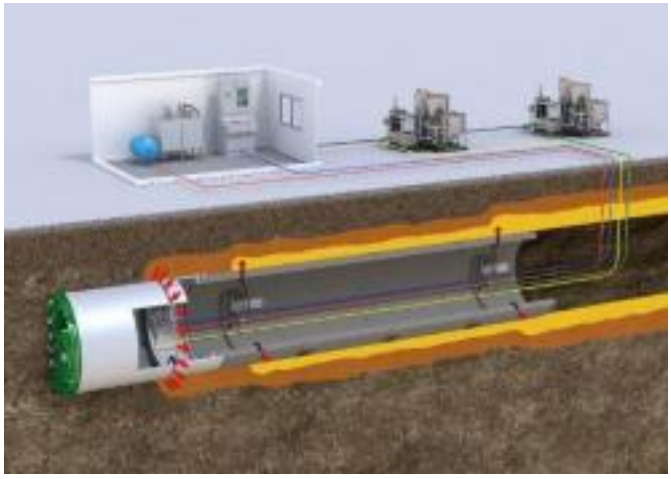

Figure 1. Overview of volume-controlled lubrication system.

In homogeneous ground, the system creates a very uniform distribution of the bentonite. This optimized continuous lubrication film can be maintained, independent from drive length, operator experience or advance rates. In changing ground conditions, the stationary sections along the tunnel are supplied with the predetermined bentonite volume by the advancing bentonite stations. An example of this is shown in Figure 2 where variable but predetermined volumes are provided throughout the tunnel drive. After selection of the prevailing ground condition in a section, the system automatically calculates the required bentonite volume, e. g. gravel needs more bentonite than sand or silt to get saturated.

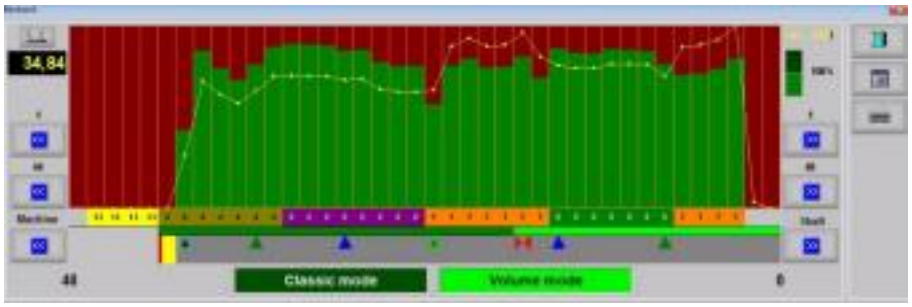

Figure 2. Exemplary visualization of the volume-controlled bentonite lubrication system with the bentonite volume injected on each tunnel meter.

The system can also be used in the conventional classic mode without volume control and parametrization. This provides maximum flexibility at all times. Monitoring, focused control and recording of relevant data (for example, lubricant volumes, pump and injection pressures, friction forces) are incorporated in the system, creating a very precise assistance system for the operator, and pushing automation and feasibility in pipe jacking further ahead.

In May 2022, two outstanding sea outfall projects with 2 kilometers (6,500 feet) length each were completed successfully. In both projects, a slurry-based MTBM, so-called AVND2000 with extension kits (for pipe ID 2,200 mm/7.2 feet and ID 2,600 mm/8.5 feet) and recovery module were deployed in different kinds of ground conditions. The volume-controlled bentonite lubrication system was used, providing efficient lubrication and reducing friction forces successfully in order to push the pipe string of 2 kilometers in both cases.

2.2 *Intermediate Jacking Stations*

Besides lubrication as described above, intermediate jacking stations are used to overcome high jacking forces in difficult ground, long-distance or large-diameter pipe jacking. They are installed in special product pipes at predetermined distances in the pipe string and serve to advance the pipe string in sections. In general, it is not foreseen to use the recoverable intermediate jacking stations continuously, but in cases when the pipe string has not been moved for a while (for example, due to maintenance reasons) it is safer to restart pushing by single sections than jacking the complete pipe string from the launch shaft. This avoids imposing extremely high jacking forces on the rear pipes. If required, the intermediate jacking stations can be used to keep sections of the tunnel moving, as shown in Figure 3, in case of downtimes of the tunneling machine.

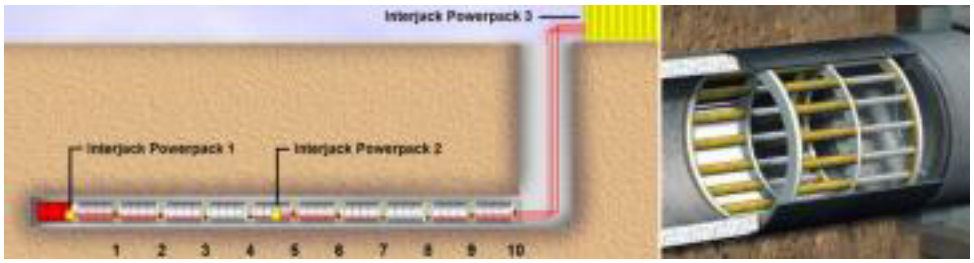

Figure 3. The use and operation of interjacking stations along the tunnel.

2.3 *Push module*

Very long pipe jacking drives, especially in challenging ground conditions, increase the risk of the pipe string getting stuck. For such demanding projects, an option is to combine pipe jacking with segment lining flexibility as a fallback option. The tunneling work can then be started in pipe jacking mode and switched over to segment lining if the tunnel stops moving. This solution requires the so-called Push Module as illustrated in Figure 4. The Push Module basically consists of an erector, push cylinders and the powerpack. In order to switch from pipe jacking to segment

lining, these components are mounted in a steel can, which is installed in the rear part of the machine right from the beginning of the project.

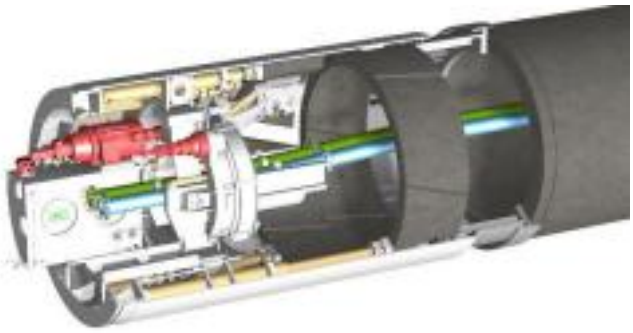

Figure 4. Example of Emergency Push Module for 2600mm (8.5 feet) inner diameter.

In the future, the use of the automated ring building system in conjunction with the Push Module will enable largely remote-controlled operation, also in segment lining mode. The vision is that man entry would only be temporarily necessary for maintenance purposes. The automated ring building system enables the segments being automatically picked up from the segment feeder and placed at the correct position within the tailskin as pre-calculated by the ring building software to follow the correct alignment of the tunnel.

2.4 *Cutting wheel design and cutting tools*

The role of the cutting wheel design with respective cutting tools is a crucial factor in pipe jacking, especially on very long drives or in hard, abrasive rock. Therefore, there is a specific focus on wear protection and prediction, monitoring techniques, and tool replacement strategies in order to facilitate the excavation process, reduce downtimes and increase productivity of the overall pipe jacking process. Very small MTBMs, like Herrenknecht´s slurry-based AVN 800 for hard rock, which are characterized by high revolution speeds, unmanned operation and no maintenance possibilities, can be equipped with special wear-resistant cutter types like Tungsten Carbide Insert (TCI) cutters to reach cutter lifetimes and drive lengths in hard and abrasive rocks which are not possible with normal disc cutters. For larger MTBM operations with the possibility of men entry for maintenance, various disc concepts, for example, monoblock versus exchangeable ring, can be considered. Hard facing solutions for wear protection and for example, the use of a camera system in the excavation chamber to control wear of the cutting tools are quite common as illustrated in Figure 5. In return, it has to be stated that wear prediction for small-diameter MTBMs is a largely undeveloped field with very little academic research and scarce information which has preciously been kept within the companies involved. Understanding the role of cutting tools and their maintenance on long-distance drives is essential for achieving safe, cost-effective, and efficient pipe jacking operation.

Figure 5. Hard facing measures and camera view into excavation chamber.

2.5 *Project references in long-distance pipe jacking*

In 1994, the current long-distance record of 2.5 kilometers (1.55 miles) in pipe jacking was set in the Europipe project in Germany with a 3,000 mm (10 feet) inner diameter Slurry TBM. In the last 10 years, a total of over 100 projects of more than 1,000 meters (3,300 feet) length have been completed worldwide using Herrenknecht equipment. In nearly all cases, AVN and AVND slurry MTBMs have been used, in the inner diameter range of 1,500 mm to 3,200 mm (5 feet to 10.5 feet). More than 40% of these long-distance projects were Sea Outfalls constructions for sewage outlets, water intakes for desalination plants or casing structures for pipeline landfalls. In coastal areas, a major focus is on the protection of the vulnerable environment. This is where trenchless technology comes in.

A new benchmark for the inner diameter of 2,600 mm (8.5 feet) was set in 2018 in Altamira, Mexico with a drive length of 2,246 meters (1.4 miles). The pipe jacked outfall casing tunnel (OD 3,200 mm / 10 feet) is one out of three landfalls for the Sur de Texas-Tuxpan gas pipeline, which connects the coasts of Texas and Mexico across the Gulf of Mexico. Trenchless Technology was chosen to cross under the environmentally sensitive areas such as the mangrove zone and coral barriers with less impact than with conventional techniques. For emergency purposes, a push module for conversion to segment lining was on standby but was not utilized.

In May 2019, the Ric-Man Construction, Inc. achieved not only the successful completion of a pipe jacking project in Painesville, Ohio, but also a new United States distance record. With a Herrenknecht AVN1500, a new casing tunnel for the 36 inches raw water intake pipeline was built under Lake Erie with a length of 1,203 meters (3,947 feet)– the longest pipe jacked drive in the US. Painesville will thereby be provided with water straight from Lake Erie in the future.

Figure 6. AVN1500 lowered into launch shaft for 1,203 meters record drive in Painesville, Ohio.

Using an AVN1800 shown in Figure 6, Ward & Burke have successfully completed a microtunnel drive of 1,132 meters (3,700 feet) in June 2020 to break the Canadian microtunnel distance record. This drive beat the previous microtunnel distance record of 950 meters (3,100) set 4 days earlier on the YDSS project in Newmarket (Ontario, Canada) into the same reception shaft.

3 LARGE-DIAMETER PIPE JACKING

The basis for decision to plan and execute a small diameter tunneling project whether with pipe jacking or segment lining strongly depends on the background of involved parties. For different reasons, planning authorities and construction companies may sometimes prefer one procedure over the other, even if there is no technical evidence of benefits or feasibility. From a planning point of view, the decision is not only driven by the specific project requirements, but also by the broad knowledge of the available technical alternatives. Ultimately, a majority of small diameter segment lining projects are executed by large construction companies acting as main contractors in the tunneling industry. Conversely, pipe jacking works are often carried out by smaller contractors that specialize in this area. Based on long traditions and know-how, they are tackling

increasingly challenging projects, comprising long drives and large diameters. Of course, the co-operation of technology suppliers and construction companies to design the best suited equipment for large diameter pipe jacking projects is indispensable for successful project completion and for a good reputation of the technology in the market.

Even if the pipe jacking procedure requires a significantly smaller jobsite footprint on the launch side compared to segment lining, the handling and storage of the jacking pipes represents a challenge that grows with the diameter. State-of-the-art on-site factories to produce large diameter jacking pipes of 3500mm outer diameter or more can solve this problem. A storage area for sufficient amount of product pipes is required for continuous tunneling advance. With rising pipe jacking diameter, the challenges faced are similar to the ones in long-distance drives with the main goal to keep the jacking forces down and to assure continuous advance with high performance at the same time. Interjacking stations and bentonite lubrication have been further developed to fulfill the requirements of increased friction forces in larger dimensions.

3.1 *Pipe brake*

The presence of groundwater also has an increased impact on the tunneling process as the tunnel cross-section increases. Even at comparatively low pressures of 1-2 bar, the use of a pipe brake may be necessary. The pipe brake is installed in the launch shaft together with the launch seal, fixed to the shaft wall by threaded rods as shown in Figure 7 or alternatively braced against the rear wall of the shaft. The pipe brake is used to secure the jacking pipes during retraction of the jacking cylinders and installation of a new pipe in the shaft jacking frame.

Figure 7. Pipe brake with launch seal installed in the launch shaft.

3.2 *Project references in large-diameter pipe jacking*

Recent milestones set by contractors in all parts of the world demonstrate the current trend towards larger diameters in pipe jacking. Similar to the evolution in drive length, the majority of about 70 projects executed with Herrenknecht equipment of 3,000 mm inner diameter and larger have been executed in the last 10 years. The main portion was for sewage and water and with rising share also for stormwater protection or storing installations. Special applications for cross passages and blind hole construction with retractable machine concept played a minor, but indispensable role in this diameter range.

Currently, a large-scale project is under way in Buraidah (Saudi Arabia), where several AVN Slurry machines are in operation to complete a total of 24km (9.5 miles) for the Main Line Stormwater project with a pipe OD of 4,200 mm (13.8 feet), in depths of up to 50 meters (164 feet).

In 2019, two large-diameter and at the same time long drives have been completed in Munich, Germany. The second construction phase of the Landsberger Strasse sewer network rehabilitation has been built to relieve the existing sewer system in the west of Munich, which dates to the middle of the 20th century. The new sewer route with an OD of 3,580 mm (11.7 feet) was constructed using an AVND slurry MTBM. For this purpose, the approximately 2.2 kilometers long route was excavated from a double launch shaft in two drives of 980 meters and 1,200 meters (3,200 feet and 3,940 feet) length in less than eight months' construction time.

The major challenge of the project was the inner-city location of the tunnel route, almost completely under the four lane, heavily frequented road Landsberger Strasse. The low overburden

between 4 and 6 meters (13 and 20 feet) required strict monitoring of the face support pressure. In addition, the logistical supply of the construction site posed a great challenge. Due to the confined space conditions of this inner-city location, pipe storage on the construction site was limited. In order to guarantee the transport of the jacking pipes around the clock, a pipe length of 3 meters (10 feet) was specified and a "just-in-time" pipe delivery was often organized. With a continuous performance of about 20 meters (65 feet) per day, more than 200 cubic meters of excavated soil had to be conveyed and removed at the same time. For this purpose, a special concept for logistics was developed to be able to transport the soil material promptly to a designated sampling area without interfering with the delivery of the pipes. Figure 8 shows Slurry MTBM, the inner-city surroundings of the jobsite installation and the considerable size of the pipe jacked tunnel.

Figure 8. Jobsite impressions Landsberger Strasse, Munich, Germany (© Wayss & Freytag Ingenieurbau AG).

During the excavation work, it was also necessary to drive through numerous unknown structural anchors that had remained in the ground from the existing development on Landsberger Strasse. This necessitated over 20 hyperbaric interventions to recover the metal objects.

The North American large-diameter record in pipe jacking has been set in December 2022 in Calgary. Ward & Burke Construction Ltd. has used an AVN2500 with extension kit, suitable for a 4056 mm OD (3,400 mm ID) pipe, on the Northwest Inner City (NWIC) – Upper Plateau Storm Separation Project. The reinforced concrete pipes of 3.3 m (11 feet) length each have been designed according to the local regulations and supplied by Langley Concrete Group. The 760 m (2,500 feet) long drive included two curves with radii of 500 m (right hand, distance 237 m) and 300 m (left hand, distance 50 m) respectively. Figure 9 shows the MTBM in the launch shaft and the jobsite team around a jacking pipe to get an impression of this extraordinarily large diameter of pipe jacking works.

Figure 9. Launch shaft and breakthrough ceremony on North America´s largest diameter pipe jacking jobsite (© Ward & Burke).

4 CONCLUSION

Technological advancements and valuable experience gained by international contractors creates

the desire to push the boundaries in terms of achievable drive length and tunnel diameter in pipe jacking, especially when using Slurry MTBMs. Current opportunities in technologies, feasibility and limitations, contractor expertise and achievements have to be taken into account when new installations are being planned, and routes are being designed. Of course, the specific project design and surrounding conditions such as diameter, tunnel length, alignment and ground conditions are crucial in selecting the most suitable and economic lining method for a tunneling project.

For Pipe Jacking, less personnel are required and due to remote-control from the surface, the level of safety is considered as a major benefit compared to segment lining. In challenging pipe jacking projects, the contractors´ experience in operating state-of-the art pipe jacking features such as volume-controlled bentonite lubrication, separation and navigation, plays a key role for production rates and final project success. In terms of tunnel diameter, the handling of the jacking pipes is considered as the most limiting factor for the feasible size in pipe jacking.

Due to the public environmental awareness and increased need for utility installations underground, advanced pipe jacking with slurry MTBMs plays a key role for fast installation, even in challenging ground like hard rock. This does not only comprise sewer and water networks but also pipelines or underground cable installations to connect and use new energy sources like offshore wind or hydropower.

5 REFERENCES

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