Enhanced Probe Drilling and Pre-Grouting Design and Recommendations on Hard Rock TBMs

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ABSTRACT

While probe drills are not strictly necessary for all projects, the incorporation and use of probe drills and pre-grouting adds capability and insurance to boring operations. Water ingress and unstable ground can be resolved before becoming a problem and resulting in costly delays through the use of enhanced, 360-degree probe drilling setups. To do this, proper design of the array of drill ports in the shield, matched to the possible ground conditions, is critical. For ground with exceptional water and instabilities expected, additional probing locations are low-cost additions that can lower risk and increase efficiency. In this paper we will look at recent and ongoing projects including the Lower Meramec Tunnel and Jefferson Barracks Phase 2. We will detail the design of those probe drill arrangements, and our overall recommendations for probing/grouting systems that best suit challenging ground conditions and keep projects running smoothly.

INTRODUCTION

Adverse geology and ground water can cause drastic problems for open gripper TBMs resulting in costly delays to the project and possible machine damage. Expected geology for a tunneling project is usually just a rough estimate based on a collection of core samples taken along the planned path and can very easily miss features such as voids, sinkholes, fissures and excessive ground water that can pose issues to the machine. Regular probe drilling in front of the machine can detect these features before they become a problem and when combined with pre-excavation grouting can consolidate unstable ground, fill voids and reduce material/water inrush to manageable levels, saving time and money over the course of the project.

PROJECTS BACKGROUND

The two projects we'll be looking at, the Jefferson Barracks Phase 2 (JB2) are the Lower Meramec Tunnel (LMT) are both open gripper main beam TBMs with diameters Ø13'-6.5" (Ø4.13m) and 11'-0" (Ø3.35m) respectively.

The JB2 project is in St. Louis and will finish the last 10,000 ft (3,050m) of tunnel from the original 17,770 ft (5,500m) project. The tunnel is at a depth of 120ft-220ft (36m-67m) and will be lined with a Ø7' (Ø2.1m) pipe to convey wastewater from Martigney Creek to the Lemay Wastewater Treatment plant. The project has been split into two phases as the first machine encountered an impassible karstic feature and was damaged by material inrush. The new machine (JB2) started boring from the other side of the feature to finish the remaining distance and complete the project. The geology expected for the remaining 10,000 ft is 90% good rock and 10% karstic limestone and dolomite formations (see Figure 1).

The LMT project is also in St. Louis Missouri, USA, and will be 6.8 miles (10.1km) long at a depth of 78ft-286ft (24m-87m) and will be lined with an Ø8' (Ø2.4m) pipe to convey sanitary flow from the Fenton Wastewater Treatment Facility to the Lower Meramec Wastewater Treatment facility at the junction of the Mississippi and Meramec Rivers. The geology expected is competent rock of shale and limestone.

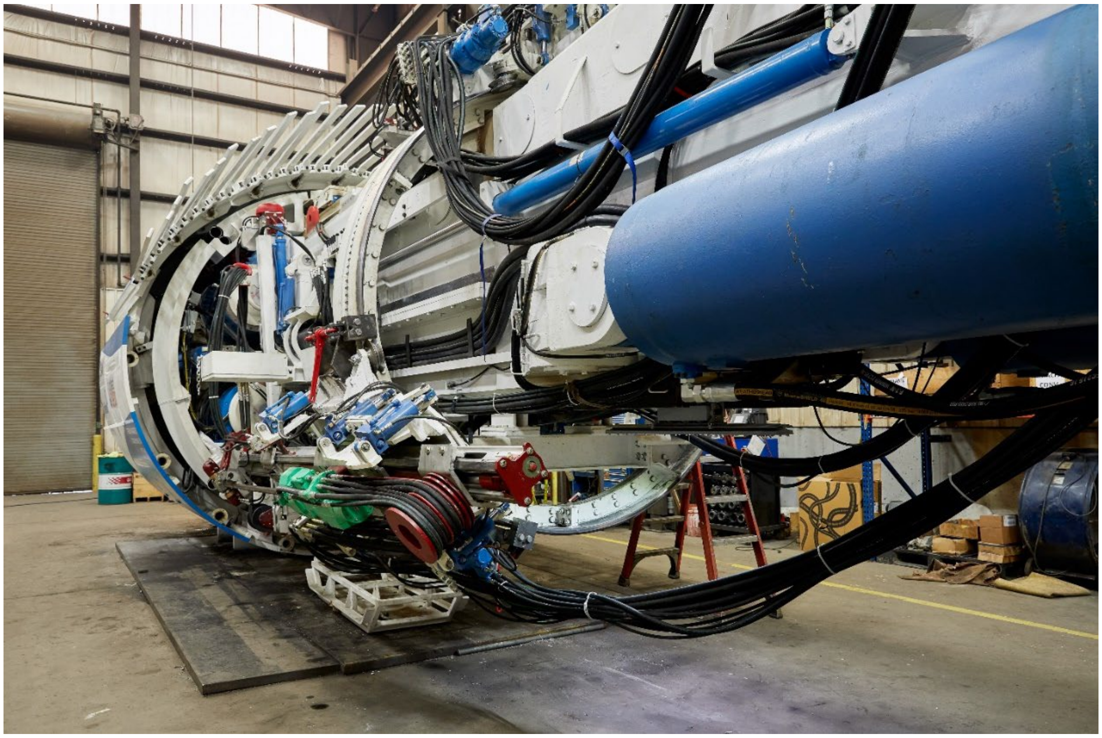
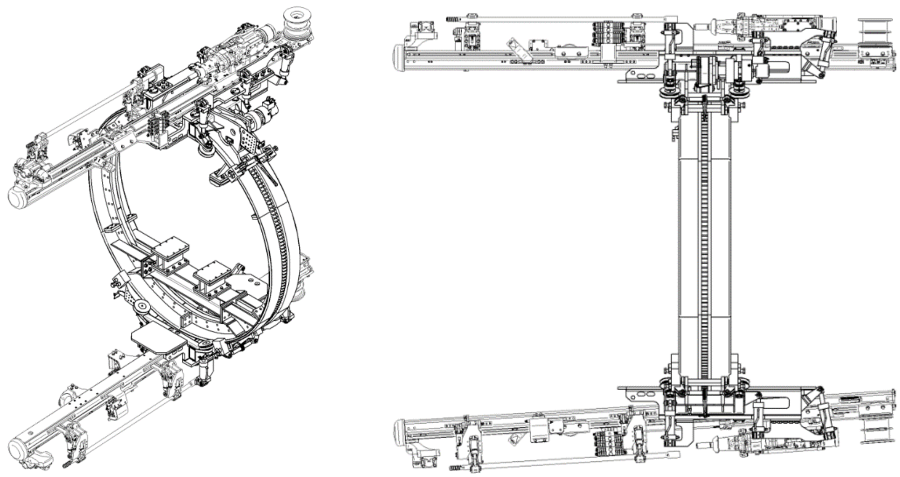


Figure 1: Jefferson Barracks Phase 2 TBM

PROBE DRILL ARRANGEMENT, TBM for Jefferson Barracks 2 Tunnel

The Jefferson Barracks Tunnel project was started with an 11"-0" Main Beam TBM (now called "JB1". This machine had good roof bolter drills, but no probe drill. The TBM encountered a large karst feature at about 7000 feet in and became inundated with sand and mud. Efforts were made to stabilize the ground so the TBM could be recovered. The remaining length of the tunnel was let as a new contract. The new tunnel design was for a 14'-6" bore TBM, with facilities for comprehensive probe drilling and Pre-Excavation grouting. This new contract became known as "JB2".

On the JB2 machine, the probe drill assembly is fitted with two Timberock hydraulic feeds with Montabert HC95LQ drifter mounted on both lift and tilt frames on a carriage giving approximately 50mm of lift to be used at -1.5° and the lift frame dropped to be used at 0° and +3.5° tilt. The carriage rides on 4 v-groove wheels and is driven by a pinion gear on an external ring gear. See Figure 2 below. The ports for drilling in front of the machine (0° and -1.5° drill tilt angles See Figure 3) have 4 ports each at the diagonals (+/-45° and +/-135° from vertical). The two drilling angles, though slightly different, allow the drill holes to diverge when the holes reach 100-150 feet, to provide good coverage of the face area. The ports for drilling about the periphery (+3.5° drill tilt angle see Figure 4) have 19 positions with guide tubes at top dead center and spaced around with increasing gaps towards the bottom half to prioritize the umbrella. The addition of the dual 360° probe drill adds great performance benefits and insurance to this new JB2 machine.



Figrue 2: JB2 Probe Drill Assembly

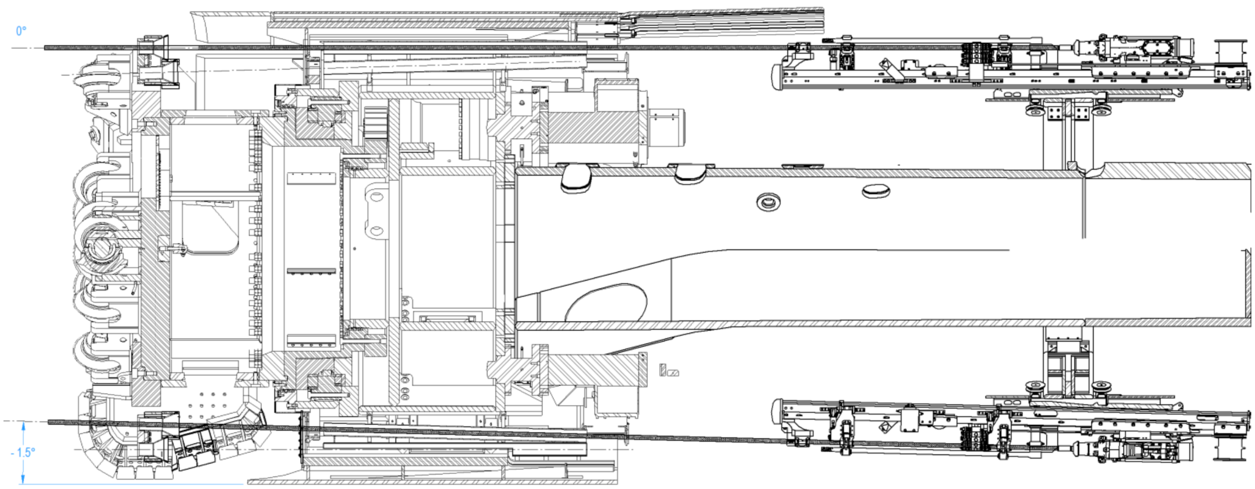


Figure 3: 0° and -1.5° Probe Tilt Angles Through Cutterhead on JB2

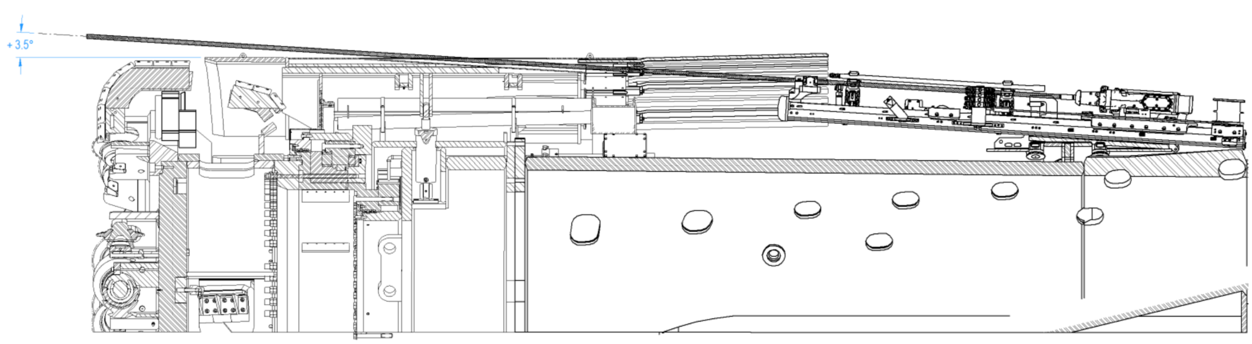


Figure 4: +3.5° Probe Tilt Angle Through Cutterhead Support on JB2

PROBE DRILL ARRANGEMENT

TBM for LMT Tunnel The LMT machine is an 11”-0” bore High Powered TBM. There is very little room around the TBM for a 360 degree probe drill positioner. The TBM and positioner had special features to allow the 360 degree positioner to function in this confined space. Also, the LMT has many short radius curves. So the TBM length had to be kept as short as possible to allow the TBM to negotiate these curves. The probe drill ring for this TBM could be moved forward and aft for this reason. With the ring in the forward position, the probe drill could drill at 0 and 5 degree angles for drilling in the face and the perimeter, respectively. However, this forward position would conflict with movement of the roof drills during mining. . So the drill ring would normally be kept in the aft position. In the aft positon, the drill could be used to drill peripheral holes at 3.5 degrees.

The LMT machine has a single hydraulic-powered chain feed with Montabert HC50 drifter mounted on a carriage with tilt angle 0° and +5°. The drill carriage rides on aluminized bronze bearings that double to locate the carriage on the ring and is driven with a single motor driving two pin gears on two pinwheel tracks. This gear design is desirable as it works with loose assembly tolerance, has high torque transmission, and allows for running with low lubrication and high contaminants. The ring is designed so the drill can be locked in position and the rest of the ring pulled back and out of the way. This configuration is for clearance of the roof drills as the machine thrusts. The ports for drilling straight in front of the machine (0° drill tilt angle) have four positions in the top half (guide tubes at +/-20° and +/-45° from vertical). The ports for drilling about the periphery (+5° drill tilt angle) have a total of 14 positions spaced roughly equally (guide tubes at +/-10°, +/-30°, +/-60°, +/-90°, +/-112.5°, +/-135°, and +/-160° from vertical). For the drill ports at 0° tilt angle, the cutterhead has two guide holes that can be clocked to allow the drill to pass through. The major drawback to this design is the additional setup time for bringing the ring forward into position before the drill can be brought around to a drill port for investigative probing and pre-grouting. The reason for this design is due to the size constraints of LMT. This set up is still better and quicker set up than previous designs on small machines where the lower sections of the ring would have to be brought in from the tunnel for drilling. Being a small bore at 11', limited space is available and special features are needed to fit the equipment. These include the multipiece ring that can retract to an aft position and angled corners on the main beam (usually a flat top). The contractor for LMT is expecting to encounter a water bearing feature that will be beneath the tunnel at first, but then rise up across the face as the machine progresses. So, drilling in the invert positions will be as important as drilling in the crown positions. With this, the probe drill can be used in the invert to grout off water before encountering it. Major efforts were made to provide a functional 360° degree probe drill on this small TBM.

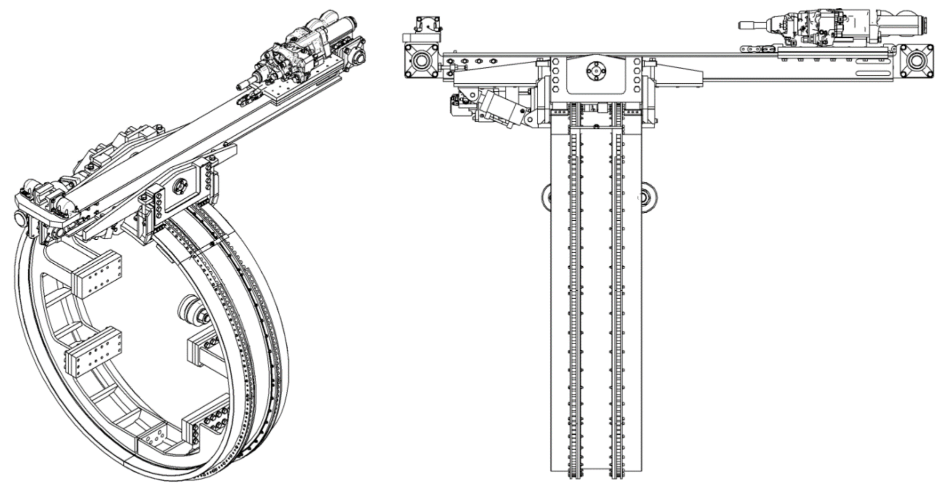


Figure 5: LMT Probe Drill Assembly

Both machines have 360° probe drilling with the ports orientation prioritized to the umbrella (above the machine) and boring ports angled horizontal or above (19/27 angled ≥0° on JB2 and 12/18 angled ≥0° on LMT). The focus on probe drilling above centerline/positive drill angle is because it's much easier to remove material drilling at an angle ≥0° (refer to Figures 4 and 5). On top of the ease of drilling, grout will propogate through the fissures in the rock and can successfully grout the path of the bore without the need to drill/grout in a full 360° pattern. Conversely, drilling down makes it harder to remove tailings from the drill hole as it is going against gravity. While probe drilling in the umbrella offers good coverage both for detecting problem geology infront of the machine and grouting unstable ground, it cannot compete with the capability full 360° probe drilling. Most previous machines are only capable of drilling in the umbrella (if they even have a probe drill) and can leave some potentially disastrous blind spots. Especially on JB2 where karst features are expected, the only way to accurately detect a void below centerline is by drilling in the area. A void under the machine could result in the machine diving or worse – becoming stuck. The addition of full 360° drill ports allows operators to detect problem features anywhere in front of the machine to prevent unwanted dives and provides coverage when going into a turn (via the periphery ports at stringline). Detecting unstable geology before encountering it is vital to smooth boring operations.

TRADEOFFS AND SACRIFICES

The primary roles of probe drills are investigating ground conditions in front of the machine and creating holes to inject ground treatment to consolidate unstable ground, fill voids and reduce water/material inrush as the machine bores forward. Identifying adverse conditions starts with surveyors conducting core drillings performed by a third party well before any boring begins. These core samples are a good starting place to get a general idea of what is to be expected but the tests can miss a lot and even close-together samples can vary wildly.

For example, on LMT from the tests conducted, ground is expected to be generally competent, but a probe drill is still necessary due to the possibility of karstic and other difficult features in this geology. Due to the small TBM size, only a single probe drill was fitted onto the LMT machine. This contrasts with JB2, where the first machine ran into significant obstacles (to the point a second machine was needed) and further features are expected. Therefore, dual probe drills with a fixed mount ring were specified so that probe drilling operations could be performed more quickly.

Probe drill assembly designs have a lot of constraints on them as well. First, the feed and drifter unit are large and, with the requirement to rotate 360° with clearance, presents a lot of potential interference. Furthermore, the assembly is vying for limited space at the front of the machine with ring erectors, roof drill, and working space for personnel. For JB2, the probe drill ring does not have fore/aft movement and is mounted on a longer main beam, aft of the roof drill travel zone. The drill can't be rotated around the main beam with the drill in the lowered and angled position. Because of this constraint on the +3.5° ports, the drill must be angled or lifted to clear the main beam. Given the geology expected on these two projects and probe assembly design on the machines, JB2 expects more adverse geology, and so the machine design prioritizes probe drilling compared to LMT with greater coverage, two drills, and a fixed mount ring.

Since probe drilling/pre-grouting can't be performed simultaneously with boring, and machine reset after a full push isn't enough time to drill a probe hole, probe drilling needs to be planned independent of the boring schedule. This downtime can be costly, but unstable ground and material inrush can also result in costly damage and delays, so the risk vs reward needs to be balanced to keep the machine on schedule and running.

EFFECTIVENESS OF PRE-GROUTING

Evaluating the effectiveness of probe drilling and pre-grouting is not very straight forward as there is no way to have a baseline to reference. Whether that be boring 200ft without probe drilling then 200ft with probing, or two tunnels side by side, the conditions, formations and features encountered will be dramatically different between the two, and drawing conclusions based on data for the benefit gained from probe drilling and pre-grouting cannot be accurately determined. Although no direct comparison can be made for an overall project, it's clear to see that discovering and grouting adverse conditions before the machine reaches them can save immensely on costs and project schedule. By utilizing probe drills and pre-grouting, problems can be remedied before the machine encounters them. The alternative can lead to high material inrush damaging the machine or, in a worst case, a stuck machine.

CONCLUSION AND RECOMMENDATIONS

With the aforementioned points in mind, probe drilling and pre-grouting should be looked at as an insurance policy to mitigate the potential issues that can arise from adverse geology. Specific recommendations for probe drilling should be made per individual projects as they need to factor in expected geology, schedule constraints, on site expertise, and available space on the machine. The available space pertains to the design of the probe drill assembly on the machine and will be dictated by expected geology and project requirements. Given that core samples for expected geology can miss a lot of potentially problematic features, and a damaged or stuck machine will result in costly delays, probe drills and pre-grouting are the best option for detecting adverse conditions in the bore path, consolidating ground and limiting material inrush for project insurance and risk mitigation. Enhanced 360° probe drilling with ports in front and around the periphery provide greater capability compared to existing machines that either only had a probe drill in the umbrella or none at all. These drill arrangements when put into use provide protection from unstable ground in any direction in front of the machine. Going forward, 360° drills should be used not just for inspection and pre-grouting but collecting measurements and data to produce reports on the effectiveness of enhanced 360° probe drilling to promote further adoption of these drill assemblies. With more machines utilizing 360° drills, the designs and operation can be further refined to impact boring operations less and reduce damaged or stuck machines. Robbins recommends that machines come equipped with 360° probe drilling with an array suited to the expected geology, and most importantly, that the operators schedule regular probe drilling and pre-grouting as needed into the boring operation to keep projects boring smoothly.