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Hard rock TBM tunneling in challenging ground: Developments and lessons learned from the field

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ABSTRACT

TBM tunneling is an ever-increasing challenge for underground construction, and with each new tunnel bored there are unknown elements when boring through the earth. The most extensive Geotechnical Baseline Reports can miss fault lines, water inflows, squeezing ground, rock bursting, and other types of extreme conditions. This paper will draw on the considerable experience within Robbins to analyze successful methods of dealing with the most challenging conditions encountered, with a particular focus on fractured and faulted ground, mixed face tunneling, and tunneling in karst or water-bearing conditions. It will discuss new methods, including Dual Mode or "Crossover" type machines, which can increase the efficiency of excavation in such conditions.

1. Introduction

Many tunnel projects are located in areas with relatively poor access along the tunnel alignment and/or in highly varying mixed ground conditions. These factors often result in limited geological information. Challenging ground conditions may include non-self-supporting rock, fault zones, squeezing ground, or voids. Regardless of the condition, there are almost always ways to mitigate risks and overcome the obstacles. The lessons learned during these encounters can additionally be invaluable for others in the tunneling industry. When faced with these uncertainties everyone involved with the project including the owner, the contractor, and the machine supplier must be prepared to tackle geological surprises. This paper describes problematic geological conditions and associated difficulties with examples from real projects, as well as the lessons learned and design improvements that came out of those challenges.

2. Tunneling in fault zones and squeezing ground

Fault zones and squeezing ground are often encountered in high cover, mountainous tunnels where geological data may be limited. Despite the risk of TBMs becoming stuck in such conditions, there are ways to keep TBMs operating and to plan ahead for zones where the TBM advance may be at risk. One such example is described below.

2.1. Turkey's Kargi Kizilirmak Hydroelectric Project

Driven through a mountain range with 600 m of cover in Central Turkey, the Kargi Kizilirmak Hydroelectric Project is one of the most challenging tunneling projects ever completed in the region. The Robbins Company supplied a 9.84 m diameter Double Shield TBM and continuous conveyor system to Turkish contractor Gülermak for excavation of the 11.8 km headrace tunnel. Initial geological reports predicted softer and less stable ground for the first 2.5 km, which would be lined with pre-cast concrete segments. The remainder of the tunnel was to be supported by a combination of shotcrete, rock bolts, and wire mesh (see Figs. 1 and 2).

The Kargi TBM was launched in early 2012. The machine almost immediately encountered geology that was substantially more problematic than was described in the geological reports. The geology consisted of blocky rock, sand, clays, and water bearing zones. This ground still allowed the possibility to retract the cutterhead if needed, to restart the TBM if it became stuck. However, after boring 80 m the TBM became stuck in a section of collapsed ground that extended more than 10 m above the crown, loaded onto and around the cutterhead. As a countermeasure that was immediately put into place to avoid the cutterhead becoming stuck in the blocky material, crews began boring half strokes and half resets (see Fig. 3).

Even with these measures, the machine encountered a section of extremely loose running ground with high clay content. A collapse occurred in front of the cutterhead and the cathedral effect resulted in a cavity forming that extended more than 10 m above

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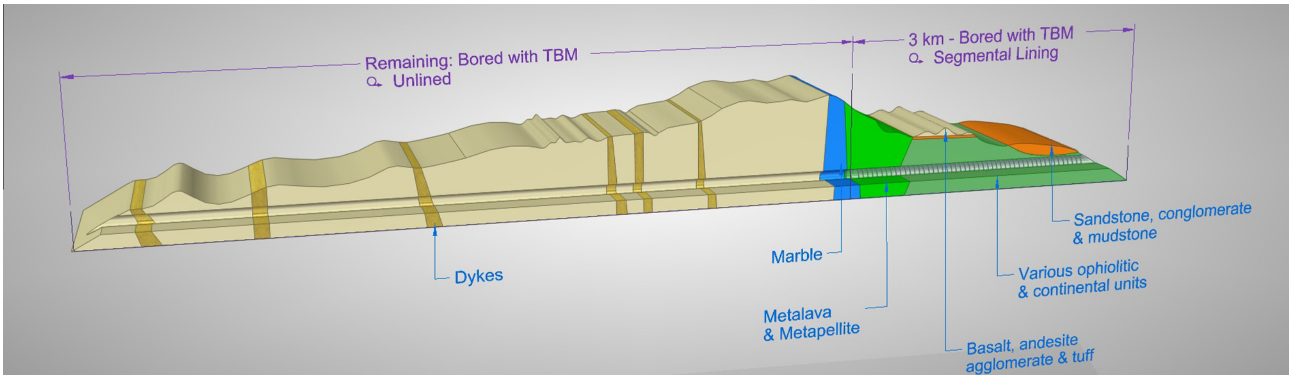

Fig. 1. Original plan of excavation and expected geology.

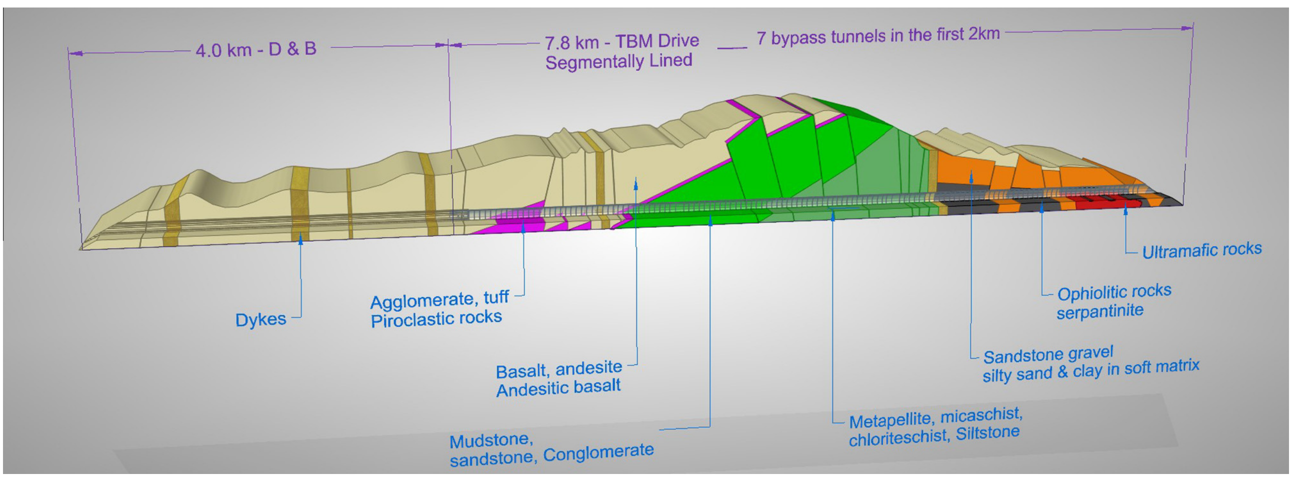

Fig. 2. Geology and outcome of tunneling works at 50% complete.

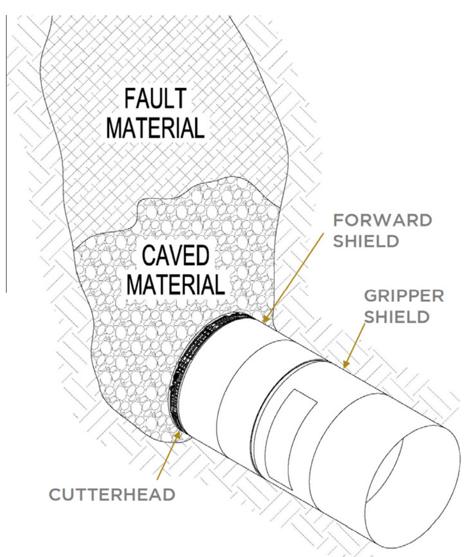

Fig. 3. TBM encountering fault zones at Kargi.

the crown of the tunnel. The weight of the collapsed material trapped the cutterhead. After several unsuccessful attempts to clean out and restart the cutterhead, consolidation of the ground above and in front of the machine was carried out. Injection of polyurethane resins via lances inserted through the cutter housings and muck buckets was the method utilized for consolidation operations; however, injection locations were restricted to the available openings and subsequent attempts to restart the cutterhead proved to be unsuccessful.

After assessing all the available options it was decided that a bypass tunnel would be required. Robbins Field Service assisted Gülermak with bypass tunnel design and work procedures to free the cutterhead and stabilize the disturbed ground. Blasting techniques were ruled out due to concern over further collapses caused by blast induced vibration; hence, the excavation was undertaken using pneumatic hand-held breakers. Bypass tunneling was successfully completed and at that point the section of bad ground was believed to be an isolated one.

These hopes were proved wrong, however, as six more bypass tunnels were needed within the first 2 km of tunneling. At this point it became apparent that the actual geology was far more complex than originally stated. Both the contractor and manufacturer worked together to develop and improve bypass tunneling and hand tunneling techniques, resulting in an average bypass tunnel construction time of just 14 days. All tunnels were completed safely and in a timely manner, though there were of course significant delays associated with the downtime. Despite the setbacks of these multiple events, the TBM did succeed in crossing numerous faulted sections that would have trapped a machine with less power. In fact, the crew measured cavity heights above the cutterhead in some of these fault zones at over 30 m.

In order to improve progress in the difficult conditions, the contractor, owner, consultants and Robbins engineers worked together