Record-Setting Large Diameter Mixed Ground Tunneling in Turkey: The Eşme-Salihli Railway Tunnel

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ABSTRACT: Large diameter tunneling has historically been seen as a challenge. Add into the equation mixed ground conditions, and it becomes a task that may seem insurmountable. However, a recently completed tunnel in Turkey is a flagbearer for changing the mindset towards these challenging tunneling scenarios that are becoming more frequent. A 13.77 m diameter mixed ground Rock/EPB TBM bored the Eşme-Salihli Railway Tunnel at rates of up to 721.8 m in one month, making it the fastest TBM ever recorded over 13 m in diameter. The machine began its bore in altered gneiss, then passed through mélange consisting of gneiss, sandstone, claystone, mudstone, quartz, and silt. By the end of the bore the machine was excavating in mainly mudstone. Core drillings were taken every 200 m prior to boring.

In this paper, we detail the project as well as analyze factors contributing to the fast advance rates. The factors include TBM choice and system design, ground conditions, TBM utilization rates and downtimes, as well as maintenance practices, crew expertise and technical support, all of which have a part to play in the overall advance rates and successful outcome. Recommendations are made as to best practices in order to achieve good advance rates on similar large diameter, mixed ground tunnels.

1 INTRODUCTION

1.1 *Project Information*

The Eşme-Salihli Railway Tunnel is part of the Ankara-İzmir High Speed Railway Project for the Turkish State Railways (TCDD). The 508 km (316 mi) line will eventually connect Polatlı in Ankara Province to Izmir, the third most populous city in Turkey, surpassing the Istanbul-Ankara High-Speed Railway as the longest rail line in the country once complete. The double-track railway system will convey passengers at top speeds of 250 km/h (160 mph), completing the journey between the two cities in 3.5 hours—a journey that would normally take 6.5 hours by car (see figure 1).

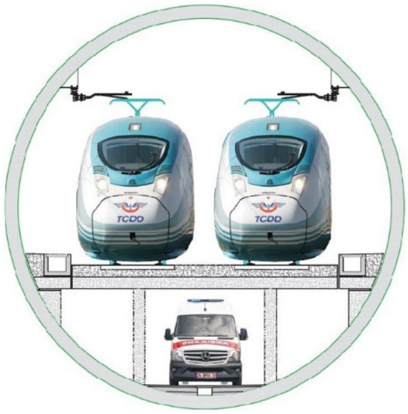


Figure 1. Finished tunnel cross section

1.2 *Geology*

Geological investigation is particularly important in the highly variable and faulted geology of Turkey. Recent Turkish tunnels, including the Gerede Water Transmisson Tunnel, where a 5.6 m diameter mixed ground rock/EPB machine completed 9 km of tunneling by navigating 48 fault zones and hydrostatic pressures up to 26 bar, underscores the challenges of tunneling in the region. Perched between the European and Asiatic land masses, Turkey can be thought of as a geologic patchwork, comprised of older rocks mixed with younger igneous and volcanic rock. More than 80% of the country's land surface is rough and mountainous, making both agriculture and travel a challenge. Adding to the obstacles, Turkey is seated on an active tectonic belt bounded by the North Anatolian Fault and the East Anatolian fault. Tunneling in such a zone is difficult at best, and nearly impassable at worst.

The Eşme-Salihli Railway Tunnel is a short section of high-speed railway, measuring 3.05 km (1.90 mi) through mixed conditions. Contractor Kolin Construction conducted 15 core drillings at 200 m intervals prior to the start of construction, with results predicting occasional groundwater and weak rock between 5 to 9 MPa (720 to 1,300 psi) UCS, with the potential for a gassy environment. Rock and soil types included sections of gneiss, sandstone, claystone, mudstone, quartzite, and silt (see figure 2).

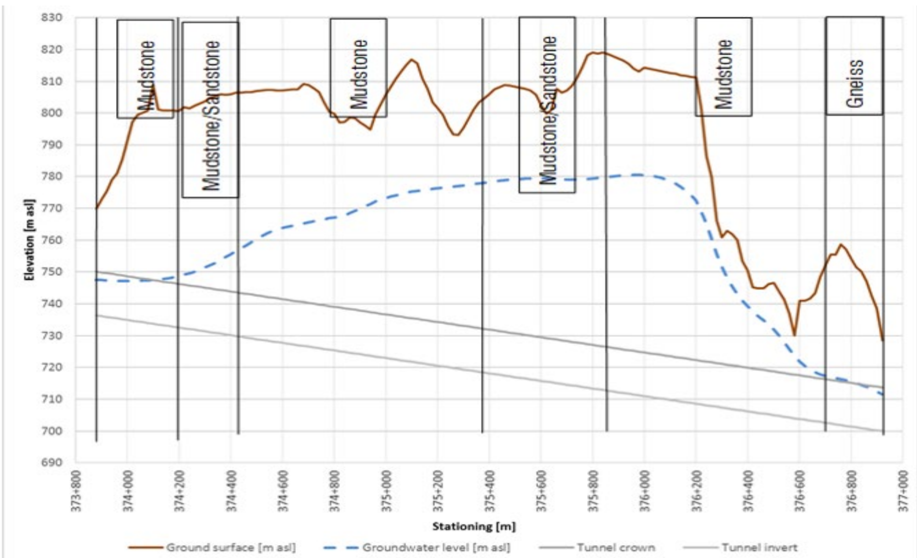


Figure 2. Geological survey results

2 LARGE DIAMETER, MIXED GROUND ROCK/EPB TBM DESIGN

A dual mode rock/EPB TBM design was created for the project, in which no design elements were sacrificed in the engineering: The machine was fully capable of operating in 100% EPB mode or 100% Hard Rock Single Shield Mode. The TBM was designed for sections of hard rock and mixed ground, in highly variable conditions including sandstone, mudstone, claystone, quartzite, schist, and mixed soil with clay.

2.1 *In EPB Mode*

In EPB mode, the screw conveyor operated as in any typical EPB machine. The screw featured a replaceable inner liner and replaceable carbide wear bits for abrasion protection. A mixed ground cutterhead was fitted with knife bits that could be switched out with disc cutters in harder conditions. Much of the cutterhead was covered in Trimay wear plate for additional abrasion protection. A wear detection pipe on the cutterhead monitored any wear occurring to the cutterhead structure itself, while wear detection bits on the cutterhead and periphery told the operator about tool wear, and if a gauge cutter had been lost. The machine design included a man lock for cutterhead inspection and mixing bars inside the mixing chamber (see Figures 3 and 4).

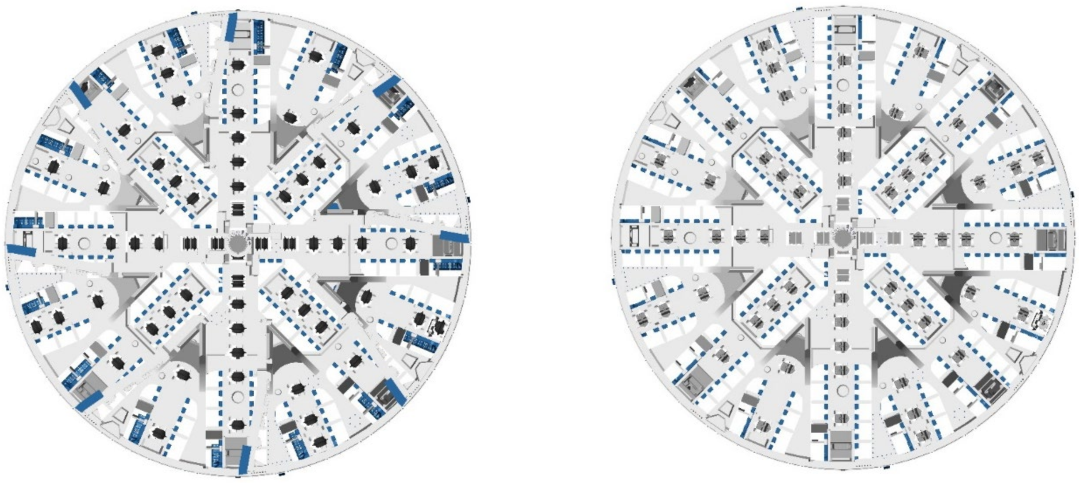


Figure 3. Left Cutterhead in Rock Configuration; Right Cutterhead in EPB Configuration

2.2 *In hard rock mode*

To convert to hard rock mode, the mixing bars and the first flights of the screw conveyor are hydraulically retracted from the mixing chamber. If EPB knife bits are installed these are exchanged with disc cutters on the cutterhead and the EPB scrapers on the cutterhead need to be replaced with hard rock bucket lips. Muck paddles are installed on the backside of the cutterhead to allow the muck to be scooped into the invert, lifted and deposited in the central conveyor muck chute. The conveyors muck loading chute is attached to the central bulkhead which is hydraulically extended into the mixing chamber. Once the chips are deposited in the muck chute, they are transported with the machine conveyor and discharged through the screw conveyor onto the backup belt conveyor (see Figures 5 - 7).

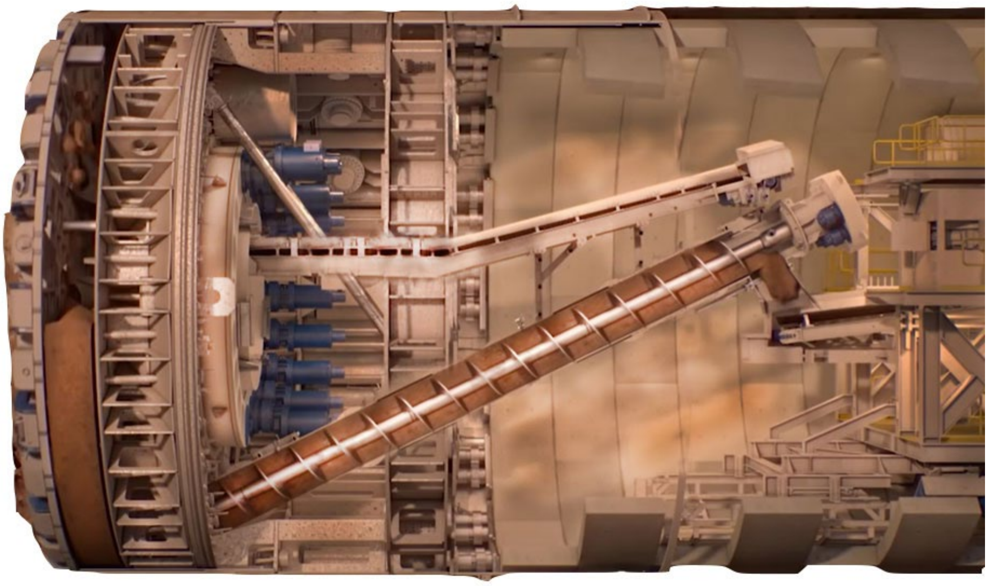


Figure 5. The Crossover TBM in Rock Mode. Belt conveyor and screw both installed

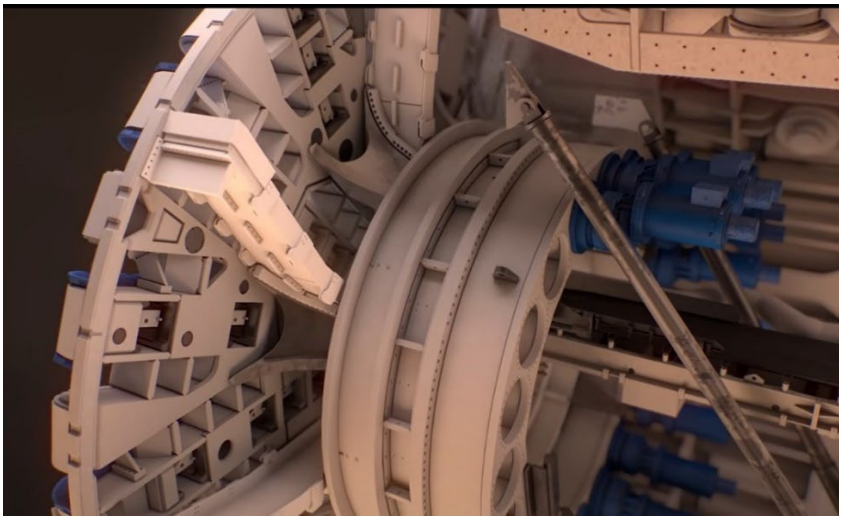


Figure 6. Cutterhead loading plates

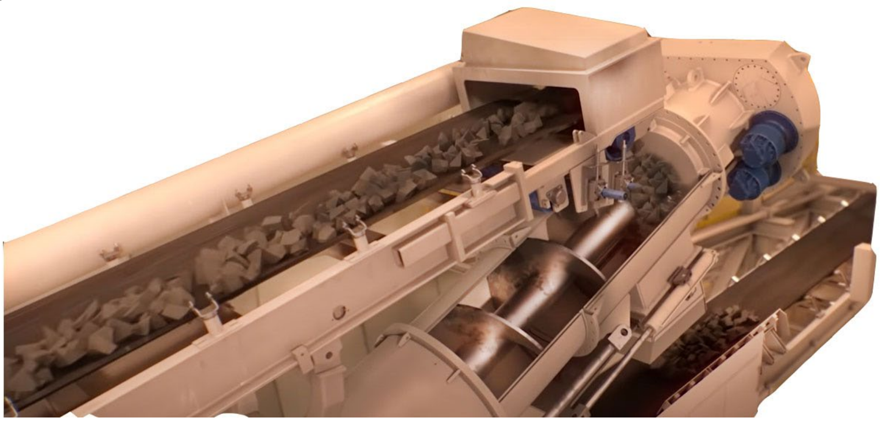


Figure 7. The belt conveyor passes through the screw conveyor to deposit muck onto the TBM belt conveyor

A skew ring offsets the torque of the machine in hard rock, allowing for more efficient single direction muck pickup. Mini grippers on the rear shield allow the machine to bore 400 to 600 mm forward, then be retracted for cutter changes.

To keep the production rate high, a two-speed gearbox with a ratio of 2:1 is hydraulically actuated to get the proper RPM for the hard rock mode. The two-speed gearbox is bypassed in EPB mode to get the proper RPM for the EPB mode.

Overall, this design is optimized for equal parts hard rock and soft ground. By contrast, if a tunnel is located in mostly hard rock or mostly soft ground, the Dual Mode machine can be customized accordingly.

3 MACHINE LAUNCH & PERFORMANCE

The 13.77 m Crossover XRE machine launched on its 3.05 km (1.90 mi) bore at the end of March 2021. The machine began its bore in altered gneiss, then passed through mélange consisting of gneiss, sandstone, claystone, mudstone, quartz, and silt. By the end of the bore the machine was excavating in mainly mudstone.

3.1 *Record-setting jobsite performance*

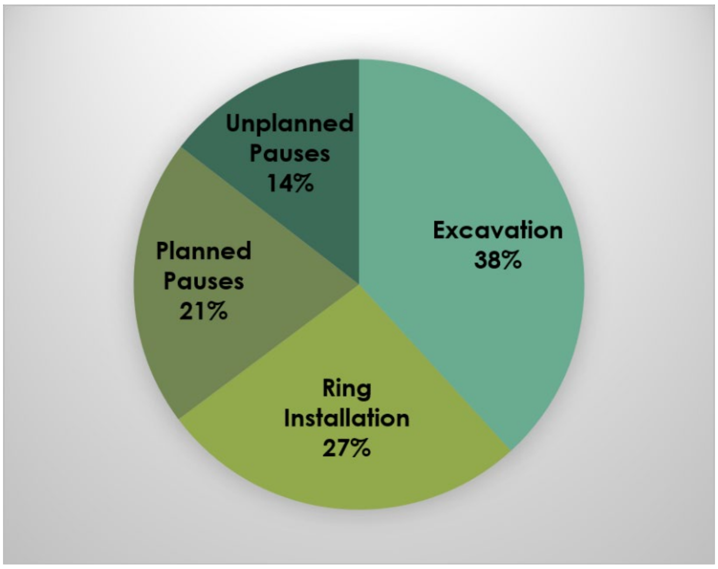
During its bore, the machine set new world records three times over for best day, week, and month in the 13 to 14 m (42.6 to 46 ft) diameter range, and finally, for all TBMs over 13 m in diameter. Its fastest rates were set in July and August 2021, with a best day of 32.4 m, best week of 178.2 m and best month of 721.8 m. While some of the crossover features proved beneficial the TBM was able to utilize the screw conveyor for mucking for the complete tunnel drive, which was a further benefit for the project's overall schedule. The machine's final breakthrough occurred in October 2021 (see Figure 8).

Figure 8. Ankara-Izmir HSR Crossover XRE TBM

3.2 *Performance Analysis*

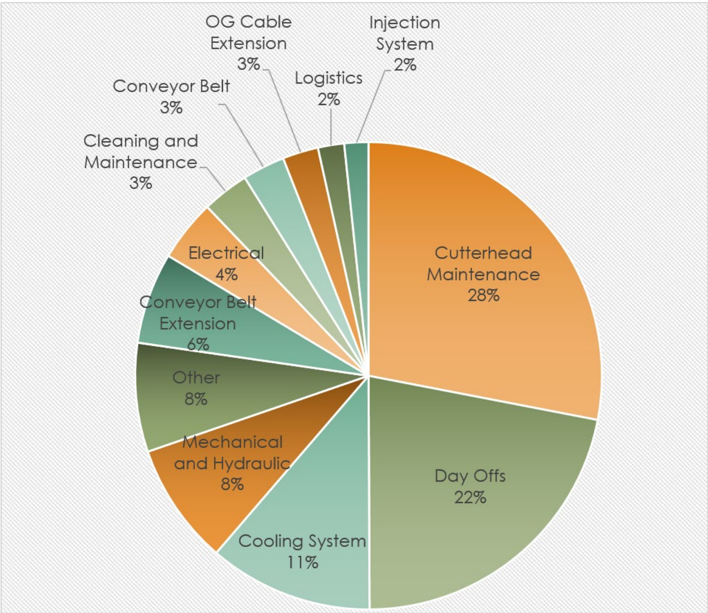
What allowed the machine to perform at high rates of advance? Utilization charts reveal that 38% of the total time was spent on excavation, 27% on ring assembly, 21% on planned downtime such as maintenance, and 14% on unplanned downtime (see chart 1).

Chart 1. Productivity pie chart



When looking at planned downtime, the most time was spent on cutterhead maintenance at 28%, followed by crew breaks at 22% (see chart 2). An average machine push took 60 minutes, while ring builds averaged 42 minutes.

Chart 2. Downtime causes pie chart



Delays caused by mechanical, hydraulic or electrical failures were very low. The contractor cited the main reasons for minimal downtime, and thus high advance rates, as regular planned maintenance, cleaning, an experienced team, and an adequate supply of spare parts. Ultimately the tunnel was completed in just 6.5 months (see Figure 9).

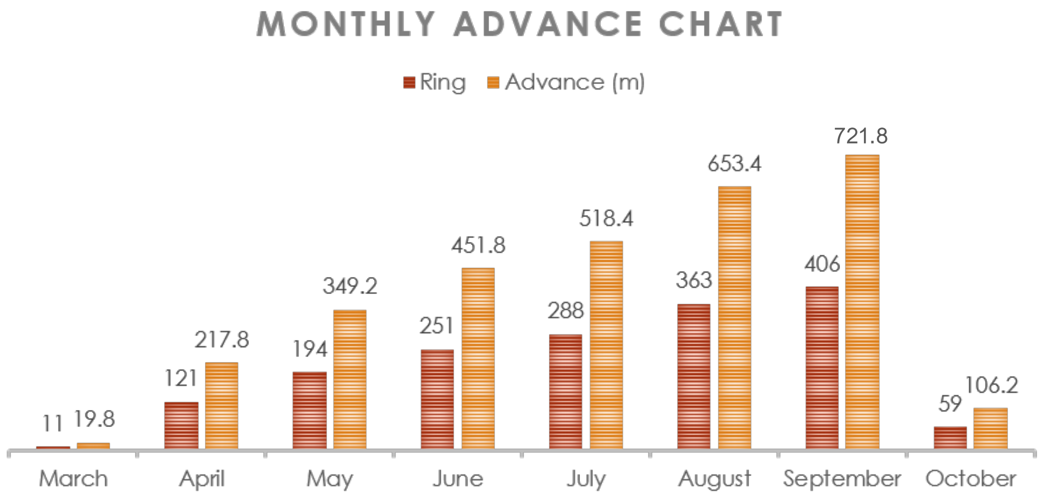


Figure 9. Monthly advance rate chart in meters bored and rings built

4 CONCLUSIONS

Large diameter, dual mode rock/EPB machines can and will excavate mixed ground conditions efficiently – even at world record rates. While similar projects in Turkish geology have met with challenges, the Esme-Salihli tunnel shows that with proper maintenance and a knowledgeable crew, equipment downtime can be kept to a minimum and advance rates can remain high.