World Tunnel Congress

Meet you
in NAPLES

WTC 2019

ITA - AITES General Assembly and World Tunnel Congress

**TUNNELS AND UNDERGROUND CITIES:
ENGINEERING AND INNOVATION
MEET ARCHAEOLOGY, ARCHITECTURE AND ART**

MAY 3 9
MOSTRA D'OLTREMARE
NAPLES 2019

EXHIBITION BROCHURE
SPONSORSHIP OPPORTUNITIES

www.wtc2019.com

Società Italiana Gallerie
Italian Tunnelling Society

ITA
AITES

Tunnels and Underground Cities: Engineering and Innovation meet Archaeology, Architecture and Art – Peila, Viggiani & Celestino (Eds)

Record-breaking results through teamwork on Istanbul's Dudullu-Bostancı Metro Line

E. Koç
Senbay Madencilik-Kolin-Kalyon JV, Istanbul, Turkey

B.A. Matheson
Terratec Ltd., Hobart, Australia

M. Bringiotti
Geotunnel S.r.l., Genoa, Italy

ABSTRACT: At 7am, on March 03, 2018, one of two TERRATEC 6.56 m diameter Earth Pressure Balance Machines (EPBMs) being used by the Şenbay Madencilik-Kolin-Kalyon JV on the new Dudullu-Bostancı Metro Line, in Istanbul, Turkey, completed an outstanding advance of 26.6 m (19 rings) in just 12-hours. The TBM and its crew worked non-stop – alternating between 20-minute mining and ring building cycles – throughout the night shift to accomplish a new production record for a TBM of this size and class in Turkey. The 14.2 km-long Dudullu-Bostancı Line runs north to south under the densely-populated Anatolian side of Istanbul and is located entirely underground at an average depth of about 30 m. Achieving consistently good TBM production rates in this dense urban environment – with limited space on a busy open-cut station site – is a testament to the importance of teamwork and well-planned logistics, and ultimately led to the early completion of tunnelling on an extremely challenging contract schedule.

1 PROJECT BACKGROUND

Istanbul was a pioneer of the urban underground railway. The city's first metro tunnel, between Karaköy and Galatasaray, is one of the oldest in the world – second only to the early London Underground lines – having gone into service in 1875. However, despite this, it wasn't until the late 1980s that construction began on a true 'modern' mass transit railway system for the city.

Since then, the population of Istanbul has almost doubled, from about 8.5 million to nearly 16 million. Traffic congestion has reached an all-time high and the city is now facing a major transportation crisis. Therefore, in recent years, work has been underway to meet the Istanbul Metropolitan Municipality's (IMM) goal of expanding the city's existing six-line, 145 km-long, metro service to an inter-connective network that covers more than 480 km by the end of 2019. Five new metro lines and three extensions of existing metro lines are currently under construction on both sides of the Bosphorus Strait.

One of these new lines is the Dudullu-Bostancı metro line (Figure 1), which runs north to south across the densely-populated Anatolian side of the city. The 14.3 km-long line, along with its 13 new stations, is located entirely underground at an average depth of about 30 m and will ultimately be fully-automated – with driverless trains, communications-based train control (CBTC) and platform screen doors at stations – providing numerous connections to other Istanbul transportation systems, such as the Bosphorus ferry (at Bostancı Harbour), the Marmaray railway, and the Kadıköy-Kartal and Üsküdar-Çekmeköy metro lines.

Figure 1. Map showing the location of the Dudullu-Bostancı metro line.

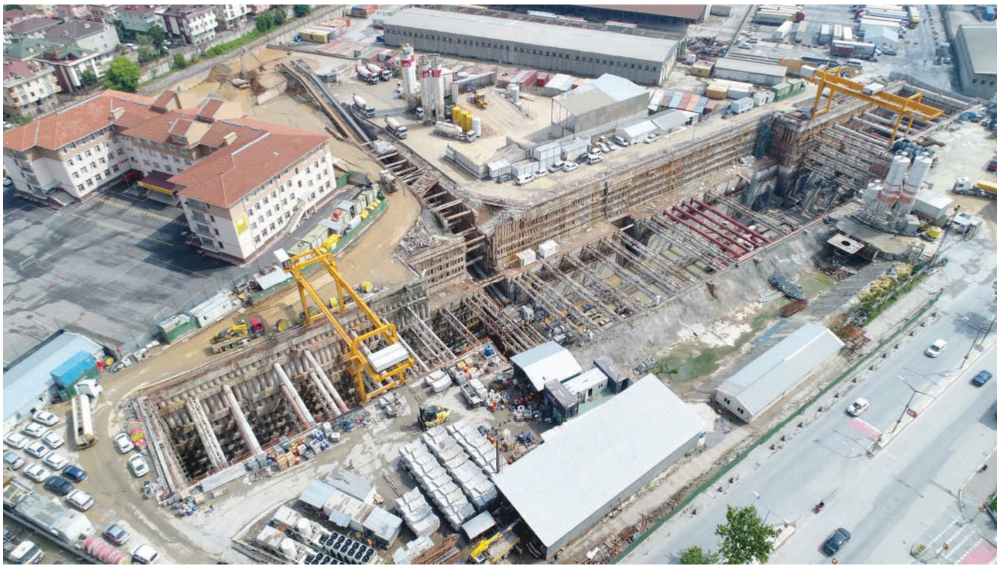

Figure 2. Aerial view of the Kayısdagi Station site.

The IMM awarded the construction contract for the line – which also includes E&M works, construction of Underground Transfer Centres (Car Parks), a Depo Area and a Management and Control Centre Building – to the Şenbay Madencilik, Kolin and Kalyon Joint Venture (SKK JV) on February 12, 2016. Two weeks later the JV mobilised on the future site of the centrally located Kayısdagi Station – which is surrounded by residential and business properties (including a school that abuts the open-cut station box) – where the project's TBM tunnelling operations would be based (Figure 2).

Figure 3. The TERRATEC S51 TBM cutterhead is lowered into the Kayısdagi Station box.

2 TBM SELECTION AND DESIGN

In order to meet the Dudullu-Bostancı metro line's fixed 2019 opening date, a challenging construction schedule was put in place, which required the project's four TBMs to commence tunnelling 10 months after contract award and complete excavation within 28 months. Members of the JV had been greatly impressed with the performance of the Terratec machine they had used on the new Mecidiyeköy-Mahmutbey Metro line – which is being built by the Gülermak, Kolin and Kalyon JV on the European side of the city (Bilgin et al., 2017) – and were keen to employ further Terratec machines on their second project for the IMM. However, with TBM delivery being on the critical path to project completion, the JV decided that the schedule risk should be mitigated by splitting the TBM order between two suppliers. Therefore, an order for two new 6.56 m diameter EPBMs was placed with Terratec and two refurbished 6.57 m diameter EPBMs were purchased from another manufacturer.

The Terratec mixed-face TBM cutterheads featured an opening ratio of about 35 percent, designed to best manage Istanbul's variable geology (Figure 3), and were fitted 17'' back-loading disc cutters that were interchangeable with knife-edge bits for areas of soft ground. Other features included VFD electric cutterhead drives – with a total installed power of 960 kW and a high-speed cutterhead – high torque screw conveyors, and active articulation systems. Total thrust was 40,000 kN, with a nominal torque of 5,459 kNm, and max. torque of 7,097 kNm.

3 GEOLOGY & PREDICTION OF RISKS

The geology along the new line comprises Paleozoic aged Aydos, Gözdağ, Kurtköy, Tuzla, Trakya and Kartal Formations. The Aydos and Gözdağ Formations are in the upper level of the Kurtköy Formation and mostly consist of high strength and laminated shale layers and very abrasive rock consisting of quartz and arenite that is highly rich in feldspar. In the Tuzla Formation limestone can be found along with thinly laminated mudstone. The Trakya Formation consists of laminated interbedded siltstone and mudstone and is very abrasive and fractured in some places. The main geological formation to be excavated was the Kurtköy Formation. Arkose is the main unit of the Kurtköy Formation and generally consists of purple-coloured gravel, sandstone and mudstone.

With the expected ground conditions in mind SKK's TBM management team aimed to mitigate any problems that may arise during excavation. Grizzly bars were prepared for the

Figure 4. Rippers were prepared to replace the disc cutters for a known 500 m zone of soft clay.

TBM cutterheads, to prevent blockages in zones of fractured and laminated rock conditions, and were ultimately used for about 60 percent of the alignment. Ripper tools were also at hand, in order change out the 17'' disc cutters for a known 500 m-long zone of very soft clay, reducing the possibility of clogging (Figure 4).

4 SITE SET-UP AND LOGISTICS

The precast tunnel lining rings that were installed by the TBMs consist of reinforced concrete trapezoidal segments (5+1), with an outer diameter of 6,300 mm, an inner diameter of 5,700 mm and a width of 1,400 mm. They were produced by SKK JV at its factory in Ferhafpasa, which is located about 10 km away from the project worksite.

While planning the logistics and TBM supply the TBM management team had to consider the traffic congestion in Istanbul. With the need for on-time segment delivery and muck removal from site, and the inevitability of severe traffic jams along trucking routes, the decision was made to conduct 70 percent of the operation during the night shift. Six trucks with trailers were used to transport the segments and these pushed hard during the night, as did the muck transports; driving 104 km round trips to a disposal site north of Istanbul.

The muck pit was allocated two clamshell excavators in order to manage the muck levels discharged by the conveyors, while the belt tower was limited to 5 m in height, in order to reduce noise levels within the residential area (Figure 5).

Although the Kayısdagi site encompasses a relatively large area, the 3,500 m^2 concrete batching plant, the 237 m long open-cut structure (which includes the station and switchbacks), and the 1,830 m^2 muck pit and conveyor ramp, take up most of the available surface

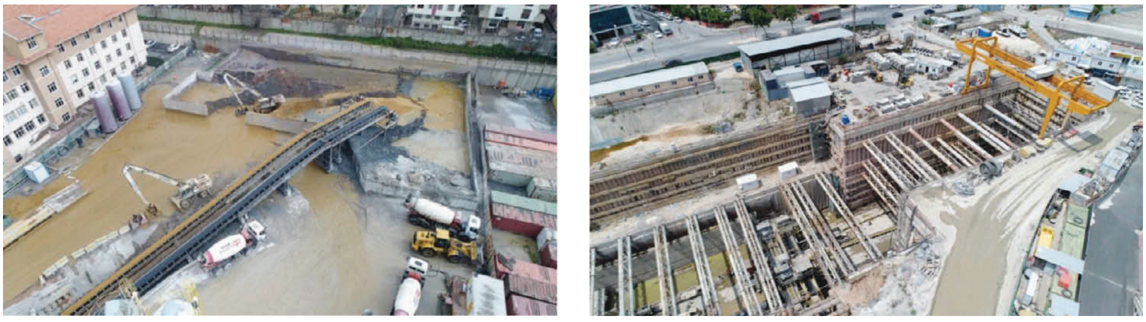

Figure 5. The muck pit and gantry cranes at the Kayısdagi site.

area. Added to this, was the additional challenge of large ground deformation loads on the station box that required the introduction of a safety exclusion zone alongside the TBM grout plant on the road side of the station structure. This enabled the JV to keep the number and size of the support struts used within the box to a sensible level, but it also eliminated much of the space that had originally been intended for segment storage, leaving room on site for just 50 sets of tunnel segments for four TBMs.

Twin gantry cranes were selected for the segment and material lowering operations. These were sited above the switchbacks and equipped with double remote-control units in order to reduce the risk of accidental damage while lowering the segments and placing them onto Multi-Service Vehicles (MSVs) as fast as possible while working in narrow spaces between the support struts. The first operator would control the crane while lifting with the hook on the surface. Then, during the lowering operation, a second operator took control once the hook had passed through the strut level and placed the segments or materials on the MSVs.

5 TBM DRIVES

The TBMs were delivered on time and assembly of the machines began at the end of 2016. By January 2017, the first two TBMs – the Terratec S50 TBM and one of the refurbished machines – had been launched on their 3,987 m journey south-west towards the coast. Shortly thereafter, the Terratec S51 and the other refurbished TBM began mining north-east on a 4,407 m trajectory towards Yukarı Dudullu station (with a planned section of NATM works due to complete the line to Depo).

TBM parameters and performance analysis were inspected by SKK's TBM management team via a program designed by the TBM Tunnels Chief Engineer, which collected all TBM data and, on monthly basis, data from all the shift engineers. This allowed the team to identify optimum operating parameters to reach maximum and continuous daily advances.

The Bostanci TBM drives progressed much as expected, achieving good advance rates and passing through stations on their way south (Figure 6), before terminating at a shaft located just north of Ayşekadın station in April 2018 (with the balance of the running tunnels to Bostancı due to be completed by NATM).

However, on the Dudullu side the abrasive nature of the ground proved challenging, especially between Kayısdagi and Modoko. On leaving Kayısdagi the geology encountered was

Figure 6. The TBM sliding operation was performed over invert segments through the stations.

Figure 7. The cast-in-situ TBM thrust ring used at the underground stations.

hard arkose sandstone and limestone. This is rich in feldspar and quartz grains that are highly abrasive and have a significantly negative impact on the operational life of the disc cutters (Seyedrrzaei et al., 2018). It also caused rapid wear to both the TBMs' cutterheads and screw conveyors, which had to be refurbished six times and five times, respectively (total for both machines). These works were carried out at the stations, with the team refining the refurbishment operations to a point where they could repair a screw conveyor in the matter of a week. Other remedial methods included the injection of anti-abrasive chemicals, and occasionally bentonite, during excavation to reduce friction. Once the TBMs passed Modoko however, the ground became gradually better and TBM utilisation rates improved.

5.1 *Station Crossing & Relaunch*

At all the underground stations, a novel cast-in-situ TBM thrust ring [designed by Enver Koç] was adopted. Using this method, a TBM relaunch was possible in two days, and without the need for enlarged NATM chambers or the installation of a heavy thrust frame. All that was required was the excavation of a 14 m-long A1 NATM tunnel (to house the TBM shield) and the radial installation of 60 x 32 mm diameter self-drilling rock bolts, with couplings attached to the heads, before the TBM reached the station. Once the TBM was in-place for relaunch, the rock bolts were extended (via the couplings) to reinforcement installed within a metal segment ring mould, which was manufactured in the site's workshop (Figure 7).

6 TEAMWORK FOR SUCCESS

Team spirit has been the key to success on the Dudullu-Bostancı metro, both in terms of the joint venture and subcontractor partnerships, the teamwork on site and the project's relationships with its suppliers, TBM manufacturers and their agents. At the outset of the project, SKK JV had appointed a project manager with extensive TBM experience and this decision provided swift and decisive action during procurement, employment and technical decisions relating to the management of the TBMs. The lines of communication between the mechanical and operational teams were also very strong and an ethos of 'being part of the solution not

Table 1. TBM Performance for Dudullu Bostancı EPB-TBMs

TBM Serial Number	Total Advance (m)	Total No. Rings	Maximum Daily Advance (m)	Ground Conditions
S50	3,987.87	2,850	37.2	Arkose & Limestone
EPBM 2	3,792.40	2,725	32.4	Arkose & Limestone
S51*	4,407.49	3,120	40.0	Arkose & Clay
EPBM 3	4,344.62	3,076	34.5	Arkose & Clay
Total	16,532.38	11,771		

* Shift record holding TBM

part of the problem' was adopted across the project. With this ideal in mind, decisions were made together as a team and focussed on results only.

TBM manufacturers need to be involved in the project as early as possible and (in the experience of the authors) should listen to the requirements of the contractor and adjust their mechanical solutions to suit the project's specific needs, from site access to ground conditions. Of course, a local presence, either in the form of a local office or a local representative, is key and ensures a 'can do' attitude to problem solving on site in real time (for example, sourcing consumables and spares locally, if necessary).

From the beginning, SKK's TBM management team aimed to gather together the most experienced workers and engineers possible for the project, but with 30 TBMs currently at work on various different projects in Istanbul, this proved a challenge. For the most part, newly graduated junior engineers – who had been identified following internships with the JV's partner companies – were selected to build the team. Following a month-long theoretical training period, during TBM assembly, the TBM management trained these young engineers as TBM operators and continued to mentor them throughout the project.

A daily bonus payment system was also applied to keep the teamwork level high. Engineers and workers were separated into three different groups of payment level and, on a daily basis,

Figure 8. Breakthrough of the S51 TBM at Yukarı Dudullu in June, 2018.

the JV paid bonuses to everyone for the 13th ring built, onwards, as long as there were no defects or offset on the built rings. These bonuses could increase a basic salary by approximately 10–15 percent on a monthly basis and really incentivised everybody to come together and fix problems. It provided excellent performance and was a major contributory factor in completing the TBM tunnelling two months earlier than scheduled.

In fact, in early March 2018, when progress rates had reached their peak, one of the shift engineers approached the TBM management and requested that the night shift be allowed to try and break the existing production record. This resulted in a record-breaking 19-ring shift that was completed by the Terratec S51 machine, which had mined about 75 percent of its alignment at this point. Equating to 26.6 m of excavation in just 12-hours, the TBM and its crew worked non-stop throughout the night – alternating between refined 20-minute mining and ring building cycles – to accomplish the record for a TBM of this size and class in Turkey. The excellent progress rates continued through to the completion of excavation, this June, when the S51 broke through into Yukarı Dudullu station (Figure 8).

ACKNOWLEDGMENTS

The authors are grateful for the support of the Şenbay Madencilik-Kolin-Kalyon Joint Venture (SKK JV) and, in particular: Project Manager, Mr. Mustafa Yurt; Tunnel Section Chiefs, Mr. Mehmet Ali Keleşoglu & Mr. Şahin Zerdeşt Arslan, Mr. Hüseyin Taşdemir; Shift Engineers Çağdaş Kaya, Serhat Palakcı, Erdal Gündoğan, Muhammed Arıoğlu, Satılmış Kalyon and Koray Yağlı; Terratec Site Operations Manager, Mr. Bill Brundan; and Mr. Erhan Ünlü and his team at Ertunnel.

REFERENCES

Bilgin, N., Acun, S., Ates, U., Murtaza, M. & Çelik, Y. 2017. *The factors affecting the performance of three different TBMs in a complex geology in Instanbul*. Proc. World Tunnel Congress 2017, Surface Challenges – Underground Solutions, Bergen, Norway, 9–15 June, 2017.

Seyedrrzaei, M., Koç, E. & Tumac, D. 2018. *Single Shield TBM Performance Analysis in Mixed ground Conditions: A Case Study in the Dudullu-Bostanci Metro Tunnel, Turkey*. Poster paper proc. ITA-AITES 2018 World Tunnel Congress, Dubai, 21–26 April, 2018.