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Overcoming TBM Launch Challenges in Doha's WWDT Project

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Abstract: Over the past two decades, Doha has experienced rapid growth, putting considerable pressure on the city's infrastructure, particularly its aging sewer system and wastewater treatment facilities. To address these challenges, the Public Works Authority ASHGHAL has initiated several projects involving both shallow and deep sewer tunnels, alongside the construction of new treatment plants to accommodate the demands for Doha's expanding population in the future. The scope of the Wakrah and Wukair Drainage Tunnel (WWDT) project includes a 13.3 km bored and lined tunnel, using two 5.85-meter diameter EPB TBMs, eight shafts, adits for future connections, and hydraulic structures. Due to project constraints and the delivery schedule of the TBMs on site concerning Covid-19 pandemic restrictions, the contractor had to launch a 148-meter-long Tunnel Boring Machine (TBM) inside a 15-meter diameter shaft located at a depth of 59.4 meters. This paper details how the contractor successfully managed these challenges and launched both TBMs. The TBM launch and commissioning were contractual key milestones. The approach involved partially excavating a Stub Adit/Logistics tunnel using a Sequential Excavation Method (SEM) to create space for multiple TBM sections at the base of the shaft, while some TBM gantries operated simultaneously by situating on the surface and connected via umbilical lines to the cutterhead and main shield of the TBM for commencement of the tunnelling operations.

Keywords: sewer tunnel; EPB TBM; launching challenges; tunnelling

1. Introduction

ASHGHAL is a Public Works Department (PWA) for the country and has launched several schemes in response to the growth and rapid expansion of the population, which has strained the country's infrastructure including sewerage system and treatment facilities. The PWA developed strategic plans utilizing shallow and deep sewer tunnels and new treatment works to serve the growing population in the years to come.

The Wakrah Wukair Drainage Tunnel (WWDT) project (C853/2) is primarily located within the western and southern utility corridors, an assigned buffer zone between the two utility corridors, and inside the Al Wakrah and Al Wukair Sewage Treatment Plant (STP).

The Project comprises the design, construction, testing, commissioning, and handover of the Drainage Tunnel. The Drainage Tunnel (DT) is approximately 13.3-km long with four temporary work shafts for TBMs launch and/or reception – WS07, WS08, WS09 and WS10 and four additional temporary shafts for the construction of permanent access shafts in between the TBM work shafts – AS08, AS09, AS10 and AS11 which shall all be converted to permanent access shafts.

The DT final inner diameter is 4.5 m. The lining concept consists of primary lining, which is a 300 mm thick fiber reinforced segmental concrete (C50/60), and a Secondary Corrosion Protection Lining (CPL) of 250 mm thick concrete (C35/45) with a 2.5 mm thick HDPE protective membrane. For additional information about concrete used please refer to Bernardeau et al. (2018).

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WWDT project sites are in an undeveloped area, and the ground surface levels along the approximately 13.3 km-long alignment range from approximately +5 to +25 m above the Qatar National Height Datum 95 (QNHD95). The sites are surrounded by Qatar Petroleum (QP) pipelines, overhead high-voltage transmission lines, other utility services, as well as expressways. There are no existing permanent roads to many parts of the sites. Please refer to Stypulkowski et al (2023, 2024) for omitted details.

2. Project Tunnelling Plan

The tunnelling for WWDT project has been planned for TBM 1 to start at WS10 and pass AS11 and WS09. After passing WS09, the TBM stopped at about 150m before (in flow direction) the shaft. During the interruption of tunneling, the Site Installation for TBM 1 was shifted from WS10 to WS09. After reinstallation of the tunnelling logistics, TBM 1 was launched again from WS09, passed AS10 and was received finally at AS09. AS09 was constructed as TBM Launch and Reception Shaft for TBM 2, which drove through WS08 and consecutively through AS08 and was than received at WS07.

3. Geology general overview

The project area is geologically a part of the Arabian Gulf Basin as described in detail by Cavelier et al. (1970) and Sadiq and Nasir (2002). The post Cretaceous sedimentation is a sequence of shallow marine limestone with occasional shale and evaporates in a shallow basin. The formations encountered in the Doha region comprise of Quaternary marine, aeolian and sabkha deposits. The Simsima Limestone is subdivided into four geological units in the project area: the Highly Weathered Simsima Limestone (HWSL), Weathered Simsima Limestone (WSL), Simsima Limestone (SL) and Basal Simsima Limestone (BSL). The underlying lower geological units, which include the Midra Shale (MSH), Khor Limestone (KLS), Rus Calcareous (RUS) and Rus Gypsum (RUSGYP), lay below the SL formation (Karagkounis et al. 2016).

Based on the available information, PHM-JV interpreted the geology as presented in Figure 1 and summarised below.

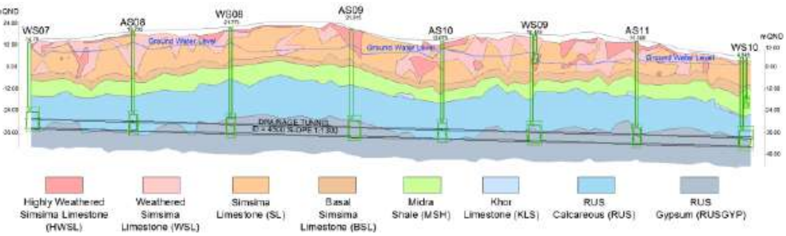

Fig 1. Interpreted geology (PHM-JV, 2022c).

4. Surface Enabling Works and Rock Grouting (Shafts)

The experience accumulated from other projects in the state of Qatar by the contractor, suggested that rock grouting (or permeation grouting) is the best option to reduce the active karstification/voids of rock formation and thus the water inflow towards the excavation, see Fig.2. Rock grouting was performed ahead of excavation using a down-the-hole hammer with a diameter of 115mm and a Tube-a-Manchete system. The mix design used was a combination of Ordinary Portland cement (OPC) between 320 kg and 420 kg, bentonite between 30 to 60 kg, and water from 800 to 900 l.

In shaft WS10, two drilling schemes were used: full-length primary-secondary grouting around the shaft perimeter, and a base plug grouted only in the last 10 m to block bottom water inflow.

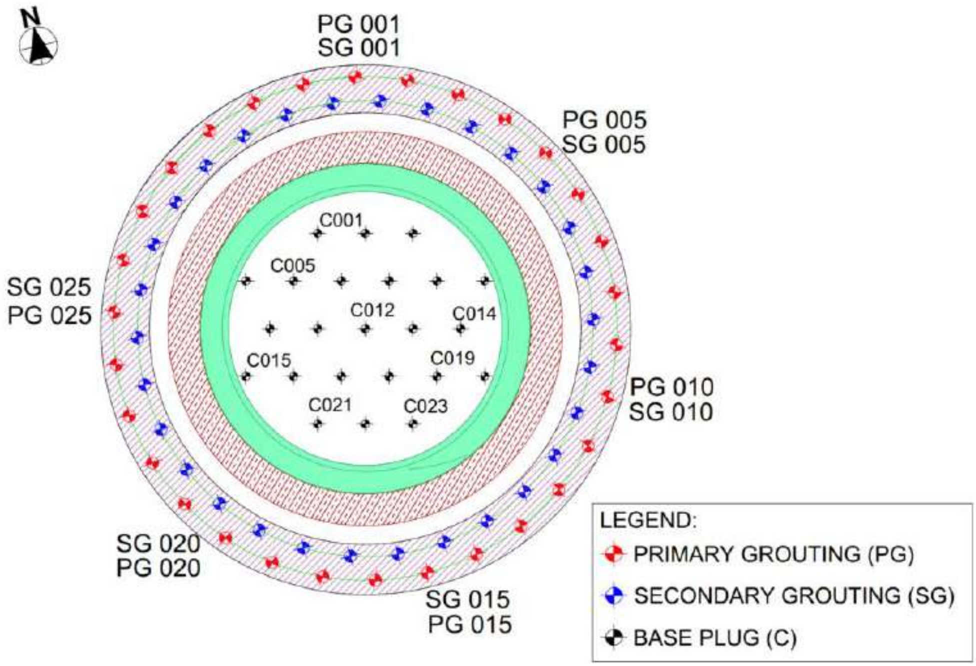

Fig 2. Rock grouting drill pattern.

For shaft AS09, only the base-plug rock grouting was required. Perimeter grouting had been completed by a previous contractor (2016-2018); after that contract was cancelled, the shaft was backfilled with lean concrete (2018). On taking over the shaft under the WWDT contract, the contractor confirmed the existing rock grouting was still fit for purpose.

A total number of 30 primary and secondary and 23 center bore holes have been drilled in WS10 with a grout consumption of 574.5 m^3, while in AS09, only 24 center bore holes have been drilled with a grout quantity of 22.3 m^3.

5. Surface Enabling Works and Rock Grouting (Launching chamber and Logistic Tunnels)

The excavation method for the TBM launching chambers and logistics tunnel is based on NATM, thus considering the groundwater conditions, the rock grouting block containing the tunnel lining inside is necessary in a similar way, as it has been described previously.

In WS10, 297 primary and secondary bore holes were drilled with a grout consumption of 1458 m3, while in AS09, 190 bore holes were drilled with a grout quantity of 590 m^3.

6. Dewatering

To mitigate the effect of water inflow in the shaft, a complementary action to the rock grouting, an integrated dewatering system consisting of dewatering wells with effective slotted casing diameter of 315 mm and French-drainage of 1 m by 1m and sump pits, permanent and temporary, was deployed in the launching shafts (WS10 and AS09), as shown in Fig. 3.

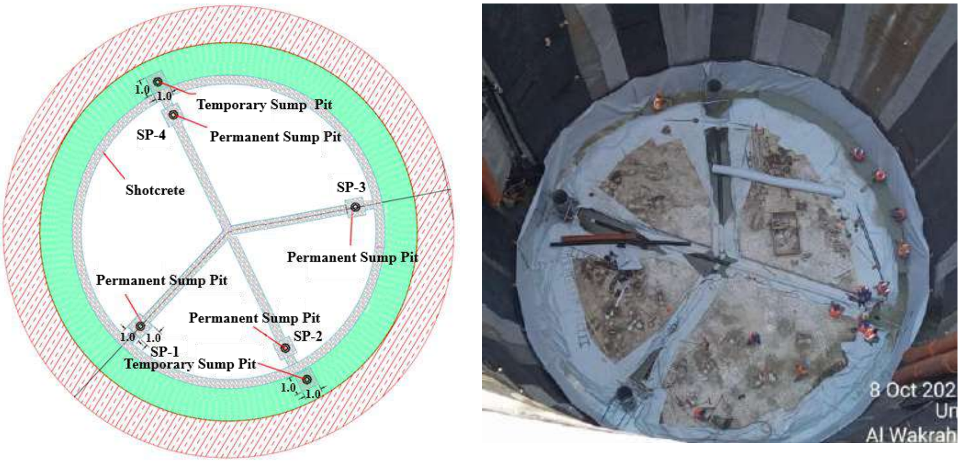

Fig 3. De-watering design and construction in shaft WS10.

The water collected from the dewatering system in each shaft was discharged into a main internal discharge line via a lay-flat hose and HDPE pipes. Extracted groundwater was discharged to the recharge wells at a depth of 450 m via a break tank through internal HDPE pipes, after maintaining the parameters stipulated in the relevant permits. During excavation of the shafts, the amount of dewatering was around 40 m^3/h, while during the TBM activities, it was around 20 m^3/h. As WS10 and AS09 shafts are two TBM launching shafts, each site has its own deep recharge wells and its associated surface facilities, in order to maintain the quality of discharge water and not to exceed the daily capacity of the recharge wells.

7. Shaft Excavation

The shaft construction consisted of excavation works and application of SCL primary support. The excavation was carried out by using conventional excavators (with more than one excavator) working in the shaft at the time, a drum cutter and hydraulic hammer. The primary support was sprayed wet shotcrete C25 distributed in a single layer of 100 mm thickness or 300 mm distributed in a double layer, reinforced with a single or double layer of wire-mesh (200 X 200 X 8mm), and installation of spot rock bolts.

8. Tunnel Excavation (NATM)

The excavation of the launching tunnel and logistics tunnel has been done by the New Austrian Tunneling Method (NATM) also known as Sequential Excavation Method (SEM). Ground conditions and geotechnical loads considered in the design of the Non TBM-Tunnel were calculated based on the data provided in the Preliminary Geotechnical Interpretative Report which showed as Strata – Rus Gypsum, ϒ [MPa] = 22.5 and Erm [MPa] = 4363.

Horizontal probe drilling along with Face mapping has been systematically done to assess the rock mass condition and its support which was based on the shotcrete (C25) with thickness between 100mm to 250mm, reinforced with two layers of wire-mesh (200 X 200 X 8mm) and rock bolts of 3m length in a pattern of 2m X 2m. Excavation was done as full circle in launch adits and by heading & benching manner in logistics tunnels, see Fig.4 and Table 1.

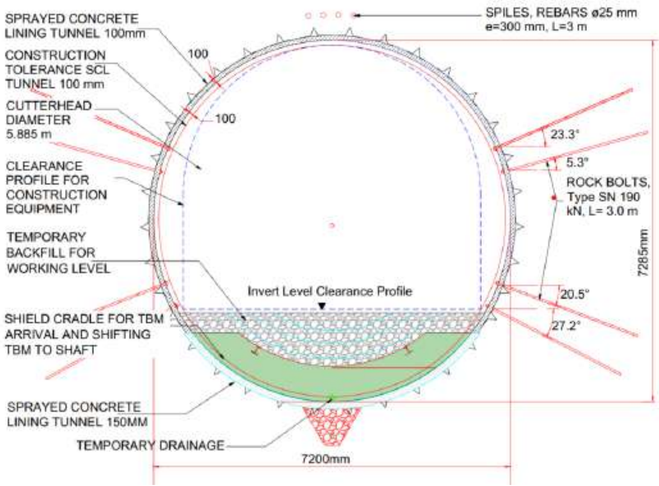

Fig 4. Launching and logistics tunnel cross sections.

Table 1. Summary of NATM tunnels.

Location	Excavation rate (m/day)	Support class	Water inflow (m^3/hr)	Maximum deformation (±mm)	Simplified geology
AS09-Logistic Tunnel	0.9	1 & 2	0.6	3.2	Rus Gypsum
AS09-Launching Tunnel	0.3	1	0.2	2.9	Rus Gypsum
WS10-Logistic Tunnel	0.5	1 & 2	0.4	2.85	Rus and Rus Gypsum
WS10-Launching Tunnel	0.7	2	0.2	2	Rus and Rus Gypsum

9. Temporary slab and thrust frame reaction installation

Once the shaft excavation was completed, the permanent drainage and waterproofing installed, the permanent slab has been poured. On top of the permanent slab, the temporary slab, which contains the cradle and base support of the thrust reaction frame, was built.

10. TBM related surface facilities

While the above-described works continued inside the shafts, at the same time, the contractor was busy installing and / or constructing the facilities at ground also, which are essential to perform tunneling works:

- Grout batching plant – cement, bentonite, retarder chemical and sodium silicate.
- Water Tanks and Cooling tower.
- Tunnel Ventilation system.
- Muck-pit and De-mucking unit.
- Segment Storage area to ensure operations of a minimum of 4 days regular production.
- Power Plant (Substation) and diesel tanks.
- Passenger Hoist – Passenger Hoist was installed for access and egress.
- Wastewater treatment Plant.
- Gantry crane capacity 60 ton.

11. TBM Umbilical launching at Shaft AS09

The TBM was launched in the shaft AS09 by using an umbilical system. Thus, after the related enabling works described in the previous sections were completed, the assembly of the TBM started with the preassembly of the drive motor, reducers, thrust cylinders, shields, segment erector and screw conveyor among other front and rear parts, Fig. 5.

The Figure below shows the assembly of the TBM parts in the shaft. Once the shield was assembled, it was pushed into the launching tunnel.

Fig 5. Assembly of the TBM in the shaft.

The following parts from backup gantry 1 and B were removed placed in shaft bottom, temporarily, for the umbilical launch. Among others, operator cabin, foam generators, B- component tank and pumps.

Water, air, and electrical connections were laid down from the surface to backup gantry 7. All the hoses between gantries 2 to 7 were connected.

Thrust reaction frame was installed, fixed and surveyed, see Fig.6.

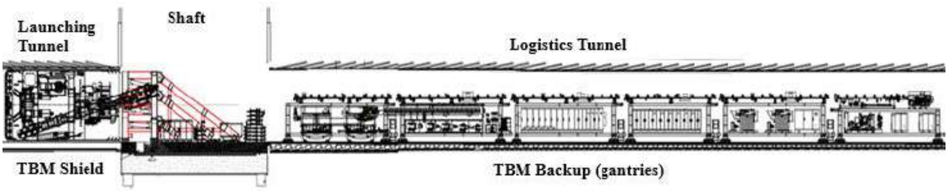

Fig 6. Final configuration of the umbilical launching shaft AS09.

Upon the installation of Thrust frame, TBM launching/initial drive started and the TBM shield advanced 90m, see Fig.7.

Fig 7. TBM and umbilical support. Rolling stock configuration.

Completion of 90 m of TBM shield advance, with umbilical, marks the end of contractually required phase 1 of the lowering and assembly works of TBM, in the shaft bottom/tunnel, see Fig.8.

TBM continued mining until there was sufficient space to install the remaining gantries until full assembly at the TBM bottom/tunnel.

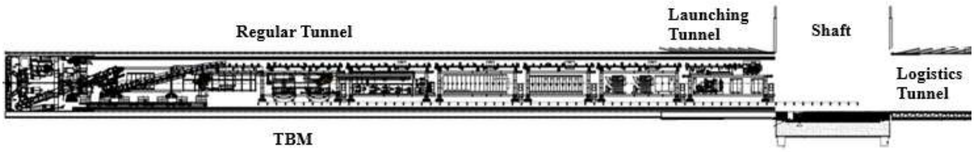

Fig 8. TBM after mining 90 m.

12. TBM super umbilical launching at Shaft WS10

The Shaft WS10 presented a specific challenge based on the geometry and site constraints, where the launching tunnel was not in the same alignment as the logistic tunnel where the backup was to be installed. In addition, the length of the logistics tunnel was not long enough to accommodate the TBM backup in one go. In this case, the logistic tunnel was 40 m out of 70 m, which was required.

After several configuration considerations, it was decided to use an unconventional umbilical configuration to assemble and launch the TBM in shaft WS10.

The TBM and its backup were split into three parts; the TBM shield in the launching tunnel, backup gantries 2 and 3 in the logistic tunnel, and backup gantries 4 to 7 connected at the surface, see Fig.9.

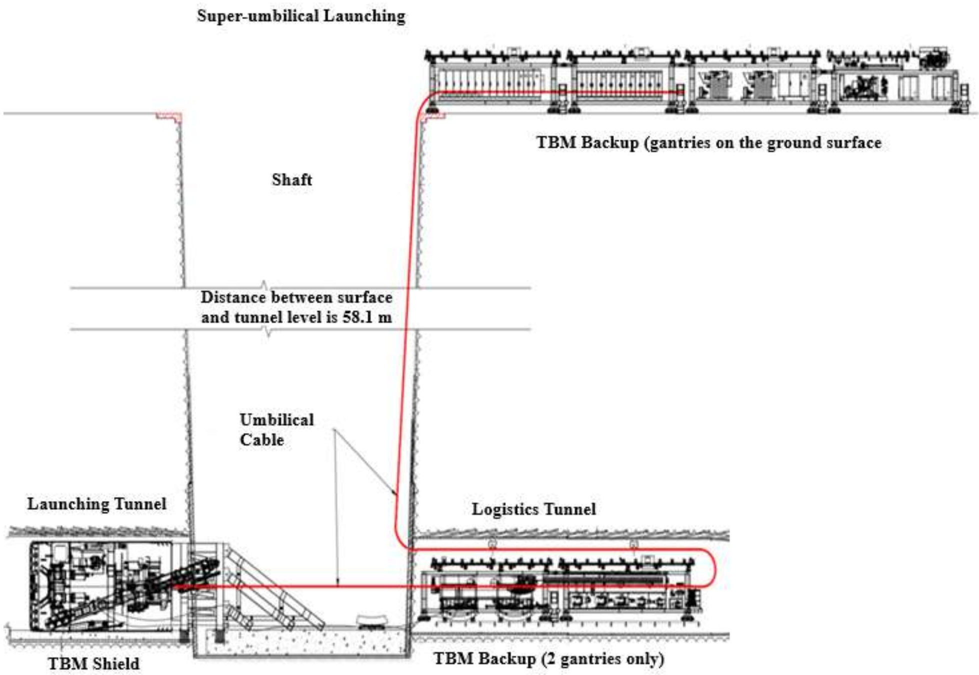

Fig 9. Super umbilical configuration in the shaft and surface.

The following assembly of the TBM and the gantries was followed:

- Lowering and assembling the TBM shield in the shaft and sliding into the launch tunnel.
- Lowering and assembling of gantry 3 and gantry 2 in the logistics tunnel.
- Lowering and assembly of the thrust frame.
- Connecting gantries 2 and 3 to the TBM shield through umbilical pipes and power cables. All other TBM backups were located at the surface level using extended power cables and hydraulic pipes running down the shaft to the TBM to be launched, see Fig.10.

Fig 10. Supraumbilical support and logistics configuration in the tunnel.

TBM was launched and mined until it reached a length of 90 m, see Fig.11. After completing 90m of tunnelling, mining stopped, all the umbilical connections were disconnected, and the thrust frame was removed from the shaft. All umbilicals were disconnected and removed from the shaft and the logistic tunnel:

- Gantry 1 and bridge were lowered from the surface, and all components for the initial drive were reinstalled towards the main machine, and also gantry 2 and gantry 3 from the logistics tunnel.
- All the backup gantries from 4 to 7 were lowered and pulled towards the TBM shield, and connections were made for the next 80 m of tunnel advance, see Fig.12. However, gantries 8 to 11 with rescue chamber and cable extensions were not connected to the main TBM, which was not essential for the initial drive.

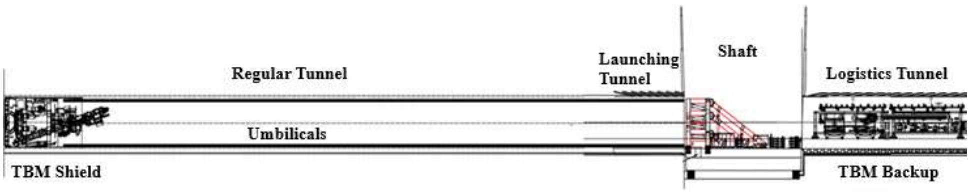

Fig 11. Mining 90 m of tunnel with super umbilical.

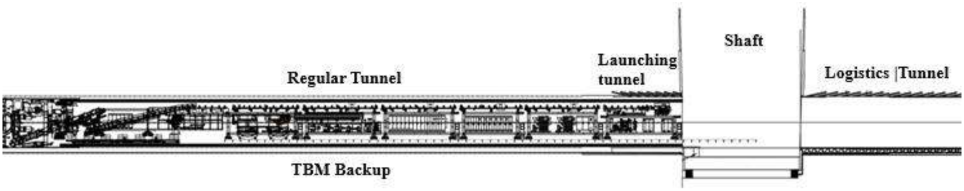

Fig 12. Removal of the umbilical and connection of the backup gantries with the TBM shield.

At this stage, see Fig.13, the excavation of the logistics tunnel to reach the final configuration with a length of 70 m restarted. Once the excavation was done, the remaining gantries were lowered and installed, considering the TBM full assembly.

Other enabling works, like the temporary concrete fill in the tunnel invert for locomotive logistics, and California switches were installed to allow the TBM to start regular mining activities.

Fig 13. Installation of California switches and final arrangement for TBM regular mining activities.

Table 2. Key dates for TBM-1.

TBM-1 - WS10-AS09	Start	Finish	Total Duration	Working days	Length (m)	Productivity Per day in rings
Lowered on	6-Jan-22	4-Feb-22	29			
Initial Drive Started	5-Feb-22	2-Mar-22	25			
WS10-AS09	26-Apr-22	5-Oct-23	542	453	7200	10.1
Best Day (Rings/Meters)			19-Jun-22 (22 / 35.2m)			
Best Week (Rings/Meters)			18 to 23-Jun-22 (113 / 181m)			
Best Month (Rings/Meters)			June 2022 (377 / 604.3m)			

Table 3. Key dates for TBM-2.

TBM-2 - AS09-WS07	Start	Finish	Total Duration	Working days	Length (m)	Productivity Per day in rings
Lowered on	2-Jan-22	27-Feb-22	56			
Initial Drive Started	28-Feb-22	22-Mar-22	22			
AS09-WS07	9-Apr-22	6-May-23	390	329	5879	11.23
Best Day (Rings/Meters)			25-Feb-23 (20 / 31.7m)			
Best Week (Rings/Meters)			22 to 27-Apr-23 (105 / 168.3m)			
Best Month (Rings/Meters)			March 2023 (356 / 569.0m)			

13. Conclusion

Constraints faced by the contractor were unprecedented. The delivery schedule of the TBMs was disturbed with Covid-19 pandemic restrictions in place. There was lack of skilled manpower availability, prolonged visa processes to enter the country were just a few of them. At the same time the contractual accountability to achieve key dates milestones were enforced. All of it pushed the contractor to develop and adopt a customized but efficient plan to launch a 148-meter-long Tunnel Boring Machine (TBM) inside a 15-meter diameter shaft located at a depth of 59.4 meters. Successful

TBM launching and completion of tunnelling works without significant delays are the testament that Umbilical launch method can be adopted as a feasible alternative. Despite having some safety concerns related to numerous pressurized hydraulic pipelines and cables hanging 60m down vertically, Umbilical Launch method is an impressive technique to launch TBMs in a confined space having limited time.

Acknowledgements

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