Launching a 148m-Long Tunnel Boring Machine from a 15m-Inner Diameter Shaft

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Abstract

The city of Doha has grown and expanded rapidly in the last 20 years, but this growth has strained the country's infrastructure, including its aging sewerage system and treatment facilities. ASHGHAL has therefore launched several schemes which involve shallow and deep sewer tunnels and new treatment works to serve Doha's growing population in the years to come. Wakrah and Wukair Drainage Tunnel (WWDT) project scope includes 13.3 km long of bored and lined tunnel using 2 no's 5.85m Diameter Earth Pressure Balance (EPB) TBMs, 8 Shafts, adits with provisions for future connections, ancillary hydraulic structures and Odour Control Facility. Based on WWDT project restrictions the Contractor was required to launch a 148m long Tunnel Boring Machine (TBM) inside a 15m Diameter shaft at a depth of 59.4m. This paper describes how the WWDT project contractor overcame these constraints and successfully launched both TBMs. The TBM launch and commissioning were a contract milestone. The methodology used involved partially mining a stub adit/logistics tunnels using a Sequential Excavation Method (SEM) to accommodate several TBM sections at the bottom of the shaft at the same time several of the TBM gantries were operational on the surface umbilically connected to the cutterhead. This paper will also provide a brief overview of 2 types of TBM launches used recently in Qatar for comparison.

Keywords: WWDT; EPB-TBM; TBM Launch; Shaft; SEM

1 Introduction

The Wakra–Wukair Foul Sewage Conveyance System (WWFSCS) & Treated Sewage Effluent (TSE) Return System Projects consists of three sub-projects (Figure 1) whose scopes are elaborated below:

Wakra-Wukair Drainage Network Branches Project - WWDNB

This drainage network is for collecting sewage from commercial & residential areas in Wakra & Wukair and Industrial area. The length of this project is 16 km, and it is being executed using micro tunnelling methods to install concrete pipes with internal diameters ranging from 400mm to 2400mm.

Wakra Wukair Drainage Tunnel Project – WWDT

Wakra Wukair Drainage Tunnel (Figure 2) will collect the sewage from WWDNB and transfer it to a future sewage treatment plant (STP). Details are mentioned below at WWDT scope of Work Section.

Wakra Wukair Treated Sewage Effluent Project – WWTSE

Wakra Wukair Treated Sewage Effluent (WWTSE) project is for transporting treated sewage effluent (TSE) from the STP through lines placed in trenched excavations using conventional open-cut excavation method. Length of line is 29 km, with diameters varying from 600 to 1400mm.

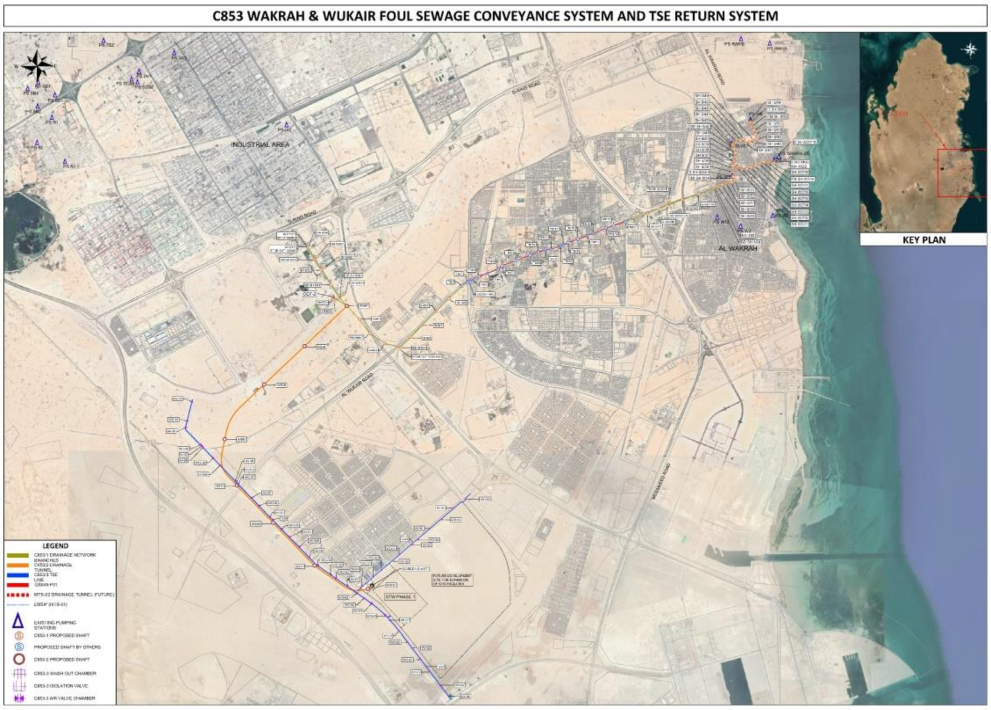

Fig. 1: General layout of WWDNB, WWDT & WWTSE

In summary, the WWFSCS will collect and transfer sewage flows from the existing and future sewerage networks of Wakra & Wukair to the upcoming Sewage Treatment Plant (STP). From the STP, treated sewage will be transferred to different locations for irrigation and other purposes.

2 Project Overview - WWDT Scope of Works

The Project comprises the design, construction, testing, commissioning, and handing over of the Drainage Tunnel. The Drainage Tunnel (DT) is approximately 13.3-km long with four temporary work shafts for TBM 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 shall be 4.5m. The lining concept consists of primary lining which is 300mm thick segmental concrete, (C50/60) and a Secondary Corrosion Protection Lining (CPL) of 250mm thick concrete (C35/45) with a 2.5mm thick HDPE protective membrane.

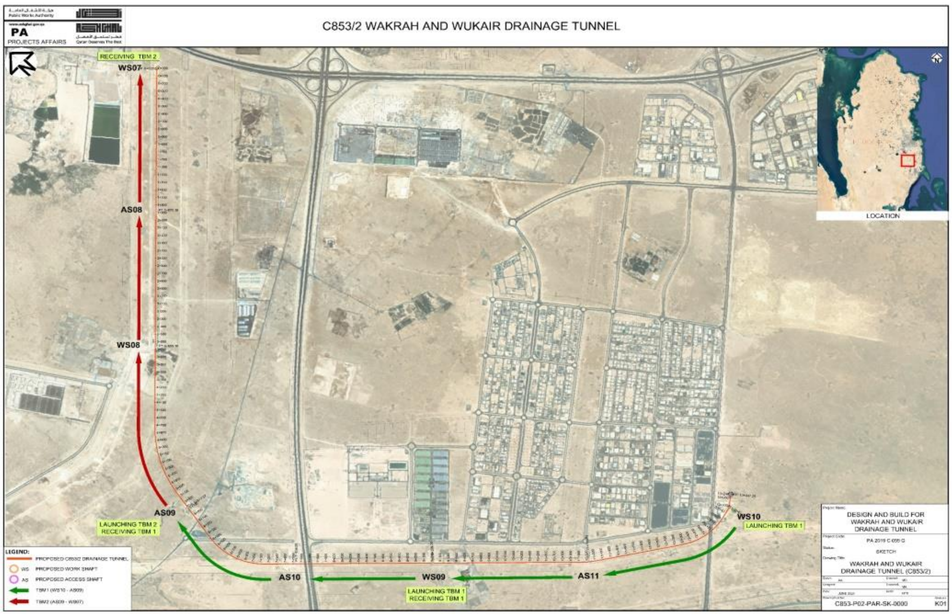

Fig. 2: WWDT Tunnel overall plan

3 TBM Introduction

EPB-TBMs were utilized for tunnelling of the WWDT. The overall length of each TBM, including 11 backup gantries is 148m which includes TBM shield parts (Cutter head, front, middle and tail shield) of 11.1m in length. The TBM tunnel is permanently supported by precast fiber reinforced concrete segmental lining rings erected within the TBM tail skin. The annulus between the excavated face and the segment extrados is filled with grout.

Tunnel backup gantries were designed for the supply of supporting systems for TBM mining works. In WWDT each TBM consists of 11 backup gantries and the supporting details are provided below (Table 1).

Table 1: Technical details of TBM Gantries-WWDT

Gantry-1	Operator cabinet, Foam generator and control cabinet
Gantry-2	Grouting system and Quick unloading device
Gantry-3	Foam solution tank, foam tank, transfer pump, polymer tank and Hydraulic pump station
Gantry-4	Grease system, grease barrel transfer hoist
Gantry-5	water tank and frequency Converter cabinet
Gantry-6	Bentonite tank, Transformer, HV switch cabinet and metal detector device
Gantry-7	Wastewater tank, cooling water tank (internal circulating water tank), Generator and air compressor
Gantry-8	Chiller unit and Emergency refugee chamber
Gantry-9	Emergency refugee chamber
Gantry-10	Pipe extension hoist, pipe storage area and crew room
Gantry-11	Working area, office room and emergency generator

4. TBM Launch

TBM launch consists of a set of procedures that need to be implemented prior to start-up of the TBM for full production. The launch includes pre-assembly, lowering down the shaft and the site assembly process both at the surface and at the bottom of the shaft. This procedure is intended to lead to the initial drive followed by full production run of the TBM.

The mechanized excavation of the tunnel follows a standard sequence forming the overall production process. While boring, the EPB TBM moves forward by pushing on the segmental lining while at the same time, backfilling the annular gap behind the segments (clearance in between the excavation outline and the outer ring surface) with grout. Friction and bond between the constructed tunnel and surrounding rock provides resistance to the thrust forces.

The main procedure for the TBM launch in the absence of segmental lining is that a special thrust frame must be installed to provide counterforce. After the cutting of the ground (mining) has started the annular gap is created which needs grouting. Special bulkheads were needed to provide confinement and prevent grout leakage into the shafts before its setting.

This paper illustrates two different TBM launch processes which have already been used in Qatar.

4.1 Musaimeer Pumping Station and Outfall Tunnel (MPSO)

Musaimeer Pumping station and outfall tunnel (MPSO), consists of a 4.43m diameter, subsea tunnel, 10.1 km in length connected via a riser shaft to a seabed diffuser field. For tunnelling purposes, an EPB TBM of 170m length (approx.) was used which included 18 back up gantries and TBM shield with a cutter head.

A construction of the tunnel was required to facilitate launch from a shaft within a relatively small construction site, while a pump station structure was being constructed simultaneously. In order to facilitate assembly of the TBM below ground, a temporary logistics shaft was constructed together with mechanically excavated sprayed-concrete lined tunnels. The size of the shaft and length of the temporary shaft was minimized to limit time and costs but had to be balanced with practical requirements for TBM assembly and tunnel construction logistics.

TBM lowering and launching preparation commenced with excavation of launch (drop) shaft which later was converted to permanent drop shaft whose diameter is 15.6m. The shaft excavation was followed by excavation of logistic shaft whose diameter was 25.2m and a SEM logistic tunnel 31.5m long along the tunnel alignment. Later both shafts were connected with a SEM connecting tunnel of 4.3m length as shown in the below Figure 3.

The launching adit was constructed for the initial position of TBM cutterhead so that the screw conveyor and other cutterhead parts could be lowered down the drop shaft for assembly. Lowering of TBM commenced with TBM shields and was followed by the backup gantries. Gantry #1 to #7 were lowered into the logistic shaft and pushed up to cutter head and was followed by lowering of gantries #8 to #11in logistic shaft. The TBM was then powered up and tunnelling started. As the TBM moved forward the remaining gantries (gantry #12 to #18) were added. Muck removal required a special arrangement to allow muck skips to be moved to a second rail line so they could exit the backup system and go to the logistic shaft to be lifted out and emptied.

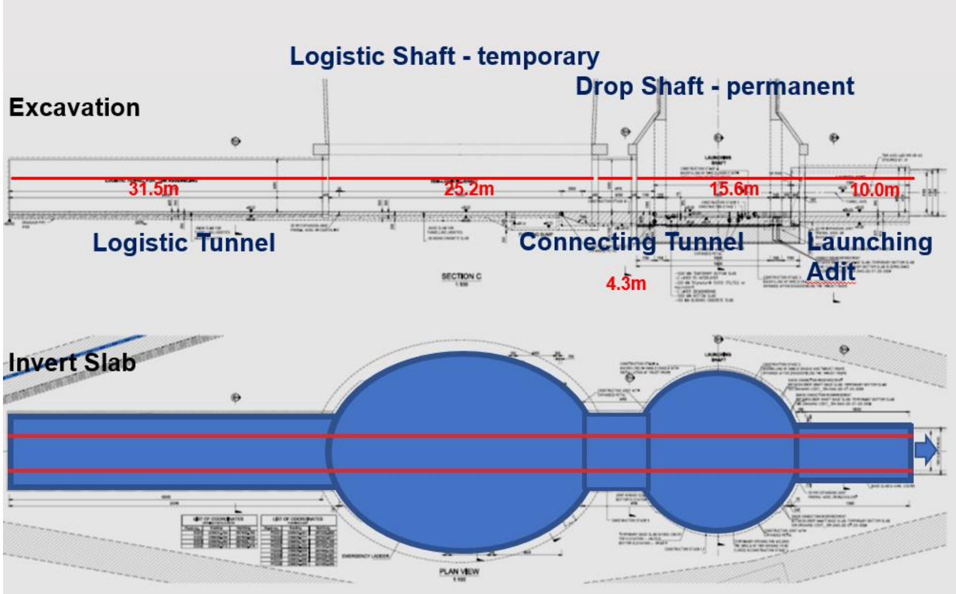

Fig. 3: Cross section and Plan view of Logistic shaft and SEM logistics tunnel

However, logistic shaft and tunnel were temporary and built solely for the purpose of TBM launch and as tunnelling completed both structures were backfilled. The 10m long Launch adit was constructed from the launch shaft towards the tunnel alignment and later became a part of the permanent tunnelling structure. The TBM lowering and launching layout is shown below (Figure 4).

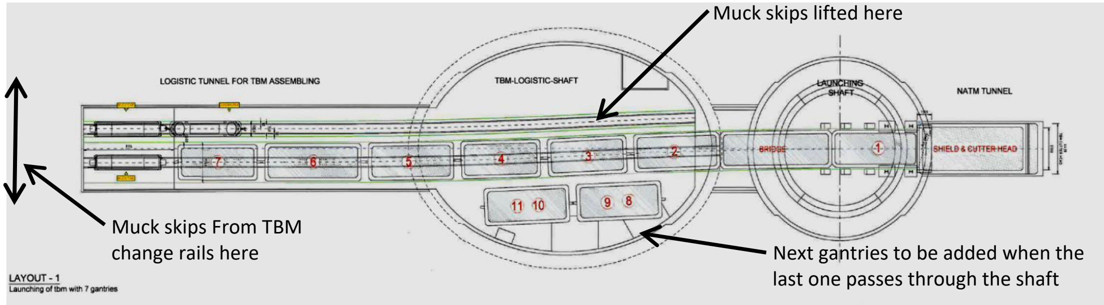

Fig. 4: Plan view of Logistic shaft and SEM logistic tunnel

Due to the existing space constraints in MPSO the method followed for the TBM launch was not as convenient as an optimal launch where full length of TBM including all back-up gantries could be locate into launching area.

4.2 Wakra Wukair Drainage Tunnel Project - WWDT

4.2.1 Shaft and SEM - Tunnels for Lowering and Launching of TBM

One launching shaft was constructed for the purpose of lowering and launching each of the WWDT EPB TBM's, namely shaft WS10 and shaft AS09, whose diameters are 17m and 15m and depths are 52.29m and 61.6m respectively. Both will be later converted to permanent access shafts.

Similar to MPSO Project launch, adits and logistics tunnels were constructed using SEM method for the TBM launch, due to space constraints and only single shaft was constructed at each site. The launch adit tunnels are approx. 15 m long and facilitate shield cradle while the logistic tunnels facilitate the TBM gantries during initial drive. The tunnel logistic layout respectively with 25m long as shown in Figure 5 below.

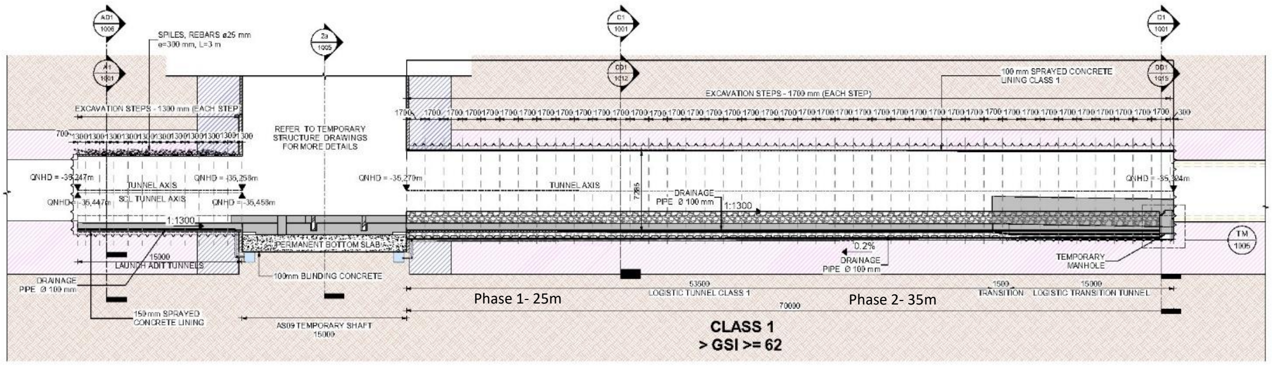

Fig. 5: Cross sectional view of launch adit & logistic tunnels

4.2.2 TBM Pre-assembly Works/Preparatory Works on Surface for Lowering

Due to the limited space at the bottom of the shaft, temporary concrete slabs were constructed at the surface. Before lowering down the shaft the preassembling of TBM parts was done at ground surface level as follows:

- Pre-assembly of Drive motor, Reducers to Main drive, Middle shield's front and rear parts.
- Preparation of Tail Skin.

4.2.3 Preparatory Works Required at Shaft Bottom Prior to TBM Lowering and Assembling:

- Completion of TBM launch adit and logistic tunnel SEM Works.
- Construction of temporary slab with TBM cradle along with the welding pit.
- In order to reach the first contractual milestone only 25m long logistic tunnel was constructed in shaft WS10.

4.2.4 Lowering and Assembly Works Inside the Shaft

Due to space constraint at shaft, the sequence of lowering and assembling works of TBM used three phase Umbilical Launch Method. The sequence of TBM Shield parts lowering and back up gantries lowering was optimized as per the space availability and site conditions. Lowering, assembling and umbilical launch in WS10 is explained below.

5 Lowering, Assembling and Umbilical Launch of TBM Parts in Ws-10 Shaft

5.1 Phase 1: TBM Shield and Backup Lowering & Assembly consisted of:

Phase 1 consisted of lowering and assembling of TBM shield in the shaft and sliding into launch adit, along with lowering and assembling of gantry #3 and gantry #2 in the logistic tunnel. Gantry #3 was lowered initially followed by gantry #2 due to TBM manufacturing setup. Installation of parts from bridge and gantry #1 was done at shaft bottom.

Lowering and assembly of thrust frame was completed at this stage and connections were made between gantry #2, #3 (refer to Table 1) from logistic tunnel and parts at shaft bottom to the TBM shield through umbilical pipes & cables (Figure 6 and Figure 7). All other TBM backup gantries were located at the surface level using extended power cables and hydraulic pipes running down the shaft to the TBM in order to launch (Figure 8).

TBM launch with umbilical advanced until 90m was completed (only main machine/shield).

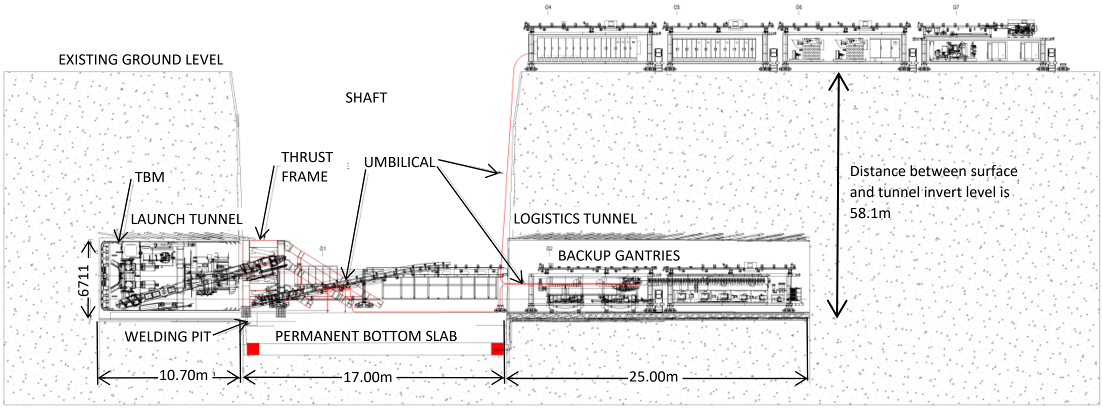

Fig. 6: TBM Umbilical launch Illustrative sketch

Fig. 7: TBM Umbilical site setup

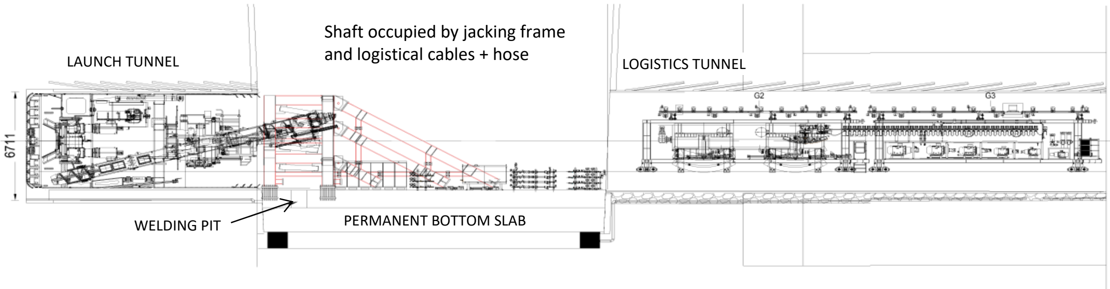

Fig. 8: TBM Pre-assembling works through shaft

5.2 Phase 2: Transfer and Connection of Backup Gantries #1 to #7, to the Shield Consisted of:

After completion of 90m of tunnelling (Figure 9), mining stopped and all the umbilical connections were disconnected and thrust frame removed from shaft, since installed rings were sufficient to resist thrust force.

Gantry #1 and bridge gantry were lowered from the surface and all the removed components for initial drive were reinstalled and pulled towards main machine and also gantry #2 and gantry #3 from logistic tunnel.

All the backup gantries from #4 to #7 were lowered and pulled towards the TBM shield and connections done for next 80 m of tunnel advance. However, gantries 8 to 11 having rescue chamber and cable extensions were not connected to the main TBM, which were not essential for initial drive.

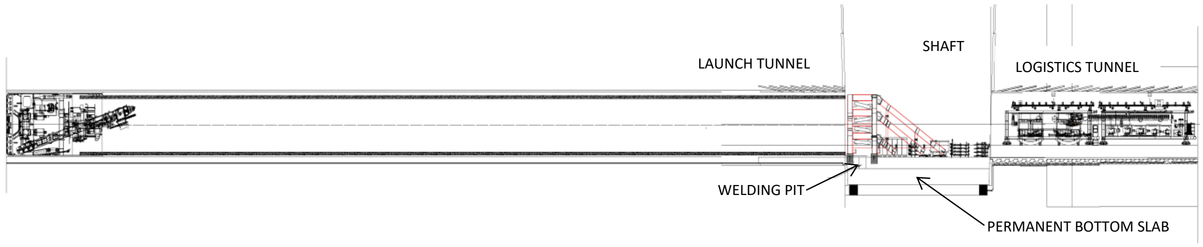

Fig. 9: TBM mining through umbilical system

Before phase 3, balance 45m of logistic tunnel was excavated via SEM and temporary concrete fill was done in the tunnel invert for locomotive logistic usage.

5.3 Phase 3: Lowering and Assembly of Remaining Backup Gantries #8 to #11 Consisted of:

In Phase 3, lowering and connections were made for gantry #8 to gantry #11 to the TBM and backfilling of tunnel entrance invert was performed for installation of rail switch. After completion of Phase 3 works, TBM Main Drive was started.

The main reason why this method as described above was implemented was to achieve the first contractual milestone of the WWDT Project. The length of the launching audit & logistic tunnel which have been constructed by SEM method and sequence of the umbilical launch had been decided accordingly. The TBM has been launched on time and the first milestone has been achieved successfully.

A simplified process of lowering and launch of TBM was followed in Shaft AS09 since entire tunnel excavation of 70m could be completed and no contractual milestone defined for the second TBM launch.

6 Conclusions

Two different TBM launching methods have been presented in which the optimal option of launching a full-length TBM at the required tunnel level was not practicable. Since the available space was limited on both presented methodologies the assembly and launch were accomplished by innovative engineering. One using an additional logistics shaft and tunnels, and one utilizing a single shaft with short launch tunnels and staged installation of TBM sections as the tunnel progressed, using an umbilical system.

The challenge was to fit as many TBM gantry sections in as short a space as possible at tunnel level, and to use lengths of cable and pressurized hydraulic hoses as an umbilical to connect to the rest of the TBM gantries at the shaft bottom, or at ground level. Due to the confined space and limited access a lot of re-work was inevitable in removal and reinstallation of gantry parts as the TBM progressed into the tunnel and up to the limits of the umbilical.

The presented methods demonstrate that even in constrained spaces, if an umbilical launch method can be used, it is possible to successfully launch a 148m long TBM in a 15m diameter shaft on time and, in the case of the WWDT project, achieve the first project milestone.

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