Planning and Implementing of Effective Enabling Works for a Successful TBM Tunnelling Project

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Abstract

The outfall tunnel, which forms part of the Musaimer Pump Station and Outfall project (MPSO), is a 10.2 km long subsea tunnel that extends from the south coast of Doha, starting onshore, and continues under the Arabian Gulf to end in a connection with a diffuser field via riser shaft. The excavation of the outfall tunnel using a Tunnel Boring Machine (TBM) with a 4.42 m diameter and 180 m long backup, starts from a 40 m deep shaft and has an inclination of 0.05% upward to the riser shaft. The tunnel is constructed by precast concrete elements of 3.7 m internal diameter passing through different geological formations typical in the State of Qatar. Although planning a TBM tunnel involves a significant amount of engineering knowledge and experience, what is equally challenging is the enabling works which are required to be designed and constructed before the TBM even arrives at the site. On this project, these works which were substantial within themselves commenced 16 months before the TBM arrived on site. This paper will discuss the planning and execution of these outstanding underground enabling works, the logistic shaft required to facilitate the assembly and launch of the TBM at the initial stage of tunnelling and also how to arrange the sequence and space in terms of TBM logistics supply requirements to allow simultaneous construction of key permanent structures, namely the drop shaft structure which resulted in 6 months saving on the overall completion on this section of the works.

Keywords: TBM; Sub-sea tunnel; Enabling works; Logistics tunnel; Logistics shaft; Drop shaft

1 Introduction

The construction of the outfall tunnel using a TBM was complex in terms of enabling works, which required detailed planning, execution, and a clash avoidance analysis with other temporary or permanent works within the project boundaries to reach the successful conclusion to the project.

The complex enabling work starts on the surface where all the required facilities to run the TBM must be strategically deployed, in general terms those facilities are related to the logistics to receipt of the container where the TBM is delivered in major and/or minor parts, areas to store TBM parts and preassemble them. Other facilities are related to the storing of temporary materials, e.g., high and low voltage cables, water pipes in the tunnel, ventilation ducts, rails and rails preassembly facilities, power plant generation, silos for cement, bentonite, additives, and precast segments. In addition, the road layout and traffic management must be perfectly designed to allocate the heavy traffic while transporting all the consumables required including the precast rings to the site and then removal from site of the excavated material for disposal.

There is another type of enabling works with less visual impact, but it is one of the most critical from the TBM operatives' point of view. This is the access to the tunnel portal via shaft not only the lowering and assembly the TBM but also to provide the rail sidings via tunnel to park and operate the rolling stocks which supply the TBM on an hourly basis, i.e., transportation of personnel in and out of the tunnel, removal of excavated soil, transportation of the precast rings, grout and general consumables needed to operate the TBM on a regular basis.

The project rolling stock and railway requirements were determined as 3 trains, which in turn determined the length of the logistic tunnel to have space enough to park the trains and facilitated the operation of loading and unloading at the bottom of the shafts.

Finally, the location and quality of the welfare to serve the TBM operations had to be designed to ensure safe day-to-day operation with the project boundaries along with the workshop area, which provide services to the TBM.

2 Underground Enabling Works

The connection between the outfall tunnel and the pumping station is through a drop shaft. Water is pumped out from the wet well into an outfall chamber before being discharged via the drop shaft into the outfall tunnel. The drop shaft will be used to support TBM launching and during the construction phase to provide the logistics and access to the TBM and outfall tunnel.

The drop shaft is a 10 m internal diameter circular shaft, and approx. 11.4 m above ground level and extend to about 43 m below ground with a total height of approx. 54.4 m. The diameter size of the drop shaft is not big enough to be used as TBM logistics shaft and for that, the initial plan was to enlarge it to allow the assembly of the TBM, its regular operation including logistic operations and access during the construction of the outfall tunnel.

Once the Qatari Public Works Authority (Ashghal) awarded the MPSO project to the joint venture Hamad Bin Khalid Contracting Company and Porr Qatar Construction (HBK-PORR) at the end of 2017, the idea was to use a launching shaft with rectangular pit shape and size of (31 x 20 on the surface and 25 x 14 at the bottom) and 43 m deep. The bottom of the launching shaft provides access to the logistics tunnel and TBM launcher chamber and was planned to be excavated to allocate the 3 tracks and rail switches required to operate the rolling stock which serves the logistics to operate the TBM and the required chamber to launch the TBM. Figures 1 and 2 show the top and longitudinal profiles of the logistics tunnel, drop shaft and TBM launching chamber. This was first proposal considered.

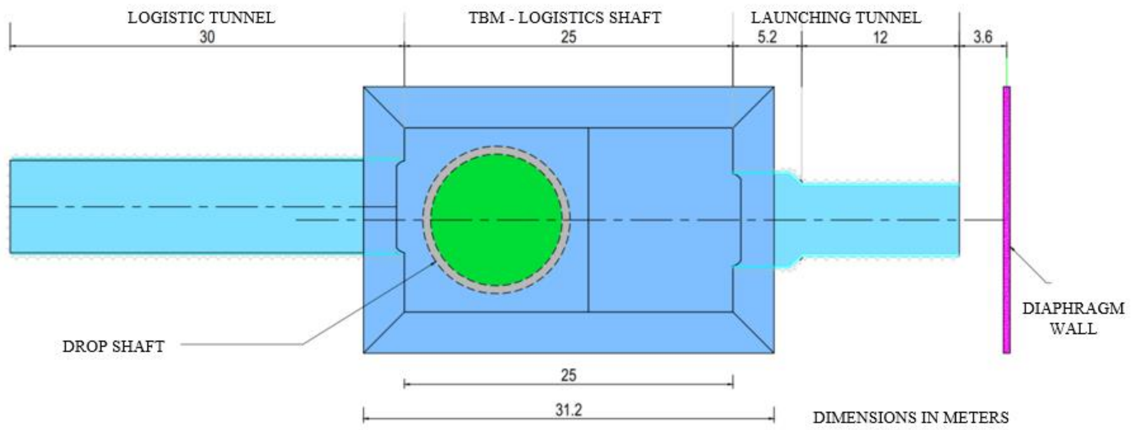


Fig. 1: Top view of Launching Shaft and tunnel, Logistics tunnel initial stage plan

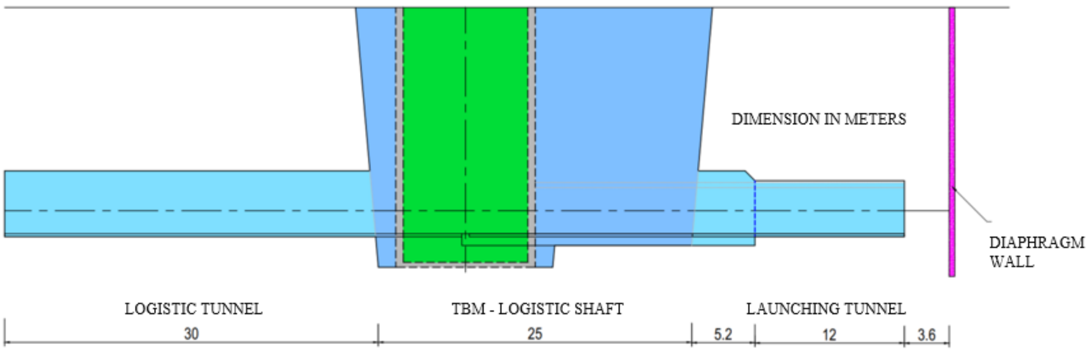


Fig. 2: Longitudinal profile of Launching Shaft and tunnel, Logistics tunnel initial stage plan

The second option evaluated at the initial stage was one oval-shaped launching shaft. Instead of a rectangular pit, the aim is to reduce the excavation and support quantities simultaneously improving the stability of the shaft due to the oval shape.

The options of a launching shaft and the drop shaft all in one excavation once the TBM finishes the excavation of the outfall tunnel seems to be the optimum solution. However, on further analysis and risk evaluation and considering the constraints and particularities of the outfall tunnel i.e., only one TBM to excavate the outfall tunnel, a long subsea tunnel with more than 10 km and only one access and egress. This represented a severe risk increment for unexpected delays. If any delay happens during construction of the outfall tunnel, it directly impacts the construction of the drop shaft and the connection of the outfall chamber and subsequent installation of utilities and land scape activities on the surface, jeopardizing the overall completion date of the project.

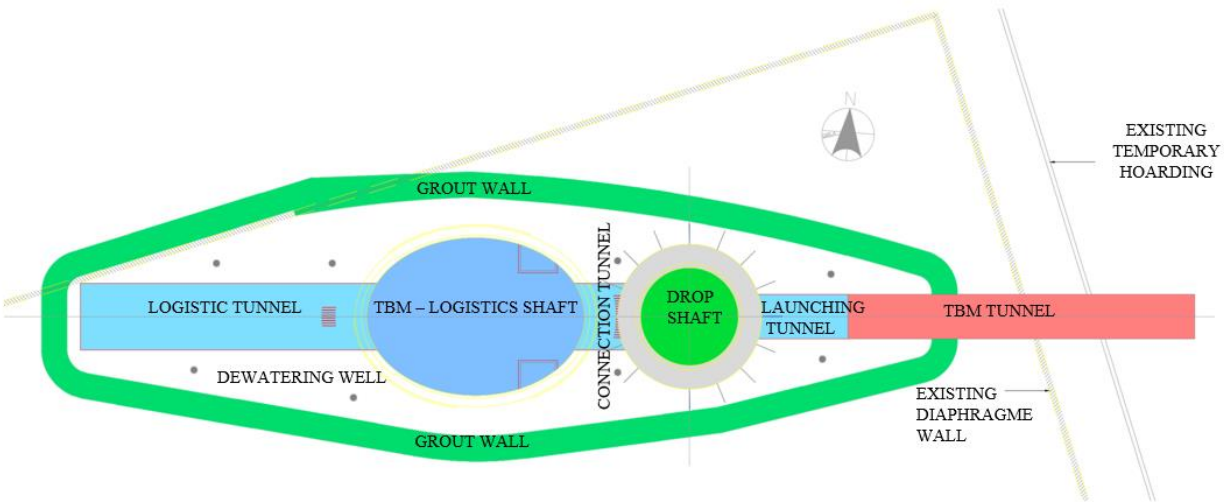


Fig. 3: Top view final concept of Launching and drop Shaft, Logistics and Connection Tunnel and Launching tunnel

The solution adopted to reduce and mitigate the risk described was to split the drop shaft from the logistics shaft, as indicated in Figure 3. There would now be 2 independent shafts which require larger efforts and resources but adding a tremendous value in term of advantages to project scheduling and providing improved TBM logistics facilities at both the bottom and the surface locations.

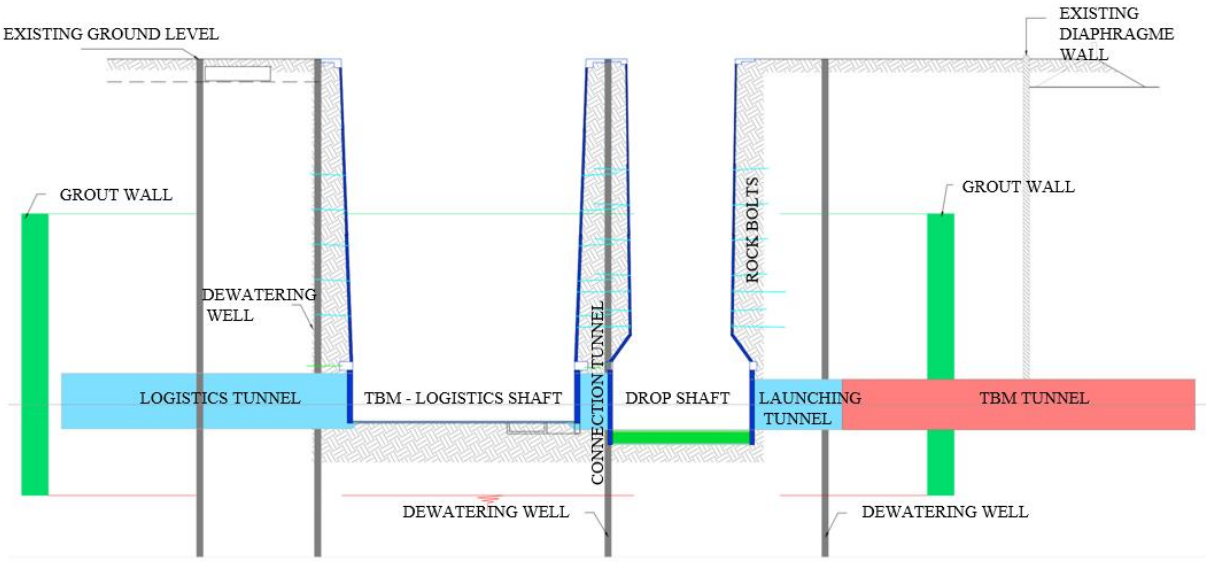


Fig. 4: Longitudinal profile of the final arrangement of drop and logistics shafts, connection and launching tunnels

2.1 Logistics Shaft and Drop Shaft (concept)

The decision to excavate independent shafts simultaneously aims to reduce the pressure on the project completion date. Delays during the construction of the outfall tunnel still allows the construction of the permanent works of the drop shaft, its connection with the outfall chamber and the surrounding landscape and rock armour among others to go ahead. This method also foresees the possibility of back-filling of the logistics shaft with low strength mass concrete in the case of any time constraints.

Figures 3 and 4 show the location of the Drop shaft, Logistics shaft and a short connection tunnel.

The Sequential Excavation and Support (SES) method was selected to excavate both shafts and support using Sprayed Concrete Lining (SCL) with wet shotcrete, wire mesh and rock bolts as primary lining support. The logistics shaft presents particular consequence of the oval shape that is the construction of concrete reinforced stiffening rings to improve the stability of the shaft. The drop shaft has the provision of the key at the bottom, not only to allocate the base slab and to control the buoyancy, but also to allow the simultaneous construction of the final concrete lining support and provide the required openings to allow the passage of the TBM logistics trains.

2.2 Logistics Shaft and Drop Shaft (Grouting and dewatering works)

The TBM project area is enclosed within a cut-off wall of an average depth of -34.3 m Qatar-National Height Data (QNHD). This cut off wall has been constructed on a pretender project phase. Thus, up to a certain excavation level (approximately 18m, below ground level), no water or very small water ingress was expected. When the excavation depth reaches a maximum depth of -40 m QHND, dewatering is required to lower and maintain the water table below formation excavation level. Dewatering is performed through 8 deep wells, with installed submersible pumps which convey the ground water to surface sedimentation tanks before discharging to the sea

In addition to dewatering, to mitigate the risk of water ingress, extensive rock grouting was carried out around the drop and logistics shaft and the TBM launching chamber tunnel. Figure 5 shows the location of the bore holes to create a second cut of wall (with primary and secondary bore holes for water tightness) around the shafts and tunnels. Tertiary bore holes within the excavation area of the shaft and tunnel acted as a grout plug on the bottom to prevent the ingress of water from the invert of the excavations and reduce the settlements which are expected to be in the range of 5 to 10 mm, refer to Figure 6. In total 76 primary, 75 secondary and 62 tertiary boreholes were drilled reaching 10,468 meters of boreholes and 1,421,754 litres of grout was injected into the strata to seal the excavation. The grout mix design was based on Ordinary Portland Cement (OPC), bentonite, and stabilizer with water and cement ratio from 1.2 to 1.8 depending on the site conditions.

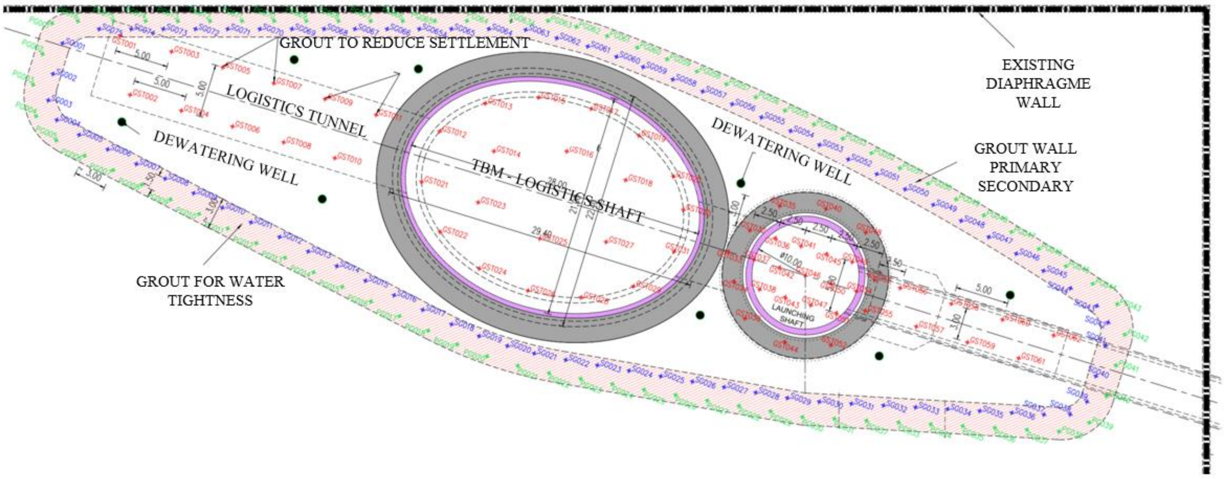


Fig. 5: Rock-grouting primary, secondary and tertiary

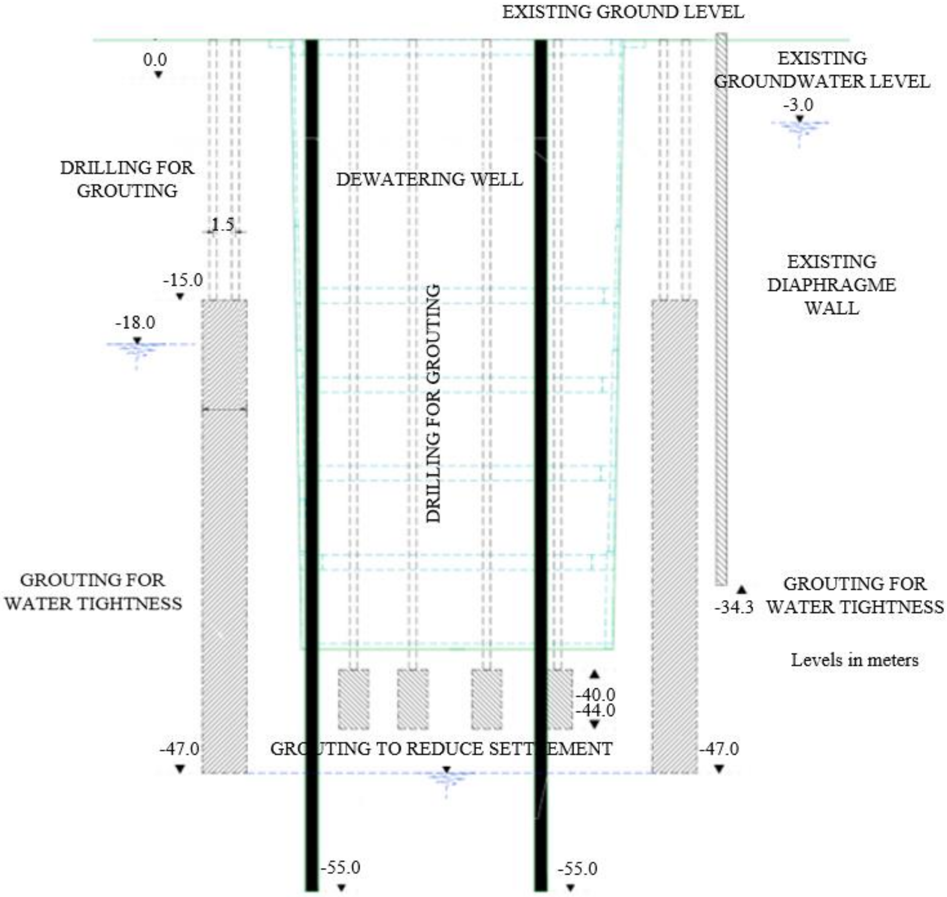


Fig. 6: Arrangement of grouting bore holes and grouting length

2.3 Logistics Shaft and Drop Shaft (excavation works)

The excavation works and application of the primary support consisting in SCL for the logistics and drop shaft was designed and implemented simultaneously. The excavation is carried out by using conventional excavators (with more than one excavator working in the shaft at the time as shown in Figure 7), a drum cutter and hydraulic hammer. The primary support was sprayed wet shotcrete reinforced with wire mesh (double layer) and installation of rock bolts.

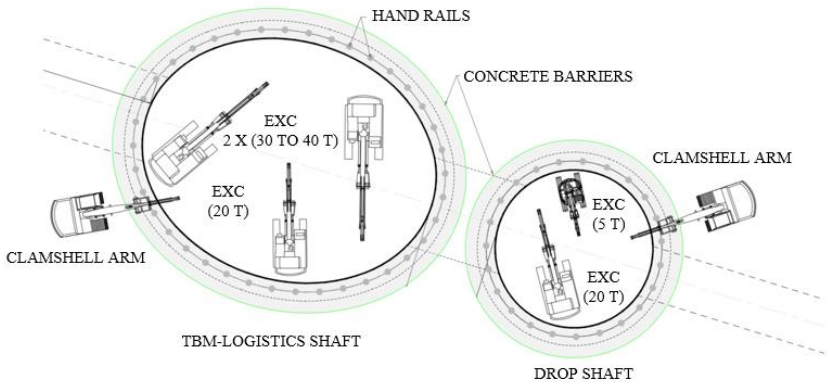
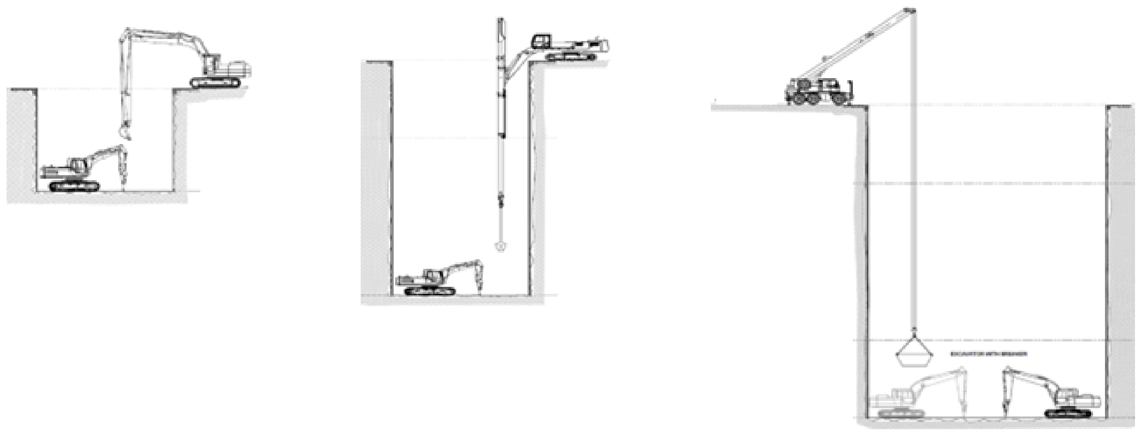


Fig. 7: Logistics and Drop Shaft Excavation Plan

The adjustment of every cycle length (between 2 and 3 m) along with the type of support to be applied was determined on site by the geotechnical engineer by related face mapping results. Excavation was planned to be carried out in three different phases, each phase having its own method of works. Figure 8 illustrates the 3 separate phases of excavation for the logistics and drop shaft works:



Phase 1: from GL to -8 m **Phase 1: from -8 to -30 m** **Phase 3: from -30 m to -43 m**

Fig. 8: Logistics and drop shaft excavation stages

As a preventive measure, water in isolated locations penetrated inside the shaft because of the rock porosity and where rock-grouting method could not seal all the gaps in hard rocks, weep holes were installed to drain the water and to reduce the water pressure over the shotcrete.

The water will be collected at the specially excavated water sump at the bottom of the excavation (one sump at each step of excavation), from the sump the water will be vertically pumped up by the means of the submersible pump into a water sedimentation tank. Figure 9 shows the general surface site layout of the logistics and drop shaft.

Fig. 9: Photo of the logistics and drop shafts during TBM operations

2.4 Logistics and Connection Tunnels. Launching Chamber Tunnel (excavation works)

The configuration of logistic and drop shafts required an internal connection tunnel, the rolling stocks require this access to operate, load, off load, park the trains underground. The launching technique of the TBM required a special launching chamber/tunnel. The New Austrian Tunnelling Method (NATM) was the method selected to excavate the required tunnels, therefore there are 3 NATM tunnel section executed on the MPSO project:

- The NATM connection tunnel section between the 2 shafts of 4.30 m in length.
- The NATM logistics tunnel extending 30 m to the land side
- The NATM launching tunnel extending to the seaside (launching tunnel) of 10 m length.

The first NATM activity was the connection tunnel between drop and logistic shaft to connect the two shafts and provide full access to the equipment and labour on formation level. The next NATM activity is the logistics and launching tunnel excavation which started together.

NATM tunnel construction sequence includes several steps, which are repeated in the same order until full completion of each excavation cycle is achieved. Once the excavation cycle is fully supported in line to the design and the relevant drawings, then the following cycle can commence following the same sequence. For this design the following steps shall be followed to comply with NATM design requirements:

Survey works; excavation; soil disposal; scaling; survey check of the excavation line and correction if and where required; geological mapping and classification of the rock mass. Recommendation of the supporting class in line to the applied rock mass classification and Detail Design criteria.

Continue with safe application of shotcrete (3 cm to 5 cm); installation of wire mesh; application of full structural thickness of shotcrete; drilling, installation and grouting of rock bolts and installation of monitoring targets on the shotcrete lining.

The Figure 10 summarized the NATM tunnel sections required for each NATM tunnel.

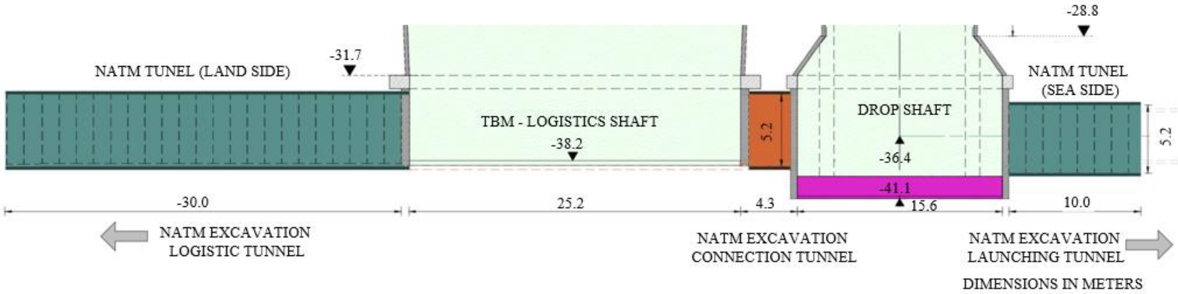


Fig. 10: Longitudinal profile logistics tunnel, connection tunnel and TBM launching tunnel all of them excavated in NATM along with logistics shaft and drop shaft

Figure 11 shows the view looking into the outfall tunnel through both logistics and drop shaft and from the back of the TBM launching chamber/tunnel.

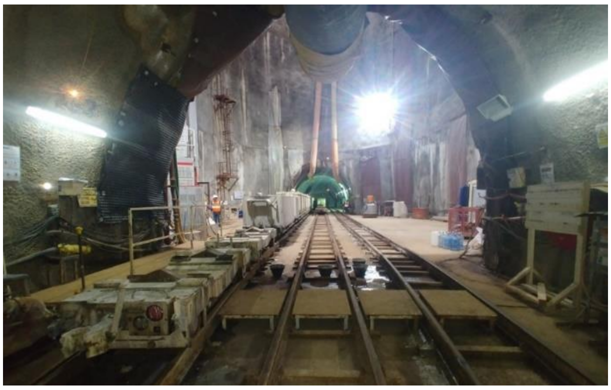


Fig. 11: View from base of drop shaft with the setup of rolling stocks tracks and logistics shaft and tunnel

3 Conclusion

The construction of the drop shaft and its connection to the outfall chamber was accomplished before the TBM achieved the tunnel completion; this was a key decision that helped to shave off 6 months from the project duration.

There were no significant TBM idle times due to logistics issues either on the surface or under the ground.

The construction of other permanent structures was not impacted due to clashing with the TBM enabling works, which confirms the importance of good planning and clash analysis at the early stage of the project.

Starting the required enabling works 16 months ahead of arrival of the TBM mitigated the risks associated with the underground enabling works.

The highlights of the facts in terms of planning, plan and implementation of enabling works related to the TBM discussed have no limitations unless contractually what is stated is something different and every contractor should follow a similar strategy to increase the possibilities of a successful TBM project.

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Cite as: Al-Marri S.Z., Peach G., Fernandez H.V., "Planning and Implementing of Effective Enabling Works for a Successful TBM Tunnelling Project ", *The 2nd International Conference on Civil Infrastructure and Construction (CIC 2023)*, Doha, Qatar, 5-8 February 2023, DOI: https://doi.org/10.29117/cic.2023.0077