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Strategic Planning for the start and completion of the longest sub-sea tunnel in the Middle East

Khalid Saif Al-Khayareen[a], Gary Peach[b] and Hernan Vigil Fernandez[c]*

[a] Public Works Authority, Doha, Qatar; kkhayareen@ashghal.gov.qa
[b] Mott MacDonald, Doha, Qatar; gary.peach@mottmac.com
[c] HBK-PORR JV, Doha, Qatar; hernan.vigil@auccqatar.com

Abstract: The outfall tunnel, which forms part of the Musaimeer 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 continuing under the Arabian Gulf to end in a connection with a diffuser field via riser shaft. Whilst the tunnel presented many challenges on its own, this paper will concentrate on the extensive project management undertaken on the Tunnel Boring Machine (TBM) launching and supply arrangements, located only 50 m from the seashore and the equally complex arrangements for the outfall tunnel to connect 10.2 km offshore with the riser shaft and diffuser bed structure. The excavation of the outfall tunnel using a TBM with a 4.42 m diameter and 180 m long gantries, started from a 40 m deep shaft and has an inclination of 0.05% upward to the riser shaft. The enabling works which were substantial within themselves commenced 16 months before the TBM arrived on site.

The diffuser structure was a 6-arm structure, measuring 294 m by 40 m connected to a central manifold in turn connected to the TBM constructed tunnel via a riser shaft drilled from an offshore platform and barges. These works took 28 months to complete to ensure the outfall tunnel which was the most critical portion of the whole project was completed on time.

This technical paper will discuss the planning, methodology and construction practices employed to the onshore and offshore structures to ensure the outfall tunnel was a project success

Keywords: TBM; Sub-Sea tunnel; enabling works; logistics tunnel; riser shaft

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1. Introduction

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 or minor parts and areas to store TBM parts and preassemble them. Other facilities are related to the store 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 and additives, 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 and muck disposal from the TBM.

There is another type of enabling works with less visual impact, but one of the most critical from the TBM operatives' point of view. This is access to the tunnel portal via shaft not only for the lowering and assembly of the TBM but also to provide the bay via tunnel to park and operate the rolling stocks which provide the logistics to the TBM, 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 in regular basis.

*Corresponding author: kkhayareen@ashghal.gov.qa (Khalid Saif Al-Khayareen).

The project requirements were set in 3 trains making necessary to excavate a logistic tunnel to have space enough to park the trains and facilitated the operation of loading and unloading at the bottom of the shafts.

Last but not least, the location and quality of the welfare to serve the site team also need to be established with the project boundaries along with the workshop area which provide services to the TBM.

2. Underground enabling works

2.1. Main elements

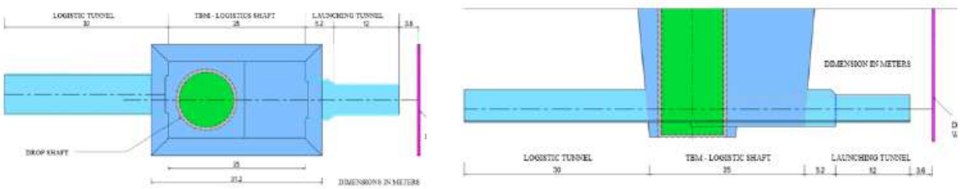
The connection between the outfall tunnel and the pumping station is through a drop shaft. Water is pumped out from the wet well into an outfall chamber before being discharged via the drop shaft into the outfall tunnel. The drop shaft will be used not only as the TBM launching shaft during the construction phase but also to provide logistics and access to the TBM and outfall tunnel itself.

The drop shaft is a 10 m internal diameter circular shaft, which is approx. 11.4 m above ground level (i.e. at the level of +14.0 m QNHD, Qatar National Height Data) and extends to about 43 m below ground (i.e. at level of -41.23 m QNHD) with total of height of approx. 55.23 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.

2.2. Initial concepts

Once the Qatari Public Works Authority (Ashghal) awarded the MPSO project to joint venture HBK-PORR at the end of 2017, the initial option 1 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 that were planned to be excavated to allocate the 3 tracks and switches required to operate the rolling stocks which serves the logistics to operate the TBM and the required chamber to launch the TBM. Fig. 1 below, shows the top and longitudinal profiles of the logistics tunnel, drop shaft and TBM launching chamber.

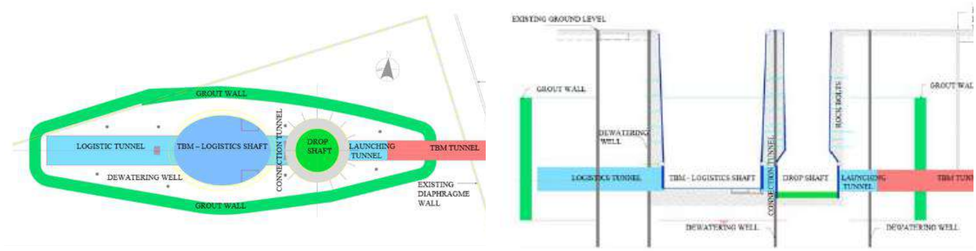


(a) **(b)**

Fig. 1. Initial proposal Top view (a) longitudinal view; (b) Logistics tunnel, drop shaft and launching chamber.

Option 2 evaluated at the early stage of the project was an oval shape launching shaft, as indicated in Fig. 2. Instead of a rectangular pit, the aim would be to reduce the excavation and support quantities while simultaneously improving the stability of the shaft due to the oval shape.

The options of a launching shaft allocating internally the drop shaft once the TBM finishes the excavation of the outfall tunnel seemed to be the optimum solution. However, 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, all together represented a risk increment of unexpected delays and if any delay happens during construction of the outfall tunnel, it directly affects 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.



(a) **(b)**

Fig. 2. Option 2 Top view (a) Longitudinal view; (b) of Logistics tunnel, drop shaft and launching chamber.

2.3. Logistics Shaft and Drop Shaft (concept)

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

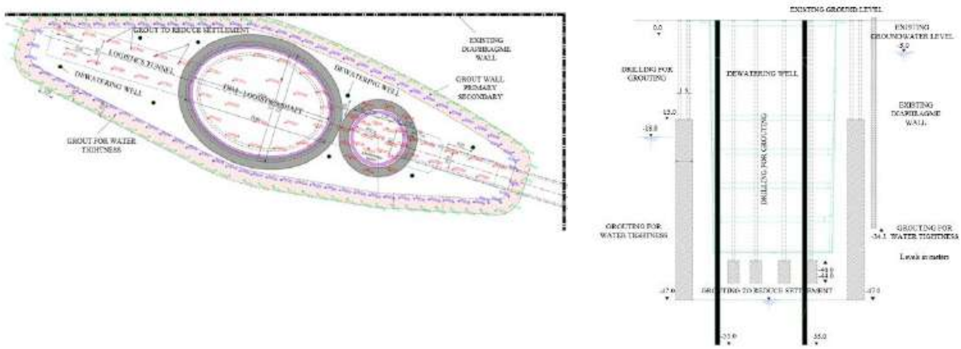
Fig. 2 show the location of the drop shaft and logistics shaft connected in between by a short connection tunnel.

The mechanical excavation method was the method selected to excavate both shafts and Sprayed Concrete Lining (SCL) with wet shotcrete, wire mesh and rock bolts was the primary lining support. The logistics shaft construction due to the oval shape resulted in the construction of concrete reinforced stiffening rings to improve the stability of the shaft. The drop shaft had 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 move the TBM logistics trains.

2.4. Logistics Shaft and Drop Shaft (Grouting and dewatering works)

The project area is enveloped within a cut off wall of an average depth of -34 m QNHD. This cut off wall was constructed on a pretender project phase to approximately 18m below ground level. No water or very small water ingress was expected. However, the excavation depth reaches at maximum -40 m QHND and therefore dewatering was required to lower and maintain the water table below formation level. Dewatering was performed through 8 deep wells, installed with submersible pumps which discharged ground water to the sea through sedimentation tanks.

In addition to dewatering, to mitigate the risk of water ingress, extensive rock grouting was carried out around the shaft, the future logistics tunnel and TBM launching chamber. Fig. 3 shows the location of the boreholes used to create another cut of wall (with primary and secondary boreholes for water tightness) all the way around the shafts and tunnels with a tertiary borehole within the excavation area of the shaft and tunnel. This acted as a grout plug preventing the ingress of water from the invert and reduced any settlement, see Fig. 3. In total 76 primary, 75 secondary and 62 tertiary grouting boreholes were drilled resulting in 10,468 meters of boreholes and 1,421,754 litres of grout. The grout mix design was based on OPC cement, bentonite, and stabilizer with W/C ratio from 1.2 to 1.8 depending on the site conditions.



(a) **(b)**

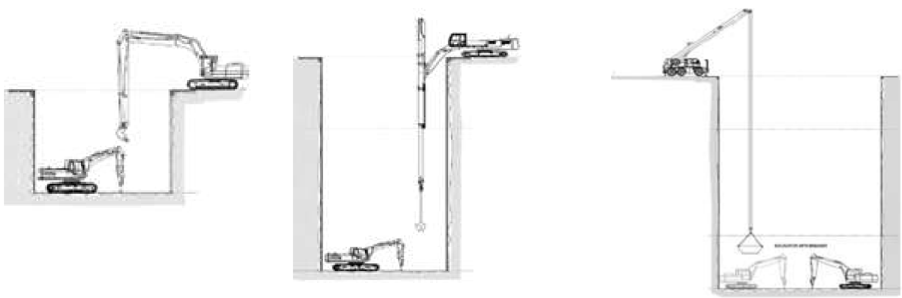
Fig. 3. Rock grouting primary, secondary and tertiary plan (a) and section (b).

2.5. Logistics Shaft and Drop Shaft (excavation works)

The excavation works and application of the primary support consisting of Sprayed Concrete lining (SCL) in logistics and drop shaft was designed to be installed simultaneously. The excavation was done by using conventional excavators (with more than one excavator working in the shaft at the time as shown in Fig. 4 with drum cutter and hydraulic hammer while the primary support was based on sprayed wet shotcrete reinforced with wire mesh (double layer) with rock bolts.

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 based on actual face mapping.

Excavation was executed in 3 different phases, each phase having its own method of works. Fig. 4 illustrates the 3 separate phases of excavation for the logistics and drop shaft works.



(a) **(b)** **(c)**

Fig. 4. Logistics and Drop Shaft Excavation Plan. (a) Phase 1: GL to -8 m; (b) Phase 1: GL to -8 m to -30m; (c) Phase 3: -30 m to -43 m.

As a preventive measure, where some water could penetrate 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 on the shotcrete lining.

The water was collected at a dedicated water sump at the bottom of the excavation (one sump at each step of excavation), from the sump the water was pumped to the surface sedimentation tank.

Fig. 5. Photo of the logistics and drop shaft during TBM operations.

2.6. Logistics and Connection Tunnel. Launching Chamber Tunnel (excavation works)

The configuration of logistic and drop shafts required an internal connection tunnel, the TBM rolling stock required space to operate, load, offload and park the trains underground according to the logistics cycle. The launching technique of the TBM required a launching chamber, see Fig 5. The New Austrian Tunnelling Method (NATM) was the method selected to excavate the required tunnels namely:

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

The NATM sections commenced with the connection tunnel between drop and logistic shaft allowing full access for equipment and manpower at the formation level. Then NATM logistics and launching tunnel excavation commenced. The breakthrough of the connection tunnel was performed when both shafts had reached final NATM invert formation level (-38.23m QNHD).

NATM tunnel construction sequence included repeating the same sequence until full completion of each excavation cycle. Once the excavation step was fully supported according to the design drawings, then the following step could commence following the exact same sequence.

The sequence was as follows: 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 for the rock mass classification and design criteria.

Fig. 6 summarized the NATM tunnel sections required for each tunnel.

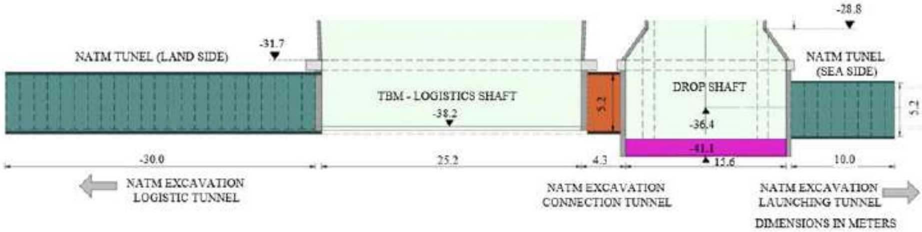


Fig. 6. NATM tunnel sections logistics, connection and launching tunnels. (a) Longitudinal profile Logistics Tunnel, Logistics Shaft, Connection Tunnel, Drop Shaft, TBM Launching Tunnel.

3. Geotechnical risk, other risks and mitigation measures during Outfall tunnel Construction

3.1. Karstification

Karst features are widespread in Qatar, with more than 9,700 depressions, sinkholes, and caves, mainly within the Eocene Rus and Dammam Formations. Gypsum, far more soluble than limestone, accelerates the formation of voids and collapses, especially in central and southern Qatar. These features often align NE-SW and NW-SE, following fracture systems, and were formed through dissolution of carbonate and sulfate deposits during Middle Pleistocene wet periods.

Large subterranean voids (>2 m) cause localized weakness that may collapse into sinkholes, simple, or compound depressions. Larger features are prevalent in central and southern Qatar, linked to dissolution of the sulphate facies in the Rus Formation. In the north, smaller features formed downward through fractures in the Simsima Limestone and Rus Formations during tectonic uplift, with upper layers more affected than deeper strata.

3.2. Hydraulic connection to the seabed

Potential hydraulic connectivity between the seabed and the TBM tunnel would impose full hydrostatic pressure on the cutterhead. Although 55% of the alignment passed through competent, low-permeability rock (confirmed by RQD and Lugeon tests), 25% consisted of weaker, more permeable zones. To mitigate, the TBM was designed to withstand up to 4.5 bar.

3.3. Mitigation of geotechnical risks

The contract required 24 offshore boreholes, but these were deemed of limited benefit for understanding hydrogeology and karst. Instead, the contractor proposed detailed marine geophysical surveys to identify cavities, seawater zones, weak rock, and discontinuities between existing boreholes. This approach, approved by the Client, provided a broader and more continuous geological model. Two advanced offshore methods were implemented: Electrical Resistivity Tomography (ERT) and Seismic Reflection Geophysical Tomography, delivering critical insights to reduce tunnelling risks.

3.4. Other risks mitigations

Plan for Advance Tunnel (PAT) was developed and implemented. This tool combining geotechnical and geophysical data improved understanding of rock mass, identified critical tunnelling areas, optimized TBM intervention points, and reduced risks. Cutterhead inspections, maintenance, and repairs are safest under atmospheric conditions; in poor ground, hyperbaric support may be required. Ground conditions are classified per meter: favourable (atmospheric only), moderate (atmospheric preferred, hyperbaric possible), and unfavourable (interventions avoided unless essential).

The TBM, designed per 2010 tunnelling specs and manufactured by CREG/Wirth, is an EPB type capable of 4.5 bar pressure. Key components include cutterhead, chamber, main bearing, screw conveyor, shields, personnel locks, thrust and erector systems, and tail brushes. With 18 gantries (160 m long), it houses electromechanical parts, tanks, and rescue chambers. The TBM installs six-segment concrete rings, 1.35 m long, with a 3.7 m internal diameter.

Real-Time Non-Destructive Monitoring. The TBM features BEAM (Electrical Ahead Monitoring), a non-intrusive polarization system predicting ground conditions up to three diameters ahead. It detects resistivity variations and displays predictions in a matrix combining resistivity and Percentage Frequency Effect (PFE).

4. Outfall tunnel construction

The outfall tunnel was constructed using an Earth Pressure Balance EPB TBM, which was designed to withstand the full hydrostatic pressure of 4.5 bar. The outfall tunnel alignment encountered and successfully managed three main geological strata, namely: Rus formulation, Midra shale and Simsima limestone. Several technical challenges arose and were managed, and the outfall tunnel was completed 56 days ahead of programme. For omitted details please refer to Peach et al 2022 and Stypulkowski et al 2023.

4.1. TBM utilization

The design and selection of tunnel logistics directly impact excavation, and performance is measured through TBM utilization. This allocates time to designated activities, eliminating overlaps, and is calculated from daily shift reports consolidated into spreadsheets. Utilization analysis helps assess efficiency, workmanship, and issues, while identifying areas for optimization such as locomotive transport idling.

Production activities are:

1. Excavation,
2. Ring building,
3. Maintenance, and
4. Extending temporary services.

All other activities are delays, classified into three groups: Mechanical & Electrical, Operational, and Geological. Operational delays also include data to evaluate transport efficiency and the need for a second California crossing.

Excavation was required to achieve 40% of the available time; logistics exceeded this benchmark. Fig. 7 illustrates a typical of TBM utilization summary recorded during tunnel construction.

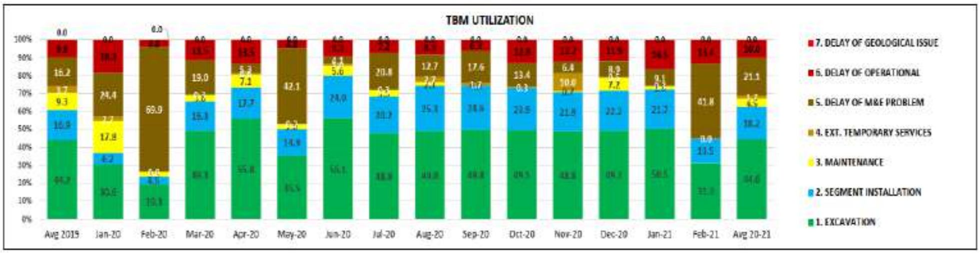


Fig 7. TBM utilization graph 2019 – 2021.

4.2. TBM progress: Baseline vs actual

The baseline programme planned a 300 m learning curve (May–June 2019) followed by 27 sections up to April 2021, assuming 24 h/day and 6 d/week.

Due to early TBM procurement and logistics, excavation began 90 days early. Despite delays causing a 14.1-day deficit by May 2020, operations recovered, and the tunnel was ultimately completed 58 days ahead of schedule. This achievement was more notable as only one California crossing was used. Refer to Fig.8.

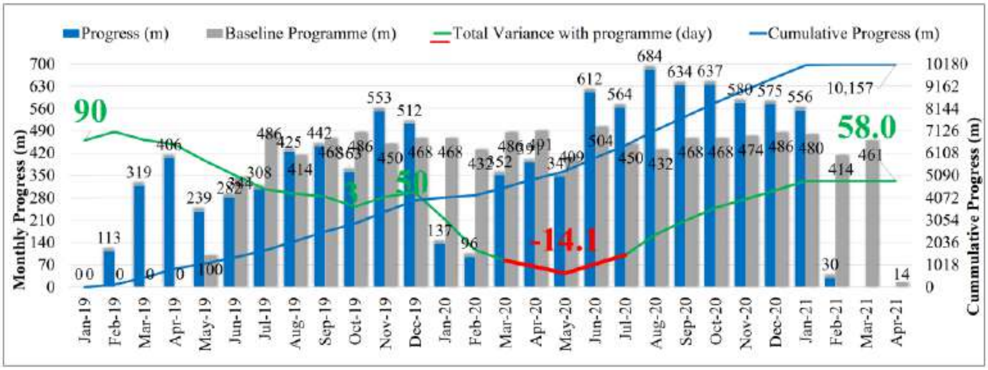


Fig 8. TBM tunnel progress summary V baseline programme up to 03 February 2021.

5. Diffuser field structure

5.1. Riser Shaft and diffuser filed arrangements

The marine diffuser field structure is shown in Fig. 9. The central manifold was located directly on top of the riser shaft and a concrete structure measuring 4 m x 4 m x 4 m and weighing 120 tons. Connected to the main manifold were 6 radial arm structures which either directly connected to the manifold or were connected by short secondary manifolds. Each arm is 140 m long and is separated from the adjacent arm by 35 m. This makes the entire structure outline 294 m x 70 m. The secondary manifolds and 6 arms were manufactured out of High-Density Polyethylene (HDPE) pipe and are of various diameters i.e. 2000,1400, 1200 and 710 mm to ensure an even flow throughout the various arms at varying flow rates from the pump station. The discharge from the structure to the sea is via 84 duck bill valves located equal spacing along the 6-arm structure.

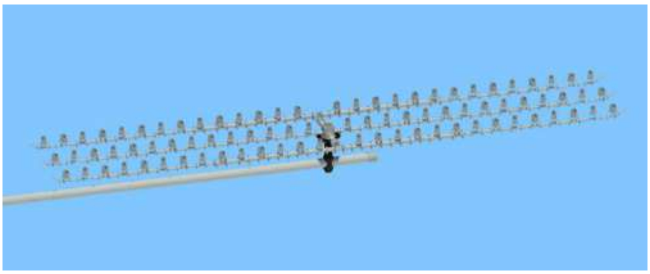
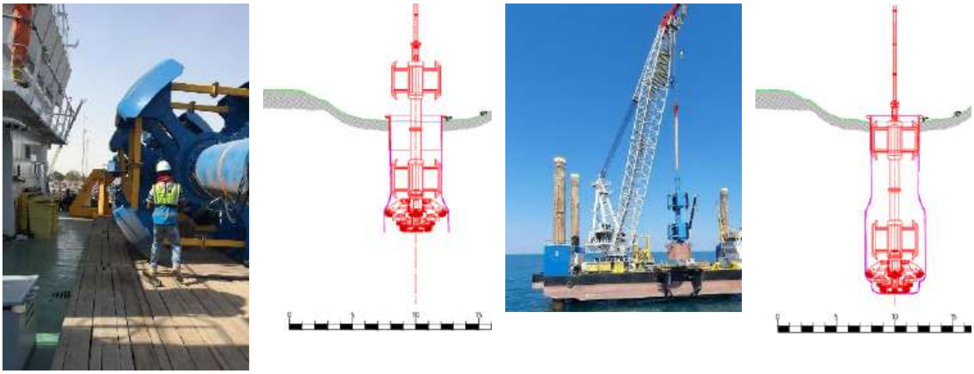


Fig. 9. Marine diffuser field structure, riser shaft and TBM outfall tunnel.

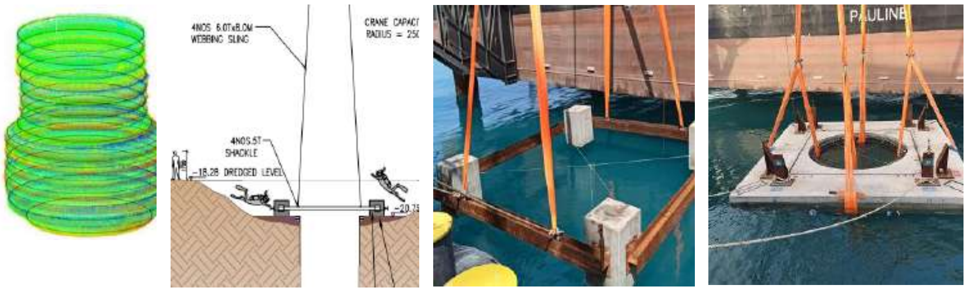
5.2. Riser Shaft Construction

The riser shaft is the structure which connects the TBM outfall tunnel to the marine diffuser bed. The invert of the outfall tunnel is 14.5 m below the seabed and the depth of the sea at this location is 15.5 m. The first stage in the construction was carried out by a dredger which on average removed 2.5 m of loose sediments located on the seabed. Near the riser shaft a further 2 m is excavated to ensure competent strata is exposed which will improve the drilling operation required to construct the riser shaft.



(a) **(b)** **(c)** **(d)**

Fig. 10. With the dredging complete the next stage of the construction was carried out from a jack-up rig which was located directly adjacent to the centre line of the riser shaft. A cantilever frame was then installed to the side of the jack-up rig, this was the location the drilling equipment was installed. (a) The drilling rig or Bottom Hole Assembly (BHA); (b) and (c) the BHA was lowered down to the correct location and commenced to drill the rise shaft; (d) the BHA can drill various diameter holes from 4 to 5.3 m by use of extending hydraulically activated arms to suit the desired diameter of the shaft. In this case the first section was drilled at 4 m diameter and the arms or extended out, to the 5.3 m settings. The 5.3 m section was the location through which the TBM excavated, giving a clearance of 500 mm each side of the TBM, which has an outer diameter of 4. 3 m.



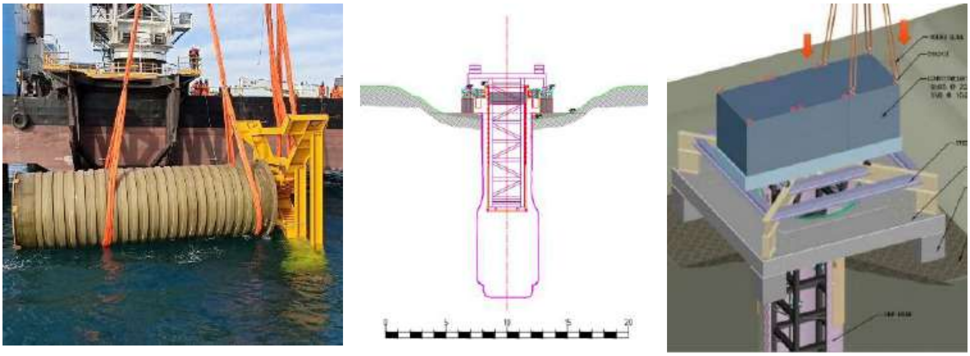
(a) **(b)** **(c)** **(d)**

Fig. 11. (a) on completion of the riser shaft drilling the BHA was then removed, and a three-dimensional survey carried out to determine the exact dimensions and position of the riser shaft; (b) the next stage was to install a steel casing into the top 3 m of the riser shaft, to provide stability and prevent collapsing of the shaft inwards; (c) Four Concrete manifold foundation blocks were then positioned and levelled into the correct requirements and connected to the steel casing; (d) a manifold concrete base slab was then positioned on top manifold foundation blocks.

The void between the GRP cylinder and the whole of the lower portion was then filled with a grout mixture which filled the void in a controlled manner, slowly displacing the seawater.

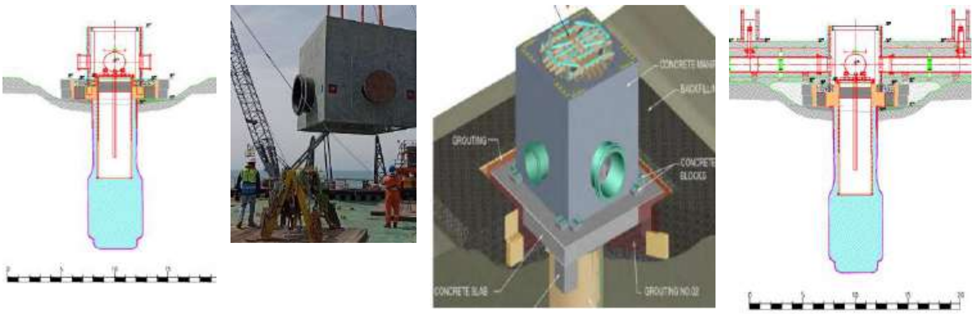
When the grout had cured the kentledge was removed and then the internal steel frame was removed, and the upper flanged secured and sealed to the top of the GRP cylinder. Both top and bottom ends of the GRP cylinder had a series of valves installed to allow venting of water. The upper valves were then used in connection with compressed air to remove all the seawater within the GRP cylinder and leave only air inside.

The central manifold which collects the combined ground and storm water from the outfall tunnel and then distributes evenly to the diffuser structure, was constructed onshore, and weighed 120 tons. The concrete manifold is shown in Fig. 13 (b) and is then lowered and positioned on top of the riser shaft and connected to the manifold base slab as shown in Fig. 13 (c).



(a) **(b)** **(c)**

Fig. 12. (a) the riser shaft internal lining protects downwards from the base of the concrete manifold to 500 mm above the TBM outfall tunnel and is made from Glass Reinforced Plastic (GRP). This is a cylindrical shape with a fixed end at the lowest end and a removable flange at the other end. The upper flanged end is removed, and a temporary steel support frame is installed within the GRP cylinder; (b) The GRP cylinder and steel frame were then installed into the riser shaft and positioned centrally within the riser shaft and connected to the four manifold foundation blocks and base slab. At this point the riser shaft was still full of sea water; (c) shows the temporary kentledge which was then placed on top of the whole structure to prevent uplift during the grout placement.



(a) (b) (c) (d)

Fig. 13. (a) the grouting operation; (b) concrete manifold; (c) manifold base slab; (d) diffuser field connection.

In due course all the diffuser field structure is connected piece by piece to the central manifold until the full diffuser bed structure is installed and covered with back fill material. Then a final layer of scour protection was installed covering the entire diffuser bed structure. At this point the riser shaft structure is ready to receive the TBM constructing the outfall tunnel.

5.3. Onshore fabrication

All the major components of the offshore diffuser bed structure were manufactured at two onshore locations in the Doha area. The major components include pipe work in a) HDPE Pipe and Connections b) Concrete Manifold c) Concrete Protection box d) Concrete collars

The main fabrication site was located at Milaha port south of Wakra, Doha. In this site all the above except the concrete collars were fabricated and assembled. These are shown in Fig. 14. To ensure an equal flow through the entire length of each of the six arms each start at 2.0 m diameter and then reduce to 1.4 m and then finally to 1.2 m.

(a) **(b)** **(c)**

Fig. 14. Onshore fabrication works. (a) Milaha Port site; (b) HDPE pipework being assembled; (c) HDPE pipework transition.

5.4. Component transportation

When each section of the diffuser field pipe structure was complete it was then assembled on shore, end was then capped with a blank flange to ensure water does not get the inside of the pipe. The pipe was then launched onto the sea, the structure was then towed out to the diffuser bed location. Fig. 13 (c) shows a pipe structure in process of being towed out to the diffuser bed location. The Concrete manifold was transported separately by barge.

5.5. Installation of Diffuser Field Structure

After the various elements of the diffuser structure had been transported to the final location, they were anchored and stored ready for installation. The main barge was positioned in line with the final seabed location. The individual sections were then manoeuvred into correct position and then the central manifold sections lowered into position first using a barge mounted crane. Final under water positioning was carried out by specialist divers. The sections of pipework and then the next section of the structure were installed. The first sections installed were the ones which connect to the central manifold, then followed by sections moving out from the central manifold. The pipe section was manoeuvred into position and buoyancy aids attached to the full length of the pipe. Water acting as ballast was slowly allowed to enter the pipe section resulting in the structure submerging in a controlled manner to the seabed, refer to Fig. 15. The final positioning was carried out by specialist divers simultaneously attaching to the already installed elements. The whole structure was then assembled section by section in this manner until the full diffuser arrangement was complete.

(a) **(b)** **(c)**

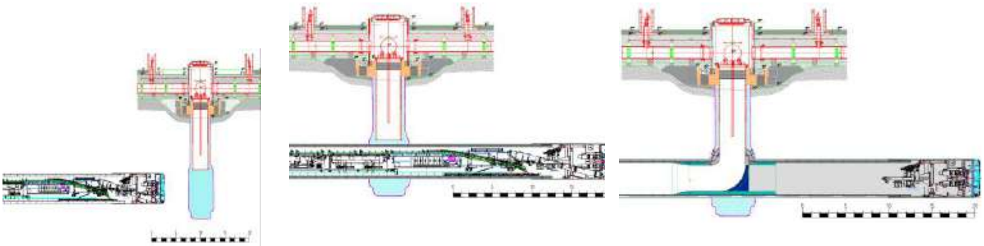
Fig. 15. Launching of pipe elements from onshore to the sea. (a) Central manifold; (b) Pipe section with buoyancy aids; (c) Submerging the pipe.

5.6. Backfilling and Scour protection

On completion of the diffuser bed structure the sequence of work was to backfill the structure for stability. The scour protection installation made of specially designed concrete followed. For the protection boxes for each of the 84 duck bill valves

5.7. Connection to Outfall Tunnel

The programme for the overall project required the diffuser bed structure to be completed prior to the arrival of the TBM, which was achieved, refer to Fig. 16.



(a) **(b)** **(c)**

Fig. 16. (a) The TBM reached to within 5 m of the riser shaft and depressurized the cutterhead and monitored the situation for any water inflow over 8 hours; (b) Since there was no water inflow the TBM excavated through the lower portion of the riser shaft and stopped 25 m beyond the riser shaft; (c) Embedding the unsalvageable part of TBM.

The TBM and associated plant and equipment was then dismantled and removed back through the outfall tunnel and at the pump station location removed to the surface. The 25 m section of tunnel beyond the riser shaft was filled with concrete. What followed was very intricate and complex series of construction activities requiring precise logistical planning and execution to complete the connection of the outfall tunnel to the riser shaft and installation of the permanent works all of which was carried out 10.2 km offshore.

6. Lessons learnt

6.1. TBM in very dry conditions

During the learning curve, excavation in the Rus Formation met expectations. After ring 450, mixed Rus–Midra Shale with higher clay slowed progress. Between rings 550–1150, fully in dry Midra Shale, large amounts of foam and water were required to control torque and thrust. Conditioner use rose from 2.4 to 25.5 m^3/ring, doubling excavated volume from 4 to 8–9 skips per ring. This required 2–3 trains instead of one. To mitigate, the California crossing was advanced to ring 550.

6.2. TBM in very high-water pressure

Two high-pressure zones occurred in weathered Simsima Limestone connected to the seabed: rings 2,000–2,130 and 2,830–4,100, where face pressure reached 3.5 bar. The TBM was adjusted to closed mode, operators briefed, and polymers tested to stabilize inflow. Two strategies were compared: slow advance with polymers (4–6 mm/min) or faster advance without polymers, conditioned only with foam (12–15 mm/min). The second option was adopted to balance safety and progress. Logistics adapted to

5 skips per ring, with all three trains modified. Only one California crossing was installed, relocated weekly to minimize idle time.

6.3. Covid pandemic

Considering the tunnel construction period incorporated the entire COVID-19 pandemic period, 2020/21 Effectiveness of COVID-19 Mitigation Measures: The absence of recorded COVID-19 cases among tunnel operatives highlights the efficacy of the safety measures. Strategies such as social distancing protocols, enhanced disinfection routines, and isolated accommodations minimized transmission risks and ensured personnel safety.

7. Conclusions

The construction of the drop shaft and its connection to the outfall chamber was accomplished before the TBM achieved the tunnel completion, and there was no TBM idle time due to logistics issues neither on the surface or underground.

The construction of other permanent structures in the pump station were not impacted due clashes with the TBM enabling works which confirms the importance of a good plan and clash analysis at the early stage of the project. Starting the required enabling works with 16 months ahead of the TBM arrival mitigated the risk associated with the underground enabling works.

This was the first of three possible outfall projects planned by Ashghal for the long-term management of rising ground water level and storm events, which will bring significant benefits to the population of Doha and surround areas.

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The project was a significant success, and appreciation is extended to all parties for the successful completion of this project.

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