Design Considerations of MPSO Marine Outfall and Diffuser Field

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Abstract

The purpose of the Musaimeer Pump Station and Outfall (MPSO) project is to receive storm water runoff and groundwater flows from the Abu Hamour Tunnel and to provide a pumping station, a marine outfall tunnel and a diffuser field to dispose of the flows into the sea. Musaimeer outfall tunnel is one of the longest storm water tunnels in the world with a total length of 10.2 km. The tunnel is connected via a drop shaft to the main pump station. This system will accommodate surface and storm water received from the drainage networks of 190 km^2 of urban areas in southern Doha. The outfall tunnel comprised precast segmental lining with internal diameter of 3700 mm sloped at 0.05% upward to the riser shaft. The riser shaft, which is located at the end of the outfall tunnel, is connected to a diffuser field positioned on the Arabian Gulf seabed. This paper will focus on the design considerations and recommendations related Marine outfall riser shaft, distribution manifolds and diffuser field. to The MPSO marine outfall was designed in two phases, first comprising installation of riser shaft, primary and secondary manifolds, 3 lines of HDPE piping with variable internal diameter, 84 diffuser duckbill valves, 84 diffuser protection boxes and scour protection. The diffuser is laid in an area of 280mX40m 15m beneath the sea water level. Second phase of marine outfall design included the meticulous connection works between GRP riser shaft and 10.2km TBM tunnel 15m beneath the seabed. Design considerations and final conclusions of such marine design works will be presented.

Keywords: Marine outfall Design; Riser shaft; Scour protection; Diffuser field; Duckbill valves

1 Introduction

Southern and Western Doha has been experiencing a rapid expansion and growth in recent years. Consequently, the need to increase drainage capacity to accommodate additional storm runoff and construction activities has become critical. In response, Drainage Networks Projects Department of the Public Works Authority (PWA) has undertaken significant studies and developed numerous projects that will provide an integrated approach for existing and future drainage systems for this area. One such project is Musaimeer pumping station and outfall, which provides for the installation of a collection tunnel, pumping station and marine outfall to discharge storm and groundwater drainage into the Arabian Gulf. PWA has successfully completed the Musaimeer Pumping station and Outfall tunnel project on Sep 2022 enabling the effective discharge to the sea. One of the most challenging parts of design and installation works included the integrated Marine outfall design which is presented in this paper.

2 Overview of the MPSO Marine Outfall

The project site is located immediately south of the land that was reclaimed for the newly constructed Hamad International Airport (HIA) at the eastern terminus of the Abu Hamour Tunnel which forms a link to allow discharge of storm flows collected in the southern and western parts of the Doha over a total catchment area of approximately 190 km^2. Hydraulic Design was implemented considering all sections of works from Abu Hamour tunnel up to Marine discharge in 10km distance from shoreline. The design high water level (surge tide) of 2.00m QNDH takes into consideration climate change effects to the year 2060.

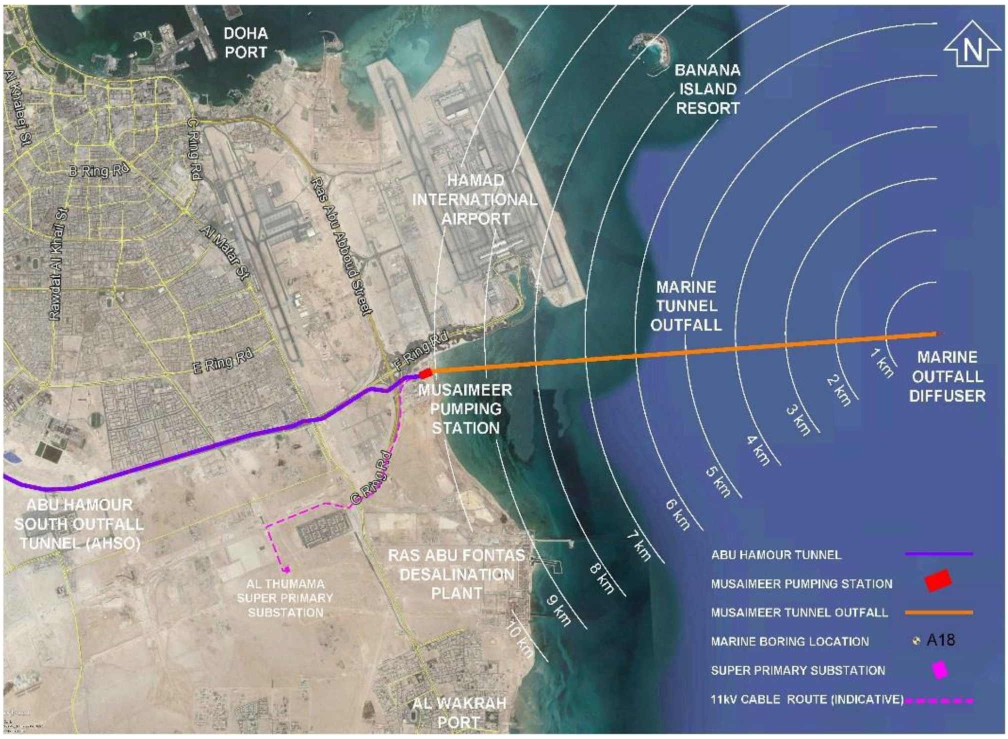


Fig. 1: Location plan for MPSO project

According to Hydraulic Design, the received flows shall be pumped to the Outfall Chamber and will flow by gravity to the subsea outfall tunnel and the diffuser field. Gravity flow system includes the outfall chamber and drop shaft, the 10km, 3.7m I.D. SFRC lining tunnel as well as marine discharge system, riser shaft, manifold, and diffuser field (figure 3). In order to avoid negative environmental impacts to potential key receptors, namely the Banana Island Resort and RAF Water Plant, based on the modelling results of the Preliminary EIA Report and Additional Environmental Studies, the outfall for the storm water discharge is approximately 10.0 km long. A multiple port outfall diffuser provides the necessary dispersion in the marine hydrodynamic environment. Rubber (duckbill) check valves were designed and installed for the Musaimeer Outfall. The outfall diffuser layout is shown on figure 4 &5. The conceptual design includes 84 diffuser ports. Qatar Construction Standards 2014 shall be followed when selecting materials to meet set design life. Materials including duplex or super duplex grades of stainless steel are recommended to be utilised within the aggressive marine environment. High durability concrete with appropriate additional protection for the tunnel and underground structures was used to minimize the effect of the corrosive nature of conveyed flows and the surrounding environment.

3 Parameters Defining the Location and Arrangement of Diffuser

Ministry of Environment and Climate Change (MoECC), in conjunction with Ashghal, agreed that a marine outfall tunnel should be added so that the discharge could be extended offshore, well into the Gulf, to alleviate any negative environmental impacts to potentially sensitive receptors. The environmental studies during preliminary design phase, included preparation of marine and land based environmental baseline surveys, a marine bathymetric survey for the proposed outfall alignment, performing water and soils sampling and testing programme, and completion of a 3-D hydrodynamic model for nearfield, far field, and water quality standards for discharge and environmental impact. The results of these studies have been included in the Preliminary Environmental Impact Assessment (EIA) Report for MoECC review and approval and subsequent Additional Environmental Studies Report. The coastline is generally shallow in depth and, as such, areas of mud and sand flats are exposed at low tide. This part of the coastline is not used for recreation, which is concentrated in areas such as Doha Bay to the north and Al Wakrah to the south. There are no protected areas or special areas of conservation within or near the project area. The outfall tunnel alignment passes beneath extensive sea grass beds, which are regarded as sensitive habitat (project's sensitive receptor). The existence of the sea grass beds was considered as an environmental constraint in selecting the type of outfall and they were considered when developing construction methods. A multiple port outfall diffuser is necessary to obtain the necessary dispersion in the marine environment. There are a variety of outfall diffusers including open port (free discharge) and duckbill rubber check valves, and for the reasons discussed below the rubber check valve was recommended for the Musaimeer Outfall.

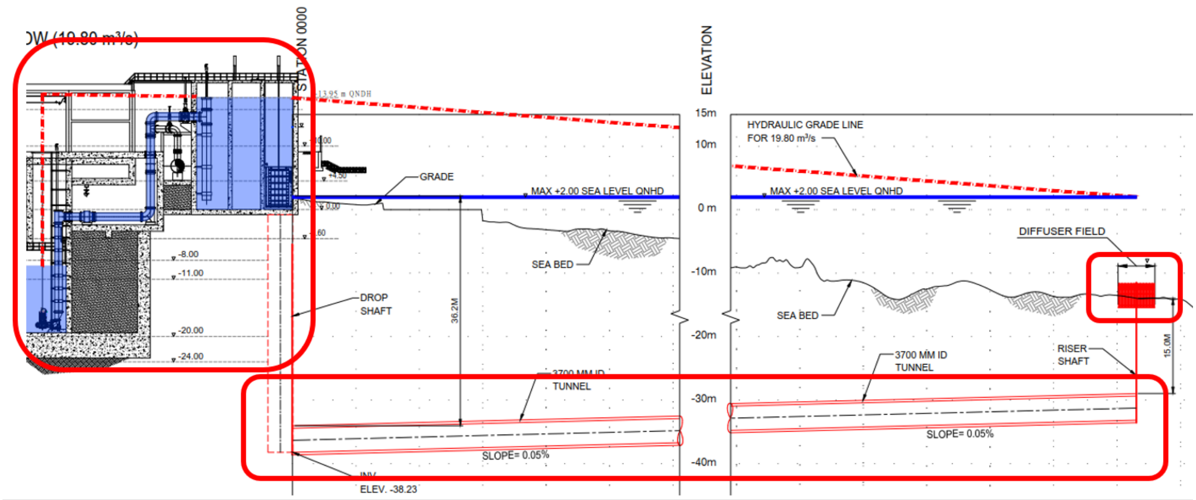


Fig. 2: Gravity flow system

3.1 Seawater Intrusion

Seawater can intrude into the diffuser and outfall pipe if the flow rate from the pump station is low. Salt water is typically 2% heavier (about 4% heavier in the Gulf) than fresh water and if allowed to intrude into the outfall pipe can cause a saline wedge that can impair system hydraulics and diffuser effectiveness and dilution. Additionally, water pressure may be significantly greater under a wave crest, as opposed to the trough, so "duckbill" check valves are recommended to prevent the intermittent entrance of seawater into the outfall pipeline. Due to the intermittent operation of the storm water outfall the prevention of seawater intrusion into this outfall over the long off-line periods is impractical, so hydraulic design has accounted for seawater intrusion. However, base flows are expected to be continuous and diffuser design should mitigate seawater intrusion and consider the use of a check valve.

3.2 Sediment Intrusion

Suspended solids in the Arabian Gulf water are relatively high, which increase during high winds that occur throughout the year. The sea floor and diffuser are shallow leading to re suspension of sand and sediment during high wave activity. The suspended solids (sediment) can enter through the diffuser port during low or no flow and accumulate inside the outfall pipe. Ambient sediment transport along the sea floor can carry bottom material and suspended material into the diffuser, and sand dunes that naturally move across the seabed can transport material into the diffuser orifice and potentially bury the diffusers. Because flow through the storm pipe will not be continuous in the future, there is a risk of sediment intrusion; to mitigate the clogging of the diffuser and outfall pipes with sediment during extended periods of little or no flow, diffusers are equipped with check valves (duckbill valves).

Discharges into shallow oceans can attain sufficient near field dilution when specific requirements are followed. Initial dilution should be maximized by implementing a diffuser field with the maximum possible length, installing the diffuser axis at 90 degrees to the predominant current and Orifices to be discharging horizontally. Diffuser spacing should allow the plumes to merge just below the surface by using the smallest feasible port diameter. Port spacing shall be $s/H > 0.3$ for un-stratified water, where s is the port spacing along the diffuser and H is the water depth. At 10,000m from the shoreline, the water depth is 15m and therefore the minimum diffuser spacing should be 4.5m. The selected size of port is 300mm port size installed in a spacing of 10m.

All diffuser ports should be the same size and depth. The sea floor and the outfall pipe can and should slope, however the diffuser check valves shall all be at the same elevation. Head loss through the diffuser should be small and the diffuser pipe will be buried so each diffuser port will require a riser pipe with an elbow on top to discharge flow to either side of the diffuser pipe. The diffuser should detach (bolted connection) from the riser for maintenance access. Check valves can resist the design head due to tidal effects and prevent inversion of the rubber check valve. Selected dimension of the diffuser field is approximately 280m x 40m.

4 Hydraulic Analysis of Diffuser Field

Following preliminary hydraulic calculations, a 3m Diameter of the 10km tunnel is selected and a 3.7m diameter GRP riser shaft is proposed at the end of the tunnel. The end of the tunnel and riser shaft diameter is smaller than the tunnel diameter to provide higher velocities that will help ensure re suspension of any sediment that has travelled along the tunnel invert. Riser shaft is connected with the main manifold and through the primary and secondary manifolds, 6 HDPE pipe branches are developed in the sea bottom. The Riser Shaft will also serve as an exit point for remotely operated maintenance vehicles during tunnel inspections so appropriate access covers will be required to allow the shaft to be opened for recovery of remotely operated vehicles. The access covers should prevent discharge from the riser shaft but be removable by divers. It is not envisaged that the tunnel will be drained down at any time during its design life and therefore the access covers do not need to provide a drop tight seal. Access to the Riser Shaft for divers should also be provided.

The assessment of hydraulic properties of the system including drop shaft, marine outfall tunnel and diffuser field, was implemented through a one-dimensional hydraulic model using Wanda Version 4.5 software. The purpose of the assessment was to calculate the required free surface levels inside the MPSO outfall chamber add drop shaft located onshore in order to provide the conveyance of design flows related to both to both wet and dry weather discharge of MPSO. Through the analysis, the final arrangement of diffuser field was also selected and verified which will be further presented herewith. The major criteria which shall be complied is to ensure balanced flow out of discharge ports for both dry and wet weather flow. Grit conveyance shall also be ensured if flow velocities in diffuser pipes are higher than outfall tunnel velocities. For this purpose, a varying diameter sizing is implemented for both piping and diffuser header system. Short-term and long-term hydraulic roughness (k factor) for concrete liner, GRP riser shaft, main diffuser header/manifold, fittings and riser pipes is implemented. Design high water level in the recipient is 2.00mQNHD, which takes into consideration climate change effects of the year 2060. 300mm Tideflex rubber duckbill valves were selected the hydraulic characteristics of which are presented in Figure 3.

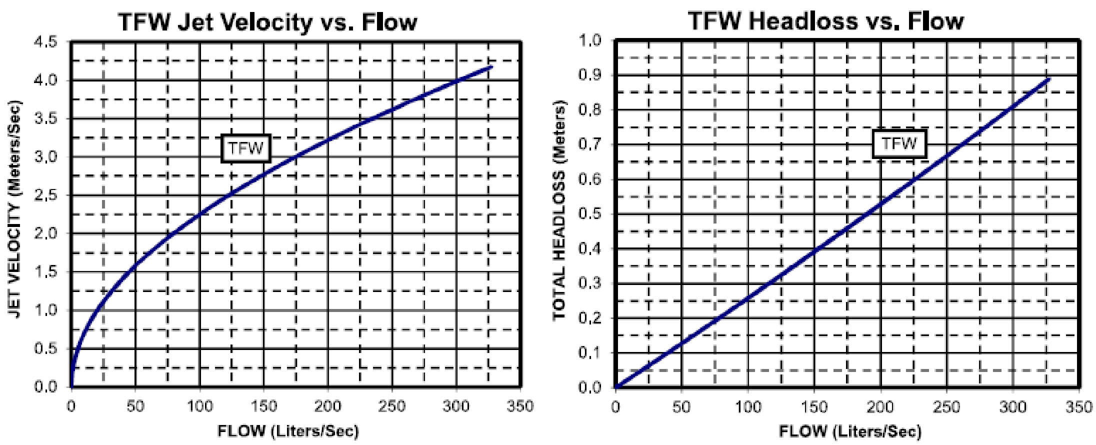
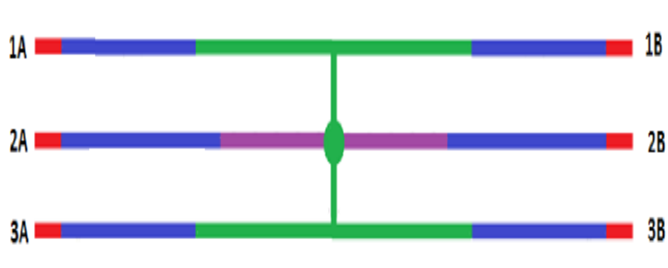


Fig. 3: Duckbill valve charts - Jet velocity vs Flow Rate and Head loss vs Flow Rate (courtesy of Tidelfex)

4.1 Results

Hydraulic assessment included 3 scenarios for dry weather flow (1.9m^3/s), wet weather flow (19.7m3/s) and tunnel flushing. Based on model outputs it was concluded that under most onerous hydraulic conditions, a water level of 13.56mQNHD in the drop shaft is required to ensure delivery of the wet weather flow (19.7m^3/s) to diffuser field. This value was derived during the simulation for the worst operational scenario with the incoming flow of 19.7m^3/s, high tide level of +2m QNHD and long-term concrete roughness value. Duckbill valves of integral bend of 45° maximum head loss reaches 0.8m under flushing scenario. As per manufacturer's data, capacity of the 84 duckbill valves is sufficient to withstand maximum theoretical flow of 27.3m^3/s whereas maximum flow delivered to duckbill valves during flushing procedure is 24.64m^3/s. Flow distribution along lateral lines was calculated with a 5% variation which falls within acceptable limits. The piping configuration has been developed and adjusted to minimize the flow variation. Finally, it is confirmed that velocities within the diffuser field do not fall below the Qatar Surface and Ground Water Drainage manual threshold of 0.7m/s during the wet weather flow.



Color Code	Material	OD [mm]	ID [mm]
(green)	HDPE	2000	1,847.20
(purple)		1400	1,293.00
(blue)		1200	1,108.20
(red)		710	655.60

Fig. 4: Diffuser field piping arrangement and size

The finally implemented arrangement following the above-mentioned requirements is depicted in Figures 4, 5 & 6. Diameter of HDPE piping is varying from 2000mm to 710mm, and diameter of raisers are also varying between 560 to 710mm. It is noticed that starting from connections with the main manifold pipe diameters are reduced while raiser diameters are gradually increased. This proposal ensures equalization of flows throughout the whole length of the diffuser.

Color Code	Material	OD [mm]	ID [mm]
	HDPE	560	517.20
		630	581.80
		500	461.80
		710	655.60

Fig. 5: Diffuser field piping arrangement and size

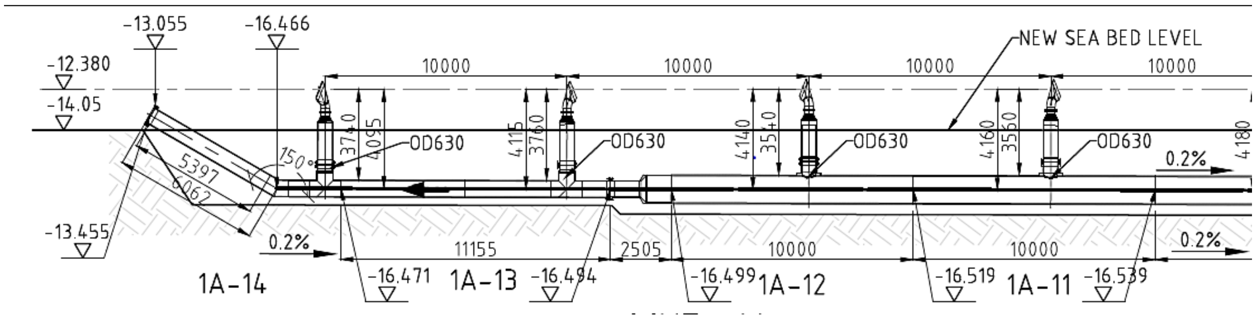


Fig. 6: Longitudinal section of diffuser pipes and ports

5 Design Criteria for Marine Works

Design criteria related to Marine works of the projects were set out in the initial stage of the project in accordance with Contractual requirements and international codes and practices. The major challenges included the selection of the proper marine grade materials as well as the Design of prefabricated part of works. The selected materials shall be able to withstand the aggressive corrosive environment of seawater complying at the same time with project's demanding service life requirements. Material selection for all Marine installation works was implemented in line with durability Assessment report meeting the required service design life of all permanent structures within the marine environment. The concrete mix design also met the durability requirements to achieve the required design life for all structures. Concrete material properties, cover to reinforcement, waterproofing requirements, exposure classes for reinforcement corrosion, surface finish, concrete mix design, grade of concrete, crack-width criteria, achieving design life of structure in accordance with Durability Assessment Report requirements.

Another challenging part is the meticulous design of prefabricated and precast sections of work ensuring transportation and installation safety during adverse weather conditions as well as during operational period.

6 Sequence of Marine Works

Installation of the marine outfall tunnel and diffuser system was performed in a safe and environmental sensitive manner, following best practices, while complying with Qatari regulations, Environmental permit requirements and international maritime regulations. The Main Contractor was responsible for design and Construction of all Marine related activities. Marine activities and respective requirements are listed in Table 1.

Table 1: Construction sequence and requirements

Construction sequence	Requirements
Dredging works	Bathymetric surveys prior and as built, ensure dredgability of the diffuser area, minimize impact on marine environment during dredging works, safe deposition of dredged material
Riser shaft construction	Selection of appropriate offshore drilling rig
Riser shaft permanent grp (glass reinforced plastic) pipe and main distribution header	Ensure structure installation within acceptable tolerances
Pipeline fabrication onshore and transportation offshore	Material selection as per durability requirements, safe transportation under any adverse weather conditions
Connection between the outer diffuser lines and the main distributor of the riser shaft	Diffuser trench and pipelines shall be adequately protected to prevent trench erosion by sea conditions, wind, waves, tides, and currents.
Installation of flanges, covers, manifolds gaskets	Installation to ensure water tightness/sea water intrusion
Diffuser pipes/raisers and duckbill valves	Installation to ensure water tightness/sea water intrusion
Backfilling of diffuser field	Ensure stability during backfilling operations, environmental impact to be minimized
Protection collar and protection boxes	Ensure stability during installation, ensure proper anchorage of protection boxes
Scour protection	Ensure stability during backfilling operations, environmental impact to be minimized
Connection of riser shaft with Outfall tunnel	Cast in situ works with proper concrete quality, removal of segments and excavate in dry conditions, waterproofing installation

Fig. 7: Various stages of Marine Construction activities

The diffuser field pipes were manufactured with openings in accordance with the hydraulically calculated diameter of the diffuser risers in equal distance between the 84 diffusers positioned in the diffuser pipes. The diffuser raisers were fixed by thermal butt fusion welding according to the standards. On the diffuser raisers, the duckbill valves of 300mm will be fixed by flange connection. The duckbills valves were flanged with the diffuser risers using a gasket considering the standard requirements. The entire horizontal pipelines, primary and secondary manifolds were backfilled re-using the previously dredged material for sustainability purposes. Following the installation of concrete collars-ballasts and protection boxes for duckbills scour protection layers were applied throughout the whole layout of the diffuser field. The final step of sequence involved the critical connection activities between riser shaft and TBM tunnel, which ensured the final hydraulic connection of the whole gravity system as, depicted in figure 8. During operational tests for the stormwater discharge through the diffuser field, system design parameters such as head losses and flow conditions had been cross verified and confirmed.

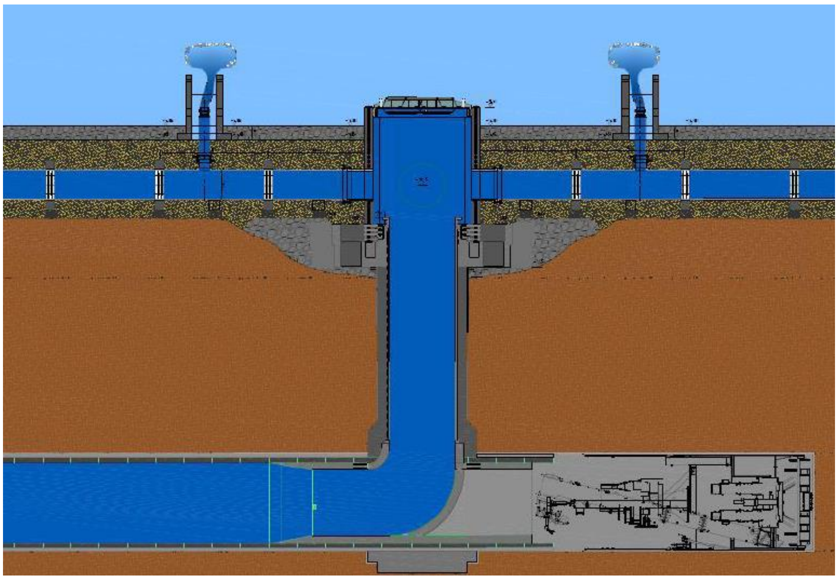


Fig. 8: Final stage of diffuser field section-Operational phase

7 Conclusions

Musaimeer pumping station Marine outfall design considerations included several challenging aspects. Gravity system shall ensure full flow conveyance of dry weather and storm weather flow through the 10km tunnel ensuring homogenous flow through the diffuser field-duckbill valves to the marine environment. All the design values, parameters and results have been cross verified and confirmed during the first 5-month operational period of the pumping station and outfall. Marine related construction activities shall be implemented with increased factors of safety compared with onshore activities, maximizing prefabrication structures, and allowing only installation works mainly to be implemented offshore.

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