LONGEST MULTI CURVATURE SEWER TUNNEL IN THE MIDDLE EAST

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ABSTRACT

With the exception growth of population and strategic plans and 2030 Vision to provide capacity to meet the needs of existing and future development in Muharraq Governorate, a BOOT Sewerage Treatment Plant and Conveyance system project was built in Kingdom of Bahrain. The project set out and covers the area of Muharraq, HIDD and Arad, consist of two parts, civil construction of the STP plant, and the other parts, sewer conveyance system. The Sewer conveyance system are constructed in two major section, main collection tunnel – Deep Gravity Sewer (DGS) and lateral connection to replace two major sewage pumping stations and 22 minor across the coverage area – Waste water collection network (WWCN). The WWCN pipeline collects the sewerage and direct it towards the DGS pipeline. The DGS convey the sewerage through gravity tunnel to the treatment plan through an intermediate lifting station (ILS). Concerning the environmental effects, disturbance to the population and neighborhood and impact on the UNESCO protected building (Fort Arad), the DGS route consist of 15.9km of pipeline of DN1000, DN1400 & DN1800 was executed by Micro-tunnelling method. The success of the project contributed the reduction of energy use, reduced risk of odor, traffic disruption during maintenance, sewers backing up and associated sewage flooding. The sewage undergoes treatment process to produce Treated Sewage Effluent (TSE) suitable for re-use in industrial application, irrigation or landscaping.

47 nos. of shafts are constructed with Secant Pilling method to provide a watertight pit for the microtunnelling activities then later converts to permanent manholes.

Trenchless installation methods have less impact on the environment and the existing infrastructure than other methods applying open cut trenching. I.CO.P. had undertaken 5.5km of the DN1800 pipeline. Two sets of Herrenknecht AVN1800 were utilized to tunnel the GRP Encased RC Jacking Pipe. The major challenges encountered during the execution of the works are the existing ground conditions (Layered of Anisotropic sequence of rock), high ground water table with influents of sea tidal, long and multiple curvature drives, historical and protected areas and tight construction tolerances.

I.CO.P claims two major milestone records on the project by executing the longest DN1800 Sea Crossing (892m) and longest DN1800 Multiple Long Curvature Drive (955m with 2 sets of S-curves). Both records are not only valid in the Kingdom of Bahrain but throughout the Middle East Region.

KEYWORDS

Microtunnelling, Curvature Drives, Sewer Pipeline, Trenchless, Deep Gravity Sewer (DGS), GRP.

1 INTRODUCTION

Muharraq is situated on an island in the north-east of Bahrain and connected to the Kingdom's main island via three road bridges. The south of the Muharraq area borders the Hidd industrial area and the Khalifa bin Salman Port. The Muharraq area is subject to constant change due to extensive land reclamation which currently amounts to approximately 40 km².

Pursuant to the Muharraq Governorate Land Use Strategy, the future land use in the Muharraq area will be of high diversity. The existing settlements consist mainly of low density housing areas and the historic old town, which is situated south of the Bahrain International Airport. In future, the Government plans to extend these housing areas to a yet unused area to the west of the airport.

Furthermore, approximately 26 km² of artificial islands will be reclaimed in the north and east, where a mix between light and high-tech industry, residential zones of differing densities and recreational areas shall be located. A plot of circa 9 km² is reserved for the future airport expansion.

Different development scenarios have to be considered for areas of Muharraq: the areas south and south-west of the airport are already densely populated and not the subject of major town planning projects. The population there will increase by a comparatively low rate of approximately 2% per year. In the region to the east and north of the airport however, large-scale land reclamation projects are planned. Therefore, it is assumed that by 2030, almost half of Muharraq’s population will be situated in these new areas.

A wastewater flow of up to 30,000 m3/day will be redirected to the existing sewer network. In light of the land reclamation and expansion projects referenced above, a significant population growth (and consequently, an increasing wastewater production from mostly domestic and some industrial sources) is expected. The Tubli Water Pollution Control Centre is no longer capable of coping with the wastewater discharge levels of the area, the commissioning of a new sewage treatment plant is necessary.

Concerning the environmental effects, disturbance to the population and neighborhood and impact on the UNESCO protected building (Fort Arad), the necessity to create a practical and feasible methodology to install the new sewer Trunk Main with careful consideration to the surrounding environmental had been a part of the EPC Contractor – Samsung Engineering Co., Ltd.. To this purpose, trenchless technologies using microtunnelling methodology had been considered and implemented. 5.5km of the DN1800mm Deep Gravity Sewer (DGS) Pipeline was awarded to I.CO.P S.P.A.. One part of the microtunnelling section which will be considered as a historical record breaking 942m long with multiple curvature drive will be discussed here.

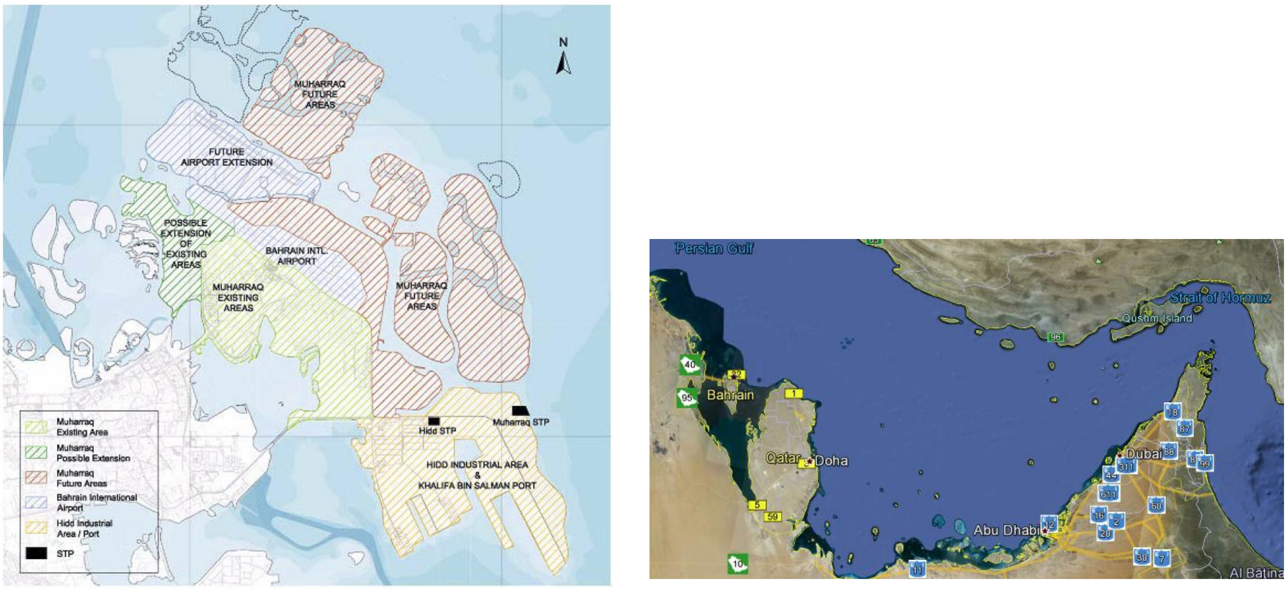


Figure 1. Location of the project site, Muharraq, Kingdom of Bahrain

2 CHALLENGES

The challenges encountered in the project especially for the long curvature drive that shall be executed by I.CO.P. S.P.A. could be categories as follows:-

- **Geological Conditions** - From the geological point of view based on the report and boreholes log, the existing ground conditions varies from sand, silty sand, clay, silty clay, mudstone, sandstone to layered of Anisotropic sequence of rock and reclaimed materials.
- **Hydrogeology Conditions** – High ground water table with influents of sea tidal
- **Ecological and Environmental Conditions** – Working area that was subsequently at the vicinity of public parks, coastlines, UNESCO protected areas, historical zones, buildings, congested urban areas with very dense population and etc.

- **Climatic Conditions** – Strong winds, sand and dust storms, periodical heavy downpours and summer ambient temperature up to 55°C.
- **Existing underground and above ground utilities** – Risk of settlements, disruptions of services, permits, relocation timeline and etc.
- **Working duration** – Summer bands, Ramadan working hours and etc.
- **Logistics, supplies and Material procurement** – limited resources, spare parts, consumable and etc.
- **Public Acceptance** – New construction methodology and first time existed / executed in mass in Bahrain.
- **Working Schedule** – Tight working program to complete the works within 12 months including mobilization.
- **Construction tolerances** – Gravity pipeline requires the installation to be within the allowable vertical tolerance of +/-25mm and horizontal +/-50mm

3 BEFORE AND AFTER

During the project commencement and design phase, I.CO.P, EPC Contractor and the design consultant had been closely working on the tunneling route, material optimization and value engineering to optimize the feasibility to construct the DGS pipeline considering the challenges and actual conditions on site. The table below compares the status of the pipe route/criteria based on the original pre engineering stage and post value engineering stage.

Table 1. Technical data of the pre and post value engineering stage (Fort Arad Section – PS B2 to PS B3)

Stage	Pipe DN	Total no. of Shaft	No. of Start Shaft	No. of Arrival Shaft	Distance between Shafts	Drive Criteria
Post/Tender	1400	5	3	2	Av. 280m	Straight
Pre/Construction	1800	2	1	1	942m	S-Curves

Figure 2. Pre Engineering/Tender Pipeline Route along Fort Arad area (PS B2 to PS B3)

Figure 3. Post Engineering/Optimization of Pipeline Route along Fort Arad area (PS B2 to PS)

4 CHOICE FOR THE TRENCHLESS METHODOLOGY

Considering the construction tolerances, project time line requirement and the numerous list of challenges herewith stated above, I.CO.P. had proposed to the EPC Contractor the following technical insights will be applied:-

- The starting shaft was constructed with secant pilling method to form a completely sealed and water tight launching pit for the microtunnelling works. Break-in/Break-out zones were consolidated with the same method.
- A remote controlled microtunnelling machines are operated from a control panel in a container which is located on surface next to the start shaft.
- Implementation of a gantry crane for all lifting purposes;
- Specially designed pipes that shall be suitable for curvature drives while maintaining the project requirement;
- Endoscope bulkhead inspection if required to minimize downtime and needs of face intervention;
- Effective spoil separation and muck handling system;
- Adequate and special cooling system for tunnel ventilation and equipment heat process unit;
- Real time monitoring system including tunnel communication and continuous gas monitoring system;

Moreover, in order to prevent any disruption to the surroundings and structures along the pipeline route, settlement control points and monitoring system will be installed.

5 MICROTUNNELLING EQUIPMENT

On the basis of the project data reported as in Table 2, an upsized Herrenknecht AVN1800TB tunnel boring machine with an airlock compression/decompression chamber was selected as the best unit for the microtunnelling works. In this project ICOP had implemented new equipment and technology into planning a complete system incorporating the systems as follows:-

- AVN-T Slurry Pressurized Method
- SLS-LT Guidance System
- Automatic Tunnel Lubrication System
- Automatic Data Logging and Control System
- Real time monitoring Intermediate Jacking System

- Special designed launch seal system with Emergency sealing unit and Pipe Brake Unit
- Automatic Chiller unit for tunnel cooling and ventilation system
- Automatic Gas monitoring system with Emergency lighting and telephone communication system
- Real time CCTV surveillance system with IP Cameras
- Pipe Joints monitoring system and Hydraulic pressure transfer ring at each pipe joints

Table 2. Main technical data.

MICROTUNNELLING PROJECT DATA	
Total length	955 m
Maximum depth below ground surface	14.0 m
Internal diameter of reinforced concrete segments	1.8 m
Outer diameter of reinforced concrete segments	2.2 m
Length of reinforced concrete segments (Curve / Straight section)	1.5 m / 3.0 m
Pipe Material	GRP Encased RCJP
Pipeline profile	Multiple Curvature
Sets of Curvature (S-Curves)	3 (R=500, 600 & 1000)
Pipeline Gradient	- 0.1 %

6 TUNNEL BORING MACHINE (TBM) AND CUTTING WHEEL DESIGN

ICOP's machine are designed and manufactured by Herrenknecht GmbH, that complies with the latest safety standards. Tunnelling machine: Closed shield, full face drilling head - Procedural Principles for Microtunnelling Machines. Controlled soil excavation and controlled extraction of the soil is necessary in order to prevent soil settlement on the surface.

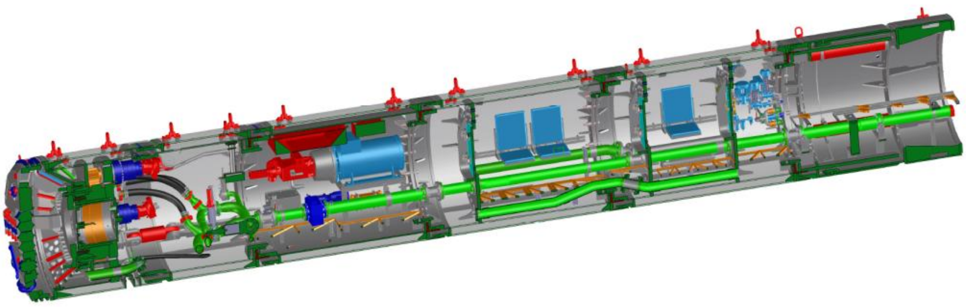


Figure 4. The Herrenknecht AVN18000TB Slurry Tunnel Boring Machine with Extension Kit OD2220

Two different types of face support can be implemented with the flushing circuit procedure. In this case, the face is supported by a combination of mechanical and flushing water support. The pressure of the flushing water can be regulated and should be 0.1 to 0.3 bar greater than the predominant groundwater pressure. The mechanical face support is provided via the arms of the cutting wheel.

Slurry Circuit for Consistent Removal of Excavated Material (Hydraulic Transportation); the excavated material is handled by a hydraulic transportation system. For this, either water or a bentonite suspension is used as the transportation medium. The transportation medium is pumped to the tunnel face from the start shaft by one feed pump using the MTBM's feed line. It stabilizes and supports the MTBM face and is mixed with the excavated material.

The cutting wheel will be specially designed for the AVN1800TB in mixed ground such as: mixture of soft ground, gravel or coarse gravel, weathered/soft rock and to overcome unforeseen underground obstacles. The Cutting Wheel will be equipped with soft ground cutting tools and disc cutters. All the disc cutters are back loading types that are able to be changed due to wear and tear and damages upon encountering obstacles.

The cutting wheel designed by ICOP is able to overcome materials of up to Maximum Unconfined Compressive Strength (UCS) of 60 MPa. In the case that the obstruction needs to be identified prior removal or the examination of the cutting tools condition in front of the cutting wheel, the use of the Video Endoscope

System XL PRO provides a video probe with visualization of the status in the cutting chamber and ground in front of the machine without the needs of man entry. An inspection may be carried out in along the course of the drive in order to rectify the necessity to change the disc cutters.

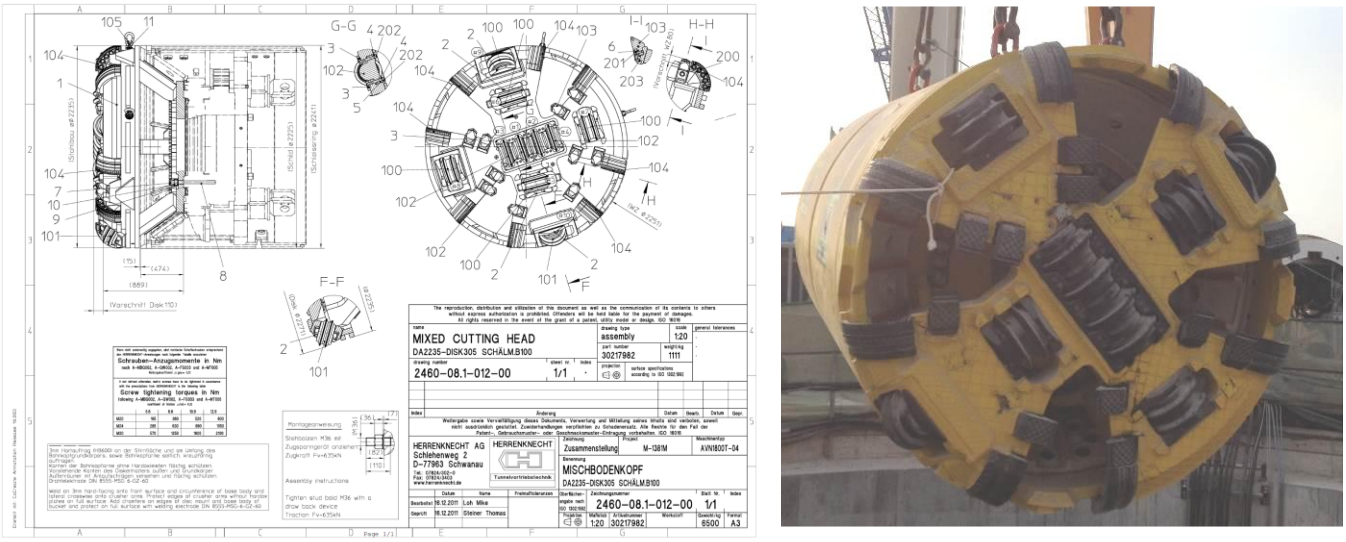


Figure 5. The Mix Ground Cutting Wheel Design with OD2225

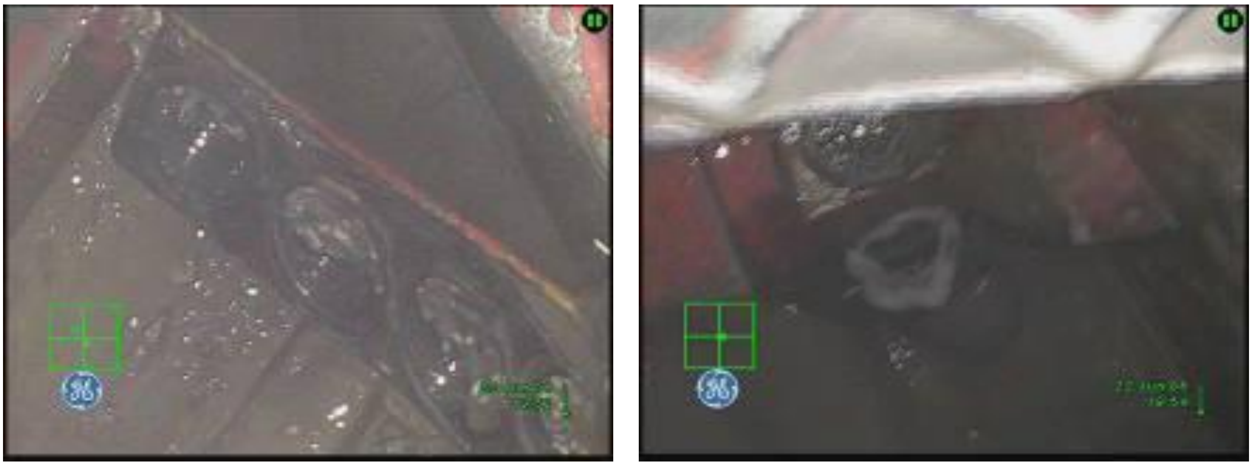


Figure 6. Photo and VDO clips from the inspection of a previous similar project by ICOP

7 AUTOMATIC INTERMEDIATE JACKING STATION (IJS)

Due to the skin friction between the external surface of the pipe and the soil, the frictional forces increase as the length of the tunnel increases. Once the jacking force registered on the Main Jacking Station reaches 80% of the allowable force applicable on the GRP Reinforced Concrete jacking pipes, the additional jacking stations preinstalled along the tunnel will be activated. The usage of the Intermediate Jacking Station is not only subject to the increment of the tunnel length but accounting of any standstill that leads to the necessity of greater initial force to restart the microtunnelling process. The first station will be allocated approximately 30m rear of the MTBM. For this reason, as a preventative measure, intermediate jacking stations are provided at intervals at each 100 meter distance and 9 stations will be installed.

In this project, ICOP implemented the automatic control program (ACIS) from VMT GmBH to create a visual and real-time monitoring of the pressure loading on the intermediate jacking station and the covering pipe section and to operate the station advancement with controller parameters and according to the setting of the operators.

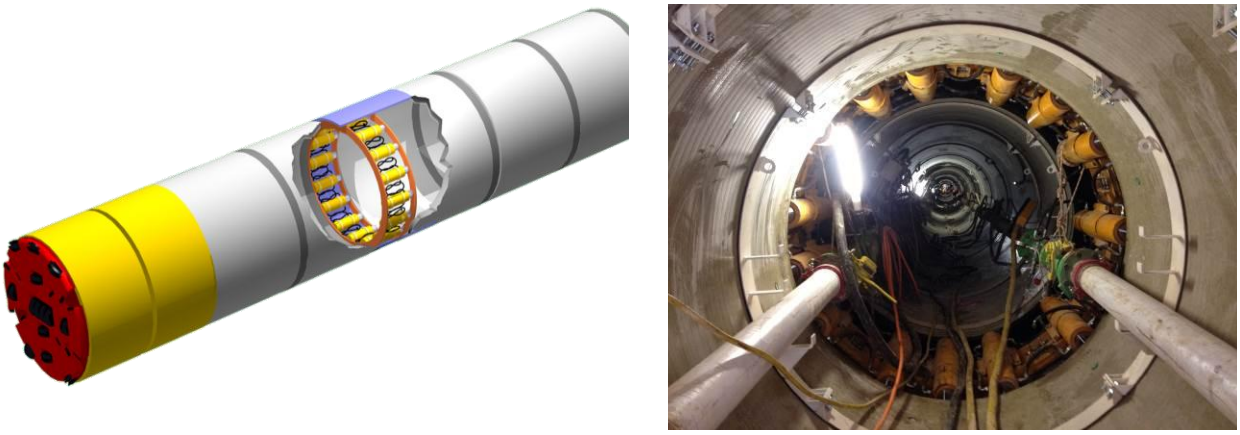


Figure 7. Typical Schema of the Automatic Intermediate Jacking System

8 SLS-LT GUIDANCE SYSTEM FOR LONG DISTANCE MICROTUNNELLING WORKS

In this project, ICOP will be incorporating the special guidance system SLS-LT (Steuerleitsystem-Rohrvortrieb - control guidance system pipe jacking) from company VMT GmbH for the long and curvature DN1800 drive. The major difficulty during pipe jacking is that the entire tunnel is constantly in motion and it is, therefore, not possible to mark stationary points in sections of the pipe conduit which have already been advanced in order to refer to them at a later point in time.

As a result, classical measurement would have to begin for every measurement at "zero" in the launch pit. As the length of the tunnel grows the amount of effort increases, especially as classical measurement can only be carried out when the microtunnelling is not in process. Therefore, it is only possible to ascertain whether the machine has drifted away from the desired axis after a period of time has passed and counteractive measures can only be introduced with a correspondingly delay. With this system it is possible to measure the position of the machine at any point in time, even when microtunnelling is being carried out. An active laser target (ELS) is rigidly mounted in the tunnelling machine (see figure 8) as a position reference system.

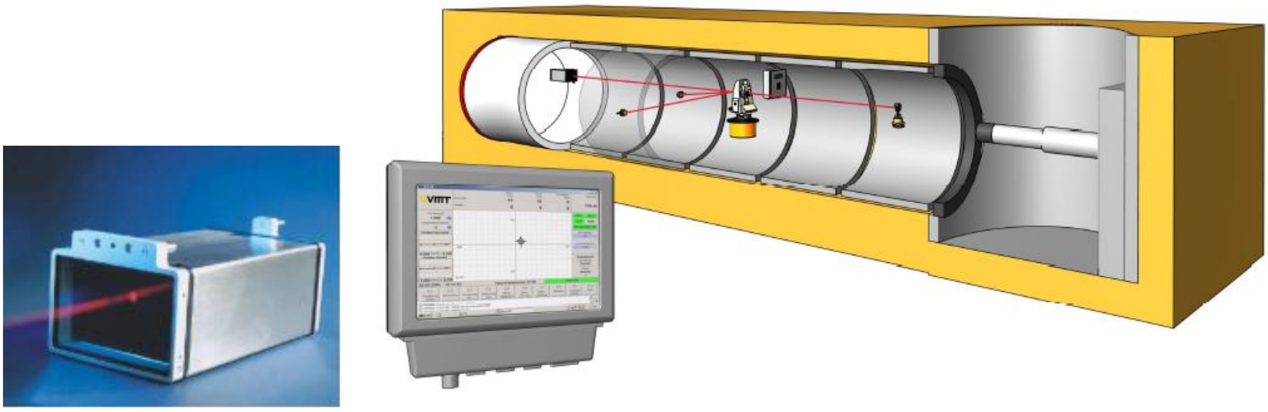
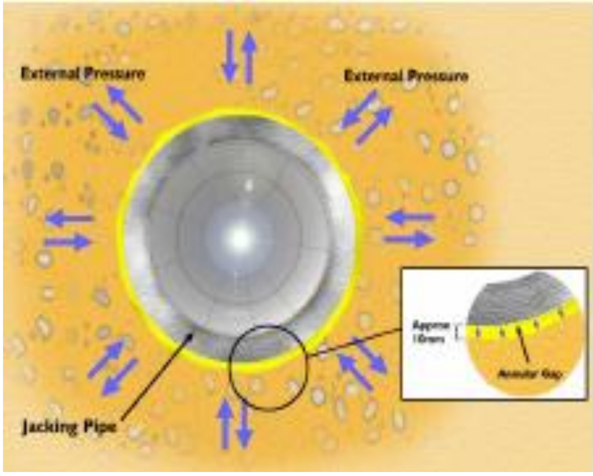


Figure 8. Illustration of the AVN Guidance System with VMT SLS-LT System

9 AUTOMATIC TUNNEL LUBRICATION SYSTEM (ALS)

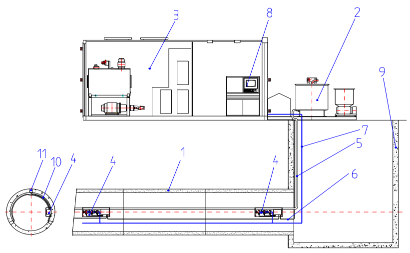
A significant factor for the strength of the microtunnelling force is the sheath friction of the pipes and the machine. The thrusting force required to compensate for the friction is, however, limited by the maximum permissible axial force load of the jacking pipes. The frictional force is dependent on the soil to be excavated, the level of the groundwater, and the quality of the machine steering and the consistent lubrication of the pipe conduit. The quality of the microtunnelling pipes is also of great importance.



The cutting diameter of the cutting head is approx. 20mm larger than the steel construction of the machine. The product pipes, on the other hand, usually have a smaller diameter. This prevents the ground from pressing directly onto the machine and the pipes. In the project, the ground condition was not stable. To achieve this, a supporting liquid is injected into the overcut. It also has a lubricating function which greatly reduces sheath friction. Bentonite and other additives was used as a lubricant and supporting agent. The injection pressure causes the supporting fluid to penetrate to a certain depth in the ground and forms a lubricating film around the pipe. The speed of the flow and the penetration depth of the suspension in the ground depend on the cross section of the pores of the soil and the flow characteristics of the lubricant.

Figure 9. Methodology and Effect of Proper Lubrication System

The bentonite nozzles were distributed as evenly as possible over the circumference of the pipe. The number of nozzles depends on the capability of the ground for allowing the suspension to spread out. For ground with which is less permeable the intervals selected should be more frequent than for ground with greater permeability. The injection starts behind the machine pipe and allocated every 9-12 m with subsequent injections. The best results were achieving a skin friction of less than 50kg/m2 between the soil and pipe surface.



1.Product pipe	4.Bentonite station	7.Compressed air supply line	10.Connecting line between Bentonite station and nozzles
2.Bentonite unit	5.Bentonite supply line	8.Control stand	11.Bentonite nozzles
3.Control container	6.Electrical cable control stand ⇨ machine	9.Shaft	

Figure 9. Typical Schema for the Automatic Lubrication System

10 AUTOMATIC DATA LOGGING AND CONTROL SYSTEM

The TBM incorporates the real time monitoring and data acquisition system. The systems enable continuous data monitoring and logging of the TBM performance on an automatic electronic recording system. With such system, the operators in the control cabin will monitor the advancement of the TBM under consideration of all equipment parameters, internal and external pressure, guidance of the machine etc. While observing the parameters, the operator will have continuous control of all electrical and hydraulic equipment such as pumps, cables, pipes, hoses, nozzles and etc.

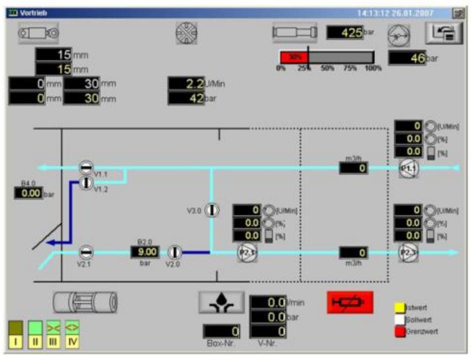


Figure 10. Automatic Data Logging and Control System

11 VENTILATION AND GAS MONITORING SYSTEM

Forced air blower system will be utilized for the air supply and ventilation system for the microtunnelling works. As per the construction methodology and type of TBM supplied for this project, the operations are done via remote control from the drive cabin on the ground. No personnel or operators are required to be permanently in the tunnel to commence any operation and tunnel advancement works. If man entry operation is borne to be necessary at any point of the tunnel or TBM, the minimum requirement for the tunnel ventilation will comply to BS 6164:2001 at 0.3m³/min/person with minimum air velocity of 0.3m/s. A tunnel blower connected with a complete either rigid or flexible duct will be supplying air into the tunnel. During the summer months or where applicable only, a heat processing system is installed on site to provide cool air into the shaft and tunnel.

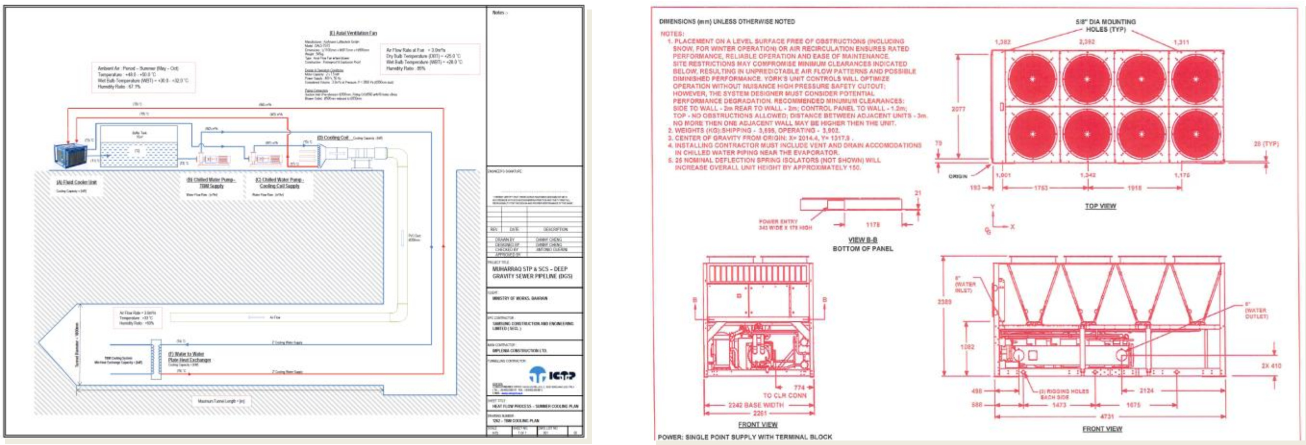


Figure 11. Tunnel and TBM Ventilation and cooling system

The TBM is equipped with an automatic gas measuring system to detect explosive gas (CH_4). The evaluation occurs by the SPS control and is indicated in the visualisation program at the control stand. The alarm device produces both Visual and Audible Signal to aware and warns the TBM operator on site during microtunnelling activities. With exceeding of a limit value, warning signals sound.

12 LAUNCHING SEAL WITH EMERGENCY SEAL SYSTEM AND PIPE BRAKE

In reasons of the existing high water table and risk of damaged sealing system at the launching seal unit, ICOP had designed a special system that includes an inflatable emergency seal system. The emergency seal system works at the range of maximum 2 bar and could be set functional to stop any water ingress through the break-in zone, allowing the replacement of any damaged launching seal. Whereas considering the hydrostatic pressure applicable to the face of the TBM, a hydraulic pipe brake unit working like a pipe clamp will be installed in the launching shaft to enable the last pipe in the ground to be clamped preventing it to retract or move during the pipe change sequence.

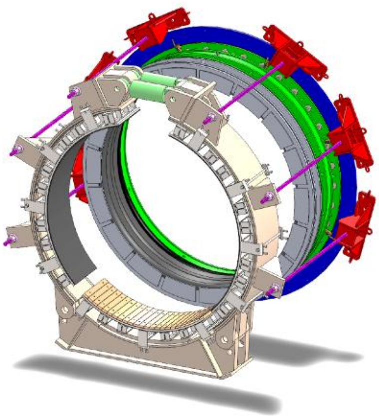


Figure 12. Pipe Brake and Launching Seal Unit with Emergency Seal System

13 GRP ENCASED REINFORCED JACKING PIPES

The pipes are considered an important factor to the works and prior controls and manufacturing including supply efficiencies shall be consider. A proper design base on the latest manufacturing state of art and applicable norms/standard required by the project technical specification is mandatory to ensure a fail proof installation and also against any uplifting scenarios. In relation to the standard technical requirement, the pipes are also to be design and manufactured contemporary to fit and suit the proposed Microtunnelling operation; additional requirement subject but not limited to the followings:-

- Pipe Joints design
- Steel Reinforcement at the pipe ends
- Sealing material and installation method
- Pipe End Squareness
- IJS Construction and connection tolerances
- Eccentricity of the GRP Lining and Concrete Pipes

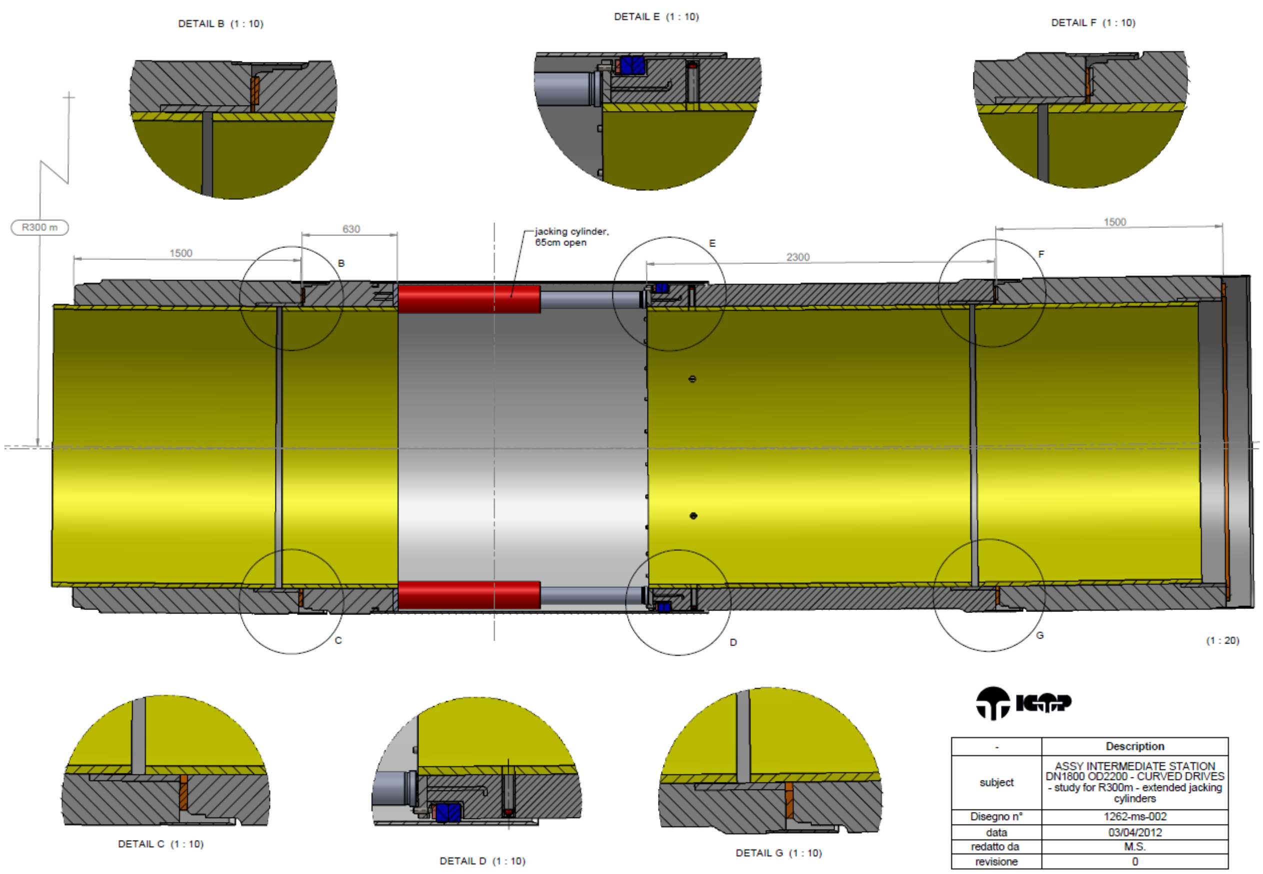


Figure 13. Detailed design of pipe connections, length, concrete properties, GRP thickness, sealing system, collars, pressure transfer rings and etc.

14 HYDRAULIC JOINT PRESSURE TRANSFER RING AND JOINT MONITORING SYSTEM

EPC Contractor had subcontracted, Jackcontrol to provide the for real time monitoring of the jacking process based on the Hydraulic joint used as pressure transmission ring. The Hydraulic joint on one hand leads even under big deflection angels to equal distributions of the axial pressures on the pipes faces, on the other hand its completely reversal mechanical behavior is a reliable base for the calculation of the resulting jacking force and its position in the pipes cross section. In comparison to pressure transmission rings made of wooden materials the Hydraulic joint decreases the risk of pipe damage under jacking loads by dimensions. In the same time much smaller radii of curvature in the alignment become possible. Thanks to the real time monitoring of the pipes given jacking capacities can be used in full range under complete control.

Figure 14. Pipe Joint and pressure transferring system including Hydraulic Joints as pressure transfer ring at each pipe joints.

15 CONCLUSIONS

Advantages of trenchless installation techniques – Microtunnelling
With the extend of high sophisticated and technologies, longer and more challenging curvature pipeline could be installed under variable and critical ground conditions.

Minimal impact on the environment due to:
- minimal surface disruption, no deterioration of existing ground water level, lower emissions.
- minimal impact on the existing infrastructure, therefore; applicability in high density urban areas,
- no disturbance of tourism, impact on existing underground utilities.

Cost saving and time impact
- saving on additional requirement for intermediate shafts
- saving on mobilization and demobilization from intermediate shafts
- permits, detours, loss of business opportunity and etc.

Construction Standards
- less risk of settlements, higher seismic safety
- achievable construction tolerances
- value engineering and higher production rates
- much controlled and systematical work sequence

Health, Safety and Environmental
- Minimized traffic congestions , road accidents and needs of detour or sophisticated traffic management
- Minimized truck and muck disposal
- Lower emissions
- Low vibration and noise impact
- Minimal efforts for the reinstatement of site after finishing the installation.

The long multiple curvature DN1800 drive is set out to be executed starting from the beginning of May 2013 and scheduled to complete within 82 working days. Upon completion of the drive, I.CO.P shall claims the major milestone records on the project by executing the and longest DN1800 Multiple Long Curvature Drive (942m with 3 sets of S-curves). This record is not only valid in the Kingdom of Bahrain but throughout the Middle East Region.

ICOP's experience in collaborating the Herrenknecht microtunnelling techniques, VMT guidance system and Jack Control system allows constructions for long multi curvature gravity sewer pipeline – in nearly every geological and topographic condition.