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Micro-tunnelling towards the Atlantic Ocean

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ABSTRACT: With the exception growth of population and demanding needs of fish as food supply, a project in the expansion of the existing cultivation plant in Spain. The project set out in Mira, Portugal consist of two parts, civil construction of buildings, structure, ponds for the cultivated fishes and the other parts, pipeline construction. The pipeline construction comes in 4 section. Two section (T1 & T2) were for intake of sea water pipeline and the remaining two section (V1 & V2) were for the discharge of sea water pipeline. Concerning the environmental effects of the water used to grow the fishes, a feasibility plan had been studied and microtunneling method had been seriously considered as the most effective method to construct the 4 sections of pipeline. Tunnelled outfall constructions are often an effective and sustainable possibility to improve the quality of live in coastal areas. With the sea outfalls the water from the fish tanks can be transported away from the coastline and discharged at locations where diffusion, dispersion and decomposition are enhanced.

Conventional methods of pipe installation for outfalls have usually required the pipe to be prepared on the jobsite and either pulled or floated into position and then sunk and anchored. In comparison, trenchless installation methods have significantly less impact on the environment and on the existing infrastructure than methods applying open cut trenching. The pipeline is better protected against damage and therefore has a higher lifetime.

Trenchless installation methods have less impact on the environment and the existing infrastructure than other methods applying open cut trenching. Additionally, the pipeline is better protected against damage and therefore has a higher life expectancy. The choice - influenced by the technical requirement and environmental factor - a microtunnel with ID 2.6m of 1.35km towards the Atlantic Ocean was executed.

1. INTRODUCTION

Mira (Portuguese pronunciation: [ˈmiɾɐ]) is a town in Mira Municipality in the district of Coimbra, Portugal. It is a coastal municipality known for its beaches, forests, and agriculture. A centre for artisanal fishery, and aquaculture, Mira's economic activities also rely on agriculture, forestry, and tourism.

In 2007, the Galician fishing company Pescanova, headquartered in Redondela, Spain, announced its intention to build several sea bass aquaculture plants in Mira. Pescanova invested about 350 millions euro in the Portuguese aquaculture plant, which was backed by the Portuguese government with about 45 millions euro in incentives. The plants incorporate wind farms to alleviate the high energy costs, as well as a fish feeding plant. The plant were projected to reach a production rate of between 30,000t and 100,000t a year.

Crossing the natural beauty dunes, natural beach, touristic zone and environmental sensitive areas is a major concern and factor in the design of the tunnels. The necessity to create a practical and feasible methodology to install the tunnel with careful consideration to the surrounding environmental had been a part of the Main Contractor - Somague Engenharia. To this purpose, trenchless technologies using microtunnel methodology had been considered and implemented. One part of the tunnel, V1 - discharge tunnel from the tanks to the sea was awarded to I.CO.P S.P.A. and will be discussed here.

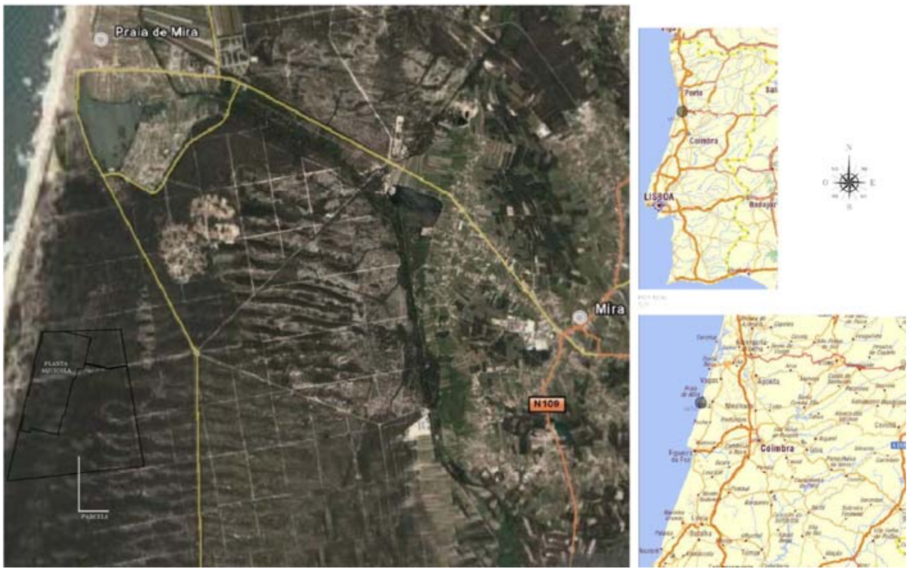


Figure 1. Location of the project site, Mira, Portugal

2. CHOICE FOR THE TRENCHLESS METHODOLOGY

From the geological report and boreholes log , the ground mainly will be sand classified as:

Silty Sand (Angular 36-42 deg Compaction)

Having decided on the microtunneling method - deemed particularly effective in preserving surface "dune zones" — and a drilling depth of - 6.8 meters to -21.0 meters below the ground surface (-6.0 to -8.0 m below the sea bed), the crossing profile was determined that guaranteed the least possible interference with the ecological and environmental areas along the route.

Use of this system does not alter the delicate lithostratigraphic and hydrogeological balance of the surface portions characterized by sandy silt, sand and ground water. To this purpose, the following technical insights were applied:

- A start pit is excavated at the land side of the pipeline. The sealed starting pit was constructed with diaphragm wall method to prevent any communication between the surface and exiting ground water;
- The Herrenknecht remote controlled microtunnelling machines are operated from a control panel in a container which is located on surface next to the start shaft.
- During excavation a bentonite film by means of lubrication was created to insulate the excavation process. Particular attention was paid at the points of lithological changes, thus preventing the various aquifers from intermingling;
- The seaside end of the pipeline is closed with a bulkhead equipped with a valve. Construction tolerances are in the range of <30mm. On the last 50 m, the pipe segments have to be securely connected in order to minimize uneven settlement and to withstand attractive forces when flooding the tunnel. The end pipe segments of the tunnel, when installing the diffusers may have to be ballasted with solid ballast to avoid buoyancy;
- All barges required for the offshore works have to be adequately moored, so that they can withstand the forces resulting from currents and machine operation during recovery;
- Balloons float will be utilize to lift the TBM during subsea recovery and dragged with a Tug boat to the port for retrieval works;

Moreover, in order to prevent any disruption to the flora and fauna presences along the pipeline route, settlement control points and automatic alarm trigger system were installed. Whereas sound proofed equipment was used and the entire project site was marked off with sound-proofing panels.

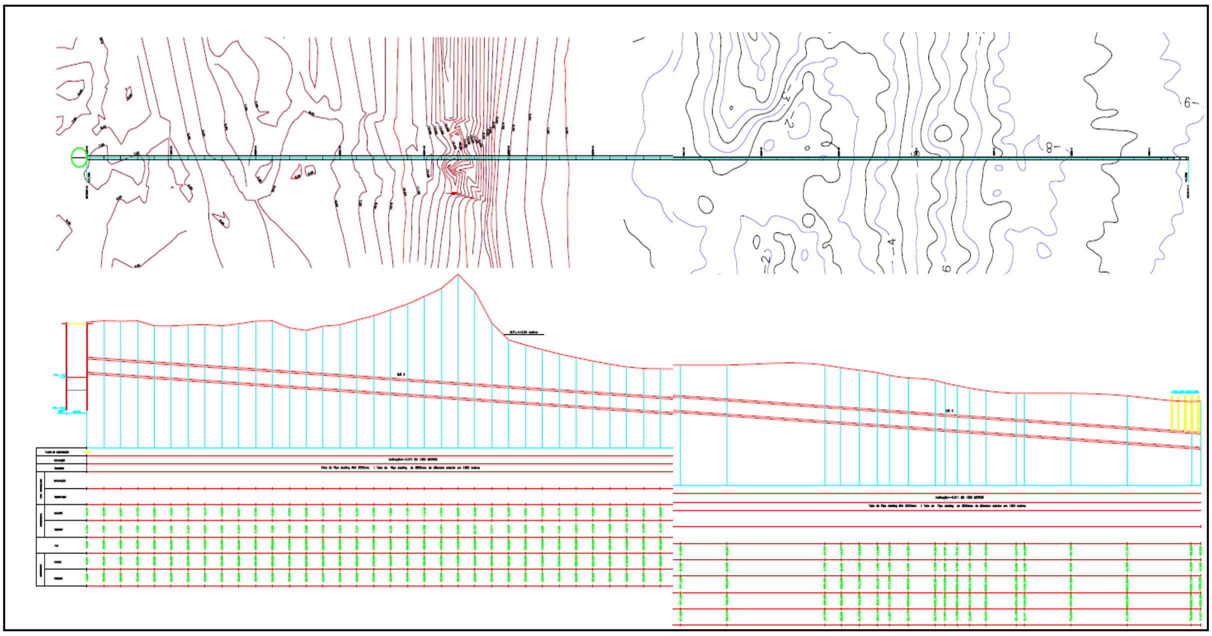


Figure 2. Pipeline profile and Cross Section of Tunnel

3. MICROTUNNELLING EQUIPMENT

On the basis of the project data reported as in Table 1, an upsized Herrenknecht AVND2000AB tunnel boring machine with an airlock compression/decompression chamber and subsea recovery unit was seleted 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:-

- D-Mode AVN Slurry Pressurized Method
- Medium Tension Voltage Supply
- Sub-Sea Recovery Mode
- Compressed Air lock Sealing
- SLS-RV Guidance System
- Automatic Tunnel Lubrication System
- Automatic Data Logging and Control System
- Automatic Intermediate Jacking System

Table 1. Main technical data.

MICROTUNNEL PROJECT DATA	
Total length	1350 m
Maximum depth below ground surface	21.0 m
Internal diameter of reinforced concrete segments	2.6 m
Outer diameter of reinforced concrete segments	3.3 m
Thickness (indicative) of reinforced concrete segments	0.35 m
Length (indicative) of reinforced concrete segments	4.0 m
Pipeline Gradient	- 1.1 %

4. TUNNEL BORING MACHINE (TBM) AND CUTTING WHEEL DESIGN

ICOP's machines are designed and manufactured by company Herrenknecht 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.

Two different types of face support can be implemented with the flushing circuit procedure. For purely geometric reasons, for machines with a nominal diameter up to 1500 mm (AVN 1500) only the so-called slurry principle can be deployed. 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. Machines with this construction are also called slurry shields.

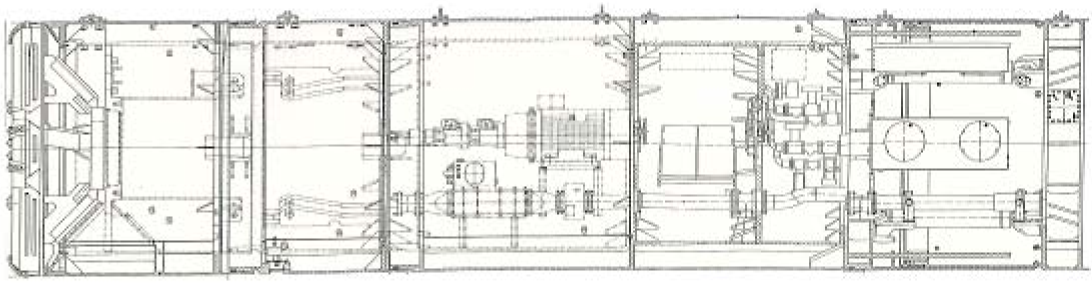


Figure 3. The Herrenknecht AVND2000AB Slurry Tunnel Boring Machine with Extension Kit OD3300

The cutting wheel will be specially designed for the AVND2000AB 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.

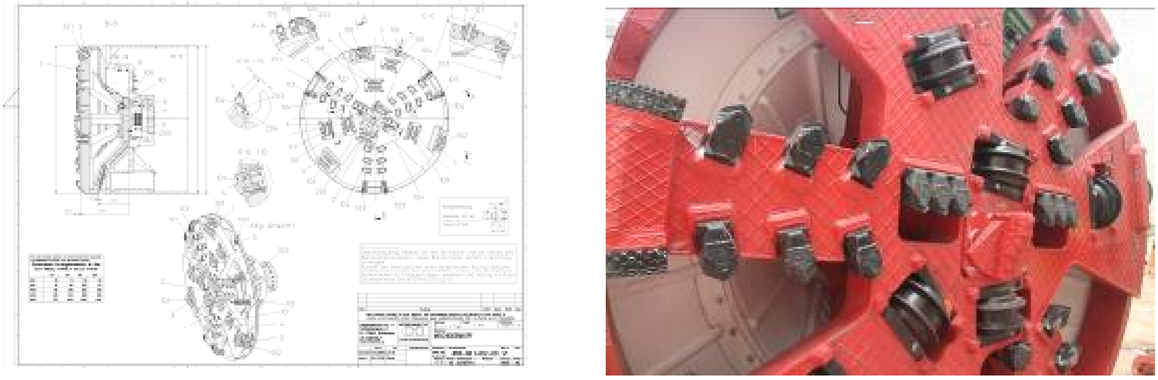


Figure 4. The Mix Ground Cutting Wheel Design with OD3380

The cutting wheel designed by ICOP is able to overcome materials of up to Maximum Unconfined Compressive Strength (UCS) of 80 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. The Video Endoscope System – XL PRO provided by Nordseetaucher GmbH provides a video probe should be always used if the compressed air technicians are unable to inspect the tools at the cutter head in complete safety. The advanced, proven inspection technology of the XL PRO range of products enables you to inspect and measure the angle, depth and distance of all damage or objects precisely and safely. Images can be recorded, stored and retrieved for precise, seamless documentation. An inspection was carried out in the Project in order to rectify the necessity to change the disc cutters.

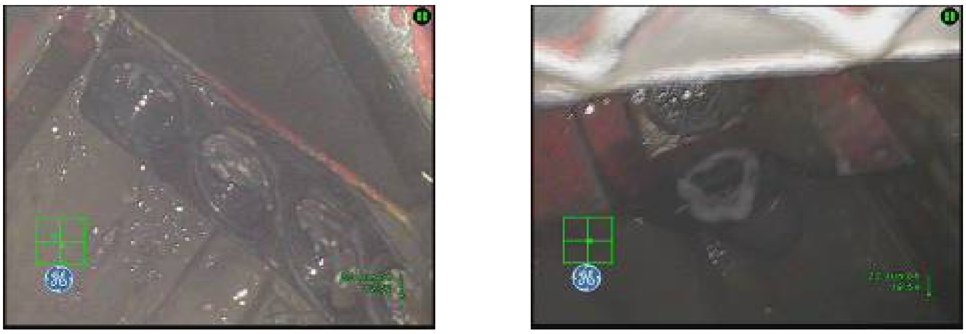


Figure 5. Photo and VDO clips from the inspection

4. D-MODE SLURRY PRESSURIZED METHOD

The primary construction characteristic in the micro range - also referred to as mixshield machines - is a space in the steerable shield of the machine which is separated by a submerged wall into the excavation and pressure chamber areas. The flushing circuit is routed as usual via the excavation chamber. In contrast to the slurry machines, the supporting pressure is regulated via the compressed air supply to the pressure chamber and the resulting compressed air bubbles. The main advantage of this is that the regulation of the supporting pressure and the amount of through flow in the slurry circuit can be separated which enables fluctuations in the supporting pressure to be kept to a minimum.

Compressed air regulating equipment ensures the exact regulation of the supporting pressure at the face. This applies in particular to very high fluctuations in the earth pressure which can be caused by fluctuations in the excavation speed, among other things. The supporting pressure which has been set should always be somewhat higher than the predominant pressure at the face. This principle has proven successful and offers an effective alternative for difficult soil conditions. If the geological conditions permit, the machine can easily be switched over to the conventional flushing circuit mode.

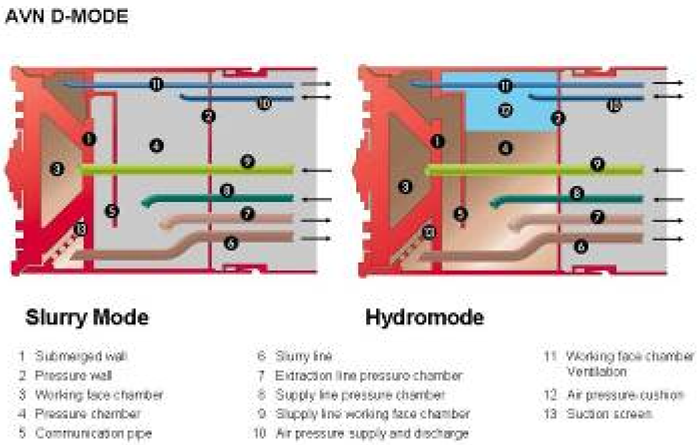


Figure 6. AVN D-Mode Dual Function and Application

5. MEDIUM TENSION VOLTAGE SUPPLY

With the needs of driving the TBM for a distance over 1000m, the needs to implement the Medium Tension Voltage supply to the TBM are taken into consideration. The system consists of a Step Up transformer unit (1000kVA) which will increase the primary voltage from 400V to 10,000kV. By the stepping up of the voltage, the needs of the cable installation supplying the power supply to the TBM will be only 35mm² compared if only 1000kV supply, then the main supply cable will have to be approximately 185mm². This does not only eliminate the needs of a bigger cable but subsequently minimized the voltage drops, easier handling and maintenance in and along the tunnel. At the TBM, another transformer which is the step down transformer (800kVA) which will bring the supply voltage down to 400V & 950V which will be connected to a distribution board energizing supply to the electric motors and component in the TBM.

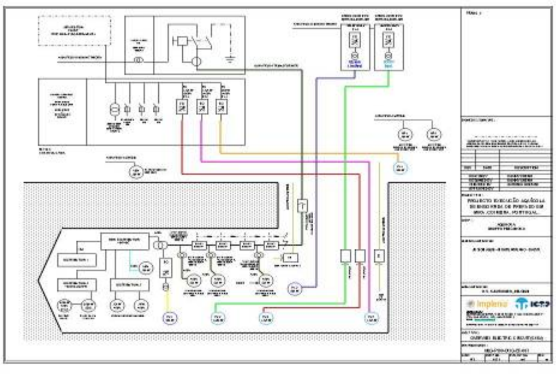
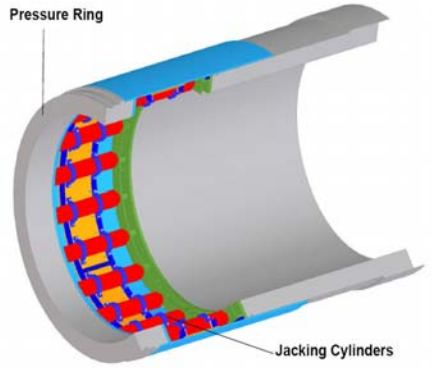


Figure 7. Electric Schema for Medium Tension Voltage Supply

6. AUTOMATIC INTERMEDIATE JACKING STATION

Due to the friction between the external surface of the pipe and the soil the frictional forces increase as the length of the tunnel increases. When a certain retention length has been reached it is no longer possible to jack through the entire route from the main jacking station in the launch shaft. As a result, additional jacking stations in the pipe conduit itself are required. It also has to be taken into account that when launching of a pipe conduit is restarted after being stationary for a period of time considerably more force is necessary. For this reason, as a preventative measure, intermediate jacking stations are provided at intervals at each 150 meter distance and 9 station was installed.



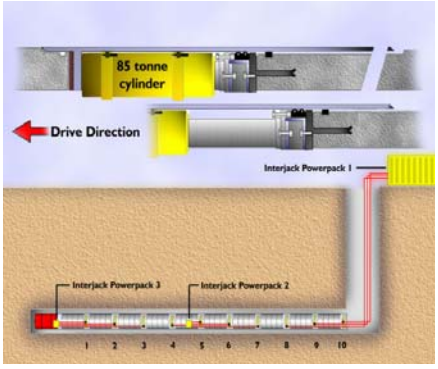


Figure 8. Typical Schema of the Automatic Intermediate Jacking System

The intermediate jacking stations are operated from the control panel in the container. Only one hydraulic supply line per station is required. In order to also keep the hydraulic losses in this area as low as possible, over longer routes half of the stations are supplied from the machine and the other half by a unit in the container.

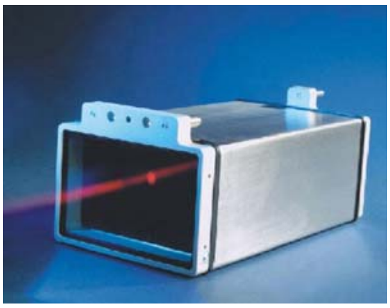
In this project, ICOP implemented the automatic control program (ACIS) from VMT GmBH to create a visual and realtime monitoring of the pressure loading on the intermediate jacking station and the covering pipe section and to operate the station advancement with controller paramterrs and according to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

7. SLS-RV GUIDANCE SYSTEM FOR LONG DISTANCE MICROTUNNELLING WORKS

In this project, ICOP will be incorporate the special guidance system SLS-RV from company VMT GmbH. In this section you will find a short description of the technique. 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 shaft. As the length of the tunnel grows the amount of effort increases, especially as classical measurement can only be carried out when the tunnelling 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.

An active laser target (ELS) is rigidly mounted in the tunnelling machine (see figure 9) as a position reference system.



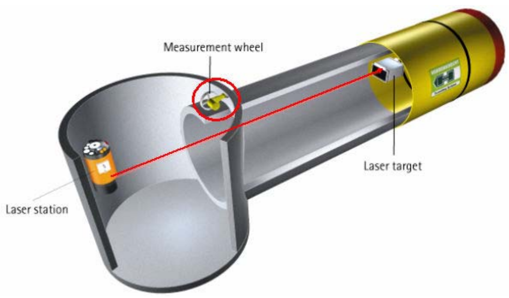


Figure 9. ELS Target

8. AUTOMATIC TUNNEL LUBRICATION SYSTEM

A significant factor for the strength of the tunnelling force is the sheath friction of the pipe conduit 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. Therefore, the reduction and control of the frictional resistance. The frictional force is dependent on the soil to be excavated, the level of the groundwater, the quality of the machine steering and the consistent lubrication of the pipe conduit. The quality of the tunnelling pipes is also of great importance.

The cutting diameter of the cutting head is approx. 40mm 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 depends on the cross section of the pores of the soil and the flow characteristics of the lubricant.

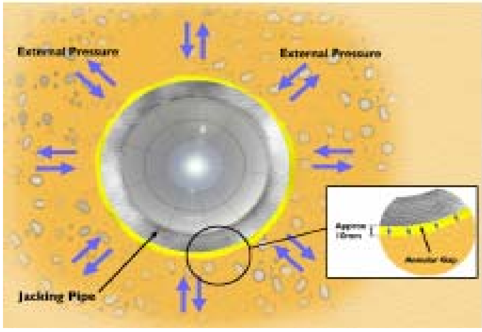
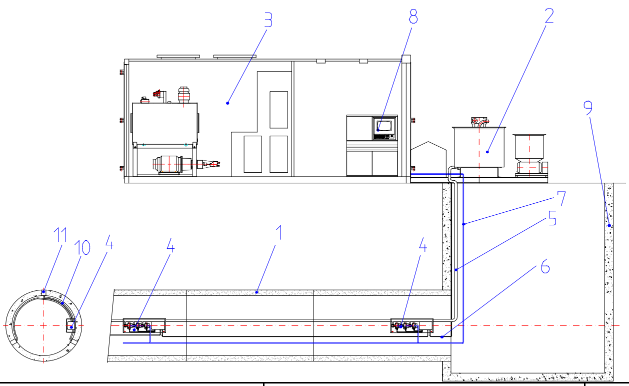


Figure 10. Methodology and Effect of Proper Lubrication System

The bentonite nozzles was 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 was 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 11. Typical Schema for the Automatic Lubrication System

9. AUTOMATIC DATA LOGGING AND CONTROL SYSTEM

ICOP uses the sohphisticated equipment from Herrenkencht AG to keep all parameters and data from the advancement of the tunnel into the system on board in the control cabin. This gives real time measurements, values and etc. for the operator to react and control the microtunneler in means of excavation, speed and etc. The signals from Analog from the front of the microtunneler and along the tunnel is transmitted via a SPS signal cable to the control cabin. This incorporate the utilization of PLC signalling from Siemens S5 & S7 module.

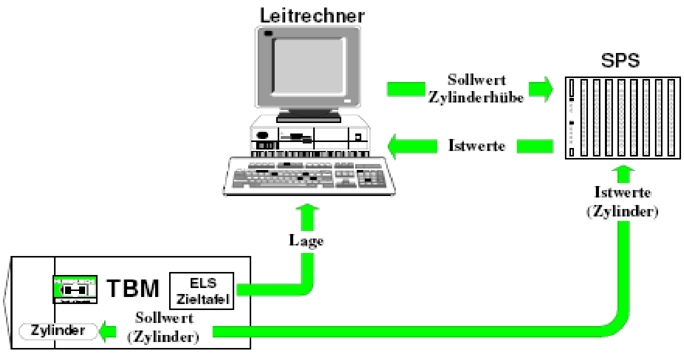


Figure 12. Schema of the Automatic Data Logging and Control System

10. SUBSEA RECOVEY MODE

The requirement of this project is to recover the tunnel boring machine from under the sea bed. This require a subsea recovery module to be installed behind the tunnel boring machine enabling the deep sea divers to dislocate the tunnel boring machine from the 1st concrete pipe. The subsea recovery can consist of 4 hydraulic cylinders that was built-in the steel sleeve and could be activated from the recover ports outside the machine pipe.

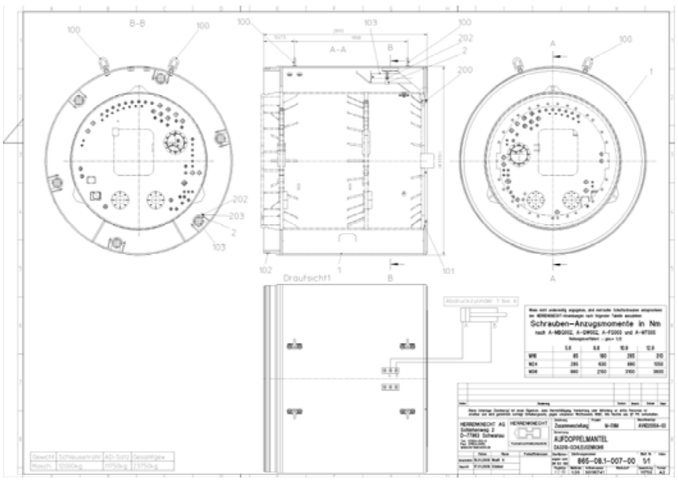


Figure 13. Design of the SubSea Recovery Can

11. DRILLING AND RESULTS

All phases of drilling were performed with great regularity, paying particular attention to compliance with the project parameters. For this reason, in order to prevent any risk of drilling being blocked, work shifts were set to guarantee steady work 24 hours a day (fig.16). The drilling operations were, therefore, completed quickly jacking from the Main Jacking Station and without needing to use the intermediate jacking stations that were set up for any eventuality.

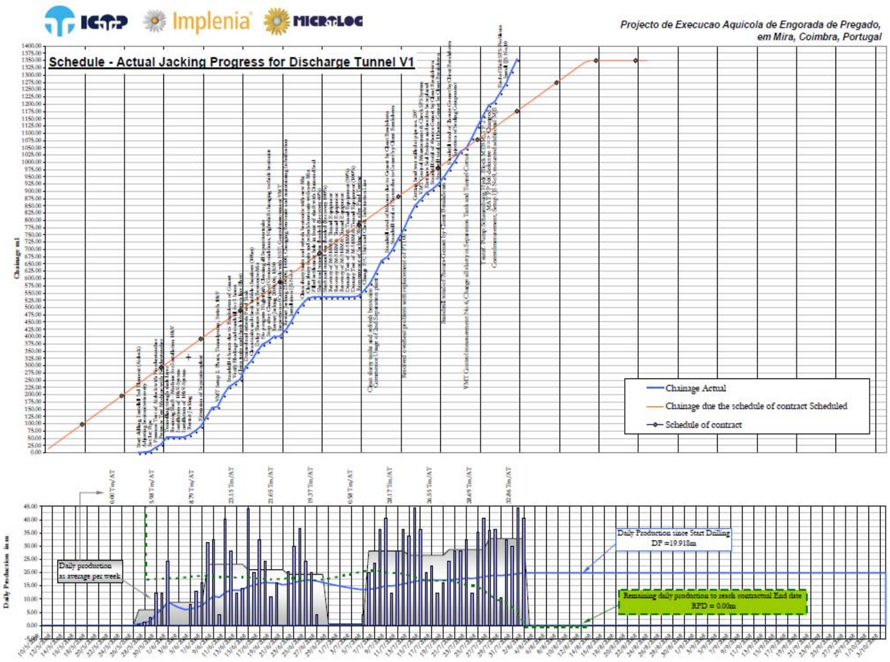


Figure 14. Production Chart

12. SUBSEA RECOVERY WORKS

Dredging of reception pit

A reception pit of sufficient size for removal of the jacking machine is established by using a dredging pump at the sea side end of the drive. The spoil is stored on a transport barge and transported to a dumping area by the barge.

Preparation of TBM for Subsea Recovery Works

Upon completion of the tunnel installation, all tunnel auxillarys, pipelines and tunnel services is dismantle and withdrawns from the pipeline. All measuring equipment from the TBM will be dismounted and safely retrieve to the ground. All the TBM Cans will be botled together tightly to prevent any dislocation during recovery. All slurry valves are shut and lines drained. All ports, connectors, piping on the Airlock Can Lock Wall will be sealed with blind flanges. Then the airlock chamber will be sealed and compress air is filled (approximately 0.7-1.2bar) in the chamber and compressing cum sealing the microtunneler for subsea recovery. Upon checking the sealing of the machine, the tunnel will be flooded to prevent any dislocation of pipes during the recovery works (Different in Pressure)

Flooding of the completed Tunnel

Upon completion of the TBM preparation for Subsea Recovery, the tunnel will be flooded to prevent any dislocation of pipes during the recovery works (Different in Pressure). The filling will be done either from the shaft or from the slurry valve in front of the TBM. The tunnel must be filled up to approximately 50cm higher than the current sea water level. The filling works must only be done when the recovery works are ready.

Dislocation of TBM and Tunnel

Once the tunnel is completely filled above the current sea water level. Divers will approach the TBM and connect the hydraulic hoses from a standalone power pack from the boat towards the subsea ports on the Subsea Can. Once connected and ensure that the path for dislocating the TBM and the Tunnel are clear and no obstruction, the subsea cylinder will be extended. The extension of the cylinder will push and advance the TBM toward the front thus separating the TBM and the tunnel. Once separated, Divers will inform the operator of the standalone power pack to retract the jacks and completed the dislocation works.

Recovery by a deballasting barge

A barge is moored at the position from where the jacking machine shall be recovered. The jacking machine is equipped with lifting eyes on its upper side. A spreader beam is connected to the barge via a rope and then to the lifting eyes of the jacking machine with the help of divers. By deballasting the barge, the jacking machine is lifted up. Water level fluctuations caused by ebb and flood may be considered to increase the lifting height. If necessary, the lifting height may also be adjusted by a winch placed on the barge. The barge or a ship transports the jacking machine to a harbour, where the jacking machine can be removed by a crane.

Figure 15. Recovery by Deballasting Barge

13. CONCLUSION

Advantages of trenchless installation techniques
Sea outfalls or seawater intakes may generally be installed by trenchless or open cut trenching methods. The main benefits of trenchless installation methods when compared to open cut trenching are:

Mnimal impact on the environment due to:

- minimal surface disruption, no deterioration of sea water quality, lower emissions.
- Minimal impact on the existing infrastructure, therefore; applicability in high density urban areas,
- no disturbance of tourism, no limitation of shipping traffic.

Higher lifetime of the pipeline due to:

- less risk of settlements, higher seismic safety; cyclonic weather conditions
- protection of pipeline, e.g. against damage by ships or sabotage.
- Less influence of environmental conditions, e.g. weather and hydraulic conditions like ebb, flood, storm, sediment transport. Minimal efforts for the reinstatement of site after finishing the installation.

Influence of currents on pipelines laid on the sea bottom:
Pipelines laid on the sea bottom are directly influenced by hydrodynamic forces resulting from currents. Typical currents caused by orbital movements of wave particles and near-coast currents can damage pipes especially during heavy sea or storms.

Hydrodynamic forces cause erosion, transport and accretion of seabed material. Offshore buildings in general influence the currents and may lead to heavy erosion or accretion near the buildings.
Pipelines laid on the sea bottom may increase the current velocity and thus turbulences. A two-phase flow of sand and water under the pipeline forms. Scours develop, which depend on the following parameters:

- Vertical current velocity profile, Turbulence, Wave reflexion, Bed material, Bed roughness.

If the pipeline is laid directly on the sea bottom, scouring can lead to a large free span of the pipeline between two supports. If the pipeline is laid on concrete supports, the scouring may cause the supports and the pipeline to sink. The bending radius of the pipeline between two supports may be exceeded and pipeline may break.

Further general advantages of a tunnelled sea outfall: The coast and accordingly the people are not affected. This procedure is environmentally friendly. The tunnel construction works do not depend on the climatic influences such as waves, storms and so on.

Also the installation of the pipe is executed from an onshore jobsite using tunnel techniques; there is no risky handling of the pipeline during installation, floating and connection with expensive offshore equipment and diver teams.ICOP Experience in collobrating the Herrenknecht microtunnelling techniques allows constructions for long sea outfall pipelines which can be jacked deep under the sea bottom – in nearly every geological and topographic condition.