Solving the Challenges of the Santoña-Laredo General Interceptor Collector

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ABSTRACT: The Santoña–Laredo General Interceptor Collector is a 1.5 km subsea tunnel currently under construction in northern Spain and part of the Santoña Marshlands Sanitation Project. It is constructed with a 4.30 m Mixshield TBM, assembled in the tight space of a 12 meter diameter shaft located in an urban area, using fibre reinforced concrete segments. The tunnel excavation passes through two different and consistent geological units withstanding pressures of up to 4 bars. Firstly, a karstified limestone formation in the first section and silty sands of fluvial, lacustrine or marine depositions with pockets of muddy silt in the rest of the alignment. This paper presents the solutions to the technical challenges of the project, the development of these solutions and how they were implemented in the project.

1 INTRODUCTION

The Santoña Marshlands estuary is one of the intertidal areas not only in Cantabria but in the Northern Coast of Spain due to the high biological productivity and its function as hibernation and transit point of several species of migratory birds.

The huge urban development, caused by the tourist inflow due to the natural beauty of the landscape and its beaches, as well as the pressure from other activities on the Marshlands and its waters has led to a loss of quality, requiring an immediate action.

The main goal of the Sanitation of the Santoña Marshlands Project is to eliminate the discharges to the marshland and to restore the quality of its waters.

1.1 *Project description*

The entire project includes more than 85 km of water pipelines, respecting the value of the extraordinary environment where the actuations are being developed. This is the Santoña Marshlands Nature Reserve, protected by the Central and Local Administrations.

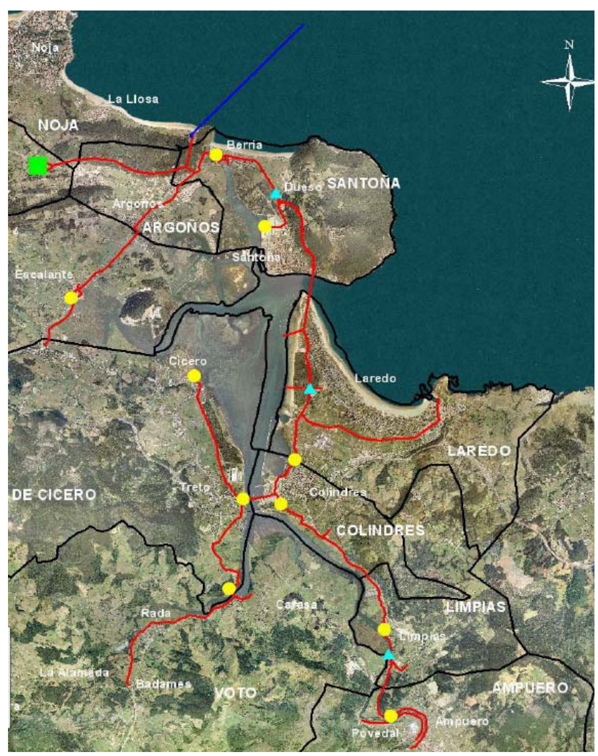

Figure 1. The Santoña Marshlands Sanitation Project

In order to minimize the effects in more sensitive areas one of the adopted measures has been the excavation of several underwater connections and tunnels, avoiding areas of high environmental value as the estuary, the holm oak wood or the sand dunes. The Santoña-Laredo General Interceptor Collector, carrying a double pipeline in a 3.50 m inside diameter tunnel is one of these measures.

The Santoña-Laredo Tunnel will be of 1444 m length, excavated from a 40 m deep shaft located in the urban area of Santoña to a 25 m deep shaft in Laredo. For the excavation of this tunnel a Mixshield TBM with 4.30 m diameter is being used. The final client, "Confederación Hidrográfica del Cantabrico" (Cantabrian Basin Water Authority), is the administration in charge for this project.

Figure 2. Location of the tunnel drive

Due to the location of the Santoña shaft, the lack of available space in the surface for installations and stockyard is one of the constraints of the project. As well as in the surface, the reduced area inside the shaft, spread in two levels (-17 m and -36 m elevation floors), is also another important issue when designing the installations placement and the logistic procedures for the excavation.

The design of the Santoña Shaft requires the ground water level to be maintained under the -17 m elevation. Considering the location of the shaft, at a distance of 50 m from the sea coast, a drainage system through the shaft floor slab and a ground water pumping system are working uninterruptedly.

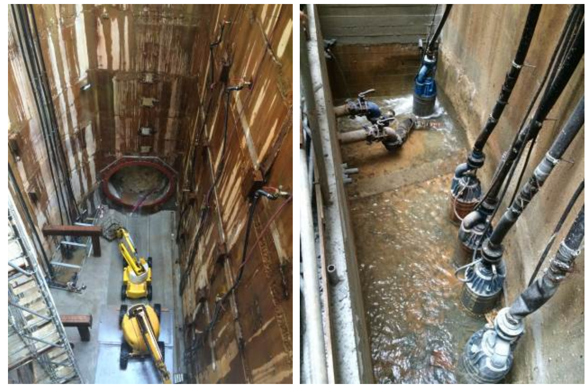

Figure 3. General view of the lower level of the shaft and drainage and pumping system

1.2 *Technical challenges*

The project presents numerous technical challenges:

- Umbilical assembly of the TBM at the bottom of a deep shaft in order to avoid excavation of an assembly cavern;
- Space constraints in the bottom of the 40 m deep shaft and on the surface due to the worksite location in an urban area;
- Expected pressure up to 4 bar and permanent ground water pumping in order to minimize ground pressure against the shaft walls;
- Employment of macro-synthetic fibre as structural reinforcement of the segments due to marine environment and associated corrosion issues;
- Design of the fibre reinforced concrete segments.

2 GROUND CONDITIONS

Geotechnical research conducted on the job site indicated the possibility of finding mixed terrain in the excavation face on a long section, because the project kept the alignment in the area of contact between the bedrock and the fluvial, lacustrine or marine deposits (usually referred to as "badlands").

Although the choice of the TBM was considered to resolve the scenario of excavation fronts with mixed ground, to reduce associated geotechnical risks, a modification of the layout was suggested, avoiding this contact surface as a preventive measure. Thus the problem of finding mixed fronts rock-soil in an important length is avoided or reduced.

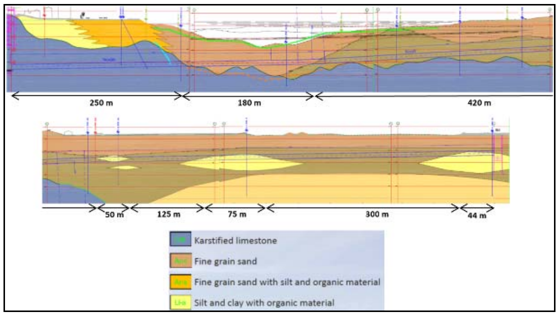

Figure 4. Tunnel alignment and geology

As you raise the alignment a new problem emerges regarding the low cover of soil over the tunnel crown in the vicinity of the channel of the Santoña estuary. This is why a sufficient cover to prevent the lifting (heave) of the tunnel in service is required, even in the worst scenario when a possible future erosion of the seabed of at least two meters in the surroundings of the channel of the estuary can happen.

Table 1. General data of the alignment

Parameter	Value	Minimum	Maximum
Length	1,444 m		
Elevation		-33.5 m (starting)	-12.15 m (finish)
Gradient		0.9%	3.0%
Overburden		10 m	40 m

3 TBM DESIGN AND LAUNCH

3.1 *TBM design*

Considering the ground conditions of the area and taking account of the Client requirements, the tunnel must be excavated using a Mixshield type TBM. A second hand 4.30 m diameter Herrenknecht machine was purchased by the Joint Venture. The Mixshield was manufactured in 2011 and has excavated 4.9 km in another project. Between February and July of 2015, the TBM was refurbished in the Machinery Facilities of Acciona Infraestructuras.

Table 2. Technical data of the chosen Mixshield

Parameter	Value
Excavation diameter	4.30 m
Total length	150 m
Continuous torque	1,200 kN·m
Maximum torque	1,600 kN·m
Main gear motors	4 nos.
Thrust capacity	18,800 kN
Thrust cylinders	11 nos.

3.2 *TBM launch*

One further requirement of the client was that an assembly gallery shall not be excavated. Considering that requirement, the Mixshield had to be assembled in an umbilical mode until the length of the excavated tunnel enables the assembly of all gantries in their normal position.

A special umbilical assembly process has been designed, using the space in both shaft levels to place the essential parts of the back-up in order to excavate in this umbilical mode.

In a first stage of the excavation process, the shield and the thrust pipe have been placed in the bottom of the shaft and the first gantry equipped with the feed and extraction pumps and the control cabin has been placed in an auxiliary structure in the bottom of the shaft.

Figure 5. Assembly of the shield, thrust pipe and gantry 1 (on top of a structure) in the bottom of the shaft

The lateral parts of gantry 3, 5, 6 and 7, containing equipment such as the electrical high voltage panels and transformers, the stone crusher power pack, the mortar injection system and the cooling system has been placed in the intermediate level of the shaft.

Figure 6. Assembly of the lateral parts of the gantries in the intermediate shaft floor

After finishing the assembly of the initial configuration for the shield, thrust pipe and gantries, the excavation has started. During this stage, a "half-ring" structure, made from the segments for the tunnel lining, has been used to push the Mixshield, using only the lower cylinders of the jacking system of the machine.

After starting the excavation and introducing the main shields through the ground, the tailskin has been mounted in the bottom of the shaft. This operation requires the total disconnection of the electrical and hydraulic cables and hoses from the main shields to the first gantry and the removal of the pushing "half-ring" segment structure.

Figure 7. Preparation for the tailskin assembly (left) and complete shield assembly ready to bore (right)

Once the tailskin had been assembled, the "half-ring" segment structure has been placed again and the excavation has continued until the thrust frame and a metallic ring has been mounted as close as possible to the borehole.

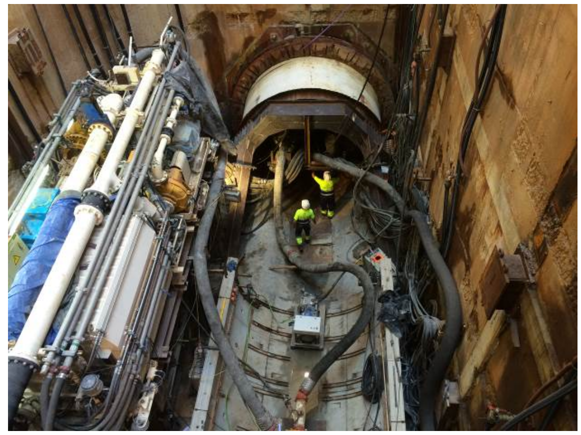

Figure 8. Thrust frame and metallic ring

After the jacking system started its normal operation, using the thrust frame structure, the first gantry "waiting" on the auxiliary structure could be placed behind the tailskin. Before lowering the first gantry two operations were required: placement and connection of the platform between thrust pipe and first gantry and positioning of the first part of the segment feeder.

Figure 9. Lowering of the first gantry to its definitive position and services connection

Another two excavation stages enabled the assembly of the second part of the segment feeder, second gantry and third gantry plus the back-up access ramp (in a temporary situation).

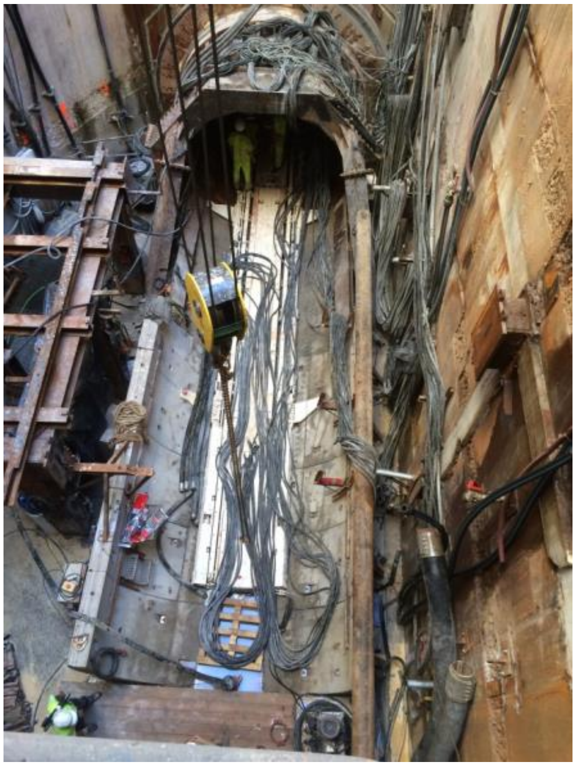

Figure 10. Second part of segment feeder and electrical cable preparation before lowering down second gantry

Figure 11. Cable preparation (left) before placement and mounting gantry 3 to its definitive position (right)

After positioning gantry 3, where the TBM segment crane is placed, the normal segment feeding procedure using the railway convoy could start.

The backfill mortar started to be injected from inside the tunnel, using gantry 3 pumps placed in the intermediate level until this moment. The pumps took the mortar from the mixing tanks that were still placed in the intermediate level until the lowering of gantry 4, in the next stage.

Figure 12. Lifting and positioning of gantry 4 in the bottom of the shaft

After gantry 4 was placed in its definitive position, a provisory ventilation system was required (the secondary ventilation system of the TBM back-up is located in gantry 12).

During all this stages, the electrical cables and water, air, bentonite and slurry hoses were disposed over the shaft and tunnel in a temporary condition and have been extended in a manual way. With the purpose to facilitate the process of extension, cables have been placed in the right side of the tunnel and hoses have been placed in the left side. After the assembly was finished, all the cables and hoses were placed in its definitive position, on the right side of the tunnel.

One of the most difficult operations during all the stages until the end of the assembly was the manipulation and extension of the provisory slurry feed and extraction hoses, used to connect the pipes of the tunnel and TBM.

Next stage consisted of lowering and positioning of the gantries 5, 6 and 7, where all the electrical systems (transformers and electrical boxes) of the TBM where placed. After these three gantries were positioned, all the electrical cables have been disposed along the machine, in their definitive condition.

Figure 13. Disposal of temporary cables and hoses along the tunnel before positioning of gantries 5, 6 and 7.

Figure 14. Disposal of temporary cables and hoses along the tunnel after positioning of gantries 5, 6 and 7.

After all the electrical system of the TBM was working in the definitive position, another stage was the positioning of gantry 8 where the water cooling circuit is located.

Next stage consisted in the positioning of gantries 9, 10, 11 and 12 where all the electric cables and hoses drums are located. As for the rest of the gantries until this moment, all the electrical and hydraulic systems had to be fully disconnected.

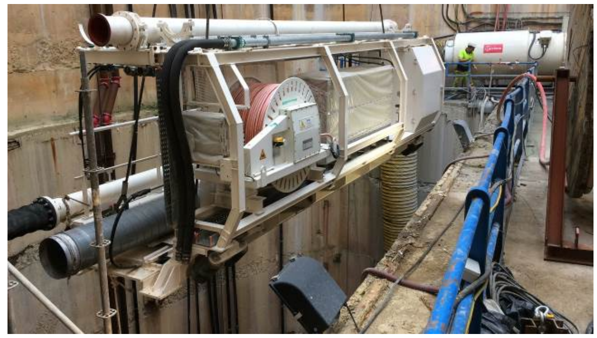

Figure 15. Hoisting of gantry 9

Figure 16. Pushing operation of gantry 9 towards the back-up prior to assembly it in its final position

The final assembly stage consisted of the lowering and positioning of gantries 13 and 14, where the secondary ventilation system, the air duct storage and the slurry pipe extension system are located.

4 SHAFT INSTALLATIONS

Lack of space inside the shaft has been a problem during the assembly stages, as well during the normal operation of the machine. The design of the auxiliary installations inside the shaft needed to meet the requirements of these reduced dimensions.

Also, a dewatering system of groundwater level behind the shaft walls had to be effective during all stages. Due to humidity and salinity of groundwater inflow, dealing with TBM assembly operations led to more difficulties with the tunnel progress.

4.1 *Lower shaft level*

Once the last assembly stage was finished and the TBM was ready to start its normal operation, the bottom area of the shaft needed to be prepared.

The definitive railway system, the air duct and the slurry pumps and valves were some of the elements that needed to be mounted and brought to operation in the bottom level of the shaft

The California rail switch, required to provide a double track in the shaft area, had to be installed inside the tunnel on a length of 35 m.

Figure 17. California rail switch installed in the tunnel

In order to have enough clearance for the train circulation, the air duct needed to be split in order to reduce the diameter along the first 30 m of tunnel.

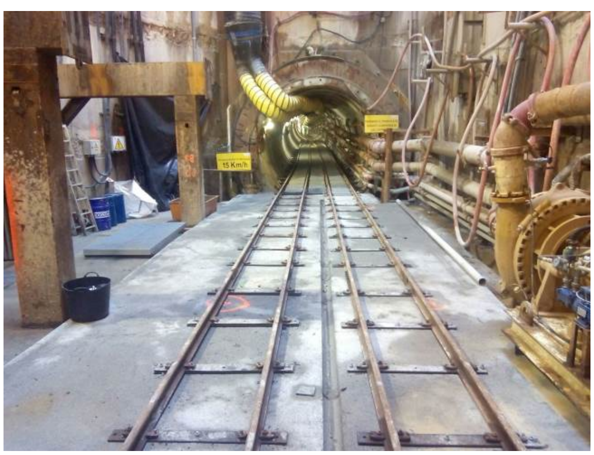

Figure 18. Double truck in the bottom level of the shaft and tunnel entrance with the definitive air duct and pipes

An extraction pump of the slurry circuit as well as a by-pass pneumatic valve system had to be installed in the bottom of the shaft. A precise installation of these elements and the circuit pipes was mandatory in order to avoid significant loss of space.

Figure 19. Double track, extraction pump and pipes located in the bottom level of the shaft

4.2 *Intermediate shaft level*

The ventilator had to be mounted on the intermediate level at -17 m, with a spiral reinforced duct through the upper level of the shaft. This suction duct allows the ventilation system to draw the surface air to pump it to the TBM.

The mortar silos and mixing system were also mounted on the intermediate level. The mortar tanks are lifted from the bottom level to the intermediate level to be filled with mortar and lowered to the bottom of the shaft again.

For this process the gantry crane is used. The placement of the mortar silos in the intermediate level minimized the travel time of the mortar tanks and maximized the available space on the surface for the storage of segments.

Figure 20. Segment silos and ventilator located in the intermediate level of the shaft

5 SEGMENTAL LINING DESIGN

A review of the design and the manufacture of the tunnel segments to meet the aggressive environment led to the decision to replace conventional rebar cages with EPC's BarChip Macro Synthetic Fibre (MSF). Structural MSF can replace or reduce ordinary rebar cages, acting as the primary structural reinforcement. Significant cost savings are often achieved by the use of fibres; mainly by the partial or entire replacement of ordinary reinforcement, but also by improving the robustness, serviceability and durability and hence, reducing maintenance costs.

The initial segment design yielded a conventional steel reinforcement cage of 95 kg/m^3. Regarding improvements in the precast operations and the related cost savings, the main contractor Acciona Infraestructuras reviewed this design with Ingemey Consultores, the final design consultant. Switching to EPC's BarChip fibre reinforcement eliminated more than 80% of the steel reinforcement. The remaining bursting ladders (16 kg/m^3) are solely for jacking forces where the synthetic fibre is the primary segment reinforcement (see Winterberg *et al.*, (2017) for the FRC segment design).

The precast segment plant is located 200 km away from the site, in the facilities of Prefabricados Nava (Asturias, Spain). A stationary precasting mode using four sets of moulds had been used, attaining a shift production of eight rings per day in two shifts.

A cost assessment including segment manufacture and reduced repair or reject rate, due to significantly improved robustness of the segments, revealed a total cost saving of nearly 40%, compared to the traditional rebar cage design. Aside from the direct cost advantages, the switch to the macro synthetic fibre eliminated the rebar cage and its inherent labour and reduced production cycle times by nearly 50%.

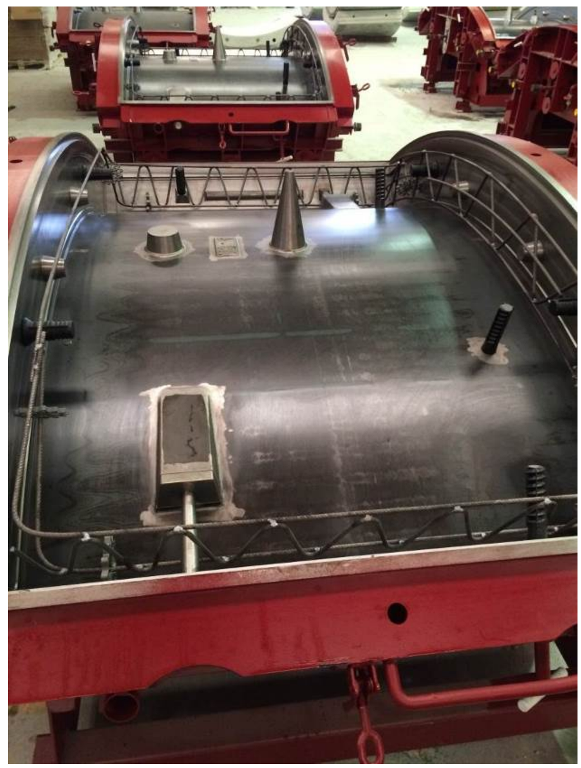

Figure 21. Moulds and bursting ladder preparation

Figure 22. Segment storage in the precast plant

6 TUNNEL DRIVE

Taking into account the complex assembly process and the design criteria for the segmental lining described in the foregoing chapters, it's time to explain the experience of the TBM launch, focusing on the initial stages of tunnel drive, during the introduction of the TBM into the rock mass.

Because of the limited space available in the launching shaft, an interference between the back-up assembly and the usual reaction frame was detected, so it was necessary to design a unusual thrust reaction frame for initial stages of the TBM launch, compatible with the requirements of space and support for back-up units assembly.

This situation led to design a temporary reaction structure consisting of half rings assembled and jointed together. These half rings were fixed and supported on the concrete block by grouting, as the TBM progress required.

In addition, the half ring structure was also used as a support for the gantries during the different stages of the back-up assembly. Therefore this was the best option to meet the thrust and assembly requirements.

Figure 23. "Half-ring" segment structure used to push the mixshield during the start of excavation

In order to verify the stability of the TBM during the earlier launching stages, a static calculation was made looking for the necessary thrust force on every jacking level to meet advance and stability requirements for the TBM, using a safety factor of 1.2 for stability and a working pressure chamber of 1.0 at the top of the cutter head. Theoretical values for the necessary thrust force were obtained under 2000 kN.

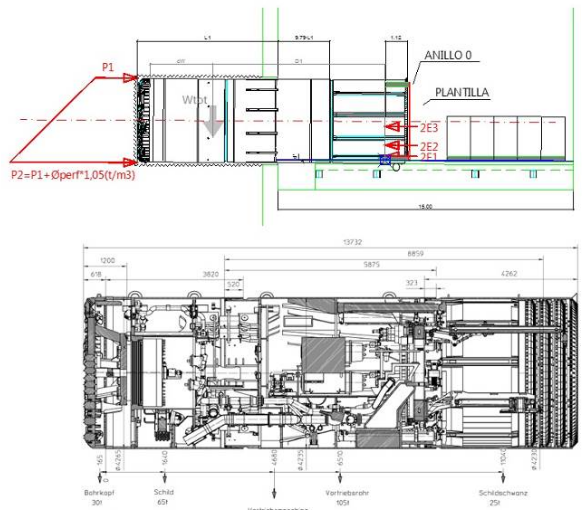

Figure 24. Stability calculation for thrust force estimation on TBM launch.

As the TBM went through the rock mass, the necessary thrust force gradually rose due to increase of friction between the shield and the rock mass surface. Moreover, during the introduction of the main shield into the ground, occasional increases in the water charge were reached at the cutter head, possibly due to the interception of karst cavities connected to the regional water table, increasing work pressure and consequently the thrust force above 10.000 kN.

Asymmetric thrust conditions with elevated forces produced a substantial deviation between the two main shields and tailskin, which was still partially inside the launching shaft. Given the magnitude of the required thrust forces, it was decided to use a steel reaction frame ahead of the half rings that allowed using the whole capacity of the thrust system, so it could mitigate misalignments between the main shield and tailskin.

The use of the steel reaction frame should be avoided with a proper handling of the active joint (joint located between the two main shields of the TBM), normally used for mitigate misalignment of TBM drive. The operation of balancing the eccentric thrust force reaction with the net force of chamber pressure was tested but did not become successful.

Because of the difficulty of driving the TBM under these conditions, the advance ratio was very low with an average of 1.0 meter per day, since every advance cycle required the installation of new half ring and fixing operations. However, lack of space in the launching shaft allowed foreseeing this situation in the study phase.

Once the situation of misalignment between main shield and tailskin was overcome, the force needed to move forward was reduced down to 4000 kN.

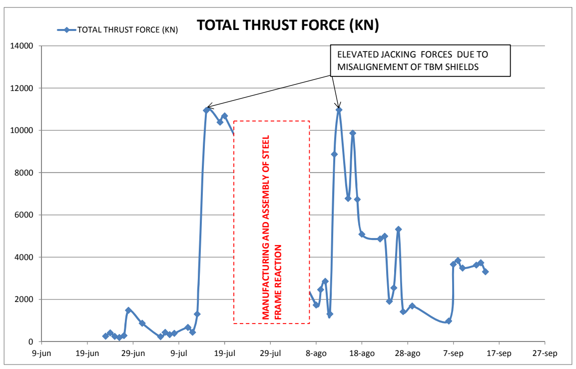

Figure 25. Evolution of thrust force during the TBM launch.

The effects on the segmental lining during these exceptional eccentric thrust forces led to appearance of cracks in the initial rings, producing crack widths over the durability design value. However, the fibre reinforcement assured the stability of the segments even without grout in the annular gap and there is no risk of corrosion to the fibres.

As soon as the contact between rings was improved, using additional PEAD packers, along with a strict procedure of segment installation, the crack appearance of FRC segments stopped.

Once the thrust forces could be reduced to allowable levels, additional packers were no more necessary to be installed between subsequent rings, since the FRC segments remain uncracked as expected in the design phase.

7 CONCLUSIONS

The gained experience in these unusual operations of umbilical TBM launching was important to complete the know-how and will help minimizing the difficulties in future projects during the first stages of boring. Proper use of the active joint could allow an improvement in the eccentric drive conditions, providing the net thrust force in equilibrium with the pressures supported by the cutter head. Furthermore, the usual steel reaction frame can be avoided when the TBM assembly has to deal with a lack of space in the launching shaft.

Summarizing, this experience shows us that launching TBMs in shafts with lack of space is a possible practice, which requires reduced advance ratios, but provides a reduction of shaft structure costs. A reduction in the launching shaft bill of quantities can be reached using a complex vertical assembly of the TBM, but it can be a high skill manpower demanding process.

The successful completion of this project will build further confidence in macro synthetic fibre reinforced segmental linings. The success and gained experience of this project will lead to the implementation of this technology in other tunnel projects.

These types of tunnelling projects (sewage, irrigation or hydropower underground pipelines) are widely present in the world market and they can raise a huge opportunity for fibre reinforced concrete lining and complex vertical assembly of TBMs.

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