New Viola Water Transfer Tunnel

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Abstract

This paper describes the construction of almost 19 km long water diversion tunnel, constructed by means of a double shielded TBM in a mountainous terrain under very restricted environmental conditions. The tunnel was mainly driven through metamorphic rock formations of which micaschist represent the predominant lithotype and in a limited section through limestones and dolomites. Rapid and important squeezing phenomena stopped the TBM advance after 2000 metres of excavation approximately. To overcome the problem SELI have designed and performed some modifications to the TBM, that were carried out inside the tunnel. After the modifications the TBM was able to restart boring without any further stoppage and the excavation of the 18 km long tunnel was completed with excellent and steady productions. In addition to describing method of excavation, TBM characteristics and performance achieved, the paper provides information on lining design concepts and modifications performed to the TBM and its’ back-up to better perform in squeezing ground.

1. Introduction

The “Impianto di Premadio - Nuovo Canale Viola” Project is located in a mountainous terrain to the north of Italy in a region known as “Valtellina” in Central Alps.

The Client, AEM S.p.A., one of the major power producer companies in Italy, awarded the contract for completing the construction of the main tunnel and related works in May 2001 to the Joint Venture between SELI S.p.A. – COLLINI S.p.A. – MONTI S.p.A., of which SELI S.p.A. was the Lead Company.

Modifications to the TBM and its’ Back-Up have been performed by specialists from SELI and WIRTH to enable the machine to advance in the extremely adverse ground conditions with particular regard to the important squeezing phenomena encountered in the metamorphic rock formations with high overburden.

2. Scope of the work and project description

The purpose of the project is to renew the existing water diversion system, which was constructed between 1925 and 1931 and comprises water catchment structures and an hydraulic tunnel to divert the water from several streams (Verva, Viola and other streams) to the lake of Cancano for hydropower generation purposes.

Fig.1 Site view

The tunnel, namely “Nuovo Canale Viola”, has a length of 18.9 km and an excavation diameter of 3.7 metres, while the alignment has mainly North East – South West direction with an overburden varying from 200 metres up to a maximum of 800
metres under the Plator’s Peaks which reach approximately 2900 metres above sea level.

From the portal, located at 1991 metres above sea level within the area belongs to the Stelvio’s National Country Park, the excavation has been carried out uphill using a double shielded TBM manufactured in 1997 by the German company WIRTH GmbH.

The gradient for the first 12500 metres of tunnel is 0.227% then up to chainage 17500 metres changes to 0.783% and for the remaining section of the tunnel changes up to the maximum value of 1.35%.

The lining, constructed by means of 200 mm thick pre-cast concrete segments, gives an internal diameter of 3.04 metres.

3. Site investigation and geological risk

Tunnelling costs for TBM projects are largely time related and therefore strongly dependent on production rates.

It is well known that geological conditions have a great influence on utilization factor, hence on production rates, therefore a reliable prediction of the rock mass conditions and their variability is essential to minimise geological risk.

This risk can be defined as the risk of additional costs due to adverse ground conditions.

It is important to note that, while the risk of encountering adverse conditions can be reasonable predicted by an accurate site investigation campaign, the effect on production rates of such conditions cannot always be predicted and largely depends on TBM design and on construction method.

For the “Nuovo Canale Viola” project a well targeted and comprehensive site investigation campaign, including geological field mapping, boreholes drilling, geophysical surveying, field and laboratory testing and photo-interpretation for all major discontinuities was performed by experts, nominated by the Client, during the design stage.

This accurate investigation campaign allowed a reliable prediction of rock properties and rock mass conditions, including prediction of major faults and zones of poor ground.

On the basis of the predicted geological conditions, critical tunnel sections, in terms of potential excavation instability and squeezing ground conditions, were foreseen.

4. Tunnelling and mucking out methods

Due to the geometrical characteristics of the tunnel, length and diameter in particular, and the geomechanical properties of the rock masses to be excavated, the Client chooses to adopt a mechanised method for the excavation using a double shielded TBM.

This type of TBM is designed to cope with a wide range of rock mass conditions.
with almost constant productivity and have been used with success by SELI in the last 30 years in more than 500 km of tunnels all around the world in the most challenging projects.

Mucking out has been performed by using a muck haulage train composed of a 25 ton diesel locomotive, 10 no. fixed body muck cars for a total capacity of 45 m³, corresponding to two strokes of 1.1 metres each of TBM advance, 1 pea-gravel car and 4 n. of flat bed cars for pre-cast concrete segments handling.

![Fig.3 muck trains and external conveyors](image)

Because of the length of the tunnel, in addition to the Californian switch, which follows the back-up platforms, it was necessary to install, along the tunnel, a train passing station to ensure easy transport and positioning underground at the desired chainage.

It is important to remark that, despite the relatively small tunnel diameter and the length of the tunnel, the muck haulage arrangement enabled the spoil removal and the supply of segments to the TBM of segments, pea-gravel and everything else was necessary for the tunnel construction, from only one access portal, with no major effect on the average advance rate.

**5. TBM and Back-up system description**

The TBM selected for the excavation of the tunnel by the previous Contractor was a WIRTH double shielded machine model SM 360/TS having a standard design for this type of TBMs and general specifications as illustrated in table 1.

**Table 1: TBM General Specifications**

<table>
<thead>
<tr>
<th>General</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Machine diameter</td>
<td>3700 mm</td>
</tr>
<tr>
<td>Main bearing type</td>
<td>Double axial</td>
</tr>
<tr>
<td>Cutters</td>
<td></td>
</tr>
<tr>
<td>Number of cutting discs</td>
<td>24</td>
</tr>
<tr>
<td>Cutting tracks distance</td>
<td>92 mm</td>
</tr>
<tr>
<td>Num. overcutting discs</td>
<td>1</td>
</tr>
<tr>
<td>Max cutter load</td>
<td>220 kN</td>
</tr>
<tr>
<td>Cutterhead</td>
<td></td>
</tr>
<tr>
<td>Max cutterhead thrust</td>
<td>5280 kN</td>
</tr>
<tr>
<td>Drive</td>
<td>4 el. motors</td>
</tr>
<tr>
<td>Power</td>
<td>1120 kW</td>
</tr>
<tr>
<td>Rotation speed (Freq. variators drive)</td>
<td>0 to 14 rpm</td>
</tr>
<tr>
<td>Torque (minimum oper. value)</td>
<td>688 kNm</td>
</tr>
<tr>
<td>Main thrust cylinders</td>
<td></td>
</tr>
<tr>
<td>Boring stroke length</td>
<td>1300 mm</td>
</tr>
<tr>
<td>Number of cylinders</td>
<td>7</td>
</tr>
<tr>
<td>Max thrust</td>
<td>12560 kN</td>
</tr>
<tr>
<td>Auxiliary thrust cylinders</td>
<td></td>
</tr>
<tr>
<td>Stroke length</td>
<td>1900 mm</td>
</tr>
<tr>
<td>Number of cylinders</td>
<td>9</td>
</tr>
<tr>
<td>Max thrust</td>
<td>16000 kN</td>
</tr>
<tr>
<td>Hydraulic &amp; Electric systems</td>
<td></td>
</tr>
<tr>
<td>Max hydr. system pressure</td>
<td>40000 kPa</td>
</tr>
<tr>
<td>Motor circuit</td>
<td>220 V; 50 Hz</td>
</tr>
<tr>
<td>Transformers</td>
<td>2x1000 kVA</td>
</tr>
<tr>
<td>Power supply</td>
<td>15 kV; 50 Hz</td>
</tr>
<tr>
<td>Approximate TBM weight</td>
<td>190 ton</td>
</tr>
</tbody>
</table>

The high power and thrust of this TBM associated with the pre-cast segmental lining system, was necessary to ensure high performance in a wide range of geological conditions.

The Back-Up system, designed to optimize the production cycle by full mechanisation of all operations related to segmental lining installation and muck haulage, consists of a towing connection trailer and 31 rolling decks, carrying all ancillary equipment, plus 1 access ramp for a total length of 213 metres.

**6. Modifications performed to the TBM to cope with squeezing ground**

During the first 2500 metres of excavation, the TBM shields were, in several occasions, trapped by the squeezing forces...
and hand mining works, carried out around the shields, needed to resume the TBM progress.

When SELI took the place of the previous contractor, designed a package of modifications to transform the standard design of the Wirth double shield machine to be able to cope with the expected rapid and severe convergence ground.

These modifications mainly consisted of:

- Improve the efficiency of the cutterhead in collecting all fines produced during the excavation by modifying the cutterhead bucket lips design;
- Increase the clearance between the excavation and the shields/segmental lining ring by increasing the cutterhead excavation diameter;
- Increase the difference in diameter between the forward and the rear shields;
- Eliminate the existing internal step between the inner telescopic shield and the rear shield by having the two shields with the same diameter;
- Create in the bottom section of the telescopic shield an opening to enable easy cleaning of the residual fines in invert area;
- Install a ZED tunnel guidance system with laser target mounted on the front shield and not on the rear as was originally set up on the TBM.

Figure 4 shows the original configuration of the TBM and the design after these modification.

Fig.4 TBM modifications design

Modifications were performed entirely underground in a cavern hand mined around the TBM.

Accurate planning of all activities allowed to complete the TBM modifications in only 3 months, including preparatory works, and commencement of excavation after only 4 months since the date of Contract award.

In addition to the TBM modifications, SELI decided to design and perform also several modifications to the back-up system in order to improve safety during tunnelling operations.

After having performed such modifications the excavation was resumed in squeezing ground and for almost 700 metres (from chainage 2700 m to 3400 m) very rapid convergence, developed closely to the tunnel face, associated with instability of tunnel walls and face was experienced.

Despite the adverse conditions, the modified machine went through this particularly adverse section of the tunnel without any stoppage and successfully complete the 18km long tunnel excavation in a time which can be considered as a record.

An important contribution to this result was the shift arrangement and working schedule, which enabled to work on a seven days a week basis, avoiding excavation stoppages during week ends.
The incredible success of the modifications performed to the TBM, lead SELI to base the design concepts for the newly developed Double Shield Universal TBM on this experience.

The fact that a standard double shield TBM was unable to advance in geological conditions where the same machine, after few modifications to the shield and to the excavation diameter, was able to outperform, gives a clear indication on how important is the detailed design of a TBM.

7. Site logistic difficulties

The particular geographic location of the project area, in addition to the specificity of the works, represents a challenge for the organization and the management of logistic aspects.

The tunnel portal, as a matter of fact, is located at 2000 metres above sea level in a rugged mountainous terrain with difficult access within the National Country Park of Stelvio.

Hence, there are three major causes of inconvenience to overcome in order to minimize the logistical difficulties:

- The altitude, which considering the geographic location, implies a very cold weather in winter time and therefore the need for special protection for the personnel involved with the various operations and for the equipment utilized at the portal area such as for example the mucking out facilities.

- The environmental regulation which imposes a very strict control of all polluted substances produced from the site activities.

- The rugged mountainous terrain associated with the abundant snow precipitation could cause avalanches and therefore a continuous monitoring for the snow condition performed by experts has been arranged on site.

8. TBM performance

The excavation of the tunnel commenced on the 11th October 2001 and was completed after 637 working days at an average advance rate of 25 metres per day.

The 12th July 2002, the maximum daily advance rate of 51 metres was achieved, whilst the best weekly advance rate was 249 metres achieved on the week ending on 30th June 2002 (working week No.36/101).

Figure 6 shows the weekly advance rate for the whole duration of the tunnel excavation.

From this graph is evident the very short period of the learning phase.

This important goal reflect the effort given to this project in terms of planning and scheduling all activities and employing experienced personnel mainly in-house trained.
As can be observed on the graph, the TBM peak productions were negatively influenced as the distance from the tunnel portal increased.

This detrimental effect is particularly evident for the last 3 km of drive.

It is interesting to observe that this detrimental effect regards only the peak values of the advance rate and not the average advance rate; this because the time spent for changing muck trains was partially spent for routinely maintenance and checks.

The TBM was capable to advance with almost constant average production rates for the whole length of the tunnel, despite the changing of the geological horizons and of the locally adverse ground conditions encountered.

By continuous monitoring of both TBM performance parameters and ground conditions, detailed analysis was carried out to optimise performance on site.
In conclusion the performance analysis proves that the Double Shield TBMs, in their most recent Universal design development, as introduced in Val Viola project, are able to cope with a very wide range of rock mass conditions, including rapid squeezing grounds that, until few years ago, were considered beyond the capability of any type of TBM.

9. Special grouting works

Grouting behind the segmental lining with cement based grout mix was carried out after the excavation completion.

Because of the very tight programme of works, which required the completion of the grouting works within 2 months, was decided to perform this activity using grout plants installed outside of the tunnel, pumping the grout mix through pipelines.

It is obvious that the main problem to overcome was the equipment selection and the design of a grout mix that can be pumped at very long distance.

Because of the high strength required to the back-filling material (pea-gravel and cement grout mix) by the technical specifications, trials were carried out to select the appropriate grout mix.

Purpose of these trials was to find the best cement based grout mix in terms of permeation ability through the pea-gravel and good flowability in pipelines for long distance (maximum distance from the grout plant 4000 metres approx.).

![Fig.11 External grouting station – piston type pumps](image)

To satisfy the strength specification and the technical requirements (permeability and flowability) it was necessary to utilise high early strength cement type 52.5R and a superplasticizer to reduce the w/c ratio.

The grout mix selected was as follows:

- Cement 52.5R 1100kg/cum mix
- W/C ratio 0.6
- Additive 7 litres/cum mix

Quality control was performed on site by frequently check the rheological properties of the grout mix; standard viscosity for the selected mix was 48s measured by Marsh funnel and required density was 1710 kg/cum measured by beam balance.
Because of the very long distance the pumps of the grout station were specially designed and built and tests were carried out to find out the maximum pressure in pipeline at increasing distance (a pressure of 200 bar were recorded at 4000 metres distance approximately).

1 inch diameter pipeline was selected to prevent segregation along the pipes.

The quantity of grout mix to be injected was estimated in 700 litres per linear metre of tunnel and on this basis, equipment, cement storage capacity and cement delivery to sites were established.

10. Conclusions

Despite the selected machine was built by an experienced and reliable TBM manufacturer, this project proved that is also necessary to employ a Contractor also experienced and capable to follow up the TBM design and construction process, suggesting to the manufacturer the technical details which can substantially modify the machine behaviour during the excavation.

From this experience the following considerations can be made:

- The same TBM, after few modifications was capable to proceed with the excavation, with almost constant production rates, regardless the extremely rapid squeezing phenomena encountered, and complete the excavation in a very short time, proves how important is the design of TBM details;

- The accurate planning of the modifications and the use of highly specialised personnel, enabled SELI to take place of the previous Contractor, perform the modifications inside the tunnel and resume the excavation in very short time.

References

