Olympic Games 2014 transportation system
The TBM tunnelling story

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ABSTRACT

The Olympic Games 2014 transportation system includes 12 tunnels with a total length of around 28km. The tunnels will be used as rail, road or service tunnels.
The paper will discuss the following 4 tunnel projects:
• Tunnel #3 South, Herrenknecht Hardrock-TBM, traffic tunnel, length 3.199m
• Tunnel #3 South, Lovat/CAT-Seli RM394DS, railway tunnel, length 4.631m
• Tunnel #3 North, Lovat/CAT RME 232SE, service tunnel, length 2.627m
• Tunnel #5, Herrenknecht EPB-TBM, railway tunnel, length 2.910m

The encountered geology is highly variable, from soft clay and argillite to semi-hard highly fractured tuff, sand stone and porphyry, soft argillaceous slates and stiff clay, semi-hard to hard fractured limestone as well as multiple fault zones with highly weathered unstable rock formations.
In order to mine successfully through these highly different soil and rock formations, BASF foams & polymers for soil conditioning, anti-abrasion-additives, tail seal greases as well as injection additives have been used.

1 INTRODUCTION

Sochi, located 500km east of Sevastopol at the border of the Black Sea, situated in a wonderful subtropical climate area, is generally known as ‘Summer Capital’ of Russia - not very plausible to host Winter Olympics. However, at a distance of only 60 kilometres from the centre of Sochi by road and 40 kilometres from the Sochi-Adler airport, the city Krasnaya Polyana with an altitude of 600m is sited against the scenic backdrop of the Caucasus Mountains, which exceed 2,000 meters in altitude – being perfectly qualified to host Winter Olympics.
The existing transport logistics consists of a small road connection from Adler to the ski-resort Krasnaya Polyana – making it however absolutely impossible to handle all the Olympic visitors. In consequence, a totally new express highway and rail link connection had to be designed and built – generally following the alignment of the river Mzymta. Several mountain ranges have to be crossed on the way up to Krasnaya Polyana, being responsible for the tunnelling system described in figure 1.

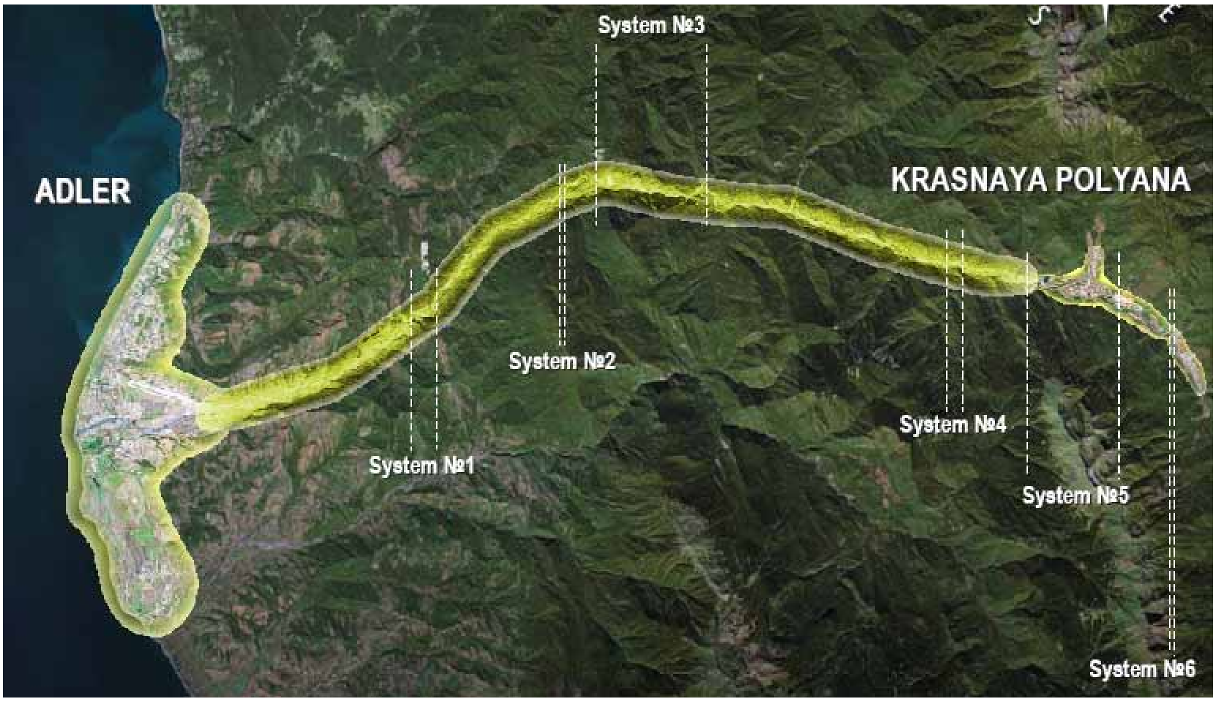

Figure 1: Location of the Olympic Games 2014 tunnel systems

The tunnelling system consists of 2 more or less parallel rail and road tunnels plus one service tunnel. For the rail and road tunnels, both traditional and TBM tunnelling method have been used, the service tunnels have been bored by TBMs only. Figure 2 illustrates the different tunnel configurations.

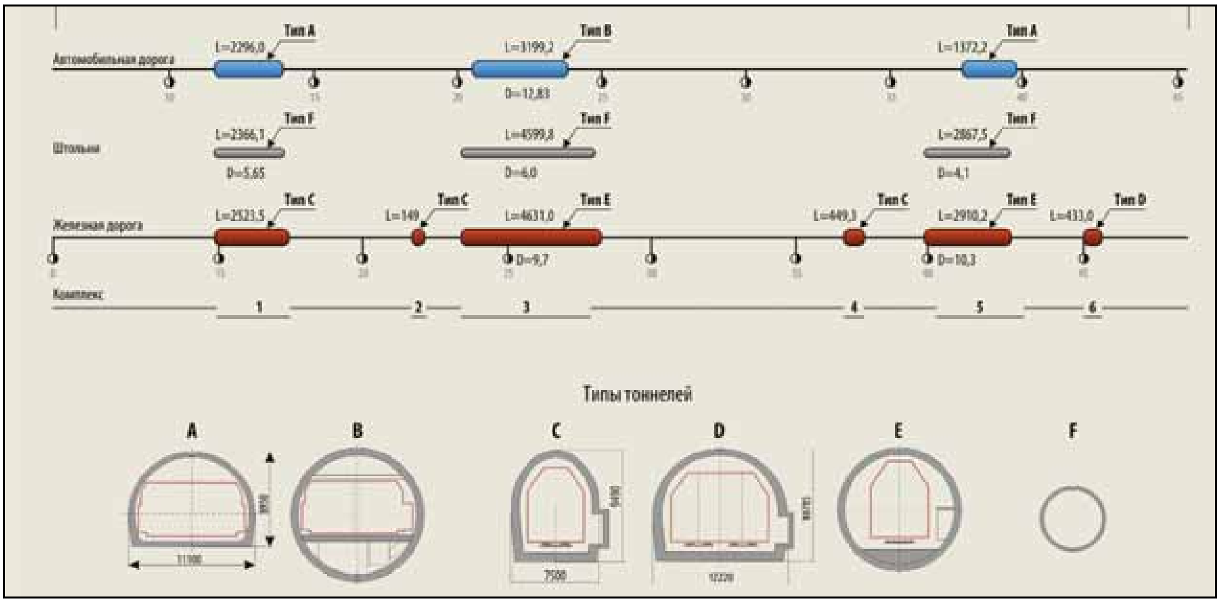

Figure 2: General tunnel configurations Adler – Krasnaya Polyana

2 PROJECT DETAILS

2.1 Railway Tunnel #5

Bamtonnelstroy Tunnel Division #18 used the Herrenknecht S-517 EPB machine to build the 2.910m long railway tunnel #5. The construction took place from April 2010 to January 2011.

The TBM was driven in an open mode as well as in the full EPB mode. Additionally, the air pressure mode was used depending upon the geological conditions.

S-517 TBM details
- cutterhead diameter: 10,690m
- cutterhead tools: 50 single cutters + 6 double disc cutters
- spacing: 100m
- maximum torque: 26.857 MNm (standard: 21.200 MNm)



Figure 3: S-517 cutterhead view and launch April 2010

The Geology along the tunnel alignment was quite variable - starting from soft clay and argillite at the northern portal to semi-hard highly fractured tuff, sand stone and porphyry in the middle of the tunnel and soft argillaceous slates and stiff clay in the second half of the drive. Unfortunately, the argillite became very sticky after being processed by the cutterhead.

2.1.1 BASF soil conditioning concept

Due to the very challenging mining conditions, BASF offered a full-range concept in order to maximize the efficiency for the contractor. The geological conditions required the application of 3 different BASF soil-conditioning agents at different sections of the tunnel:
- MEYCO SLF 41 foam for the soft soil at the portal area
- MEYCO ABR 5 anti-abrasion agent for the limestone rock
- RHEOSOIL 143 anti-clay agent for the stiff clay.

Furthermore, MEYCO TSG 6 tail sealant was used to prevent water ingress into the TBM.

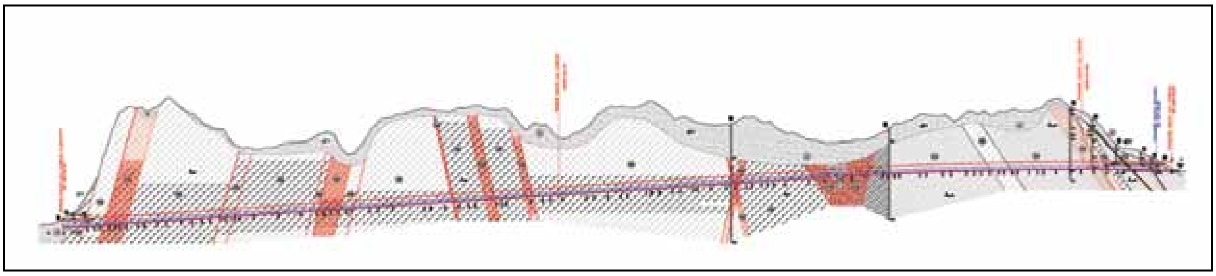
Figure 4: geological profile of tunnel #5, including numerous fault zones

The main difficulties from the soil conditioning point of view were the quite frequent changes of geological conditions. Within 5-10m distances, changes from limestone to stiff clay were observed - which could change back to limestone again during the next 5m. To keep mining successfully and fast, it was necessary for the TBM operator to be able to switch quickly from one type of the soil conditioning agent to another. Accordingly, out of the 4 storage tanks at

the TBM gantry, 2 were filled with the anti-abrasion agent MEYCO ABR 5 and the remaining 2 tanks were filled with the anti-clay agent RHEOSOIL 143. The operator could then switch instantly out of the driver's cabin from one additive to another during mining.
Right after the TBM entered into the argillite zone, the main problem were big clay balls coming onto the belt. The anti-clay agent RHEOSOIL 143 proved very successfully to be a perfect solution to avoid the creation of clay balls and increase significantly the TBM speed.

Figure 5: Clay balls on the belt without and with Rheosoil143

A very important parameter is the cutterhead torque. It is an excellent indicator about the actual machine situation and the ground treatment. For comparison, the torque during hard rock excavation in open mode was around 12-13 MNm
During excavation in soft ground geology, the medium torque dropped for the open mode significantly about 30% down to 7,5-9 MNm. Changing into closed mode, the cutterhead torque increased drastically to the maximum installed torque of 25-26 MNm – when no soil conditioning agents were used (compressed air mode). The use of MEYCO soil conditioning agents enabled a torque reduction of about 30% down to 17-18 MNm – enabling the TBM driver to work with a completely filled working chamber and constant and high TBM speed. And – of course – lots of energy could be saved in addition.
The EPB pressure that was used reached 0,4-0,7 bar at the TBM crown and up to 4 bar at the TBM bottom.
In average, the advance rate reached 335m/month, attaining maximum rates of advance of 400m/month. During open hard rock mode the TBM speed was 25-30 mm/min (7-10 rings/day (12,6-18m)), during closed EPB mode the TBM reached speeds of 30-55 mm/min (10-16 rings/day (18-28,8m)).

2.1.2 Changing the excavation method from open mode to closed EPB mode

The key parameters that were securely controlled during mining in EPB mode were:
- Pressure in the TBM chamber
- Cutterhead torque
- Quantity of excavated muck (to avoid over excavation compared to the theoretical value (for this TBM it should not exceed 0,89-0,91 m^3 of muck per every 10 mm of TBM advance).

When the monitoring of the above parameters indicated a necessary change from open mode to EPB mode, the main problem was the rapidly growing torque at the cutterhead and the screw. In average, cutterhead torque and screw torque increased by around 20-30% compared to open mode excavation in the same type of ground. As soon as the cutterhead torque started growing, the TBM operator was increasing the foam injection to the cutterhead face from FIR=40% up to FIR=60% using the anti-clay agent RHEOSOIL 143. Also two additional foam lines were installed to inject foam inside the TBM chamber in order to reduce further the torque (rotation resistance) and in order to obtain a better mixing of soil and foam before it comes into the screw conveyer. Such measures allowed decreasing the cutterhead torque from 25-26 MNm in clay, which is critical for this machine, down to 17-18 MNm.
Generally it turned out to be very positive, that an EPB TBM was used for this tunnel #5 – instead of the initially planned hard rock TBM. The different operations modes and of course the higher installed cutterhead torque enabled the TBM to drive successfully through the

different soil and rock formations as well as through the fault zones. The use of a standard hard rock TBM would have been much more difficult, as described for tunnel #3 south.

Figure 6: S-517 breakthrough on February 2nd, 2011

2.2 Traffic Tunnel #3 South

The 3.911m long traffic Tunnel #3 south was built by using a Herrenknecht S-534 hard rock TBM. Construction period: November 2010 – November 2011. Average rate of advance reached 200m/month with maximum advance rates of 400m/month.

Cutterhead configuration:
- diameter 13210 mm
- total number of disc cutters 77 (65 single disc cutters + 6 double disc cutters)
- spacing between discs 100 mm in the center
- opening factor: 8,4%
- cutterhead torque: 13.400 MNm

Figure 7: S-534 cutterhead view and launch

The geology is mainly formed by semi-hard to hard fractured limestone and porphyry that are quite stable and favorable for mining except that there are also 4 fault zones with highly weathered unstable rock formations as indicated in figure 8. Additionally, at the both portal zones there were major landslides that needed to be handled separately.

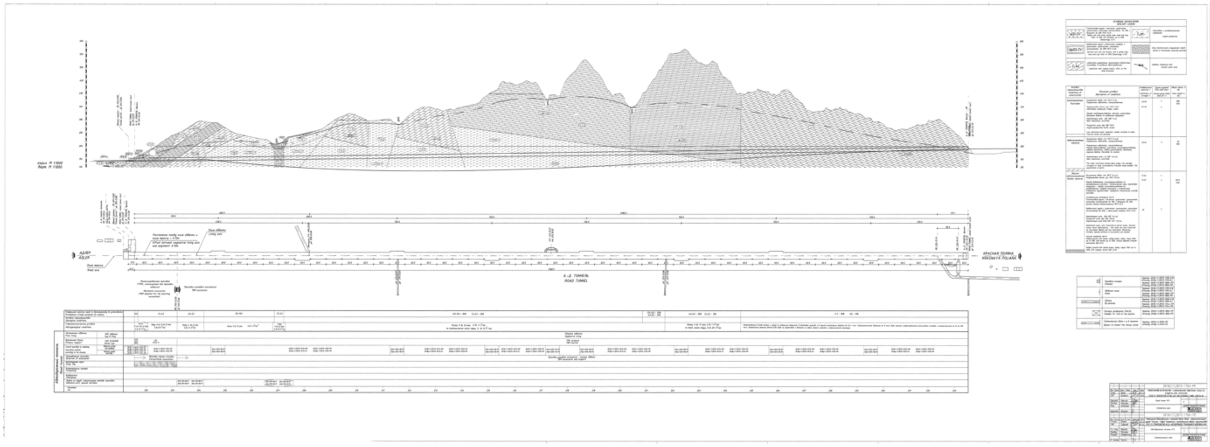

Figure 8: Geology tunnel #3

Mining conditions at the tunnel #3 required the application of 2 different BASF soil-conditioning agents:

- MEYCO ABR 5 anti-abrasion agent for certain hard rock zones
- RHEOSOIL143 anti-clay agent for the main part of the tunnel to prevent the cutter head blocking with muck and keep the belt clean. Furthermore, MEYCO TSG 6 tail sealant was used.

From the soil conditioning point of view, no big difficulties have been encountered. Rheosoil143 proved to be a good solution to keep the cutterhead and belt clean and ensured a high rate of advance. The main challenge during mining was to pass through the 1st and the 2nd fault zone where the TBM got stuck after a tunnel crown collapse. In order to get the TBM liberated, a conventional tunnel had to be built.

For the following fault zones, a pre-injection concept was developed together with Amberg Engineering and Bamtonnelstroy. BASF pre-injection and soil stabilizing material like MEYCO MP 355 polyurethane and MEYCO PM 320 silica have been widely used. When mining through the consolidated fault zones, RHEOSOIL 143 was used to ease boring and avoid clogging problems.

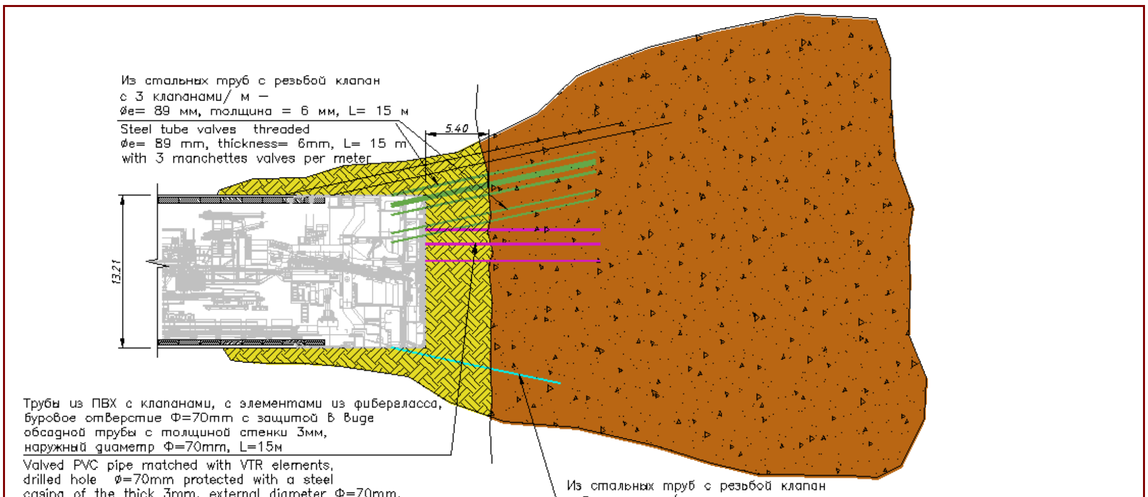

Figure 9: pre-injection from the TBM into the fault zone

During the limestone and porphyry hard rock sections, the anti-abrasion additive MEYCO ABR 5 has been used replacing the standard water injection. Statistics on average disc cutter lifetime based on the disc cutter replacement data through 2.500m TBM drive lead to the conclusion, that disc cutter lifetime has increased in average by 20-25% against normal wear and disc wedging could be reduced by 15%.

Figure 10: Rock treated with water spray (left) and with ABR5 anti-abrasion additive (right)

2.3 Railway Tunnel #3 South

The 4.631m long railway tunnel #3 south was built by using a Lovat/CAT-Seli RM394DS double shield hard rock TBM. Construction period: May 2010 – December 2011. The average rate of advance was 185m/month with a maximum rate of advance of 450m/month. The TBM was driven in open hard rock mode only.

Figure 11: Lovat/CAT-Seli RM394DS cutterhead and launch

The geology of tunnel #3 (south) is approximately the same as for the parallel traffic tunnel, formed by semi-hard to hard fractured limestone and porphyry that are quite stable and favorable for mining except for the 4 fault zones with highly weathered unstable rock formations.

Mining conditions at the tunnel #3 required application of MEYCO ABR 5 anti-abrasion agent for certain hard rock zones and RHEOSOIL 143 anti-clay agent to prevent the cutter head blocking with muck and keep the belt clean. This TBM was not equipped with a tail seal system.

From the soil conditioning point of view no big difficulties have been encountered. RHEOSOIL 143 again proved to be a good solution to keep the cutterhead as well as the conveyor belt clean and allowed a high rate of advance.

2.4 Service Tunnel #3 North

The 2.627m long service tunnel #3 north was built using a Lovat RME 232SE EPB TBM. Construction period: Jaunary 2011 – September 2011. The maximum rate of advance was 350m/month. The TBM was working in open mode as well as in full EPB mode.

Figure 12: Lovat RME 232 cutterhead view and launch

At the tunnel #3 (north) geology is mainly formed by siltstone, marl and mudstone - which usually became quite sticky after being processed by the cutterhead.
The mining conditions at the tunnel #3 north required the application of RHEOSOIL 143 anti-clay agent to prevent the cutterhead from blocking with muck. MEYCO TSG 6 tail seal grease was used to fill the brushes to prevent water ingress inside the TBM. MEYCO EPB 11 EP2 main bearing lubrication grease was also used. RHEOSOIL 143 once again proved to be a perfect solution to keep the cutterhead and the overall TBM clean to keep high rate of advance.

6. CONCLUSIONS

Generally, the TBM tunnels have been built successfully within the given timeframe. Apart from the landslide situation, the main tunnelling difficulties were the fault zones as well as the stickiness of the clayey soils.
The EPB machines drove relatively quick and easy through the fault zones as well as through the hard rock zones. The change from open mode excavation to closed EPB mode did work well after certain training and underlined well the flexibilities of the EPB TBMs. Also for the double shield hard rock machines it was much easier to manage the fault zones – only the 13,20 m single shield hard rock TBM got stuck several times and had to be liberated by conventional tunnelling.
But successful TBM tunnelling needs more than only the right selection of TBMs, also the correct choice and use of soil conditioning agents, anti-clay agents as well as anti-abrasion agents has a significant impact on the tunnelling speed and the overall cost situation. In case such high performance additives are used, it is essential to perform on-site training together with the TBM personal in order to demonstrate the soil conditioning benefits and establish exact criteria for necessary change of additives or for the necessary change of parameters of the additive in use.

ACKNOWLEDGEMENTS

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