La construction de deux tunnels dans des conditions de contrainte-déformation difficiles: les résultats de la première comparaison réelle entre NATM et ADECO-RS

The construction of two tunnels in difficult stress-strain conditions: the results of the first real comparison between NATM and ADECO-RS

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Résumé

Les XXII Jeux Olympiques d'hiver ont eu lieu en Février 2014 à Sochi (Russie). La Fédération de Russie a fait une série d'investissements majeurs dans la ville afin de combler le manque d'infrastructures et de donner l'accès nécessaire aux stations de ski et le village olympique à Adler. La nouvelle Rocade de Sochi est une de ces nouvelles infrastructures et sera composé de huit tunnels bitubes pour une longueur totale de 16 kilomètres. Pour ces importants travaux la Fédération de Russie a eu l'occasion de tester les meilleures et les plus innovants des technologies existantes au niveau international pour l'excavation souterraine. Pour la similitude de la géologie à Sochi avec l'un des Apennins italiens, le gouvernement russe a décidé d'appliquer l'approche ADECO-RS pour percer le tunnel le plus long et le plus complexe de la Rocade de Sochi, avec le conseil de Rocksoil SpA pour la conception du tunnel. Toutefois, les autres tunnels le long de la Rocade, tous dans des conditions géologiques similaires, sont entraînés en utilisant NATM, comme d'habitude en Russie. Les travaux de construction ont déjà commencés et tous les tunnels progrèssent en parallèle, il est donc le premier véritable comparaison directe, dans des conditions difficiles, tout à fait semblable, entre NATM et ADECO-RS. L'expérience acquisée dans l'excavation des tunnels de Sochi en utilisant NATM ou ADECO-RS sont présenté et comparé dans le document.

Abstract

The XXII Olympic Winter Games took place in February 2014 in Sochi (Russia). The Russian Federation made a series of major investments in the city in order to fill the lack of infrastructures and to give the necessary access to the ski areas and the Olympic Village in Adler. The new Sochi By-pass is one of these new infrastructures and will consist of eight twin-tube tunnels for a total length of 16 kilometres. For these important works the Russian Federation took the opportunity to test the best and most innovative technologies existing at the international level for underground excavation. For the similarity of the geology in Sochi with the one of the Italian Apennines the Russian government opted to apply the ADECO-RS approach to bore the longest and most complex tunnel of the Sochi By-pass, with the consultancy of ROCKSOIL S.p.A. for the tunnel design. However, the other tunnels along the by-pass, all in similar geological conditions, are driven using NATM, as usual in Russia. Construction works have already begun and all tunnels are progressing in parallel, it is therefore the first real direct comparison, under quite similar difficult conditions, between NATM and ADECO-RS. The experiences gained in the excavation of the Sochi tunnels by using NATM or ADECO-RS are reported and compared in the paper.

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1 Introduction

During the preparation for the XXII Winter Olympic Games in Sochi (Russia) from 7 to 23 February 2014, the Russian Federation allocated important investments in fixing the city's lack of infrastructure and in strengthening its transportation web. One of these projects is the new Sochi by-pass motorway, also known as "the alternative to the Kurortnyi road", which runs parallel to the black sea and makes it possible to reach the Olympic sites and the Adler airport without having to cross the city.

Construction of the new artery, which remained of decisive and strategic importance, presented many obstacles, especially regarding the short time slot available. Indeed, the project required the construction of eight double-bore natural tunnels, as well as open-cut sections, embankments and bridges for a total length of 16 kilometres (fig.1). In searching for a solution, the Russian Federation heard about the exceptional success of the ADECO-RS approach, used in Italy to build more than 100 km of tunnel – between line tunnels, access tunnels and safety tunnels – for the high-speed railway between Bologna and Florence (within the territory of the Tuscan-Emilian Apennines, which presents similar grounds to those of Sochi). The Federation therefore decided to minimize risks and to adopt the same approach for the design and for the construction of the 8 and 8A tunnels (these two being the longest and most complex of the motorway) after verifying the reliability of the approach by sending Russian technicians to investigate the major Italian ADECO-RS tunnel sites. Following this decision, Rocksoil S.p.A. in Milan was appointed the detailed design in 2010, followed by the working design of the two tunnels as well as the necessary technical assistance during construction.

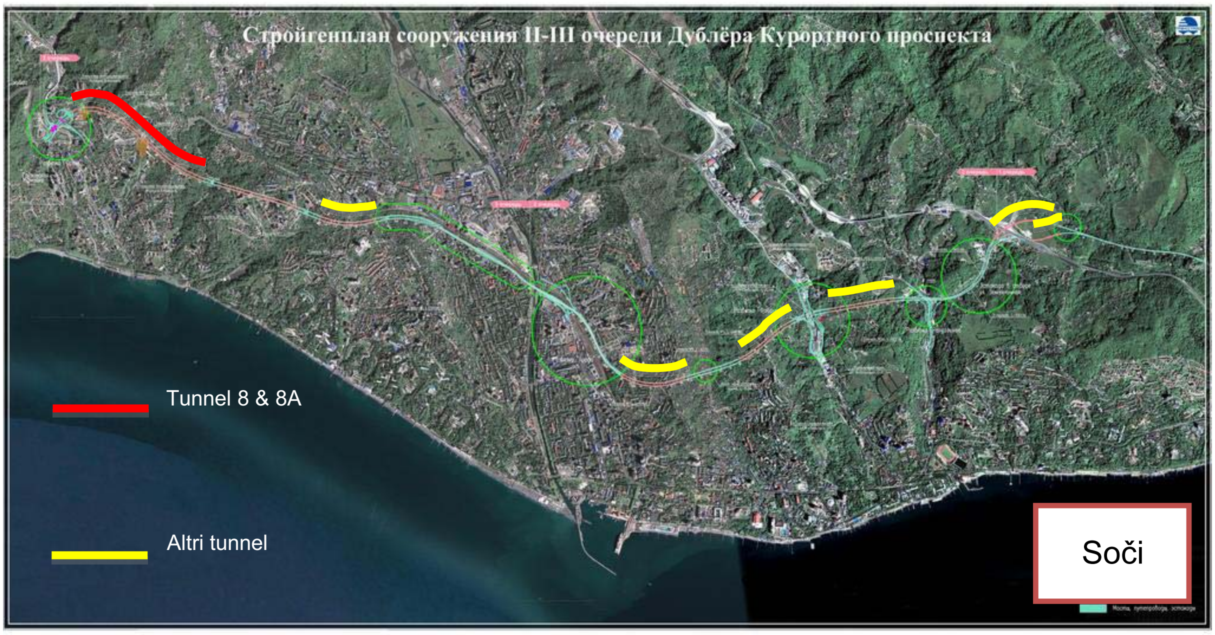

Figure 1. The "alternative to the Kurortnyi road"

2 The project

The new Sochi by-pass motorway presents two separate carriageways, each with 2 lanes per direction, adjusted for a design speed of 120 km/h. Construction required the excavation of a series of tunnels. Of these, the T8 and T8A were the most difficult due to the geological context faced as well as – considering the reduced times available to design, construct and open the works – due to the length of the underground layout (1,550 m for the T8 tunnel and 1,523 for the T8A tunnel) and due also to size of the excavation faces, which could vary from 120 m^2 up to 220 m^2. The project required the construction of 3 lay-bys in the tunnel and the implementation of widened face sections, so as to guarantee necessary visibility on bends. Furthermore, at the exit from the northern portal, the tunnels needed to welcome 3 lanes for the presence of an important junction connecting the new road with the existing one. Added to this was the low average coverage of the crown, in a heavily anthropized context.

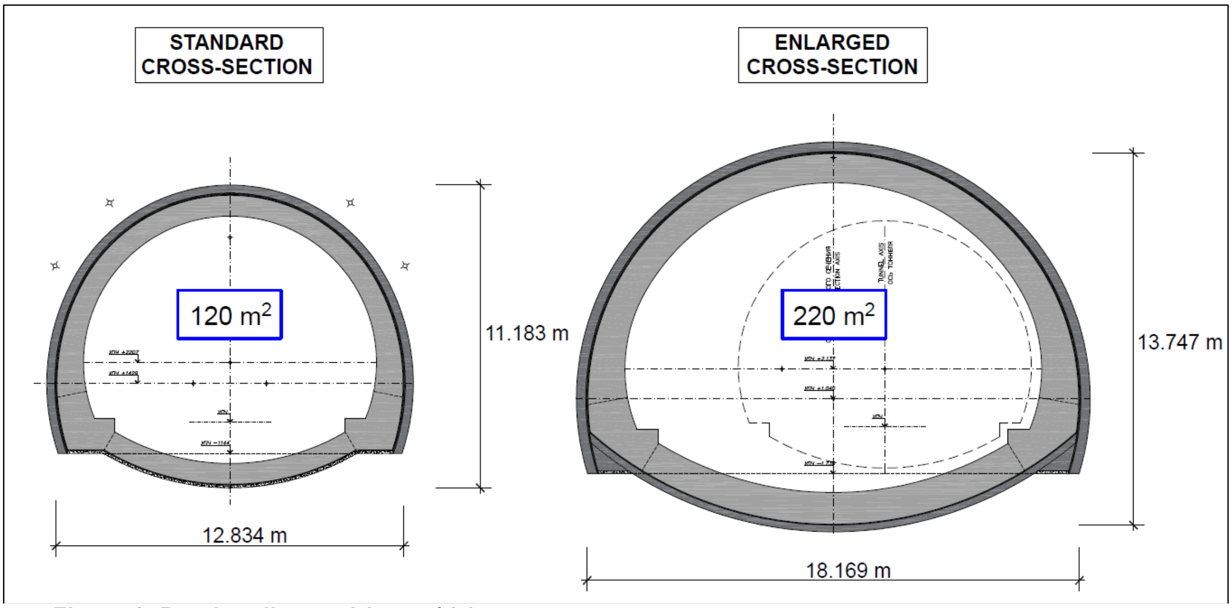

Figure 2. Road outlines - 2 lanes / 3 lanes

Figure 3. Standard and widened outline

2.1 Geology and Geotechnics of the T8 and T8A tunnels

2.1.1 The geography of Caucasus

Sochi is located at the western slope of the Caucasus Mountains, a chain which stretches for around 1,100 – 1,200 km between the Black sea and the Caspian Sea. Like the Italian Alps, the mountain system formed during the Cenozoic era - around 25 million years ago - following the collision between the Arabian plate and Eurasian plate.

The Caucasus mountain chain is actually made up of two separate chains: the Greater Caucasus and the Lesser Caucasus, these run parallel to each other, separated by the valleys of the Kura and the Rioni rivers, and finally meeting again at the Surami pass (949 m a.s.l.). The Greater Caucasus stretches between the cities of Sochi and Baku, and is today the political frontier between Russia in the north and Georgia and Azerbaijan in the south. On the other hand, the Lesser Caucasus passes through the states of Georgia, Azerbaijan and Armenia. Many of the peaks are higher than 5000 m, such as Mount Elbrus (5642 m), the Dykh Tau (5205 m), the Shkhara (5200 m), the Koshtan Tau (5144 m), the Janga (5051 m) and the Kazbek (5047 m).

The project layout of the T8 and T8A regards a coastal hill belt, with softened morphology and mostly made up of low elevations with a rich vegetation. This coastal path is part of the southern slope of the Greater Caucasus and is crossed by many rivers and canyons. The distinctive trait of this hill landscape is the high geomorphological dynamicity – the result of many factors interacting with each other: the current rise of the area, the following exogenous processes of disaggregation and - not least of all - the typical climate of this coastal area.

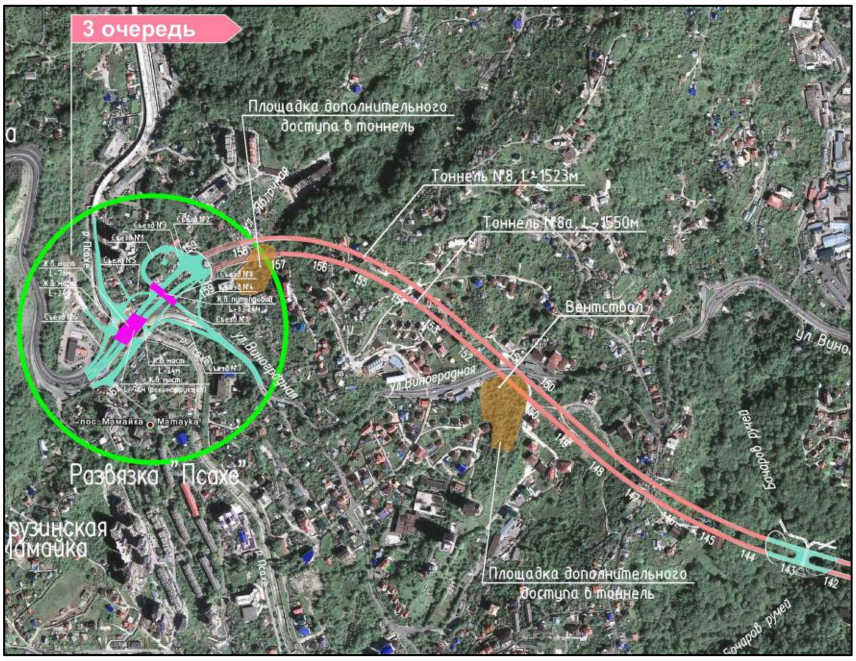

Figure 4. Aerial survey of the area

The area presents two main geological formations: the “Sochi formation” and the “Mamai formation”. Each of these are flyschoid units on the southern margin of the main Greater Caucasus chain.

The Sochi formation follows most of the layout for the T8 and T8A tunnels, from the southern portal to the middle area (highlighted in green in fig. 5). This area is for the most part made up of dark grey shale and clay siltite; these rocks are poorly lithoidal, brittle, and with rare or low levels of sandstone. The shale is frequently laminate, rapidly alterable and sensitive to contact with water.

The Manai formation is present in only a few areas at the northern part of the tunnels (highlighted in brown in fig. 5) and alternates siltite, marl and grey/green-grey fine sandstones; and local levels of scale-structured shale of a blue and grey colour.

From a tectonic point of view, the project area belongs to the Greater Caucasus seismogenic structure, which includes a long belt of mostly constant faults, sub-parallel to the Black Sea’s coast (NW-SE) and characterized by an extension towards NNE-SSW (red lines in fig. 5).

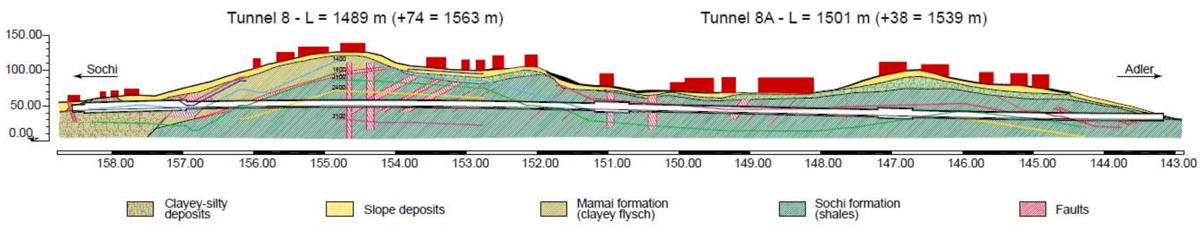

Figure 5. Geological profile in axis with the T8 tunnel (fault areas in red)

In general, the external geological processes (mudslides, landslides, etc.) and the internal ones (seismicity) heavily affect the area of the region; analysis of the seismic and tectonic context, as well as the development of these dangerous geological processes required care during the design stage. Many faults were found along the tunnel's length, generally characterized by intensely fractured and narrow strips. The plicative tectonics were equally evident, with wide folds which locally determined verticalization in the Sochi formation. An important tectonic contact is present towards E-W, causing the Mamai formation to pass over the Sochi formation, and affects the tunnel track for around 250 m near the north portal (fig. 5).

Both formations are largely covered by elluvium-colluvial coverings of varying thickness: from a few metres near the south portal, up to 10-15 m in the central section and near the north portal. These coverings directly affect excavation in the portal areas and in those segments with reduced covering, they are characterized by reshaped rubble portions of silty clay and have been set in place by gravity and by the alteration of the ground mass below, furthermore their geotechnical traits are quite poor.

There are a few extents affected by active landslide movements in the area of excavation and in particular near the north portal, these extents affect significant volumes of ground and portions of the underground rock mass. Intense rainfall, which often affects the territory (especially in autumn) favours the saturation of the ground and the complex distribution of interstitial pressure between the numerous lithologies. Each of these is poorly water resistant and can easily give way to the triggering or reactivating of landslide phenomena.

2.2 The portals and the midway access to the tunnel

Lacking the necessary eminent domain at the north and south portals, due to an underestimation of the need on the behalf of the authorities, the works were delayed for about a year. For this reason, in accordance with the client, it was decided to insert a midway access with connection to the tunnels located under the overhead Federal Road. Since this was the only technology available at the moment in Russia, the portals were built using large-diameter pile bulkheads in reinforced concrete, fittingly contrasted by means of bracing and strutting (fig. 6).

Figure 6. North portal almost finished

2.3 The applied section types

From the diagnostic study of the T8 and T8a tunnels, developed according to the ADECO – RS approach, it was clear that the excavation would need to take place in either unstable or short-term stable (stress-strain behaviour categories "C" and "B") core-face stability conditions for the entire length of the underground layout. It was therefore designed during the therapy phase to advance in full face for the entire length, in order to achieve this it would be necessary to use correctly scaled section types alongside necessary protection and/or reinforcement measures of the core face and to implement the casting of the kickers and of the invert near the excavation face. In particular, at the landsliding north portal, the C2W section type with an invert strut was designed in order to limit deformation to the highest level. Figure 7 reports the main designed section types; as regards the C

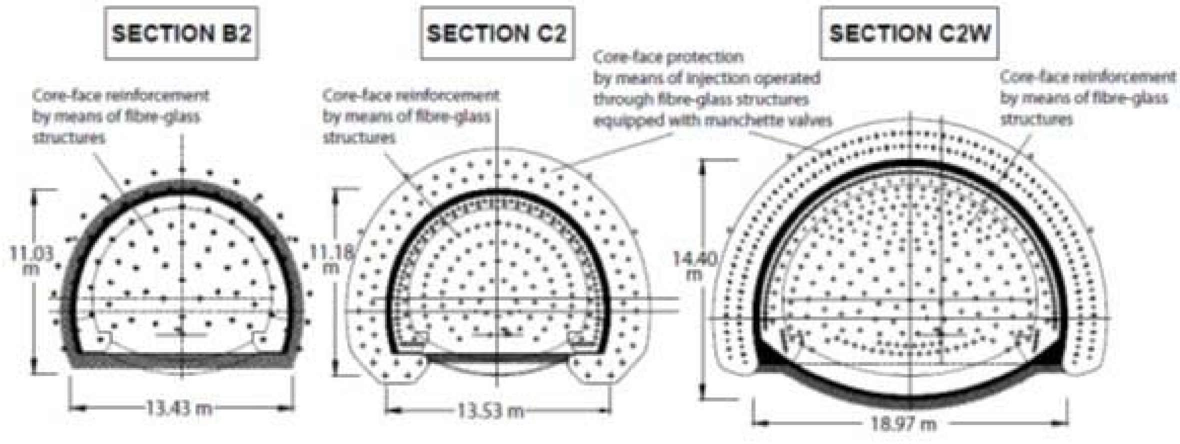

Figure 7. Applied section types

section type, alongside reinforcement of the core-face by means of fibre-glass structures, the figure highlights the treatment along its outline which was carried out by operating injections through fibre-glass structures equipped with manchette valves. For those few tunnel sections that didn't require systematic treatment of the core face, due to significant horizontal mass pressure, the decision was made to bring the systematic casting of the second-phase lining in proximity to the excavation face.

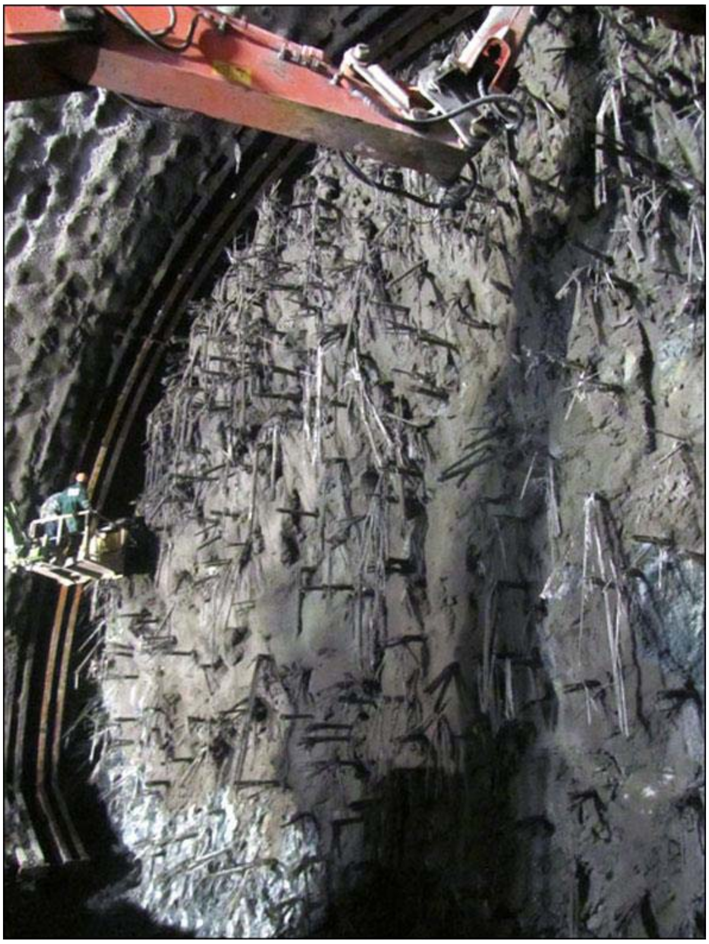

Figure 8. Face of the T8A tunnel – North portal in the landslide area – slope deposits

2.4 Tunnel 8 - 8A : Production

During the detailed design phase, the construction times were defined according to:

- Past experience in similar contexts.
- *Start up* times for the acquisition of necessary machinery.

- Necessary time to acquire the required *know how* and resulting reduced production for at least 6 months.
- Logistical difficulties due to transportation of construction material, machinery and necessary spare parts to the site.
- Socio-cultural context.

Some of these are difficult to evaluate in that they are linked to factors that can be difficult to quantify. For example, the enormous investments allocated towards construction in Sochi lead to an incredibly high request and concentration of raw material. The transportation and rail systems weren't initially capable of supporting such a massive movement of material; furthermore, the winter weather conditions made it difficult for ships to dock, thus invalidating sea delivery as well. Despite the fact that authorities progressively provided all raw necessities, this still created significant difficulties towards the efficient application of a highly industrial system such as the ADECO-RS.

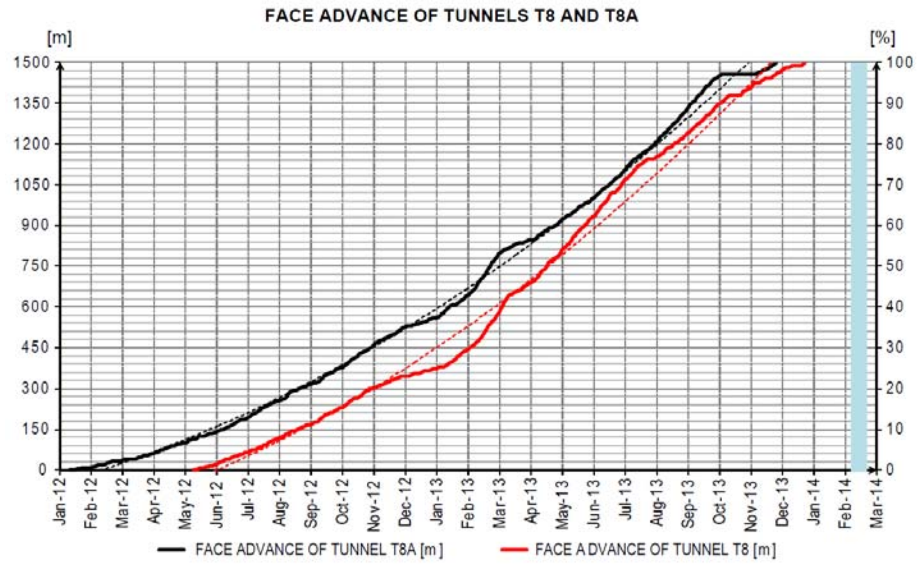

Figure 9. Production levels while excavating the T8 e T8a tunnels

Overall, the project forecast the following times and stages: 18 months for the excavation of the T8 tunnel (1,550 m), 22 months for the excavation of the T8A tunnel (1,523 m). Indeed, the two tunnels differ in the length of the three lane carriageway (furthermore located in a landslide area): this section is 85 metres long for the T8 tunnel, while it's 170 m long for the T8A. Production levels varied according to the diverse geological conditions, the size of the sections of excavation and the applied type of pre-containment and lining used. Excavation productivity also increased over time thanks to the Transtoy Company's growing familiarity with the ADECO-RS approach. When advancing in extreme depth under landslide conditions and using exceptionally large sections of excavation (up to 200 m^2) production averaged between 12 and 13 metres/month of completed tunnel (already lined), up to values between 57 and 88 metres/month of standard sections of excavation (120 m^2) and geological conditions that didn't require particularly heavy stabilizing operations (fig. 10).

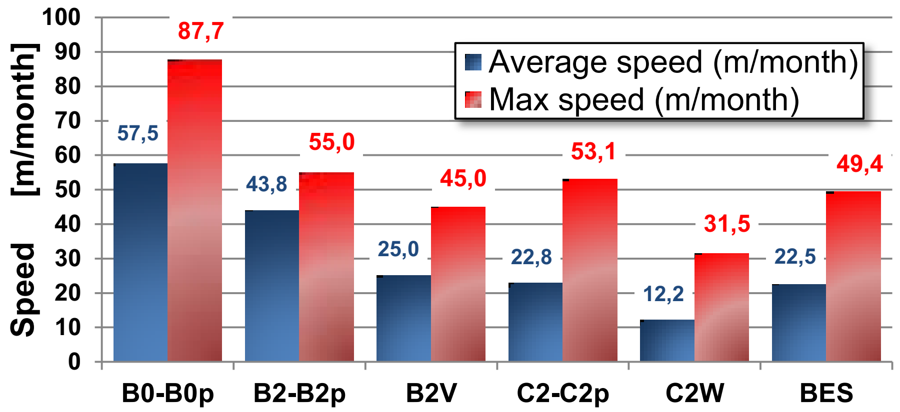

Figure 10. Excavation production for each section type – Tunnels 8-8a – ADECO-RS approach

2.5 “Dubler Kurortnogo Prospekta” tunnel productions

The “Dubler Kurortnogo Prospekta” tunnel, as illustrated in the introduction, is made up of 6 double-bore tunnels for a total of: 10 tunnels bored using the NATM approach (New Austrian Tunnelling Method) and 2 tunnels using the ADECO-RS approach (Tunnels 8 and 8a). It was the first time that these two approaches were directly and reliably compared to each other, in relatively similar conditions (despite the difficulty regarding those tunnels constructed using the ADECO-RS). Illustrated below, the two approaches are compared both in terms of average production and in terms of “bored volume/month” and in terms of “metres of tunnel finished/month”.

The geological conditions affecting the 8-8a tunnel excavation were clearly worse than those of the other tunnels, and the excavation sizes were also greater. Indeed, the 8-8a tunnels occupy a harsh geological context and measure excavation sizes between 120 m^2 and 220 m^2, while the tunnels bored using the NATM passed through better contexts with excavation sizes just equal to 113-115 m^2 (lay-bys are not considered, figure 11).

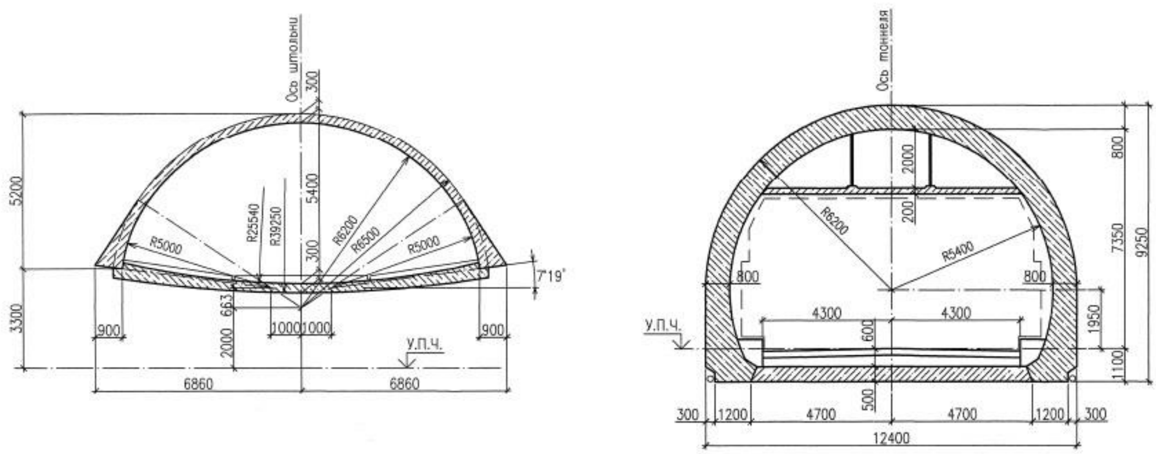

Figure 11. Preponderant section type of tunnels excavated using NATM

Despite this, the comparison between the two approaches clearly exhibits extreme efficiency of the ADECO-RS system over the NATM: in terms of volume of excavation/month for single face the ADECO-RS approach produced results 2.4 times higher than the NATM; in terms of linear metres of completed tunnel, productivity was 40% greater than the NATM approach (fig. 12 and fig. 13).

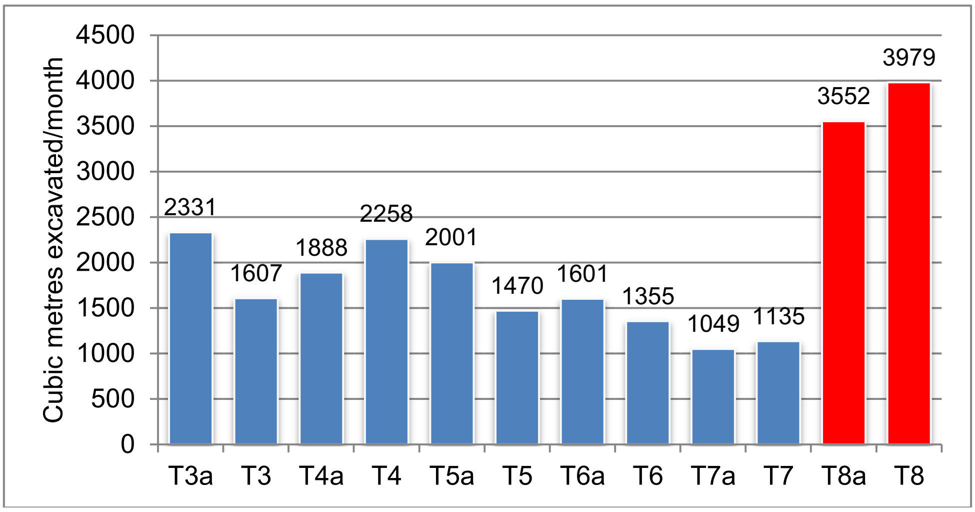

Figure 12. Cubic metres bored/month for single excavation face – comparison between NATM and ADECO-RS

Equally interesting is the comparison of time passing from the breakthrough of the excavation face and the completion of final lining casting, which corresponds to the completion of all the tunnel’s safety measures.

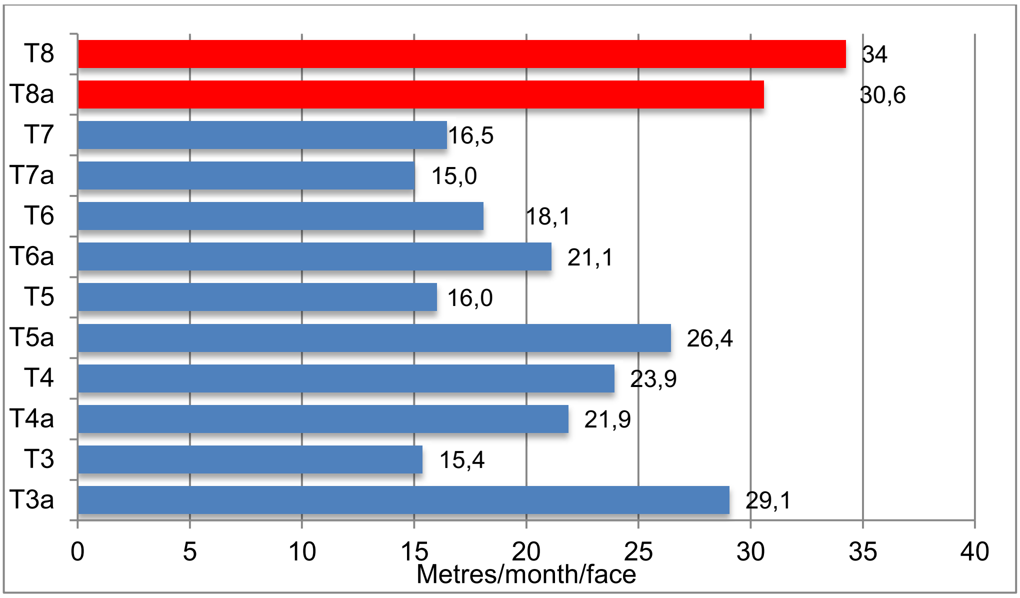

Figure 13. Average production of finished tunnel – metres month/excavation face

The ADECO-RS approach is naturally fast in closing the lining (fig. 14), in the case of SOCHI this was completed under 3 weeks. Instead, the NATM approach showed much greater times: from a minimum of 10 weeks to a maximum of 43; such a time frame has clear repercussions on safety. From this point of view, the ADECO.RS method can complete all necessary safety measures for the tunnel in a short time frame, thus greatly limiting the deformation phenomena linked to excavation.

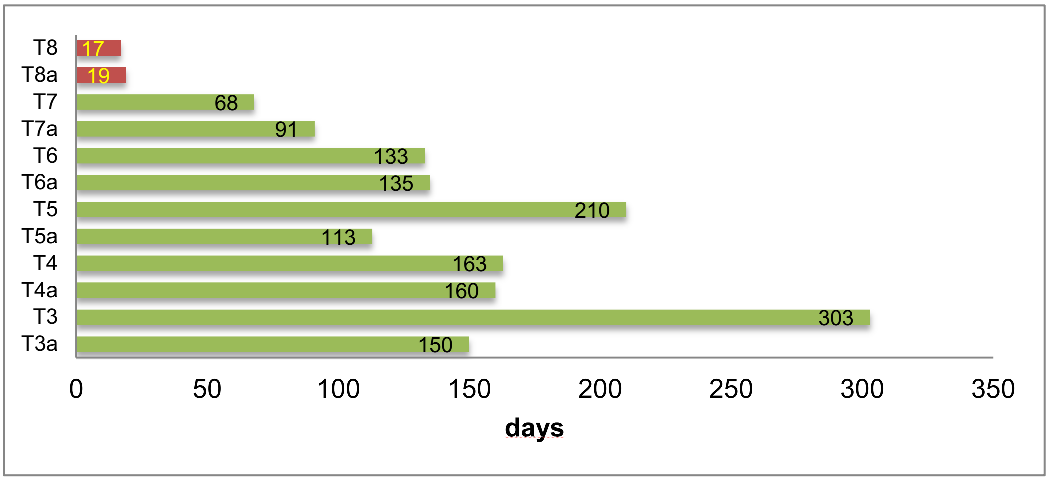

Figure 14. Time passing between the breakthrough and completion of the lining

3 In conclusion

The first implementation of the ADECO-RS approach in Russia has been positive, both in terms of production and in tunnelling safety. Russia has a strongly-rooted tradition towards the NATM system, but the Federal Administrations have of late been following a philosophy of deep technological innovation towards industry and production. The ADECO-RS approach enters perfectly in said new attitude and is of special interest to administrations and construction companies for its capability in tunnel construction within definite times and costs.

Introducing the ADECO-RS approach in Russia will certainly take more time and will necessarily pass through a series of phases which required many years in Italy.

The article reports the main differences observed in terms of production and of safety between the two different approaches used when excavation the Dubler Kurortnogo Prospekta tunnel (ADECO-RS and NATM). A direct and reliable comparison was finally possible due to the similar conditions they faced (despite the fact that it was certainly more difficult for the tunnels bored using the ADECO-RS method).

In terms of production and safety the ADECO-RS approach is clearly victorious, unfortunately it wasn't possible to compare times and costs due to a lack of necessary data from those tunnels bored with the NATM. It is however certain that despite the many bureaucratic, organizational and technological obstacles, The Russian Federation's decision to support the ADECO-RS approach in constructing the longest and most difficult tunnels for the Sochi winter Olympics has been without doubt, a successful one: the two tunnels bored using ADECO-RS, each of which is more than 1,500 m long, were opened to traffic in early February 2014, thus guaranteeing – within the detailed design's times and costs – access to this fundamental connecting artery in time for the important appointment.

4 References

Lunardi P. 2008. Design and construction of tunnels: Analysis of Controlled Deformations in Rock and Soils (ADECO-RS), SPRINGER-Verlag Berlin Heidelberg, 576 pp.