Construction of the T8 and T8A tunnels in the "Dubler Kurortnogo prospekta" in Sochi (Russia). First implementation of the ADECO-RS approach in the Russian Federation

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During the preparation for the XXII Winter Olympic Games in Sochi (Russia) from 7th to 23nd 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 final design in 2010, followed by the detailed design of the two tunnels as well as the necessary technical assistance during construction.

Fig. 1 – The "alternative to the Kurortnyi road".

1. 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

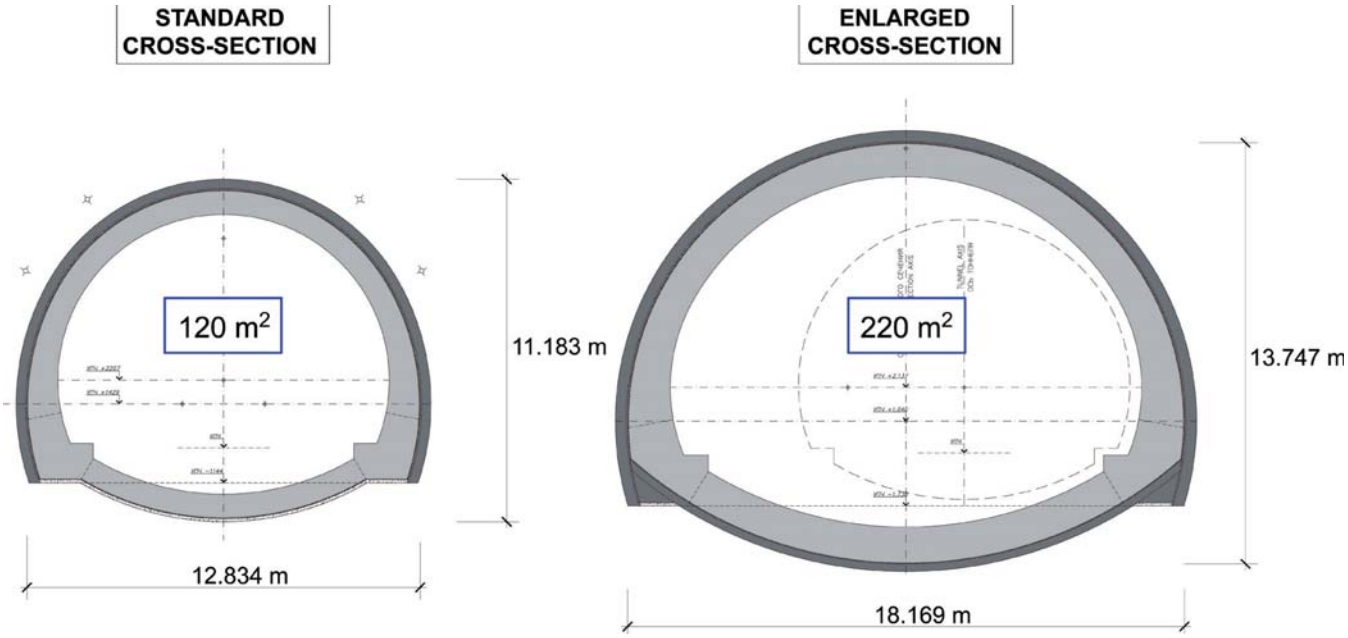

Fig. 2 – Road outlines - 2 lanes / 3 lanes.

Fig. 3 – Standard outline.

Fig. 4 – Widened outline.

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.

1.1. Geology and Geotechnics of the T8 and T8A tunnels

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).

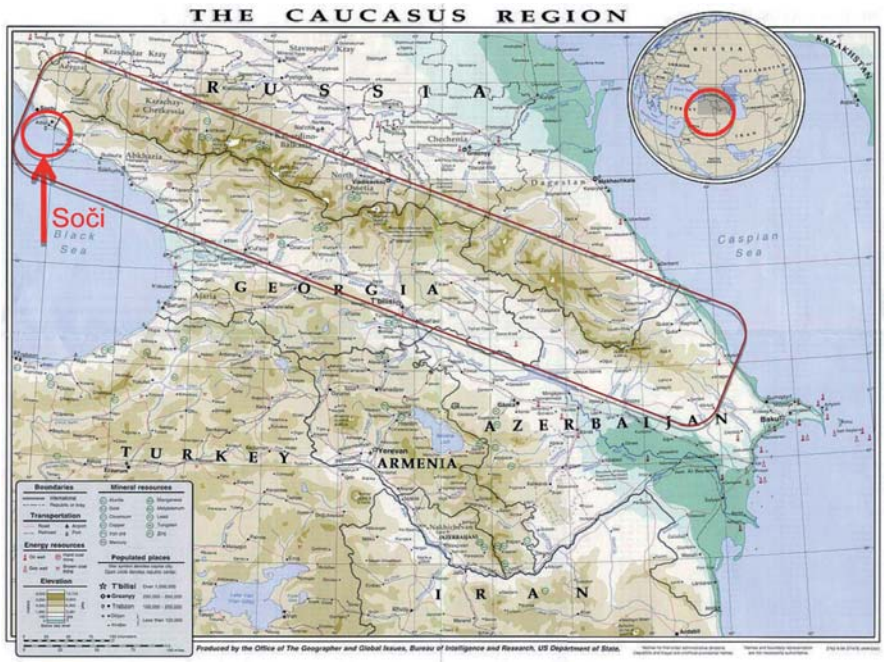

Fig. 5 – The Caucasus mountain chain.

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

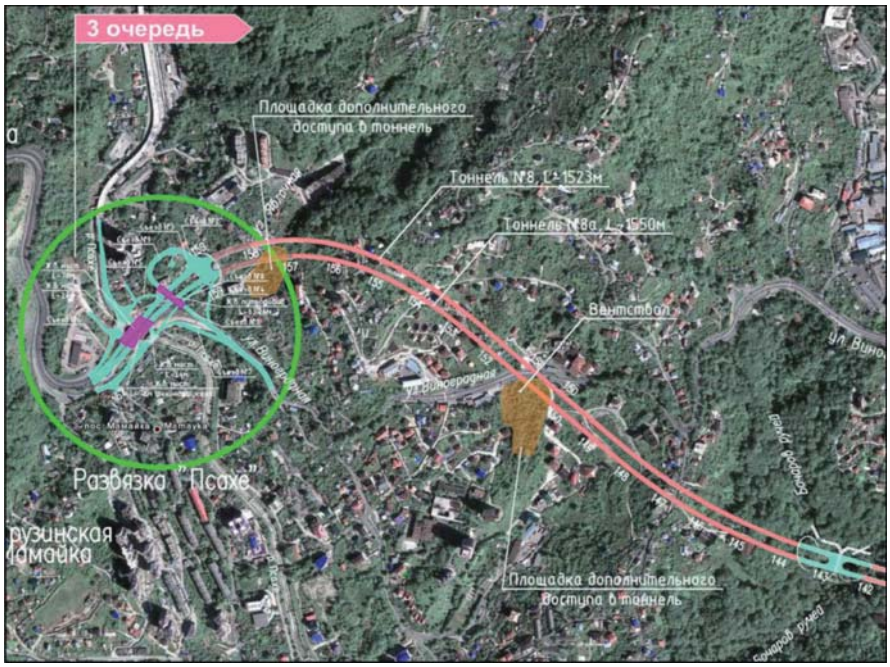

Fig. 6 – Aerial survey of the area.

– not least of all – the typical climate of this coastal 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. 7). 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 Mamai formation is present in only a few areas at the northern part of the tunnels (Fig. 7) and alternates siltite, marl and grey/green-grey fine sandstones; and local levels of scaly 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. 7).

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. 7).

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

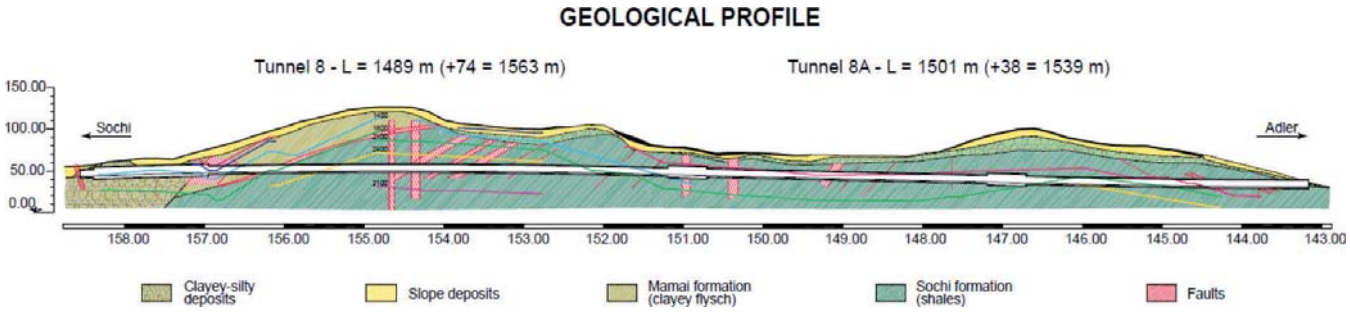

Fig. 7 – Geological profile in axis with the T8 tunnel (fault areas in red).

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

1.2. 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 (Figures 8, 9).

1.3. 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 11 reports the main designed section types; as regards the C 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.

1.4. The approval stages of the projects in Russia and their management during the work process

The approval stages of the project documentation in Russia are very similar to those in Italy, but with substantial differences in their

Fig. 8 – North portal during construction.

Fig. 9 – North portal almost finished.

Fig. 10 – Core-face reinforcement by using a tunnelling rig machine.

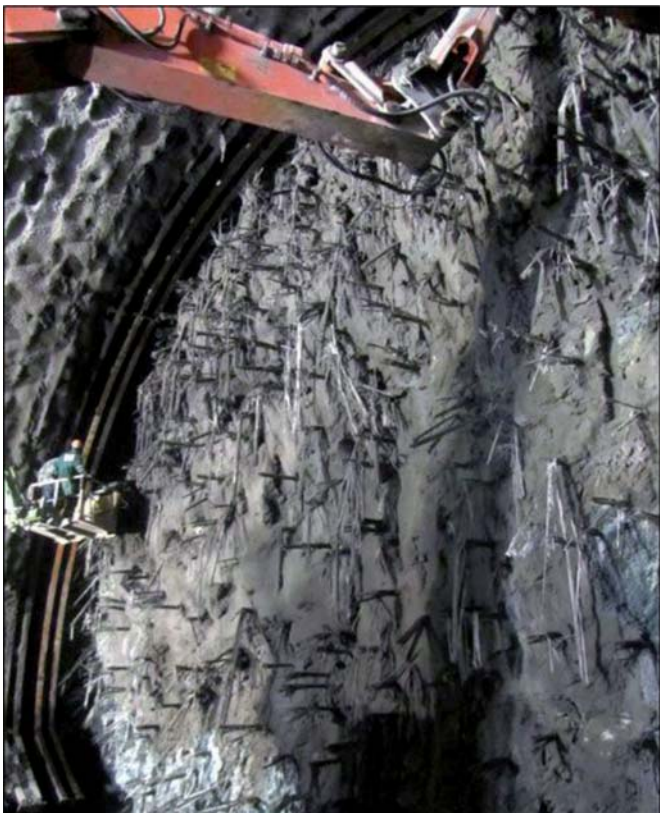

Fig. 12 – Face of the T8A tunnel – north portal in the landslide area – slope deposits.

approach. According to Russian regulation, the "detailed" design has to follow an approval procedure on the behalf of a state entity called "Expertise", which effectively defines the project's costs and solutions. This can have an enormously negative impact on the management of the underground excavation due to the fact that - as all experts in this field are well aware of - geological, geotechnical, and hydro-geological changes are frequent and not always foreseeable. In the here-present case the geological studies on which the detailed design was based had not followed the International quality and scrutiny standards, causing uneasiness towards the "Expertise" project of the underground layout.
The ADECO-RS approach, precisely in the way it had been conceived, made it possible to overcome these problems; indeed, by using the systematic and combined measure of extrusion and convergence and by interpreting the data almost in real time, it was possible to gain perfect control on the stress-strain response of the ground and adapt the excavation techniques to the conditions met in the best possible way and within the previous project solutions. Local administrations - such as the Chernomorye (Federal Road Agency's Directorate for construction and reconstruction of motor roads of the Black Sea coast) and the Rosavtodor (Federal Road Agency) - helped achieve this result and modify the rigid and complex Russian procedures so as to adapt them to the characteristics of the ADECO-RS approach, which are very different from those of the NATM that Russia has been for a long time used to.
This normative adaptation is quite delicate and complex in that it involves many indi-

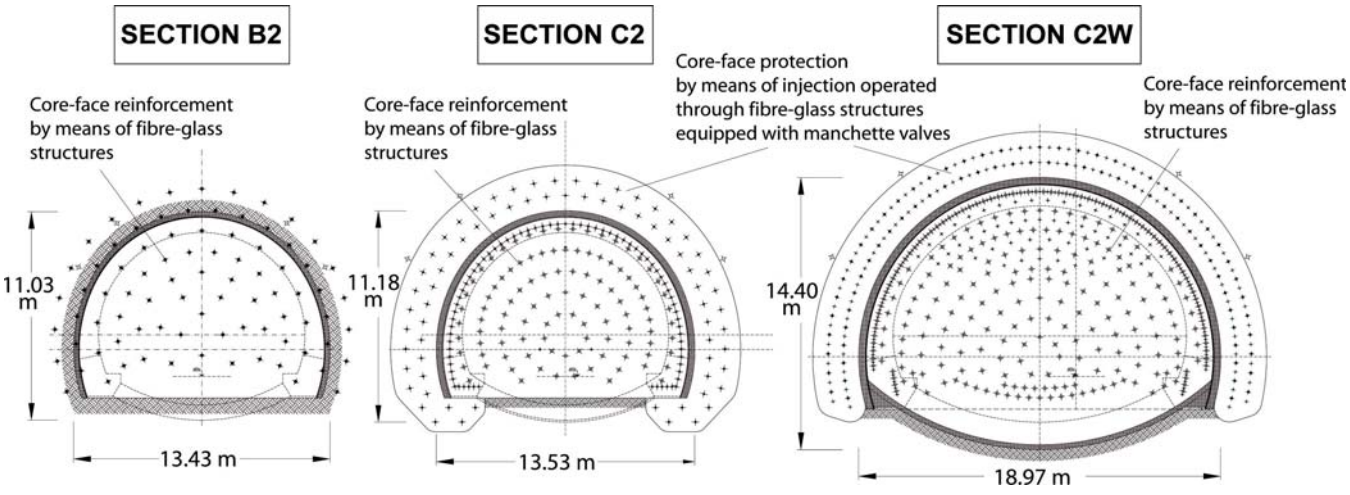

Fig. 11 – Applied section types.

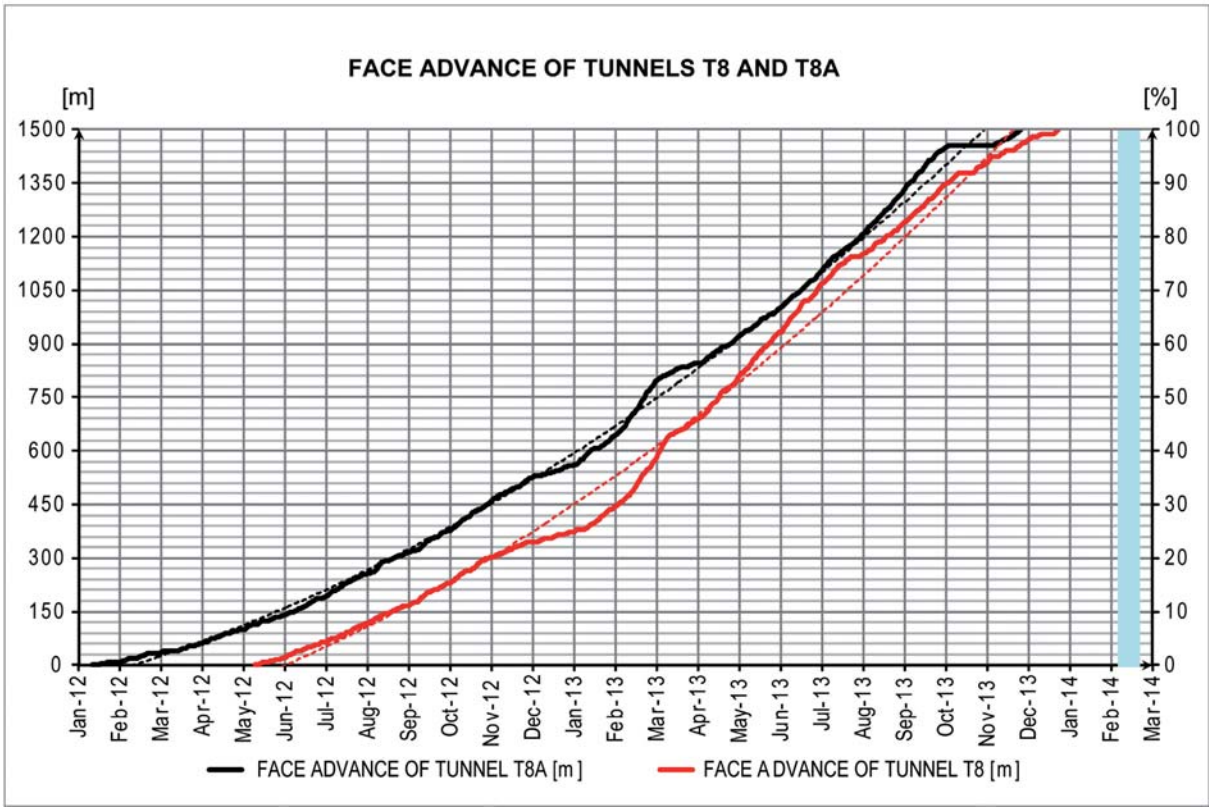

Fig. 13 – Production levels while excavating the T8 e T8a tunnels.

vidualities related specifically to engineering, contracting and economics, and is still being studied. Developing a more suitable group of rules for the modern design and construction developments brought about by the ADECO-RS approach will help optimize design choices made during tunnel advance, in function of the real stress-strain response of the excavation mass.

1.5. Dispossession and unauthorised constructions

A delicate aspect, which as mentioned previously heavily delayed the beginning of the work, was the lack of eminent domain areas at the north and south portals. Introducing the midway access partially reduced said delay but also caused the implementing company (TRANSTROY) great expense in terms of time and of energy in that it had to manage 8 faces at the same time and use many more machines than initially projected.
That of the machines was another problematic issue, in the country of Russia it wasn't possible to find any tunnelling rig machines – which are indispensable for the excavation-face treatments used during the ADECO-RS approach – nor were there any workers capable of using them, making it necessary to hire and train new personnel which required both time and patience.
Another important issue which created serious difficulties was that of unauthorised construction in the city of Sochi. According to a census in April 2013 there were more than 800 unauthorised buildings, some of which had been built in quiescent and active landslide areas; these constructions caused a disruption to the hydro-geological and static balance of the slopes into which they had been built, severely affecting many works, including the T8 and T8a tunnels. Indeed, in many cases the tunnels had to pass under sizeable constructions, where tens of piles would interfere with the excavation sections. For example, near the midway access the works intercepted the deep foundation of an unauthorised structure which hadn't been censed, built with partially gravel piles in a river bed in a landslide area; this caused material to enter the tunnel and distorted the structure above. Only the design structures of the ADECO-RS made it possible to intervene fast enough so as to stop the building from collapsing, which cannot be said for similar cases encountered in tunnels excavated using other approaches.

1.6. 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

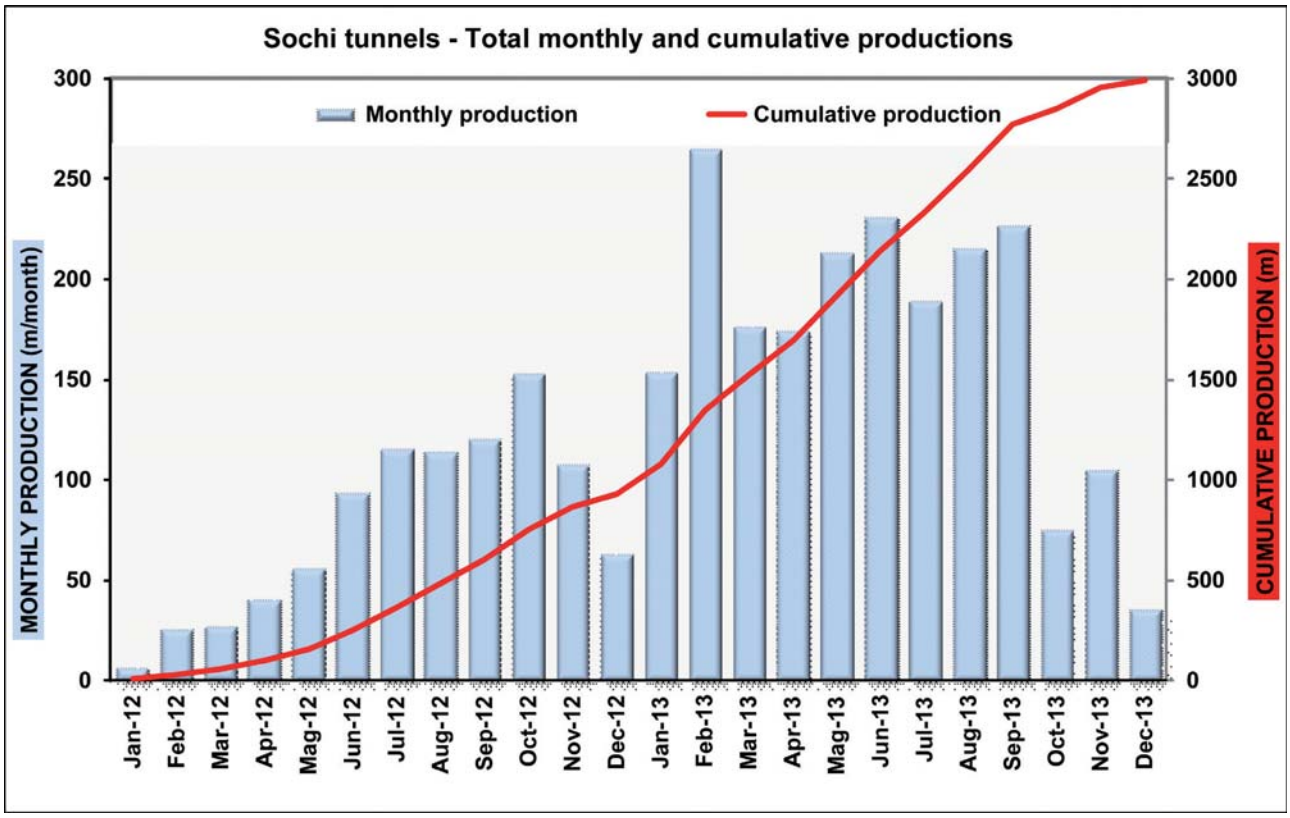

Fig. 14 – Total monthly and cumulative productions.

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.
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 in the landslide area, despite the geological difficulties and the large cross-section to be tunnelled, remained relatively constant and in the order of 20 metres per month for each tunnel; as for the other sections, the values varied between 40 and 90 metres per month for each excavation face. Excavation productivity increased over time (Fig. 14); this is linked both to the progressive attack of the excavation faces, as well as the Transtoy Company's growing familiarity with the ADECO-RS approach.

2. Conclusions

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 customers 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.
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, 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.

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La realizzazione delle gallerie T8 e T8A nell'ambito del "Dubler Kurortnogo prospekta" a Sochi (Russia). La prima applicazione dell'approccio ADECO-RS nella Federazione Russa

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In vista dei XXII Giochi olimpici invernali che si sono svolti a Sochi (Russia) dal 7 al 23 febbraio 2014, la Federazione Russa ha devoluto importanti investimenti per colmare le carenze infrastrutturali della città e potenziarne la rete di trasporti. Tra i progetti realizzati c'è la nuova tangenziale di Sochi, detta anche "Strada Alternativa alla Kurortnyi", che correndo parallelamente alla costa del Mar Nero permette di raggiungere i diversi siti olimpici e l'aeroporto di Adler senza dover attraversare la città.
La costruzione della nuova arteria, ritenuta a ragione particolarmente importante e strategica, presentava numerose incognite, soprattutto per i tempi contingentati disponibili. Il progetto prevedeva infatti la realizzazione di ben otto gallerie naturali a doppia canna, nonché trincee, rilevati e ponti per uno sviluppo complessivo di circa 16 chilometri. A fronte delle difficoltà, la Federazione Russa, ha cercato di minimizzare i rischi adottando per il progetto e la costruzione dei tunnel 8 e 8A, i più lunghi e complessi della tangenziale, l'approccio ADECO-RS, che già aveva dato ampia prova di affidabilità nella realizzazione di oltre 100 Km di gallerie, in terreni analoghi a quelli di Sochi, per la nuova linea ferroviaria AV/AC Bologna-Firenze. A seguito di questa decisione, la ROCKSOIL S.p.A. di Milano nel 2010 ricevette l'incarico di redigere il progetto esecutivo e poi anche quello costruttivo delle due gallerie e di fornire la necessaria assistenza tecnica in corso d'opera.
Le gallerie da realizzare misuravano: 1550 m di lunghezza la galleria T8 e 1523 m la galleria T8A; le dimensioni delle sezioni di scavo variavano da 120 m^2 a ben 220 m^2 in corrispondenza delle piazzole di sosta od ove necessario per garantire la visibilità in curva. All'uscita dall'imbocco nord, inoltre, le gallerie dovevano accogliere 3 corsie per la presenza, vicino all'imbocco, di un importante svincolo per collegare la nuova viabilità con quella esistente. Un'ulteriore difficoltà era rappresentata dalle coperture in calotta mediamente basse, in un contesto fortemente antropizzato.
Dal profilo geologico, il tracciato delle gallerie interessa la fascia collinare costiera, caratterizzata da morfologie dolci e costituita prevalentemente da bassi rilievi con ricca vegetazione, attraversando due formazioni geologiche principali: la "Formazione di Sochi", costituita da argilliti e siltiti argillose, e la "Formazione di Mamai", costituita da flysch argillosi a struttura scagliosa, entrambe sede di zone di faglia dislocate lungo il tracciato stesso.
Dette formazioni sono diffusamente coperte da coltri eluvio-colluviali che hanno interessato direttamente gli scavi nelle zone di imbocco e nelle tratte con più ridotta copertura. All'imbocco nord le gallerie hanno attraversato porzioni d'ammasso soggette a movimenti di frana attiva.
La mancanza di sufficienti aree di esproprio in corrispondenza degli imbocchi nord e sud, a causa di una sottovalutazione delle necessità da parte degli organismi competenti, ha causato un ritardo nella partenza dei lavori di circa un anno. Entrambi gli imbocchi sono stati realizzati mediante paratie di pali di grande diametro in c.a., opportunamente contrastati con interventi di tirantatura e/o puntonatura, dato che questa era l'unica tecnologia al momento praticabile in Russia.
Lo studio di diagnosi dei tunnel T8 e T8a, sviluppato secondo l'approccio ADECO – RS, aveva permesso di prevedere che gli scavi si sarebbero dovuti realizzare, lungo tutto il tracciato sotterraneo, in condizioni prevalenti di nucleo-fronte stabile a breve termine o instabile (categorie di comportamento tenso-deformativo "B" e "C"). Di conseguenza, in fase di terapia si è progettato un avanzamento sempre a piena sezione, mediante l'adozione di sezioni tipo adeguatamente dimensionate con i necessari interventi protettivi e/o di rinforzo del nucleo-fronte e la realizzazione del getto delle murette e dell'arco rovescio vicino al fronte di scavo. Per i pochi tratti in galleria che non richiedevano il sistematico trattamento del nucleo-fronte, si è comunque portato il getto sistematico dei rivestimenti di seconda fase in prossimità del fronte di

scavo, essendo presenti significative spinte d'ammasso orizzontali.
Le fasi approvative della documentazione progettuale in Russia seguono pressochè lo stesso iter italiano, ma con sostanziali differenze di approccio. Il progetto "esecutivo", secondo le norme Russe, deve seguire una procedura approvativa da parte di un ente statale definito "Expertise", che blinda di fatto il progetto nei costi e nelle soluzioni. Tale questione può avere impatti negativi enormi sulla gestione degli scavi in sotterraneo, in quanto, come ben noto agli esperti del settore, i cambiamenti geologici, geotecnici e idrogeologici possono essere frequenti e non sempre prevedibili. Nel caso in esame, se si considera che gli studi geologici sui quali si era basato il progetto esecutivo non avevano seguito gli standard di qualità e approfondimento internazionali, si può ben immaginare l'alto grado d'incertezza del progetto "Expertise" per quanto riguardava il tracciato sotterraneo.
L'approccio ADECO-RS, proprio per come è concepito, ha permesso di superare molte di queste problematiche; infatti, attraverso la misura sistematica e combinata di estrusioni e convergenze e l'interpretazione dei dati di misura in tempo quasi reale, si è potuto ottenere il perfetto controllo della risposta tenso-deformativa del terreno allo scavo adattando nel miglior modo, nell'àmbito delle soluzioni già previste dal progetto, la tecnica di scavo alle condizioni incontrate. Il risultato si è potuto raggiungere anche grazie al valido supporto delle Amministrazioni Locali, che hanno consentito per quanto possibile di modificare le rigide e complesse procedure russe per adattarle alle caratteristiche dell'approccio ADECO-RS, molto diverse da quelle del NATM alle quali in Russia si è da tempo abituati.
Un altro aspetto problematico è stato quello dei macchinari, dato che in Russia non erano disponibili macchine come i posizionatori, indispensabili per l'esecuzione dei trattamenti al fronte di scavo previsti dall'approccio ADECO-RS, né c'erano operai in grado di utilizzarli, per cui si è dovuto procedere alle necessarie acquisizioni e all'addestramento, che ha richiesto tempo e pazienza.
Altra questione che ha creato seri problemi è stata quella dell'abusivismo edilizio nella città di Sochi. Durante il mese di aprile 2013 sono stati censiti oltre 800 fabbricati abusivi, costruiti purtroppo anche in zone di frana quiescente o attiva. Le gallerie hanno dovuto sottopassare fabbricati, anche di importanti dimensioni, con decine di pali di fondazione talvolta interferenti con le sezioni di scavo.
Infine, gli enormi investimenti impegnati per la realizzazione delle opere olimpiche di Sochi hanno portato a una richiesta e concentrazione di materie prime di incredibile entità. Nella fase iniziale il sistema viario e ferroviario non erano in grado di supportare l'enorme movimentazione di materiali e le condizioni meteoriche invernali rendevano difficoltoso l'arrivo delle navi in porto rendendo inefficiente anche il trasporto via mare. Ciò ha creato significative difficoltà per l'efficiente applicazione di un sistema ad elevata industrializzazione quale l'ADECO-RS.
Nonostante le oggettive e del tutto particolari difficoltà, la produttività degli scavi ha mantenuto una sua linearità, con un generale incremento nel tempo, riconducibile anche all'acquisizione, da parte dell'impresa Transtroy, di una crescente dimestichezza con l'approccio ADECO-RS.
Complessivamente il progetto prevedeva le seguenti tempistiche: 18 mesi per lo scavo della galleria T8, 22 mesi per lo scavo della galleria T8A. Le produzioni mensili hanno segnato valori tra 40 e 90 metri/mese per ogni singolo fronte di scavo, scendendo a 20 m/mese solo nella zona di frana all'imbocco nord, a fronte della particolare difficoltà geologica e dell'importante sezione di scavo.
In definitiva, la prima applicazione dell'approccio ADECO-RS in Russia ha evidenziato risultati positivi in termini di produzione e sicurezza negli scavi. La Russia è un paese con radicate tradizioni nell'utilizzo del NATM, ma le Amministrazioni Federali e le imprese di costruzione, che stanno seguendo ormai da anni una logica di profonda innovazione tecnologica per quanto riguarda tutti gli aspetti industriali e di produzione, hanno mostrato grande interesse per l'approccio ADECO-RS e la sua capacità di scavare gallerie con tempi e costi certi anche nelle situazioni più difficili.
Nonostante le numerose importanti difficoltà burocratiche, organizzative e tecnologiche che si sono dovute superare, si può dire che la scelta della Federazione Russa di dar fiducia all'approccio ADECO-RS per la costruzione delle gallerie più lunghe e difficili tra quelle realizzate per i giochi olimpici invernali a Sochi si è dimostrata assolutamente vincente: le due gallerie, di oltre 1500 m di lunghezza ciascuna, sono state aperte al traffico nei primi giorni di febbraio 2014, garantendo, nei tempi e nei costi previsti in sede di progettazione esecutiva, la disponibilità della fondamentale arteria di collegamento in tempo per l'importante appuntamento.

Panoramica della zona olimpica di Sochi. Sullo sfondo le montagne del Caucaso interessate dai lavori del "Dubler Kurortnogo prospekta".