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ADECO & NATM comparison: the case of Višňové Tunnel

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ABSTRACT

The paper presents the application of the “A.DE.CO-RS Approach” for the construction of “Višňové Tunnel” in D1 Motorway. It is a double lane tunnel of the D1 Motorway “Lietavská Lúčka – Višňové – Dubná Skala”, about 7450 m length. It's located in the Žilina district of Slovakia.

In a Yellow FIDIC contract, the JV Salini Impregilo–DUHA proposed to the Client a variation of the excavation approach from N.A.T.M. to A.DE.CO-RS. Tunnels excavation had started with NATM in April 2015 and after that, in September 2015, the application of A.DE.CO-RS begun.

The A.DE.CO-RS Approach increased in few months the average face production from 45 m/month up to 70 m/month that, thanks to the industrialization of the excavation process, has reached the maximum of 130-180 m/month for face, to reduce, as a consequence of a worsening of the geomechanical context, to 80-110 m/month. Today about 6 km of tunnels have been excavated, mainly with the A.DE.CO-RS Approach. The “full-face” approach showed good production rate, much better on respect to the N.A.T.M. system.

The main feature of the A.DE.CO-RS approach is that the design Engineer focuses primarily on the deformation response of the ground to the action of excavation. This deformation response is first analysed and predicted, starting ahead of the face and using a variety of instruments (full scale and laboratory tests, mathematical models), then it is controlled by using appropriate stabilisation measures. As a consequence, the approach controls the deformation response acting first and foremost ahead of the face, using pre-confinement action, and not just ordinary confinement action as in traditional approaches. In this way the A.DE.CO-RS approach is able to successfully tackle any type of ground and stress-strain conditions, especially in difficult ground.

Key Words: Conventional Excavation Method, N.A.T.M, A.DE.CO-RS, Design Method, Construction Method, Full Face Excavation.

1. PROJECT OVERVIEW

Construction of a new stretch of dual-carriage motorway, approximately 13.5 km in length and running past Lietavská Lúčka, Višňové and Dubná Skala in the Žilina region (Žilinský kraj) of northern Slovakia, is now under way. The section forms part of the D1 motorway, which is to link Bratislava with the Slovak-Ukrainian border via Žilina and Košice, creating a southern bypass around Žilina.

The new Lietavská Lúčka–Višňové–Dubná Skala section of the D1 built under the project connects the Hričovské Podhradie–Lietavská Lúčka and Višňové–Dubná Skala sections. It forms a part of the Baltic-Adriatic corridor of the Trans-European

Transport Network. The D1 motorway contributes to improving regional transport links along the transportation corridor linking Bratislava, Žilina and Košice, as well as international connections with neighbouring countries, particularly Ukraine. This should bring benefits such as reduced journey times both for local inhabitants and international road users.

Part of the new stretch of motorway takes the form of a tunnel, situated near Višňové and around 7.5 km in length. The project also includes construction of 10 bridges, 18 retaining walls with a total length of nearly 3 km and two noise protection barriers. On the above-ground sections of the Lietavská Lúčka–Višňové–Dubná Skala stretch of road, the speed limit has been set at 100 km/h.

2. DESIGN AND CONSTRUCTION APPROACHES FOR UNDERGROUND WORKS

Two main types of approach have been followed to date in the design and construction of underground works: one is mainly empirical, the other theoretical. Some authors working on the first type have proposed systems to assist design engineers in the design of tunnel stabilisation and lining works, which are based on geomechanical classifications. Some of the most well known of these are those produced by Bieniawski (R.M.R. System) [2] and by Barton (Q System) [3]. Both identify geomechanical classes on the basis of a series of geomechanical and geostructural parameters. Stabilisation works which determine tunnel section designs are associated with each class. In theory it is possible to immediately select the most appropriate tunnel section type to ensure the long and short term stability of a tunnel by extrapolating the necessary parameters from core samples and direct measurements at the face.

Unfortunately, an extremely distorted use of this type of classification has been made, as people have tried to use them as the basis for complete design and construction methods and not as a simple support tool for tunnel designers which the Creators of the systems intended. When used for purposes other than those for which they were designed, geomechanical classifications, and as a consequence those design and construction methods that are based on them, such as the N.A.T.M., suffer from considerable shortcomings. They are difficult to apply in the domains of soft rocks, flysch and soils, give insufficient consideration to the effects of natural stress states and the dimensions and geometry of an excavation on the deformation behaviour of a tunnel and fail to take account of new constructions systems. These constitute objective limitations, which make design and construction methods that are based on them inevitably incomplete and not universally valid.

2.1. The new Austrian method (NATM)

The New Austrian Tunnelling Method (N.A.T.M.), developed between 1957 and 1965 by Parcher and Rabcewicz [5], which laid claim to the technological innovations of the Sprayed Concrete Lining or SCL Method, is a design and construction philosophy based on purely observational criteria. The starting point is a system for classifying rock masses based on a qualitative description of the conditions present when an underground opening is made. The geomechanical parameters of the design, the excavation system (full or partial face) and the tunnel section type are associated to each rock type on an empirical basis and the final dimensions are in any case decided during construction on the basis of cavity convergence measurements.

The principal merit of the N.A.T.M. is that it explained the importance of using reinforcement and active stabilisation instruments to make the rock mass contribute to the stability of a tunnel by dating the deformation properties of linings to the deformability of rock mass. Its main shortcomings, are:

- it is impossible to perform preliminary design of construction with it in enough detail to allow estimates of construction times and costs to be made that are sufficiently reliable;
- it is inadequate for the more difficult terrains and stress-strain conditions, which it erroneously presumes can be tackled with partial face tunnel advance;
- practical implementation suffers from too much subjectivity, the result of being based on what are essentially qualitative parameters.

In 1963 Rabcewicz changed the name from the “Sprayed Concrete Lining Method” to the “New Austrian Tunnelling Method” to claim the merits of this technological progress in the use of steel ribs, sprayed concrete and rock bolts in the construction of tunnels for “his country of origin”. Subsequently he sought, together with other engineers (Parcher, Müller, etc.), to set the method in a scientific framework by formulating a series of principles which were not always found to be correct (Fig.1).

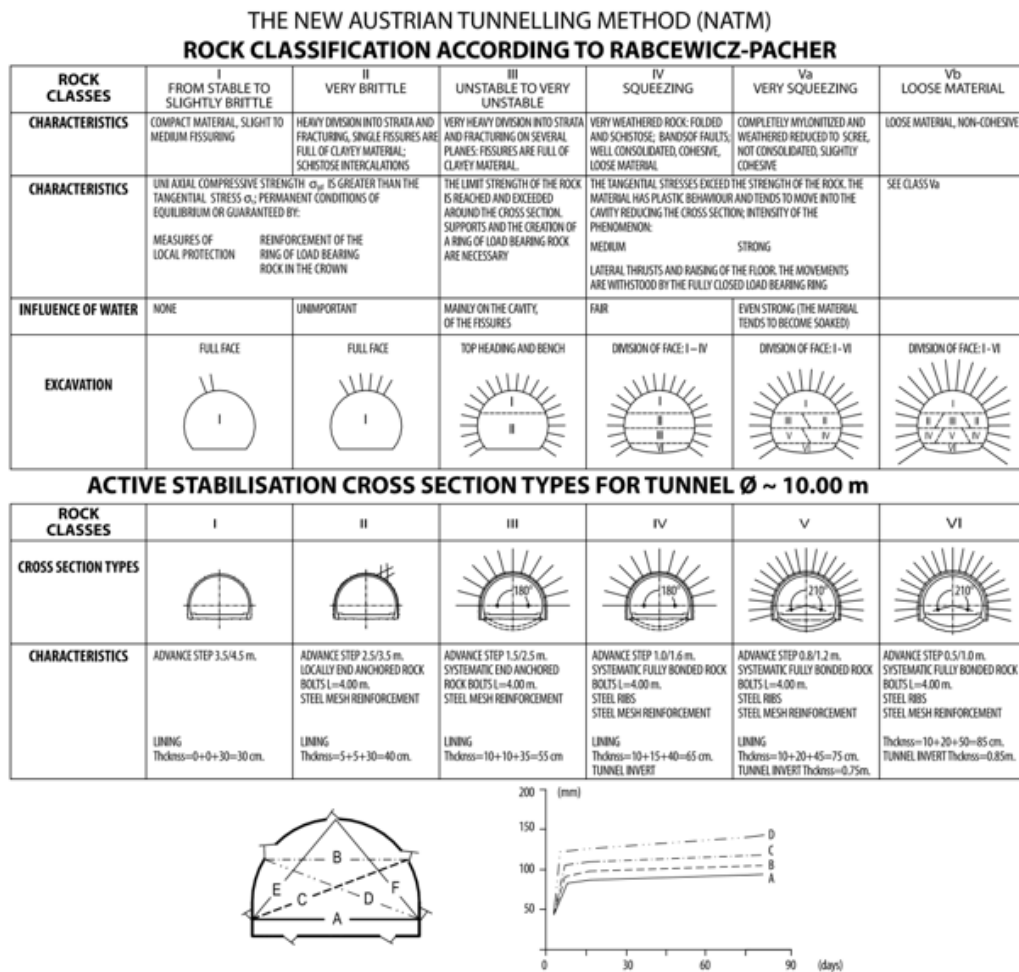


Figure 1. The New Austrian Tunnelling Method.

A distinctly theoretical approach has been used as an alternative to empirical approaches based on geomechanical classifications, which has produced interesting developments, even if it has so far been limited to the design phase only of underground works. It uses mathematics to describe the stress-strain behaviour of the ground and the lining structures as far as is possible in order to decide the dimensions of the latter. The most important results which this type of approach has generated are:

- definition of the concept of the confinement pressure of the cavity, with which the design engineer is able to control the extent to which the plasticised zone around the tunnel develops (plastic radius R_p), as demonstrated analytically for the first time by Kastner in 1962 [6] (Fig.2.a);
- recognition that the problem of calculating the size of a tunnel lining is a completely three dimensional problem and that it is not acceptable to overlook this, especially when tunnel advance is through terrains in which stress states are high in relation to the strength and deformability of the ground [7] (Fig.2.b);
- the demonstration that the pressure exerted by the surrounding rock mass on the stabilisation and lining structures of a tunnel is not predetermined, but depends, amongst other factors, on the method of excavation and of placing the structures themselves (as can be seen from the “characteristic line” [7] and the “convergence-confinement” calculation [8] methods, Fig.2.c).

The theoretical approach has furnished tunnel designers with the calculation tools they need to evaluate the stress-strain behaviour of a rock mass and to calculate the dimensions of the stabilization and lining structures of a tunnel. However it does not give adequate consideration to the construction stages and therefore it does not constitute a fully integrated method of design and construction.

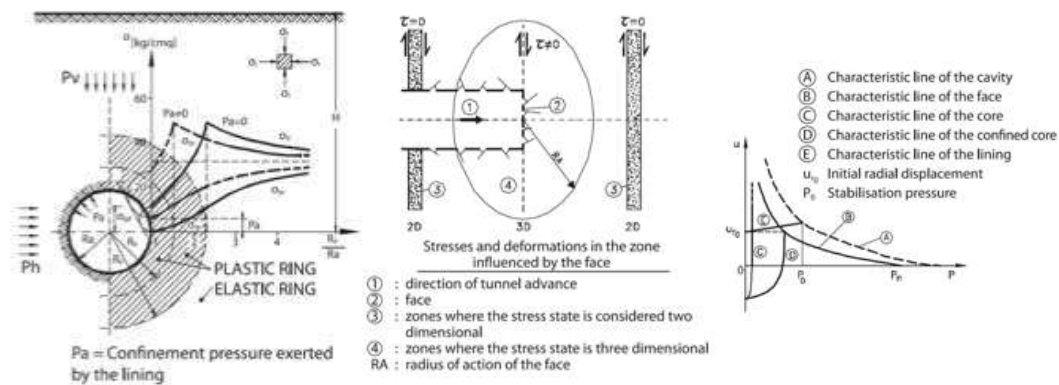


Figure 2. The theoretical approach of underground works design and construction: a) confinement pressure of the cavity; b) identification of three-dimensional problem; c) characteristic line method.

2.2. Fundamental requirements of tunnel design and construction method

Modern tunnel construction is based on comparing the deformation that is measured with the deformation predicted in the tunnel design and have to satisfy the following requirements:

- the method must be valid and applicable in all types of ground and under all stress conditions;
- the method must provide design and construction instruments that are able to solve the problems of different statics conditions in all types of ground;
- the method must distinctly separate the design stage from the construction stage, although allowing for refinements to be made to the specifications during construction;
- the method must allow projects to be reliably planned in terms of construction schedules and costs.

In order to formulate a modern and universally valid approach, the problem of the design and construction of underground works must be reformulated and the phenomena that occur during the excavation of a cavity have to be examined in terms of cause and effect. The experimental and theoretical research was started in 1975 with the aim of throwing light on the relationships between modifications to the stress state of the medium induced by tunnel advance (the action) and the consequent deformation response (the reaction).

The first research stage was conducted by using instruments and visual observation to monitor the stability and deformation behaviour of the advance core and walls of tunnels, paying particular attention to extrusion of the face, preconvergence of the cavity and convergence of the cavity. The second stage of research thus commenced to seek possible connections between the deformation of the face advance core system (extrusion and preconvergence) and that of the cavity (convergence) and confirmed that the rigidity of the core played a determining role in the stability of a tunnel both in the long and short. The third research stage experimentation was performed on how it was possible to use the advance core as a stabilisation tool by acting artificially on the rigidity of the core itself to regulate deformation of the cavity (Fig.3).

The synthesis of the research lead to the formalization of the A.DE.CO-RS Approach (Analysis of COntrolled DEformations in Rock and Soil).

2.3. The design and construction of tunnels according to A.DE.CO-RS Approach

In order to frame the design and the construction of underground works the ADECO-RS approach divides them into two chronologically separate moments (Fig. 4): a design stage and a construction stage. The design stage consisting of:

- survey phase: referred to the geological, geomechanical and hydrogeological knowledge of the ground and to the analysis of the existing natural equilibriums;
- diagnosis phase: referred to the analysis and the theoretical forecasting of the behavior of the ground in terms of Deformation Response, in the absence of stabilizing operations, according to the stability conditions of the core-face;
- therapy phase: referred, firstly, to the definition of the methods of excavating and stabilizing the ground to control the Deformation Response; and subsequently, to the numerical evaluation of the effectiveness of the solutions chosen; in this phase the section types are composed and the possible variability depending on the actual deformation behaviour of the tunnel in the excavation phase, which will be measured during the operating phase.

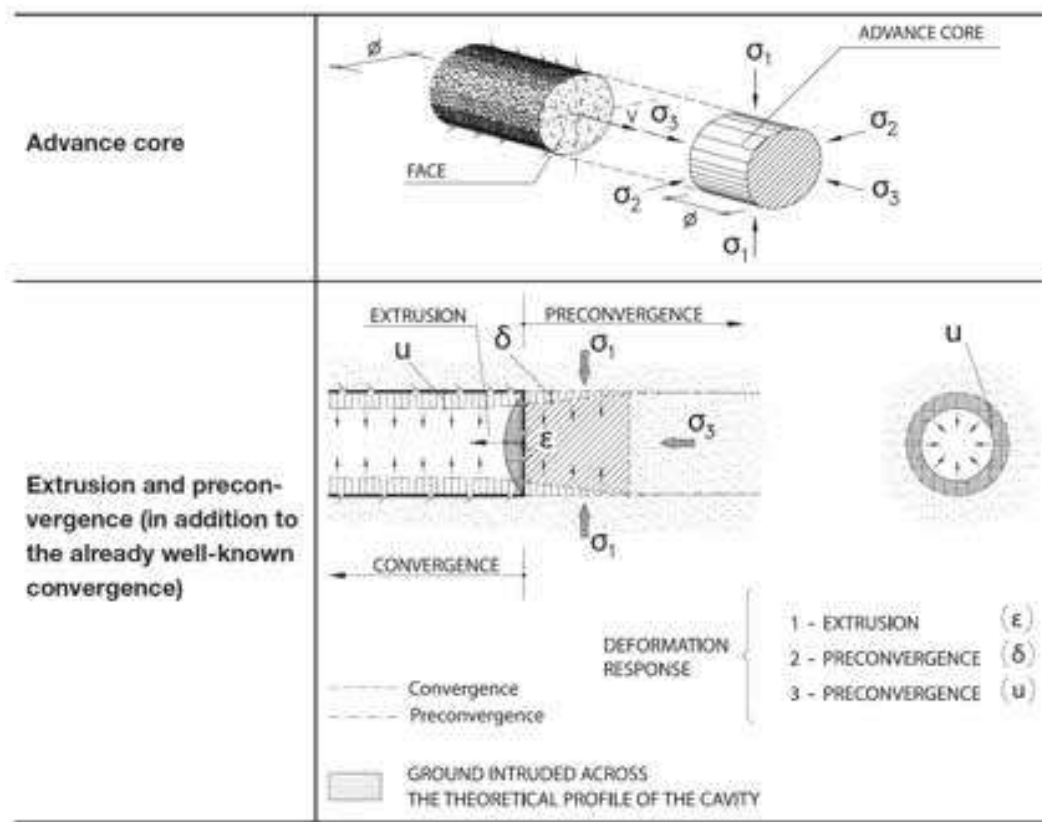


Figure 3. The influence of Advanced Core

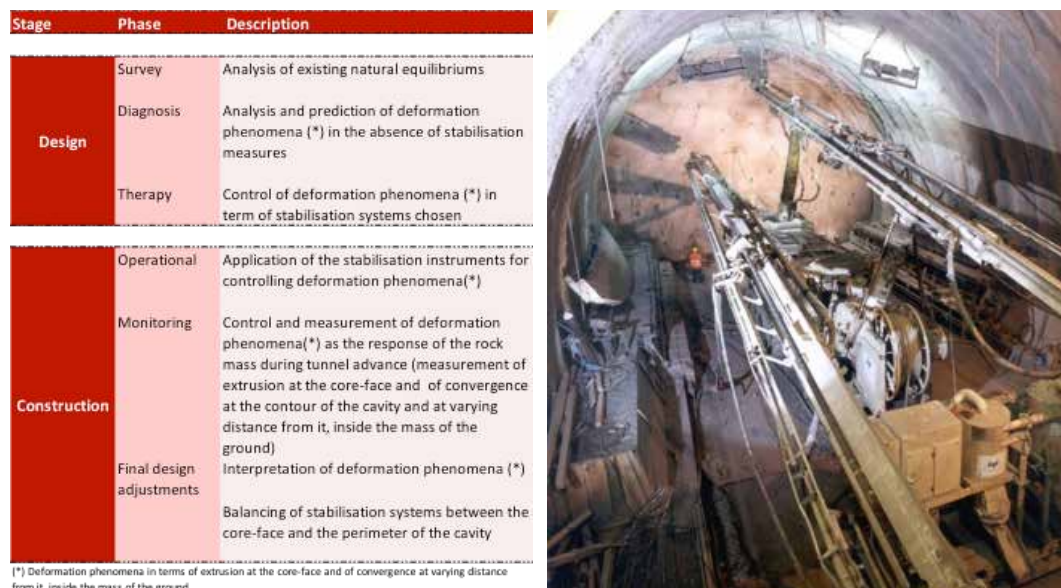


Figure 4. A.DE.CO-RS Design and Construction Stage

The construction stage consisting of:

- operational phase: referring to the actual construction of the tunnel, in which the application of the stabilizing instruments for controlling the Deformation Response is implemented.
- monitoring and final design adjustment phase: during the course of the work, referring to the measurement and experimental interpretation of the actual

behaviour of the ground to excavation in terms of Deformation Response, for the finalization and the balancing of the stabilizing systems implemented between the core-face and the excavation perimeter, and for checking the chosen solutions by means of comparing actually measured deformations with the ones that are expected theoretically.

The approach based on the A.DE.CO-RS differs in various important aspects, from other methods used to date as a framework of reference:

1. the design and the construction of a tunnel are no longer seen as they were in the past but now represent two quite distinct moments with a clear and well defined physiognomy in terms of timing and practices;
2. the approach employs a new type of conceptual framework for underground works based on one single parameter common to all excavations: the stress-strain behaviour of the face-advance core system;
3. the approach is based on the prediction, monitoring and interpretation of the deformation response of the rock mass to excavation and this becomes the only reference parameter employed. First it is theoretically predicted and regulated and then it is experimentally measured, interpreted and experimented with as a means of fine-tuning the design of the construction that is being built;
4. the concept of preconfinement is introduced to complete the already well known concept of confinement; this addition makes it possible to drive tunnels in an orderly programmed fashion even under the most difficult statics conditions without having to resort to improvisation during construction;
5. the approach involves the use of conservation systems aimed at maintaining the geotechnical and structural properties of the ground, seen as the “construction material”, as unaltered as possible when these play a fundamental role in the speed and rhythm of tunnel advance. A particular characteristic of the approach is its introduction of a new conceptual framework for viewing underground works.

It has been observed that deformation of the ground during excavation and therefore the stability of the tunnel itself are dependent on the behaviour of the core of ground ahead of the face (advance core). Given this observation, the stability of the face-advance core system is employed as a basic element in the new conceptual framework. Consequently, by making reference to one single parameter valid for all types of ground (the deformation response of the advance core), the method overcomes the limitations of systems used until now, especially when soils with poor consistency are encountered. Three fundamental behaviour categories can be identified:

- Category A: stable face, stony type behaviour;
- Category B: face stable in the short term, cohesive type behaviour;
- Category C: unstable face, loose ground type behaviour.

Where there is stable face behavior (Category A), the overall stability of the tunnel is practically guaranteed even in the absence of stabilisation intervention. In case of Category B and Category C, in order to prevent instability of the face and therefore of the cavity, and to try to return to stable face conditions (Category A), preconfinement measures must be adopted, appropriately balanced between the face and the cavity, of an intensity adequate to the stress conditions relative to the strength and deformation properties of the medium. The behaviour of the face is then influenced by these factors:

- Geotechnical parameters of the soil (strength and deformability)
- Overburden of the tunnel (geostatic stresses)
- Size of the tunnel (diameter and shape)
- Excavation system
- Constructional procedures

By means numerical analyses, both preliminary evaluation by Characteristic Curves Methods, and more refined F.E.M. or F.D.M. Analyses, the core-face categories are detected and, consequently, the properly interventions defined.

3. THE APPLICATION OF THE A.DE.CO-RS APPROACH FOR VIŠŇOVÉ TUNNEL

“Višňové tunnel” is a double-track tunnel of the D1 Motorway “Lietavská Lúčka – Višňové – Dubná Skala”, about 7450 m length (Fig.5). It’s located in the Žilina district. The tunnel will be built with two tubes following the alignment of the existing pilot tunnel, which will be used as a drainage tunnel during service. The tunnel width category is 2T 7.5, with maximum speed 100 km/h. Two traffic lanes, 3.5 m width, are provided with clearance 4.8 m of height. The maximum vertical degree is 3.4%.

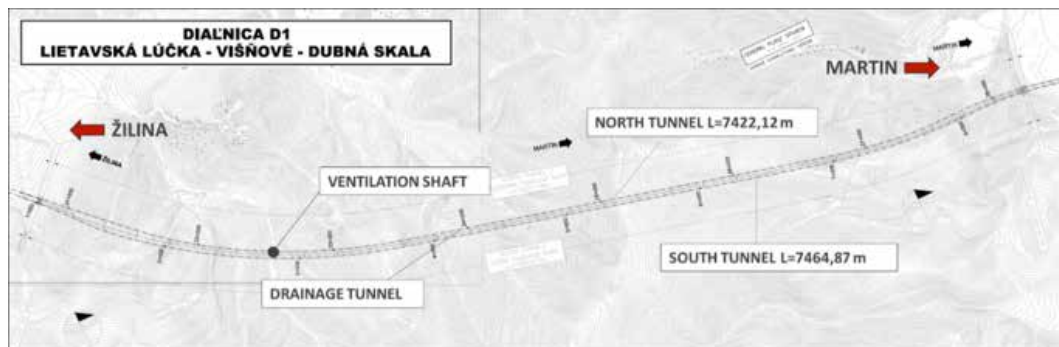


Figure 5. Višňové Tunnels layout

Višňové tunnel is located on the territory of Malá Fatra. Malá Fatra is 55 km long mountain range in the north-western part of Slovakia, extending southeast of Žilina in the line of the major arc of the Western Carpathians. The main ridge runs from the southwest to the northeast. Middle of the mountain range is divided by Vah river. At this point the river created a 12 km long narrow valley known as the Strečnianska gorge. Altitude of mountain range, on the projected route of the tunnel, ranges from 800 to 1,300 meters. Geological conditions along the alignment of the tunnel have been verified by pilot tunnel, excavated in the years 1998-2002. Based on survey work carried out, the rock mass, starting from the west portal, are so defined (Fig.6):

- flysch formations represented by claystone complex of central-Carpathian Paleogene
- mudstone–sandstone-limestone complex of formation Upper Triassic and Lower Jurassic (Liassic), with max overburden 90 m
- limestone-dolomite formation, represented by a complex of carboniferous rocks of Triassic krížňanský Nappe Mala Fatra, with max overburden od 250 m
- lower terigen formation of the lower Triassic malofatranská unit
- formation of varis granitoids, which is represented at the heart of Mala Fatra (730 m).

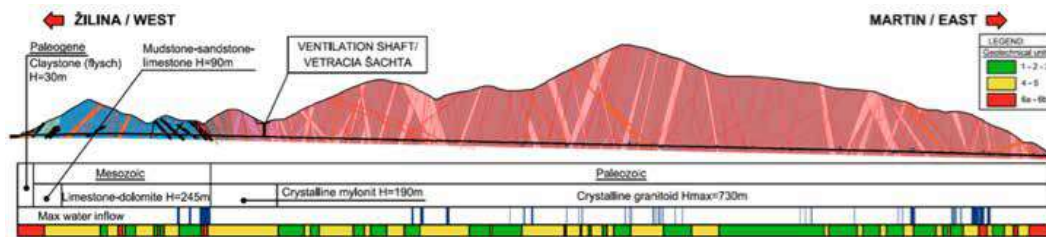


Figure 6. Višňové Tunnels geological profile

From a geotechnical point of view, the data collected during the pilot tunnel excavation allowed to define seven geotechnical units, from 1 to 6a and 6b, according to rock-mass properties (strength and deformability) and rock-mass discontinuities (fractured zones, faults and tectonic contacts). The Table 1 reported the characterization of the geotechnical units present along the tunnel alignment, in term of RMR and QTS; Mohr-Coulomb parameters are also listed. The 43% of the tunnels is interested by geotechnical unit 1, 2 and 3: these represent good rock-mass condition, intact or little weathered granitoid and limestone, locally fractured, with low deformation. Another 46% by the units 4 and 5, characterised by weathered and tectonically disturbed rock-mass, fractured to strongly fractured; low rock strength due to joints with collapsing of rock from free unsupported surfaces, occasionally squeezing conditions. And finally, just 11% is related to the units 6a and 6b, mainly at the tunnel portals, where weathered and tectonically disturbed claystone sandy and sandstone (6a) and carbonatic breccias and claystone carbonatic (6b) are present; they are strongly fractured, with low interlocking and quickly subsiding ($QTS < 40$).

GEO-UNITS	QTS (Tesar, 1989)	RMR (Beniawski, 1989)	γ [kN/m ³]	c' [kPa]	ϕ' [°]	ν [/]	E [MPa]	E_{def} [MPa]	σ_c [MPa]
1	> 84	81 ÷ 100	27.1	1 000	60	0.13	10 000	5 000	120
2	68 ÷ 84	61 ÷ 80	27.1	900	60	0.15	4 400	2 200	100
3	54 ÷ 68	41 ÷ 60	27.1	800	54	0.17	2 500	1 200	80
4	40 ÷ 54	21 ÷ 40	26.9	600	45	0.19	1 700	750	70
5	≈ 40	≈ 20	26.8	400	40	0.21	1 000	400	50
6a	< 40	< 20	24.0	20	33	0.25	60	25	20
6b	< 40	< 20	26.8	100	30	0.25	500	200	40

Table 1. Geotechnical unit parameters

3.1. The project and the applied designing methods

The tunnels have been originally designed by N.A.T.M. approach but the Joint Venture between SALINI IMPREGILO (75%) and DÚHA (25%) won the tender for the design-build and the Detailed Constructional Design has been performed applying the A.DE.CO-RS Approach.

Figure 7 summarizes N.A.T.M. approach and A.DE.CO-RS approach applied in Višňové tunnel comparing the section types. The first difference which is possible to underline is related to the excavation mode. In case of N.A.T.M. the tunnel is sequentially excavated and supported while in case of A.DE.CO-RS the excavation is full face performed. In both cases the initial ground support is always shotcrete shell in combination with reinforcement and ground reinforcement depending on ground condition.

In a typical NATM tunnel the cross-section (or tunnel face) is divided up into a number of smaller faces. There are typically three, the crown, bench and invert. Excavation is incrementally advanced in steps, shotcrete is used after each incremental excavation to form a new panel to the lining. A 50 mm sealing layer is generally first applied to the excavated face on which the new panel is to be formed. Shotcrete is then generally applied in two layers, each reinforced by steel mesh, to form a NATM lining typically 150 to 300 mm thick. The second layer may be applied before advancing the excavation or it may be delayed until a later stage in the cycle. Steel lattice girders can be incorporated into the lining. They may provide some limited measure of support to the excavated crown prior to shotcreting and shortly thereafter when the shotcrete is weak. They also provide assistance in profiling the tunnel and in achieving the correct shotcrete thickness. Excavated material is usually placed temporarily on the completed tunnel invert to provide a running surface for plant during further construction. The speed of construction is important in limiting ground settlement as once the ring is closed significant ground movement normally ceases. The ring is closed when the last panel of shotcrete in an advance is formed. This is typically some five rounds behind the leading cut. A secondary or final tunnel lining is usually added at a later date inside the primary sprayed concrete NATM lining. The secondary lining is usually formed of cast in-situ or sprayed concrete (HSE, 2014 [9]). Figure 8 shows a general scheme for NATM working cycle. The excavation and support cycle must be repeated at least 3 time before close the ring, in addition it is necessary to remove muck twice. Those are the main reasons causing generally low production rate on respect to A.De.CO Approach, especially in worse rock-mass conditions.

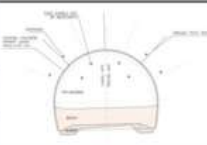
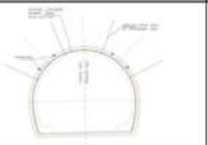
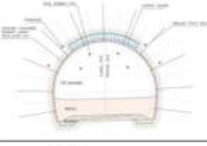
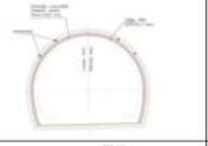
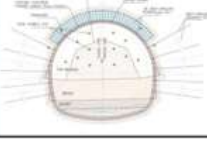
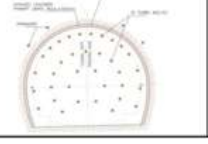
GEOMECHANICAL UNIT	EXPECTED BEHAVIOUR	NATM APPROACH		ADECO APPROACH	
		Section type	Interventions	Section type	Interventions
1 - 2 - 3 (RMR 60+100)	A		1) Shotcrete shell 2) Swellex Rockbolts		1) Shotcrete shell 2) Swellex Rockbolts
4 - 5 (RMR 20+60)	B		1) Shotcrete shell 2) Swellex Rockbolts 3) Lattice girders 4) Steel forepoles		1) Shotcrete shell 2) Steel ribs
6a - 6b (RMR <20)	B/C		1) Shotcrete shell 2) Steel Anchors 3) Lattice girders 4) Steel forepoles 5) Supporting Core 6) Face dowels		1) Shotcrete shell 2) Steel ribs 3) Fiberglass elements 4) Invert casting

Figure 7. Design Concept

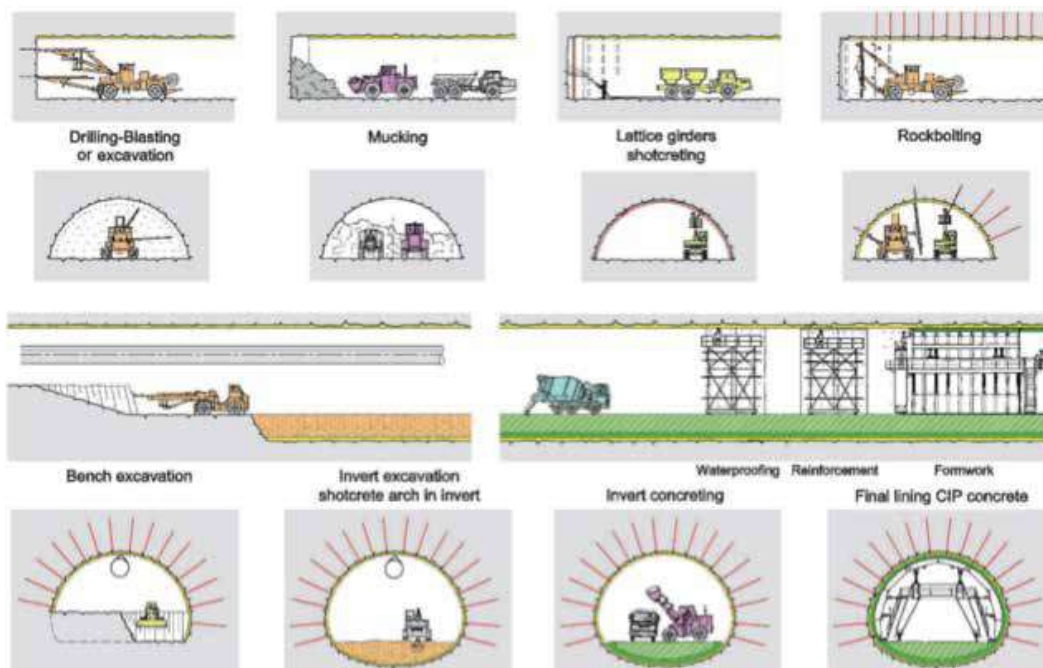


Figure 8. N.A.T.M. Work Phases (NATM Poster by ILF, Inc. Consultants)

With reference to the ADECO-RS Approach, a typical cycle-work for tunnel construction is reported in the following Figure 9. The main phases are:

- Pre-confinement of the core-face, by means of fiber-glass reinforcements or grouting activities, or pre-support system, or drainages pipes ahead of the face (if necessary, according to face categories)
- Full-face excavation (top-down), with excavation step depending on the geomechanical conditions, ranging from 1.0 m up to 3.0 m. The excavation will be made by drill&blast or by mechanical system, with concave shape.
- Placing of fiber-reinforced shotcrete on the face (if necessary)
- Confinement of the cavity, placing steel bolts or steel ribs
- Completing the pre-lining, placing fiber-reinforced shotcrete (or reinforced with wire-mesh)
- Excavation and casting of side walls and invert (at a defined distance from the face)
- Waterproofing installation
- Placing vault reinforcement (if required) and casting the final lining (at a defined distance from the face)

The analysis of the monitoring data (mainly geological face mapping and extrusion-convergence measurements) will allow to confirm the predicted section type and regulate the intensity of the interventions and of the executive phases (such as, excavation step, distance from the face for invert casting and final lining casting).

3.2. The Production data analysis

The first parts of the tunnels were excavated by the N.A.T.M. system. At the portal, in geo-units 6a and 6b, section types 7MP and V6-Z6 were used; for the top-heading excavation (0.8-1.3 m step), forepolings in crown were used (R32 L=3.0 m or Ø51 mm L=6.0÷9.0m), coupled with self-drilling radial anchors R32 or R51 L=4.0-6.0-8.0 m; locally steel tubes R32, L=8.0 m, were placed for core-face

confinement. First lining were composed by shotcrete layer, with wire-mesh and lattice girders. Bench excavation has been performed for 1.6-2.6 m excavation step, with shotcrete and lattice girders. In geo-units 4 and 5 section types V4-Z4 and V5-Z5 were applied, using steel forepolings Ø28 L=4.0 m in crown (just for section type 5), radial Swellex bolts L=4.0 m, shotcrete with wire-mesh and lattice girder (top excavation for 1.3-1.7 m steps and bench excavation for 2.6-3.4 m steps). Once ready the needed equipment, the tunnels excavation have been continued by means of the A.DE.CO-RS approach, adopting full-face excavation and face and cavity pre-confinements, where necessary. For geo-units 1, 2 and 3 core-face “stable” conditions occur (category A), the deformation exhibits mainly in the elastic domain, no convergence are expected in the range 1.0-3.0 cm; section types A0 and A1 have been provided, with D&B excavation step in the range 3.0-4.5 m, Swellex bolts, L=4.0 m, and shotcrete, reinforced by steel fibers. For geo-units 4 and 5 expected behavior of the core-face is “stable at short time” (category B): the deformation exhibit in the elasto-plastic domain, with low extrusion and expected convergence and settlement in the range 2.0-6.0 cm; plastic zone at the face is 1.0-2.5 m, and increases up to 4.0-8.0 m around the cavity. No ground reinforcements for the core-face are required, but pre-support in crown could be necessary to maintain the excavation profile and avoid local collapsing of fractured rock-mass. Section types B0 and B0V have been provided, with excavation step in the range 1.0-1.6 by mechanical system (up to 3.2 m if D&B is used for section type B0); the confinement of the cavity has been supported by steel ribs: 2 IPN 160 (or 1 HEA 160) spacing 1.0-1.6 m and shotcrete, reinforced by steel fibers. For section type B0V, steel forepoles, 88.9 mm of diameter and 12-15 m in length, cemented with grout, have been placed. Finally for geo-unit 6a and 6b core-face “stable in a short time”, or “unstable” condition (category C), in very tectonised rock-mass, could be occur. The deformation exhibit in elasto-plastic domain: extrusion has been expected in the range 4-8 cm, with convergence and settlement in the range 5.0-10.0 cm. Plastic zone at the face is 2.0-4.0 m which increases around the cavity up to 9.0-12.0 m. To minimize this deformation response, pre-confinement was necessary, reinforcing the advance-core ahead the current face with fiber-glass elements; sections B2 and B2V have been provided with excavation step equal to 1.0 m: 35 cemented fiberglass structural elements, Ø60/40 type L=18 m length, overlap 8.00 m, have been installed in the core-face, steel ribs 2IPN200 spacing 1.0-1.2 m and shotcrete (10 cm shotcrete at the face).

Starting from May 2017, due to contractual reasons, the South-Eastern tube, with good rock mass conditions, has been again excavated applying the NATM approach, providing for the execution of 3 different section types (A2/1p, A2/2p and A2/3p), characterized by the application of a shotcrete layer (5.0, 10.0 or 15.0 cm thick), swellex rock bolts 3.0-4.0 m long (for section type A2/1p and A2/2p only if necessary) and lattice girders (only for section type A2/3p, coupled with IBO forepoling if necessary).

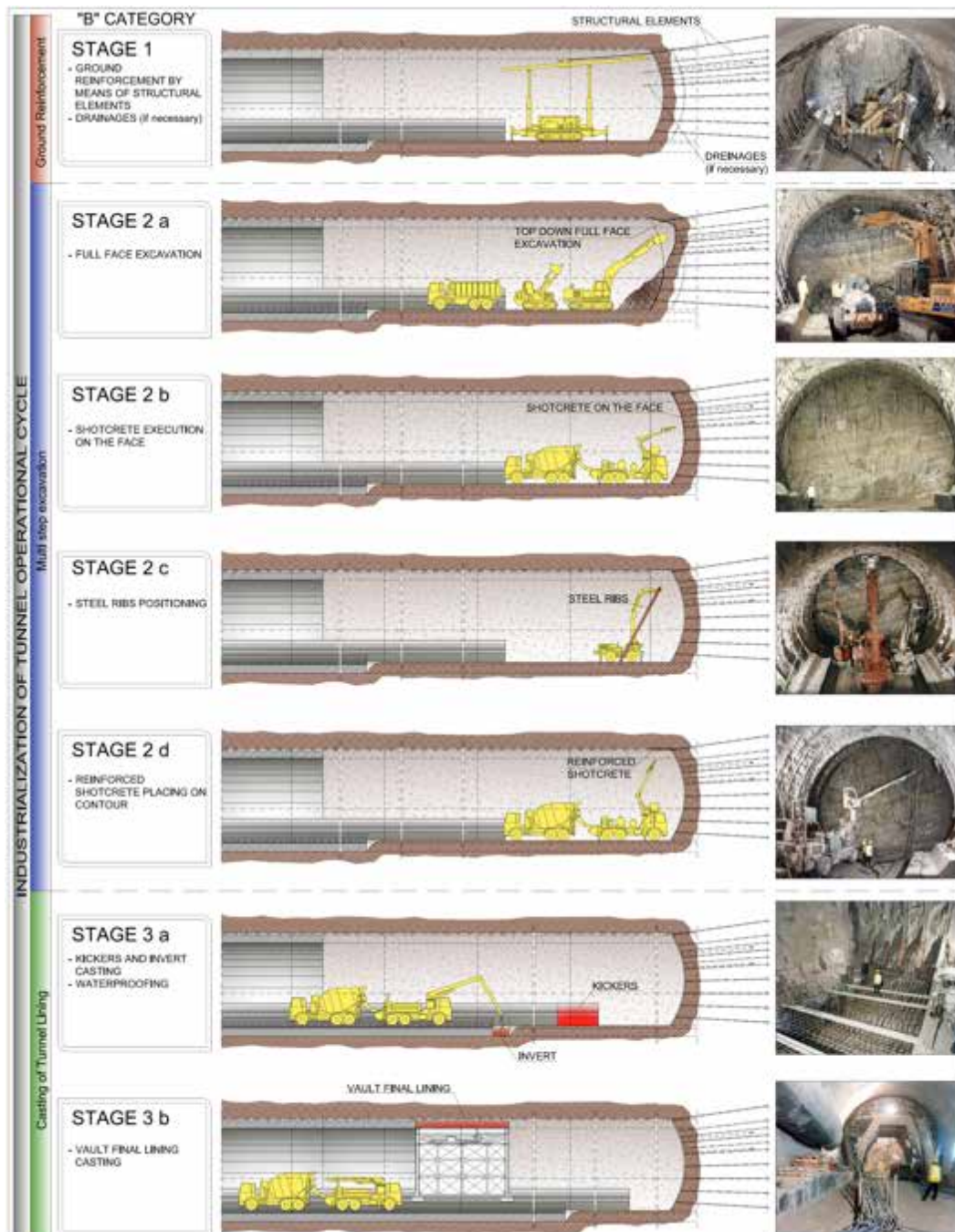


Figure 9. A.DE.CO - RS Work Phases

Today more than 10 Km of tunnels have been excavated and the production data are summarized in the graph in the following Figure 10, where the two excavation approaches are distinguished. As it can be seen, the ADECO.RS approach shows very good production rates, much better than N.A.T.M. system especially in the worst geomechanical conditions, as in correspondence of the portals, where the initial production rate of about 45 m/month (for each tunnel face) has been immediately increased up to 70 m/month with the application of the "full face" approach, reaching then productions rate of about 130 m/month with the industrialization of the excavation process.

In correspondence of medium rock mass conditions (Unit 4 or 5) the NATM approach shows advance rate included between 1.5 m/day (sections V5-Z5) and 2.5 m/day (sections V4-Z4), significantly lower than that obtained with the application of section types B0/1 and B0/2 in similar contexts (advancement rates of 2.8÷3.3 m/day).

The presence of high NATM performances in the last months is strictly linked to the geomechanical conditions of the tunnel that are better in the Eastern front faces (where NATM is applied) than in the Western front faces. In any case it can be noticed that similar section types guarantee production rates absolutely comparable: section type A2/1p and A2/2p can be assimilated to ADECO section A0/1 and A0/2, where 5.8 m/day have been achieved, while section type A2/3p can be related to section type B0/1, with production of 3.3 m/day; even if the ADECO approach provides for the excavation of the entire face, with significant advantages for the overall work progress, while for NATM bench and invert have to be successively excavated.

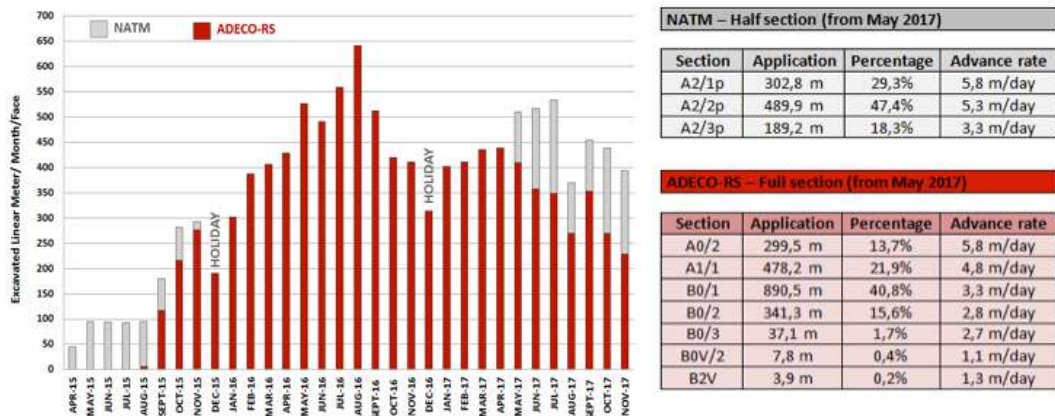


Figure 10. Višňové Tunnels: Monthly production and average daily production (from May 2017)

Moreover, the parzialitation of the excavation, in crown, bench and invert, involves to place the pre-lining step-by-step, with the risk to make unstable the crown pre-lining, or increase its settlement, during bench excavation.

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