COMPARISON OF TUNNELLING METHODS NATM AND ADECO-RS

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ABSTRACT

The New Austrian Tunnelling Method (NATM) has been often used in the Czech Republic in last two decades. One of the methods, without application in the Czech Republic, is an Italian method called ADECO-RS, which has reached significant use in Italy and some other countries. It is the method of controlled deformation, which uses mainly the horizontal anchoring of the tunnel face to reinforce the area in front of the face (advance core). This technology is especially important in weak and soft rocks where is necessary to excavate quickly and smoothly with minimum disruption of initial stress state of the rock mass in the vicinity of the excavation. The use of NATM can be in some cases uneconomical and technically inadequately challenging and in such cases would be appropriate to choose another technology.

Given the facts above, in the Czech environment there is no data available for comparison of these methods not only in terms of numerical modelling, but also in terms of feasibility and usability.

The paper summarizes history of the tunnelling methods and it is closer devoted to NATM and ADECO-RS tunnelling approaches. The basic principles of both methods are set and further the comparison of these methods is made on a theoretical level.

The paper hereinafter includes the analysis of fibreglass face anchors application during the construction of three-aisled Veleslavín Station and the impact assessment of tunnel face anchoring during the excavation of ventilation tunnel on the newly built part of the Prague Metro „V.A“.

The paper also deals with practical knowledge gained during the technical visit of Italian Val di Sambro Tunnel which is built according to ADECO-RS approach. These findings are essential for the correct interpretation of Lunardi method.

KEYWORDS

NATM, ADECO-RS, tunnelling methods, advance core, deformation response of the rock mass

INTRODUCTION

The necessity for tunnels and the benefits they bring cannot be overestimated. Tunnels improve connections and shorten lifelines. Moving traffic underground, they improve the quality of life above ground and may have enormous economic impact. Of course, the construction of tunnels is risky and expensive and requires a high level of technical skill. [1]

Despite great development and expansion of tunnelling in the world, a price of some tunnels in the Czech Republic is higher than in Western EU countries. For the last 20 years New Austrian Tunnelling Method was a prevailing tunnelling method in the Czech Republic (leaving aside the TBM technology, which is becoming increasingly used in recent years), thus it could be one of the reasons for high prices. The method which has not been used in the Czech Republic yet but with which a number of tunnels was built in adverse conditions, is the method called ADECO-RS (L'Analisi delle Deformazioni Controllate nelle Rocce e nei Suoli). This method was developed in eighties in Italy by Professor Lunardi.

The methods mentioned above differ in philosophical views on the behaviour of ground mass during excavation and the method of stabilization of the excavated opening. The result is a completely different approach towards the tunnelling technique and calculation of primary and secondary lining. So far just a small effort was generated to promote ADECO-RS method in the Czech Republic. [7]

NATM

NATM was originally developed for use in the Alps, where tunnels are commonly excavated at depth and in high in-situ stresses conditions. The principles of NATM are fundamental to modern day tunnelling, however most city tunnels are built at shallow depth and without the need to control the release of the in-situ stress and instead want to minimise settlement. [2]

NATM broadly based on the following principles:

- Mobilization of the strength of rock mass.
- Shotcrete protection and flexible support.
- Measurements - every deformation of the excavation must be measured.
- Closing of invert - quickly closing the invert and creating a load-bearing ring is important.
- Rock mass classification determines support measures - there are several main rock classes for tunnels and corresponding support systems for each.
- Dynamic design – the designing is dynamic during the tunnel construction. Every face opening classification of rock is done and the supports are selected accordingly.
- The tunnel is sequentially excavated and supported, and the excavation sequences can be varied.

ADECO-RS

This method was developed in eighties in Italy by Professor Lunardi. As the name ADECO-RS (L'Analisi delle Deformazioni Controllate nelle Rocce e nei Suoli) says, it is a method of controlled deformation. Its introduction to tunnelling practice can be dated as occurring in 1985

when it was tried out for the first time in the world by the Professor Lunardi and Doctor Bindi during the construction of some tunnels on the Florence-Arezzo section of the new high speed railway line between Rome and Florence. [4]

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ADECO-RS broadly based on the following principles:

- The deformation response of the medium to the action of excavation must be principal question with which a tunnel designer is concerned, because, amongst other things, it is an indicator of the triggering and position of an arch effect or in other words the level of stability reached by the tunnel. [5]
- The deformation response begins ahead of the face in the advance core and develops backwards from it along the cavity and that it is not only convergence, but consists of extrusion, preconvergence and convergence. Convergence is only the last stage of very complex stress-strain process. [4]

Fig. 1. Drilling of the tunnel face anchors, Val di Sambro Tunnel, Italy (author's archive)

- There is the existence of a direct connection between the deformation response of the face - advance core system and that of the cavity in the sense that the latter is a direct consequence of the former underlining the importance of monitoring the deformation response of the face-advance core system and not just the cavity.
- It is possible to control deformation of the advance core and as a consequence also control deformation of the cavity by acting on the rigidity of the core employing measures to protect and reinforce it.
- The application of ADECO-RS concept requires the use of equally rigid linings as an absolutely essential condition.
- It is important that maximum care and attention must be paid to ensure that the continuity of action in the passage from preconfinement to confinement occurs as gradually and as uniformly as possible. [6]

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Theoretical Comparison of NATM and ADECO-RS

Conventional tunnelling methods, among which the two above-mentioned methods belong, are able to more or less respond to actually encountered geotechnical conditions and operatively change the means and method for stabilising the excavation. Changes in the state of stress are associated with deformations of the excavated ground surface or the primary lining, as well as the whole area in the vicinity of the excavation. In a built-up area or in the cases where a tunnel passes under structures or facilities sensitive to subsidence, the choice of the technological construction procedure is affected by a requirement for limitation of deformations of the overburden. Experience from practice and results of 3D mathematical modelling have proved that a part of ground mass deformation takes place ahead of the tunnel face. Another part occurs before the primary lining is installed and an anchoring system or other measures are implemented. The latter part of deformation takes place freely and is not controlled by accompanying measures. The remaining part of deformation produces loads on both primary and secondary tunnel linings, thus it can be controlled by accompanying measures. The proportion of the free deformation to the controlled deformation varies, depending on geotechnical properties of ground mass, the height of overburden, the excavation dimension and the construction method.

The practice has proven even a negative effect of dividing the tunnel face into a higher number of partial headings. The ground mass near to the excavated opening degrades and its geotechnical properties worsen. Each subsequent partial excavation therefore passes through a worse environment than the preceding one was.

Dimensions of the primary lining are optimised and the technical solution is economically favourable if the optimum moment for the installation of the primary lining or implementation of accompanying measures stabilising the excavation is found. Limiting values of the tunnel settlement overburden are set because of a damage risk to buildings in the zone affected by excavation. This principle is applicable only in cases where limiting values of the tunnel settlement overburden do not have to be maintained.

The time factor of the excavation support must be assessed from two aspects, from the aspect of its influence on the stability of the face and from the aspect of its influence on the loads acting on the lining. The growing time gap between the excavation and activation of the lining may cause a growth in stability problems both transversally and longitudinally. On the other hand, regarding the loads acting on the lining, an optimal time gap in the activation of the lining may reduce the load on the lining imposed by the rock mass. These two contradicting requirements must be harmonised and an acceptable compromise must be found. A condition for effective exploitation of the composite action of the rock mass-lining system for achieving minimum loading while maintaining stability of the tunnel and keeping the rock mass deformations within allowable limits (both transversal and longitudinal) is, among others, that deformational manifestations of the rock mass are objectively determined not only behind the tunnel face but also ahead of the face, with the aim of determining the part of the overall deformation which is no more transferred to the lining. Stress-strain manifestations of the rock mass are affected above all by stabilisation measures implemented at the face and its reinforcement. [7]

Veleslavín Station

The tunnel face fiberglass anchoring was used only in terms of increasing its stability without taking into account the influence on increasing the stiffness of advance core. In such unfavourable geological conditions, it is difficult to achieve constant progress of excavation and associated continuous deformation response of the rock mass. From the measured values of convergence a gradual process of settlement without significant skips was apparent. This behaviour can be partially attributed just to the systematic use of horizontal face anchors, which - for greater effect in reached conditions - had to be located into the face in a denser regular grid.

Unfortunately neither preconvergence ahead the tunnel face nor the extensometric measurements of the tunnel face extrusion were monitored, of which the effect of fibreglass face anchoring would be evident and it could be derive the number of anchors per m^2 of the face necessary to achieve the desired behaviour of the rock massive in conditions reached by excavation.

Fig. 2. Face anchors installation, Veleslavín Station, Czech Republic (author's archive)

Ventilation Tunnel within the Prague Metro Extension – Construction Object „02-29/01"

Although the realization of the access tunnel itself preceded the remediation of the excavation environment - which was a combination of sealing vertical walls made of double jet grouting columns carried out from the surface and the containment over the tunnel top-heading from sub-horizontal jet grouting columns reinforced with micro piles – it is an underground construction in the Czech tunnelling industry that reasonably resembles ADECO-RS.

Unfortunately contractor did not use the ADECO-RS approach in encountered and very complicated conditions due to fear to accept a non-traditional solution.

Construction phases according to ADECO-RS approach in the Val di Sambro Tunnel

The first activity is **ground improvement of the core-face** which starts with drilling and continues with insertion of 100 fibreglass elements at the face (L=24, 00 m, overlapping = 12, 00 m). The fibreglass anchors are implemented to the core-face variably, anticipated in the design as a function of the deformation response observed during construction (extrusion-convergence) can be up to 140, of which 40 operated so as to constitute a zone of improved ground around the advance core. The next step is cement grouting of the fibreglass elements.

Note: Drainages surrounding the core-face if necessary.

The second workflow consists of **excavation and primary lining installation.** The first advance cycle is carried out, planned length: 6 m, excavation step: 1 m. First layer of shotcrete is sprayed onto the face and the walls followed by installation of double IPE 240 steel ribs every metre. After that the wire mesh is installed. Second shotcrete layer 30 cm thick around the cavity is sprayed and stabilised by the steel ribs and wire meshes.

Note: placing of struts at 2-3 m max far from the face.

Fig. 3. Excavation process, Val di Sambro Tunnel, Italy (author's archive)

The construction process further comprises tunnel invert and kickers casting (execution of an invert excavation step, placing of the steel cages, casting of the tunnel invert and kickers), placing of the waterproofing consisting of a layer of geotextile and a PVC sheet, reinforcement cages installation and final lining casting (by using a formwork on wagon).

Notes:

- Repetition of the cycle until the 12 metres or 16 metres are excavated (the advance cycle can vary between 12 and 16 m)
- After the advance cycle is completed, a plug is carried out onto the face by means of 25 cm thick steel fibres shotcrete
- The final lining follows at 30 to 60 m from the face
- Advance rates are approximately 1.2 to 1.4 m of finished tunnel (already lined)
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Time schedule of the advance cycle: Carrying out an advance cycle requires from 10 to 11 days:

- 5 days for the core-face reinforcement (drilling, insertion and cementation of 100 to 140 fiberglass tubes (7 at a time) 24 m long with the 12 m overlap if the advance cycle is 12 m, 8 m if the advance cycle is 16 m)
- 2 to 2.5 days to excavate from 6 to 8 m, including tunnel advance, mucking, installation of 6 to 8 steel ribs (2 IPE 240, step 1.0 m) with strut in the invert, shotcreting (30 cm thick)
- 12 hours for excavation, reinforcement and concreting of 6 ÷ 8 m kickers and invert (distance from the face always between 3 and 9 m in case of 12 m advance cycle, between 4 and 12 m in case of 16 m advance cycle)
- 2 to 2.5 days for the excavation of the remaining 6 to 8 m of the advance cycle
- 12 hours for excavation, reinforcement and concreting of the remaining 6 to 8 m of kickers and invert

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CONCLUSION

Theoretical study and comparison of ADECO-RS and NATM methods defined basic assumptions and principles of both methods and set different approaches to tunnelling which have a major impact on the efficiency of the methods used in different conditions.

In the Czech Republic the New Austrian Tunnelling Method was a prevailing tunnelling method in past two decades. And so design and construction of the tunnel - where local conditions permit - should be tried out according to ADECO RS method.

The impact of advance core anchoring inclusion in statistical analysis and design of the tunnel itself could have a positive effect not only on the safety of underground works and the exposure of the excavation works on the surface, but also on the costs directly associated with the implementation of primary and secondary lining. The horizontal anchoring of the tunnel face may become a very suitable technological supplement reducing deformations of the excavated opening and the lining, as well as the magnitude of the settlement trough which makes it particularly suitable for shallow tunnels in urban areas.

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