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DEFORMATION ANALYSIS DURING TUNNEL EXCAVATION IN POOR ROCK MASS

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Abstract

The problem of large deformations is very pronounced when excavating longer tunnels in poorer rock mass, which can result in serious potential hazards to safety, costs and time of tunnel construction. Taking the Golubinja tunnel, located on the route of corridor Vc, as an engineering background, displacement monitoring was carried out on a certain section of the right tunnel tube with a length of approximately 230 m'. Displacement monitoring was carried out in relation to different distances during the excavation of the top heading-bench and the bench-primary invert in a poorer rock mass with a defined RMR of 17 to 26 points. The designed tunnelling method is based on the principles of the New Austrian Tunnelling Method „NATM". The results show that in complex geological conditions, displacements can be effectively controlled by defining the optimal distance between the excavation phases of the top heading-bench and the bench-primary invert. Through a detailed analysis of the collected data, the mathematical functions of the dependence of the displacement in relation to the distances between the excavation phases of the top heading-bench and the bench-primary invert were obtained. The functions can be used as a tool for a quick and simple analysis of displacements depending on the distance between the excavation phases of the top heading-bench, and the bench-primary invert in a poor rock environment.

Key words: tunnel, excavation, deformation, bench, top heading

1 Introduction

Rock-primary support interaction is one of the most important issues in underground engineering, which is of great interest for the design of support structures, safety and construction costs, as well as environmental protection [1]. Modern design and construction of tunnels requires appropriate techniques and technologies in all phases of the tunnel design. Taking the Golubinja tunnel, which is located on the pan-European route Budapest-Osijek-Sarajevo-Ploče, defined as Corridor Vc, displacements were monitored in relation to different distances during the excavation of the top heading-bench, and the bench-primary invert on a certain section of the tunnel in the rock mass with a defined RMR of 17 to 26 points.
The Golubinja tunnel is located on the section Poprikuše-Nemila, which is part of the main section Doboj south (Karuše) - Sarajevo south (Tarčin). The total length of the tunnel is approximately 3,600 m', while the wheelbase distance between the tunnel tubes varies between 25-70,0 m'. The designed tunnelling method is based on the principles of the New Austrian Tunnelling Method „NATM", with the construction of both tunnel tubes. In the tunnel, 3 parking niches per tube as well as 11 passages for pedestrians were designed [2].

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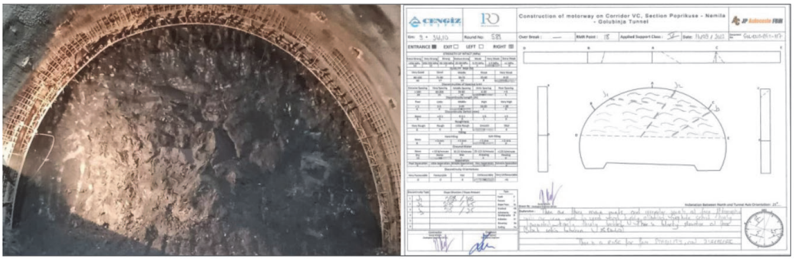
Figure 1 Geographical location of the Golubinja tunnel on the route of the Corridor Vc

2 Engineering-geological characteristics of the rock mass in the “Golubinja“ tunnel excavation zone

The Golubinja tunnel is located in the Dinarid ophiolite zone. Ultramafic rocks (leherolites, peridotites, dunites and sepentinites) play a dominant role [3]. Based on the geological mapping of the open face during the excavation of the right tunnel tube on the analysed section of the tunnel (from chainage km:9+263 to km:9+528), the excavation was carried out exclusively in materials made from ophiolitic melange [4]. The mélange is made of shale-clay material containing fragments of graywacke, sandstone, ultramafite, spilite, and diabase. The melange is dominated by a sedimentary-metamorphic sequence that is tectonically broken and degraded. The general characteristic of the structure of the material through which the Golubinja tunnel is constructed is mostly represented by a silt-shale matrix (70-90%), and the remaining part is made up of fragments of smaller or rarely larger sequences of graywackes, basalts, diabases and spilites. Also, there is a pronounced vertical and lateral shift of the mentioned lithologic members, as well as a change in physical-mechanical characteristics. In lithostratigraphic terms, there is no general legality that could be used to predict and evaluate the representation and condition of the rock mass for excavation without the face of the excavation being open. There is a frequent occurrence of underground water at the face of the excavation, which further devalues the physical and mechanical characteristics of the rock mass. Based on the results of the mapping of the open face of the excavation on the analysed section of the tunnel, it can be concluded that the state of the rock mass according to the RMR classification has values that classify them into IV and V categories (the RMR ranged from 17 to 26 points).


Construction of motorway on Corridor VC, Section Poprikuse - Nemila - Golubinja Tunnel

Km: 9 + 341,10 Round No: 585 Over Break: — RMR Point: 18

ENTRANCE ■ EXIT ☐ LEFT ☐ RIGHT ■

Figure 2 Excavation face in the Right Tunnel Tube and geological report km: 9+341.10

3 Analysis of deformations of the surrounding rock mass using “NATM“ during tunnel excavation

The selection of the construction method for a tunnel with a larger cross-section is mainly based on the conditions of the rock through which the tunnel is being constructed [5]. During the construction of a tunnel with a larger cross-section, excavation and installation of the primary support are in most cases carried out continuously [6]. There are no special rules that would facilitate decision-making when choosing an adequate tunnel excavation method in complex geological conditions. This decision is mainly influenced by engineering experience, not theoretical calculations [7]. The New Austrian Tunneling method “NATM” is based on the concept according to which the surrounding rock that is surrounding the underground opening becomes a load-bearing structural component through the activation of the annular body of the supporting rock through which the tunnel is constructed [8]. Prof. Müller states in his research that the time of closing the ring is of crucial importance and it should be done as soon as possible [9].

The determination of the relationship between the disturbed part of the rock mass around the tunnel excavation and the bearing capacity of the primary support is shown in Figure 3. The soil response curve shows the interaction of rock/primary support and deformations over time. When choosing to install a stiffer primary support (shown as ‘2’), it will bear a greater load because the rock mass around the opening has not deformed enough to bring the stresses into balance. Therefore, the safety factor will decrease sharply. After point C, the behaviour of the excavated material becomes non-linear. If the primary support (1) is installed after a certain displacement (point A), then the system comes to equilibrium with a lower load on the primary support. A special feature of NATM is that intersections always take place on the downward path of the curve [10]. This implies a less rigid support that causes the necessary deformation as in the case of NATM application. Moreover, the rock support must be neither too rigid nor too flexible. After point B, “harmful loosening” begins and the required support pressure to stop loosening increases greatly.

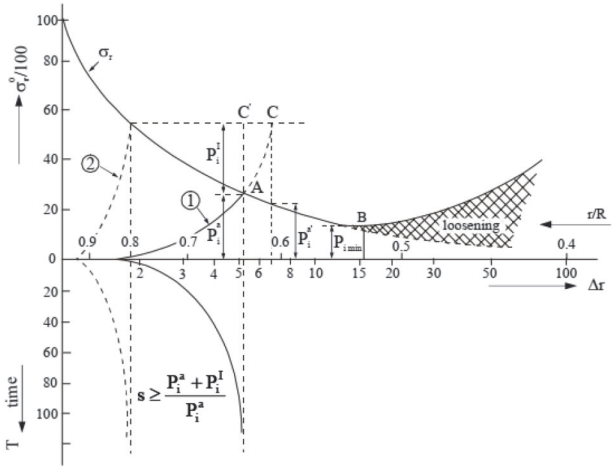


Figure 3 Soil and primary support interaction curves [10]

Tunnel excavation causes a disturbance of the initial stress state in the soil and creates a three-dimensional arc-shaped stress regime around the advancing tunnel face. Such a stress regime is indicatively shown in Figure 4.

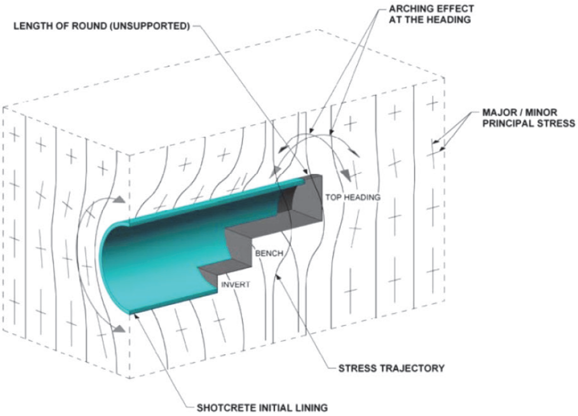


Figure 4 Stress flow around the tunnel opening [11]

At the face of the tunnel, stresses occur around the tunnel opening in the shape of an arch, as well as in front of the tunnel excavation, and behind it on the newly constructed primary lining in the longitudinal direction. Also, stresses act on the sides of the excavated part perpendicular to the tunnelling direction. The extent of stress disturbance around the active direction depends mainly on the conditions of the environment through which the tunnel is being constructed, the volume of the excavation and the progress step. This disturbance begins up to two excavation diameters in front of the face of the active tunnel as indicatively shown in Figure 5.

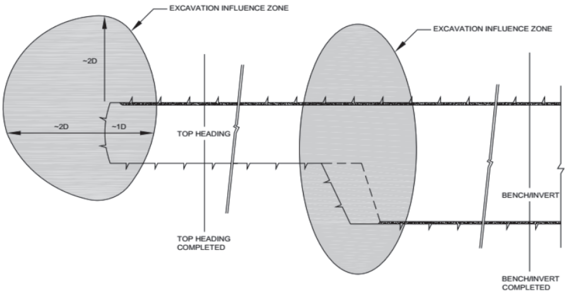


Figure 5 NATM tunnelling and disturbances at the excavation face [11]

Experimental and numerical research of soil deformation response shows that the real cause of the entire process of stress and deformation that is triggered during tunnel excavation lies in the regulation of the stiffness of the advanced core using appropriate overlapping techniques, the controlled excavation method, as well as the ring closing time [12]. Figure 6 shows a graphic representation of the total deformations depending on the distance between the top heading and the invert [12].

It is precisely the first and most important task of the designer to determine how and in what way the arch effect can be caused after the excavation is done, and to ensure that this effect is properly formed by stabilization procedures in complex geological conditions [13].

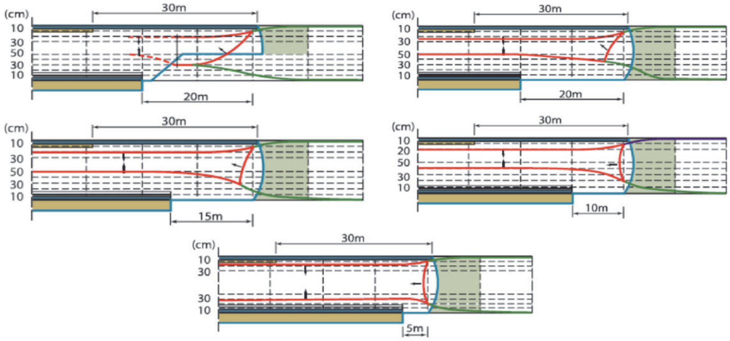
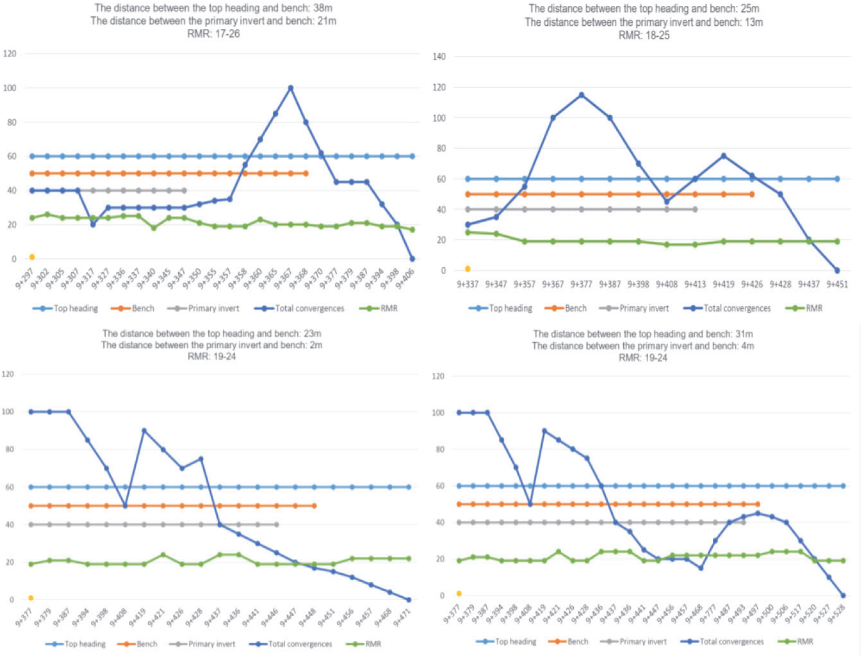


Figure 6 Influence of the distance of the primary invert from the face of the excavation on total deformation [12]

4 Analysis of the deformations of the surrounding rock mass in relation to different distances during the excavation of individual phases of the Golubinja tunnel

During the excavation of the “Golubinja” tunnel, geodetic monitoring of the displacement was carried out with a total station using built-in measuring marks (3 measuring marks in the top heading and 2 in the bench) in the cross-section of the tunnel tube at a mutual longitudinal distance of 10m. Monitoring was carried out on a certain section of the right tunnel tube from the chainage km: 9+297 to km: 9+528 (231m’) in relation to different distances during the excavation of individual phases, namely: top heading-bench, and bench-primary invert in poor rock mass with a defined RMR of 17 to 26 points. The collected data were processed and presented in the continuation of the work in the form of a graph, Figure 7.


The distance between the top heading and bench: 38m
The distance between the primary invert and bench: 21m
RMR: 17-26

The distance between the top heading and bench: 25m
The distance between the primary invert and bench: 13m
RMR: 18-25

The distance between the top heading and bench: 23m
The distance between the primary invert and bench: 2m
RMR: 19-24

The distance between the top heading and bench: 31m
The distance between the primary invert and bench: 4m
RMR: 19-24

Figure 7 Presentation of the displacement (vertical axis in (mm)) of the top heading-bench and bench-primary invert in the right tunnel tube from km: 9+297 to km:9+528

From the graphical representations, Figure 7, it is clear to conclude that the convergences begin to grow exponentially when the distance between the bench and the constructed primary invert increases, and that we have the least recorded convergences if the primary invert is executed immediately after the excavation of the bench. By analyzing all the collected data presented in the form of a graph, Figure 7, and processing them in detail, a graphical correlation of the dependence of the expected convergences was established in relation to the distance between the top heading and the bench, Figure 8, as well as the distance between the bench and the primary invert during tunnel excavation in similar geological conditions, Figure 9.

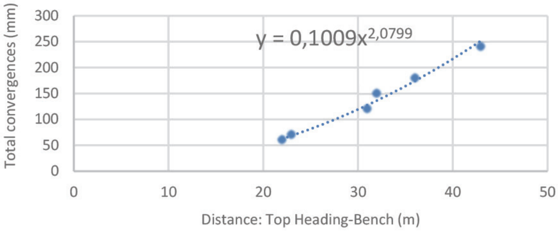


Figure 8 Display of expected deformations depending on the distance between the top heading and the bench

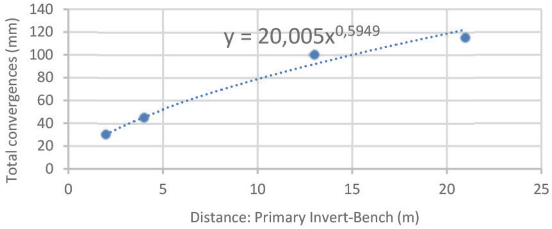


Figure 9 Display of expected deformations depending on the distance between the primary invert and bench

Using mathematical software, mathematical functions were obtained that are dependent on the expected convergence and distance of the top heading-bench excavation, as well as a mathematical function which, depending on the expected convergence and distance of the bench-primary invert.

5 Conclusion

The construction of each tunnel requires unique terrain research and innovative design solutions. The effects of the bearing capacity of the surrounding rock and the primary support show different characteristics depending on the geological conditions through which the tunnelling is carried out. Based on the engineering practice of tunnels for highways with a large cross-section, and collected data from the Golubinja tunnel, this work reveals the possibility of deformation control by defining the optimal distance between the excavation phases of the top heading-bench, and the bench-primary invert in complex geological conditions. Through a detailed analysis of the data collected during the excavation of the “Golubinja” tunnel section on the route of the Vc corridor, mathematical functions were obtained and they can be used as a tool for a quick and simple analysis of the displacement depending on the distance between the excavation phases of the top heading-bench, and the bench-primary invert in poor rock environment. When excavating tunnels in complex geological conditions, it is very important to establish and maintain a constant rhythm of excavation, leaving no time for the “core” to deform. It is necessary to form an artificial “arch effect“ because it is a condition for the stability of the excavation.

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