ADDITIONAL SUPPORT MEASURES IN THE KOBILJA GLAVA TUNNEL

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Abstract

The paper presents specific aspects of the construction of the Kobilja Glava tunnel, which is being built as part of the I Transversal, section Vogošća-Sarajevo, with an emphasis on the use of additional support measures. Due to the poor characteristics of the rock mass – marl, significant subsidence was regularly monitored during excavation in the tunnel's tubes, both inside the tunnel and on the surface of the terrain. In specific geological sediments with poor geological and geotechnical characteristics, there is a need for the use of additional support measures, such as temporary invert, "elephant foot," support sail, etc., aimed at stabilizing the tunnel, preventing further movement, and preventing the encroachment into the designed profile of the secondary lining.

Keywords: *tunnel, construction, monotoring, elephant foot, temporary invert, support sail*

JEL classification of work: *L74 Construction*

1 INTRODUCTION

The physical-mechanical properties of the rock mass in which a tunnel is constructed have a significant impact on the construction process. Accordingly, the physical-mechanical properties of the rock mass directly influence the selection of tunnel construction methods.

In accordance with the standard BAS EN 1997-1:2017, tunnels fall into the third geotechnical category, which involves unusually large risks or exceptionally demanding soil conditions or loads. Although extensive research and complex analyses are carried out during the design phase, predicting the geotechnical behavior of such a structure is difficult, so the standard allows the use of the so-called observation method, where the project is monitored during construction.

Therefore, during tunnel construction, continuous geotechnical monitoring of the tunnel, the surface above the tunnel, and surface structures is conducted. This method helps identify stress and deformation redistributions in the rock mass surrounding the future tunnel and monitors the stability of the tunnel and all existing structures throughout all phases of construction.

In Mission G32, conducted during excavation and other works on the primary tunnel lining, support measures are planned to ensure the stability of the tunnel during excavation.

Despite these measures included in Mission G32, post-monitoring results showed the need for additional support measures to stabilize the tunnel. An overview of the additional support measures is provided in the following text.

2 REGULAR MONOTORING DURING CONSTRUCTION PHASE

Regular monitoring and quality control during the construction phase is one of the most important segments in the proper implementation of NATM tunnel excavation, aiming to "control" the impact of deformations in the rock mass on the primary support system.

During regular monitoring, the following criteria need to be compared to assess deviations from the expected behavior of the support system:

Rating 4 - In accordance with the expected behavior

Measured deformation levels range from 0-50% of the expected deformation tolerance.

The necessary action is to maintain the prescribed frequency of deformation measurements.

Rating 3 - Slight deviation from expected behavior

Measured deformation levels range from 50-75% of the expected deformation tolerance. The necessary action involves increasing the frequency of deformation measurements at critical profiles to determine deformation trends, speed of change, and prioritized deformation vector directions. A visit to the critical zone in the tunnel and reconnaissance of the lining condition (cracking of the primary lining, condition of anchor strain plates, and other signs of increased primary lining mobilization) (Figure 1).

Figure 1. Condition of IBO anchor strain plate/crown (photo by N. Halilbegović, 2024.)

Rating 2 - Deviation from expected behavior

Measured deformation levels range from 75-90% of the expected deformation tolerance. Necessary actions include increasing the frequency of deformation measurements at critical profiles, determining trends, speed of change, and prioritized deformation vector directions. A visit to the critical zone and reconnaissance of the lining condition (cracking, anchor plate condition, etc.) (Figure 2). If necessary, additional support measures are implemented based on numerical analysis and frequent monitoring of rock mass behavior.

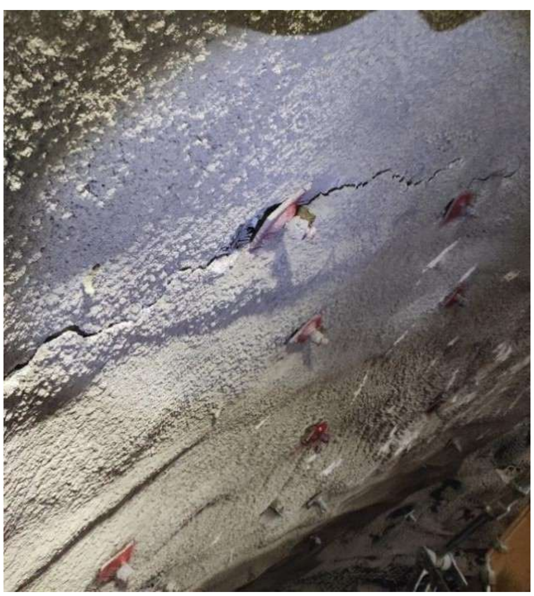

Figure 2. Cracks in the shotcrete/crown (photo by N. Halilbegović, 2024.)

Rating 1 - Significant deviation from expected behavior

Measured deformation levels exceed 90% of the expected deformation tolerance. Necessary actions involve increasing measurement frequency, determining trends and speed of deformation, and visiting the critical zone in the tunnel to check the condition of the lining (Figure 3). If required, additional support measures are implemented based on numerical analysis, and frequent monitoring of the rock mass behavior is performed. Geodetic profiling is done to determine minimal tolerance for transitioning to the sub-profile.

If necessary, the installation of longer anchors is performed next to anchors with damaged strain plates. Local repairs to the primary lining are carried out at locations where larger cracks have appeared.

Figure 3. Condition of steel arch - grillage/crown (photo by N. Halilbegović, 2024.)

2.1. Deformation Measurement

Deformation measurement is also a very important segment of monitoring during construction according to NATM. It is essential that deformation measurements, both in the tunnel and on the surface, be continuous without interruption. In poor rock environments such as clays, reference points (measurement profiles) for deformation measurement are installed every 5 meters in the crown and every 10 meters in the bench. This approach enables timely information on the actual conditions during tunnel excavation. 3D optical measurements are used for deformation monitoring. Electronic total stations with integrated coaxial distance measurement are generally used for 3D observation. The points are observed using specially designed reference points that have a well-defined central point.

Depending on the type of work, two types of reference points are used, such as bi-reflective reference points and prism reference points (Figure 4). Bi-reflective reference points have reflective foil on both sides. They are used for distances up to 140 meters and are used to monitor the normal cross-section. The reference point is positioned freely, and readings are taken based on several cross-sections and reference points. Polar coordinates of the reference point represent original readings that define the cross-section. Absolute 3D coordinates of the cross-section are calculated from the polar coordinates.

The purpose of 3D measurement is to:

1. Verify geological surveys,
2. Adapt the support system to actual conditions,
3. Verify the correctness of all support measures.

Figure 4. Prism reference point/crown (photo by N. Halilbegović, 2024.)

3 ADDITIONAL SUPPORT MEASURES IN THE KOBILJA GLAVA TUNNEL

In specific geological environments, environments with poor geological and geotechnical characteristics such as marls, there is a need to use additional support measures such as: temporary invert, "elephant's foot", support sail, etc.

3.1. Temporary invert

In soft rocks such as marl, where we have large deformations and subsidence both in the tunnel and on the surface of the terrain, a temporary invert (temporary foot vault) is performed as an additional underground system of measures (Figure 5 and 6).

The technology for performing a temporary invert consists of excavation and transport of the excavated material to the landfill and installation of shotcrete on the previously reinforced surface. Shotcrete is installed with a pump for shotcrete, the so-called robot. As a rule, the thickness of shotcrete (C25/30) can be from 20 to 30 cm, depending on the quality of the rock mass of the treated section of the tunnel, and the reinforcement is carried out in two layers of reinforcing mesh (Q257) with mutual overlaps of min 30 cm (in practice it is an overlap of two cubes), the overlap must be realized both longitudinally and transversely at the joints of the nets. The reinforcing meshes are connected to each other with 3 mm thick steel wires. After concrete has been installed in the temporary invert, work on that position is suspended for a minimum of one hour, followed by backfilling of the temporary invert in order to allow access to machines for continuing work on other positions, as required by the basic principles of NATM.

It is important to point out that the distance of the face of the tunnel excavation from the temporary invert must not be more than 3m, because otherwise the installation of a temporary invert with the role of taking over current pressures does not make sense.

The purpose of installing a temporary invert is to take over pressures and deformations until the complete closure of the ring is performed by performing a permanent invert, more precisely in preventing further increase in displacement as well as preventing entry into the designed profile of the secondary lining. When excavating the permanent invert, together with the excavated material, the temporary invert is removed and transported to the landfill.

Figure 5. Excavation of the temporary invert (photo. N. Halilbegović, 2024)

Figure 6. Installation of shotcrete on pre-reinforced II reinforcement zone/temporary invert (photo. N. Halilbegović, 2024)

3.2. "Elephant's Foot"

"Elephant's foot" as an additional support measure is applied on the contact part of the calote and the step (Figure 7). The technology of performing the "elephant's foot" consists of a slightly deeper excavation in the side of the calotte than usual in order to form a space for its installation. The "elephant's foot" is prepared on the construction site, by welding additional reinforcing bars for the pulley (lattice support) and according to the previously agreed detail that defines the thickness of the reinforcing bars, the method of welding them for the pulley and the overlap (Figure 8). Reinforcing bars that are used as an integral part of the "elephant's foot" must have appropriate certificates, and after the welding process, and before installation, the welds are additionally tested.

The purpose of installing the "elephant's foot" is to prevent the further increase of displacement as well as to prevent entry into the designed profile of the secondary lining. It is often the case in soft rocks and poor soils that micro piles are additionally installed under the "elephant's foot".

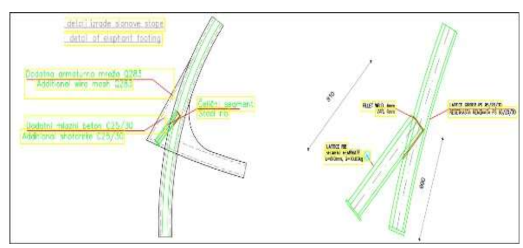

Figure 7. Detail of making the "elephant foot"

Figure 8. Detail of the "elephant's foot" installation (photo: N. Halilbegović, 2024)

3.3. Securing the face of the excavation - support sail

Securing the face of the excavation, as one of the additional support measures, includes the protection of the active face of the calote by installing shotcrete on a previously installed zone of reinforcing mesh, additionally reinforced with IBO anchors (Figure 9).

The front protection technology consists, first of all, of the formation of a support core during excavation, which is reinforced with one zone of reinforcing mesh (Q257) (Figure 10). After installing the reinforcing mesh, shotcrete (C25/30) is usually installed in a thickness of 5 cm. The face of the excavation is then additionally strengthened by installing IBO anchors (fi32mm), length 12m1. A total of 8 anchors are installed. Anchors must be activated no later than 24 hours after installation.

It is important to point out that the face of the excavation secured in this way is left until the excavation of the next step of the calotte, where during the excavation of the calotte the secured face is also removed. If the rock mass is of lower quality, the reinforced supporting sail with anchors can be kept during the excavation of two to three new steps of the calotte, in such a way that the central part of the calotte is left during the excavation, while one halo around the supporting sail is excavated, just enough to can access the installation of load-bearing elements of the primary substructure.

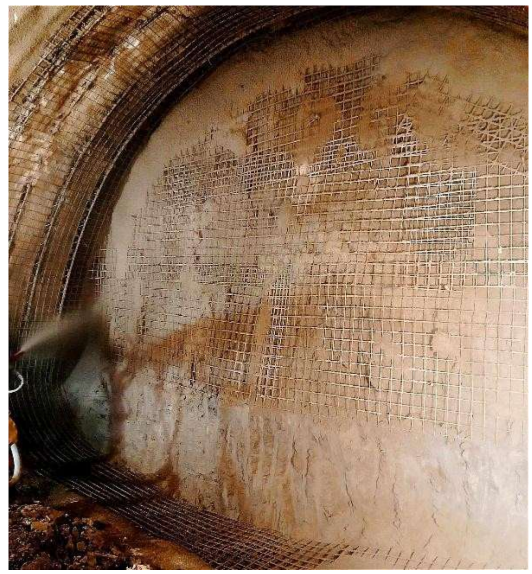

Figure 9. Installation of shotcrete on the pre-reinforced face of the excavation/top heading (photo by N. Halilbegović, 2024)

Figure 10. Support sail/top heading (photo. N. Halilbegović, 2024)

CONCLUSION

Tunnels are highly specific and complex structures, making it very challenging to predict the actual geological and geotechnical characteristics of the terrain. In practice, it has been observed that the true geological characteristics of the ground are usually determined only during the excavation of the tunnel shafts.

After each step of excavation, geological mapping of the tunnel face is performed, which includes rock mass classification, typically based on the RMR (Rock Mass Rating) system. Based on this mapping, the type of primary lining is determined.

Although extensive research and complex analyses are conducted during the design phase, predicting the geotechnical behavior of such a structure is difficult. Therefore, the standard permits the use of the so-called observation method, where the project is monitored during construction. Continuous geotechnical monitoring of the tunnel will be conducted during construction.

The paper discusses specific aspects of the construction of the Kobilja Glava Tunnel. Due to deformation and subsidence of the terrain resulting from poor characteristics of the rock mass—limestone—additional support measures had to be implemented, such as temporary invert, elephant foot, and support core, with the aim of stabilizing the tunnel and preventing further movement as well as encroachment into the designed profile of the secondary lining.

While it is crucial to carry out geotechnical investigations and complex analyses of the stress-deformation state of the rock mass on the tunnel lining before starting the excavation, primarily to dimension the appropriate support system to ensure tunnel stability during excavation, it is equally important to control the influence of stress and pressure from the surrounding rock mass on the tunnel lining during the construction phase. This is achieved by adapting the excavation and lining technologies to the actual conditions on-site, in line with the core principles of NATM (New Austrian Tunneling Method).

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