doi.org/10.62683/SINARG2025.167

Research paper

REHABILITATION OF THE TUNNEL KOSMAN DURING THE CONSTRUCTION OF THE SMOKOVAC - MATEŠEVO HIGHWAY SECTION IN MONTENEGRO

Nikola Čađenović[1], Ivan Maretić[2]

Abstract

During the construction of the first section of the Montenegrin motorway from Smokovac to Mateševo, over 35 km of traffic tunnels were excavated. Such a volume of tunnel construction faced numerous challenges, with the primary task being to ensure the stability of the excavation.The most significant instability of the tunnel excavation was registered in right tube of the Kosman tunnel. During the underground excavation, in the portal zone, there was an intensive inflow of groundwater, which led to the collapse of the rock mass with the opening of a wide channel towards the surface. The Kosman tunnel was formed in soft rocks represented by tectonically altered flysch sediments, siltstones, marls and sandstones. At the moment of collapse, the rock mass was characterized as an excavation of the worst category, and all safety measures were applied according to the main design. Work was suspended and additional measures were implemented to secure the tunnel excavation. The paper analyzes the conditions that led to the collapse of the rock mass, as well as the applied remediation measures. It is estimated that the main reason for the instability was the intensive inflow of groundwater into the tunnel excavation.

Key words: *Kosman tunnel, flysch, rock mass, fracture, groundwater*

[1] Dipl. inž. geologije, Monteput doo, Crna Gora, cadjenovicnikola@hotmail.com, ORCID N/A.
[2] Dipl. inž. građevinarstva, Monteput doo, Crna Gora, ivanma@t-com.me, ORCID N/A.

1. INTRODUCTION

During the construction of the first section of the Montenegrin highway from Smokovac to Mateševo, more than 35 km of traffic tunnels were built. Such a volume of tunnel construction faced numerous challenges, with the primary task being to ensure the stability of the excavation.

One of the major problems arose in November 2016 during the excavation in the right exit portal zone of the Kosman tunnel, when the primary support was deformed, the excavation face cracked, and a wide channel opened up to the surface. This collapse was caused by a intensive inflow of groundwater and occurred despite all safety measures that were implemented in accordance with the main design [1, 2].

The contractor typically used a primary tunnel support of type Vpc to secure portal sections in quaternary sediments with low overburden. This type of primary support is used for the worst categoru of excavations, according to RMR classification (Rock Mass Rating - Bieniawski 1974). For the Kosman tunnel, the application of this type of primary tunnel support was planned for a length of 10 m from the exit portals. The initial collapse occurred 10 m from the tunnel portal in degraded and tectonically altered flysch sediments represented by siltstones, marls, and sandstones. The deformations rapidly progressed and in just a few hours they covered the tunnel's overburden, forming a channel 6-7m in diameter that reached the ground surface, Figure 1.

Figure 1. The soil that filled the right exit tube of the Kosman tunnel after the collapse of the excavation face

An analysis was conducted on the conditions that led to the collapse of the rock mass. It was concluded that the instability of the tunnel excavation was caused by an intensive inflow of groundwater. Under the pressure of the groundwater, the tunnel excavation collapsed, and since the layers of overburden of the rock mass were only a few meters, the surrounding ground also collapsed.

2. PRIMARY TUNNEL SUPPORT OF THE KOSMAN TUNNEL

The exit portal of the Kosman tunnel is formed in flysch sediments, dominated by siltstones, marls, and sandstones, the rock is tectonically damaged and very degraded at the surface. The general dip of the layers is towards the north with variations from northwest to northeast, and the general angle dip is about 30 degrees. Siltstones and marls are generally thinly layered (0.5-10 cm), while sandstone layers are thicker (2-50 cm). At the surface of the terrain, there is dusty clay with a thickness of 4-5 m, which is deluvial from the flysch rocks.

The collapse of the rock mass occurred during the underground excavation in the soft rock mass, which according to the geotechnical study has the following parameters: γ_z=23 kN/m^3, UCS=7 MPa, GSI=18, mi=6. The physical-mechanical characteristics of the rock mass were obtained using the RockData software package and using the tunnel excavation application assuming Mohr-Coulomb failure conditions.

The obtained cohesion was c=20 kN/m^2; the angle of internal friction was φ=38.5 ° and the deformation modulus D=41.9 MN/cm^2. The surface of the terrain consists of 4-5 m thick deluvial sediments which have the following physical-mechanical parameters: γ_z=21 kN/m^3, cohesion c=13 kN/m^2 and angle of internal friction φ=27 °.

Static calculations were performed using the finite element method, and numerical modeling was carried out in accordance with the excavation and installation phases of the protective structure. During the tunnel excavation, the RMR classification (Rock Mass Rating - Bieniawski 1974), method was used, and the primary support system used in the main design was based on the NATM concept. For the portal zones, a Vpc type structure was adopted, intended to secure the tunnel portal zones. The contractor excavated 35 km of tunnel, forming 10 double--tube tunnels, and the stability of the entire portal section in the quaternary sediments with low overburden was ensured by Vpc-type structures.The designer explained this attitude by the fact that in the portal zones, rock mass has cracked due to atmospheric influences and that a part of it has been turned into soil to a great depth.The remaining rock has poor physical and mechanical characteristics, resulting in very low stability after excavation.

These are poor conditions for tunnel excavation, which create great difficulties in construction with a high risk of collapse, which requires a strong supporting structure to ensure safety. The portal zones of tunnels in which the Vpc primary support type was implemented proved to be stable.

The primary tunnel support of the Vpc type involves applying 26 cm of shotcrete in layers, two layers of Q188 mesh reinforcement, installation of 4 m long SN anchors in a 200x60 cm grid, and the installation of steel lattice girders 115-30-36 cm at a distance of 60 cm. The excavation was carried out in phases, first the calotte and then benches, with the installation of a temporary invert. The tunnel face was secured by installing a forepoling/piperoof, formed from IBO anchor bar with a diameter of 76 mm and a length of 9 m. Piperoofs are installed with an overlap of 2 m and are formed at an angle of +5 ° to the horizontal plane.

The main design allows deformation of the primary support up to 18 cm. The entire pressure of the rock mass is received by the primary tunnel support and it is not intended that the secondary tunnel lining receives the pressure of the rock mass.

This type of support ensures the security of the portal zone formed in the quaternary sediments, however, after excavation progressed to degraded flash sediments, groundwater appeared at the contact of these two units. On the night of 18-19 November, after heavy rainfall, significant influx of groundwater was registered into the tunnel excavation. After only a few hours, the primary support began to deform, and the rock mass along the tunnel face began to collapse. Deformations increased rapidly and the next day the terrain above the right exit portal collapsed into the tunnel excavation, creating a wide channel on the surface of the terrain with a diameter of 6-7 m, Figure 2.

Figure 2. Area above the right exit portal of the collapsed Kosman tunnel

3. APPLIED REMEDIAL MEASURES IN THE KOSMAN TUNNEL

During the excavation, successive geological mapping of the tunnel face was conducted, so the geological structure along the tunnel excavation was known. Geological reports characterized that the tunnel face was predominantly built by deluvial sediments, and in some places degraded siltstones with interlayers of marls appeared. After 9 m, face of the tunnel is built by soft rocks represented by siltstones, marls and sandstones. Tunnel excavation was carried out in the soft rock, and the contractor believed that the underground excavation conditions were improving. This largely corresponded to the data provided in the main design, where the primary type of tunnel support (Vpc) was used to secure the first 10 m of the tunnel excavation. Due to the high proportion of marls and siltstones, flysch sediments represent a hydrogeological barrier and groundwater appeared in contact with these sediments. The contractor noticed that the inflow of groundwater into the tunnel excavation was increasing, but did not immediately drill drainage boreholes, believing that the geological structure was improving and that the water volume would decrease over time.

After the first heavy rains, large quantities of groundwater appeared directly at the contact of deluvial and flysch sediments. The tunnel drained the water along the entire slope catchment area. The contractor attempted to reduce the water inflow by applying layers of shotcrete, however the water pressure increased and due to complete water saturation, water began to leak from the installed SN anchors. Larger pieces of shotcrete started to break and it was then noticed that several steel girders were deformed. Workers were evacuated from the worksite. The deformations rapidly increased, and within a few hours, there was a collapse of the tunnel face, as well as part of the installed primary tunnel support. The overburden was only 8 m high and the next morning, a wide channel with a diameter of 6-7 m was observed forming on the ground surface above the right exit portal.

After the tunnel collapsed, water, soil, and stones flowed out of the tunnel portal for several days. The contractor immediately changed the main design of the Kosman tunnel. After conducting calculations, the contractor designed the primary tunnel support type Vpc-t. The rehabilitation of the Kosman tunnel began with the installation of fiberglass anchors with a diameter of Ø25 mm and a length of 9 m, which are installed with an overlap of 2 m. Then, drainage boreholes with a diameter of Ø50 mm and a length of 9m are placed at the face of the excavation. The contractor inspected the primary support of the tunnel that remained in place after the collapse and then geodetically determined its position. Then, to stabilize the slope, the contractor began to form a cut and cover section, in the right exit portal of the Kosman tunnel in a length of 10m as shown in Figure 3.

Figure 3. Formation of cut and cover section in the right exit portal of the Kosman tunnel in a length of 10m

When the secondary concrete lining in the tunnel portal area was completed, the phased excavation of the tunnel began, first the calotte, then the benches, with the sequential installation of a temporary invert.

Tunnel excavation was secured by installing of a primary support the Vpc-t type, which involves applying 26 cm of shotcrete, two layers of Q188 mesh reinforcement, the installation of SN anchors 6 m long in a grid of 150x60 cm, and the installation of steel arches type HE160A at a distance of 80 cm. Steel arches with extensions were formed at the contact between the tunnel calotte and the bench. The tunnel face was secured by installing a forepoling/piperoof, formed from IBO anchor bar with a diameter of 76 mm and a length of 9m. The piperoofs are installed with a 2 m overlap and are formed at an angle of +5 ° to the horizontal plane. The main design allows deformation of the primary support up to 10 cm. The deformations were below this value, so the contractor installed a secondary lining of reinforced concrete with a thickness of 45 cm, thus completing the remediation works.

4. CONCLUSION

The instability of the excavation that occurred during the construction of the Kosman tunnel was not caused by geological conditions. The geological structure was in accordance with the main design.

The type of primary tunnel support (Vpc), which is commonly used in the construction of portal sections of tunnels in the quaternary sediments, with low overburden has proven to be safe in numerous tunnels. In the first 9m of the Kosman tunnel excavation, no significant deformations were registered, until a large amount of groundwater appeared. The contractor did not immediately drill drainage boreholes, believing that the geological structure was improving and that the water volume would decrease over time. However, after heavy rains, the inflow of groundwater significantly increased, and the primary tunnel support cracked in just a few hours, not giving the contractor time to react.

The data presented in this paper indicate that the change in the stress state in the field is a result of complete saturation of the geological working environment with water [3,4, 5]. The remediation works were carried out over several months and required very high material costs.

REFERENCES

[1] **Main Design tunnel 10 - Kosman – Construction, Main tunnel support**. *China Road & Bridge Corporation d.o.o.Peking – Part of a foreign company*, Podgorica, 2016.

[2] **Main Design tunnel 10 - Kosman – Construction, Portal design**. *China Road & Bridge Corporation d.o.o. Peking – Part of a foreign company*, Podgorica, 2016.

[3] Berge, K.O: **Water control reasonable sharing of risk.** *Norwegian Tunnel Society, Publication No. 12*, Oslo, 2002.

[4] **Pre-Excavation Grouting in Tunneling, 4th edition**. *BASF Construction Chemical Europe Ltd*, Zurich, 2011.

[5] Arestegui Miguel: **Cost Estimation for Underwater Tunnel Projects based on Uncertainty and Risk Analysis - Master Thesis TB4910**. *Norwegian University of science and technology department of civil and transport engineering*, Trondtheim, 2014.