IZGRADNJA TUNELA U JAKO KARSTIFIKOVANOJ KREČNJAČKOJ MASI SA VELIKIM KAVERNAMA: SLUČAJ TUNELA VJETERNIK

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Rezime: *Izgradnja tunela Vjeternik, koji se nalazi na deonici Smokovac–Mateševo u Crnoj Gori, predstavljala je značajne inženjerske izazove zbog trase koja prolazi kroz izrazito karstifikovane krečnjačke formacije sa velikim kavernama. Tokom iskopavanja, naišlo se na ogromnu kavernu visine preko 30 metara, što je zahtevalo hitne izmene projektnih rešenja i primenu specijalizovanih mera stabilizacije. Te mere su obuhvatale ugradnju čeličnih lukova, drenažnih sistema i betonskih ploča, uz dodatno armiranje unutrašnje obloge. Rad ukazuje na nedostatke prethodnih geoloških istraživanja i naglašava potrebu za obimnijim inženjersko-geološkim i geofizičkim analizama u budućim tunelskim projektima. Poseban akcenat stavljen je na značaj stručnog nadzora i prilagodljivih projektantskih pristupa. Iako je fokusiran na tuneliranje, rad je podjednako relevantan i za donosioce odluka koji su odgovorni za finansiranje inženjersko-geoloških istraživanja.*

Ključne reči: *tunel Vjeternik, karstifikacija, kaverna, geotehnicki rizici, unutrasnja obloga, dilataciona spojnica*

TUNNEL CONSTRUCTION THROUGH HIGHLY KARSTIFIED LIMESTONE WITH LARGE CAVITIES: CASE OF VJETERNIK TUNNEL

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Abstract: *The construction of the Vjeternik tunnel, located on the Smokovac–Mateševo section in Montenegro, posed significant engineering challenges due to its alignment through highly karstified limestone formations with large cavities. During excavation, a massive cavern exceeding 30 meters in vertical extent was encountered, requiring urgent design modifications and the implementation of specialized stabilization measures. These included steel arches, drainage systems, and concrete slabs, with additional reinforcement applied to the inner lining. The paper highlights shortcomings in prior geological investigations and emphasizes the need for more extensive engineering-geological and geophysical surveys in future tunneling projects. It underscores the importance of experienced supervision and adaptive design strategies. Although focused on tunneling, this paper is equally relevant to decision-makers responsible for funding engineering-geological investigations.*

Keywords: *Vjeternik tunnel, karstification, cavern, geotechnical risks, inner lining, settlement joint.*

1. INTRODUCTION

Tunnel Vjeternik is a twin-tube tunnel located on the Smokovac–Mateševo section in the mountainous region of Montenegro. Its total excavated length is 5,891 m, comprising 3,039 m for the left tube and 2,852 m for the right tube. Approximately 99% of the tunnel was excavated in Jurassic and Jurassic-Cretaceous limestones, represented by three main varieties: massive reef limestone, dolomitic limestone, and stratified limestone. Only the section near the northern portals was excavated in the Flysch formations. During excavation, numerous karst cavities of varying dimensions and volumes were encountered. Designer intervention was required on seven occasions, resulting in design changes or adjustments. The following section details the discovery of an exceptionally large void (karst cavern) within the bedrock encountered during excavation of the right tunnel tube.

2. MANAGING LARGE KARST CAVITIES DURING TUNNEL CONSTRACTION

During excavation of the left tunnel tube, a karst cavern was gradually encountered beginning at chainage LK 22+185. The cavern measured approximately 11 m in width and 7.5–9 m in length along the road grade line and was divided into two separate voids by a natural pillar measuring about 4.3 m in width and 5 m in length (Figure 1a). Its vertical extent reached over 21 m below the designed road grade line and up to 32 m above the tunnel crown (Figure 1b). The overburden was approximately 90 m above the cavern. The cavern was unfilled and dry at that time (July 2017). The Cavern was inspected by a speleologist, and he noted wall

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traces indicating evidence of past intensive water circulation. He observed that the cavern, containing multiple pipes, was aligned with a deep fault. No stalagmites or stalactites were present, and there were no traces of flora or fauna, indicating that the cavern had no significance from a bio-speleological perspective or speleological standpoint.

Figure 1a & 1b. *1a. Tunnel face at km 22+220 on the left side, 2b. Look into the cave on the right side*
Source: Face mapping reports

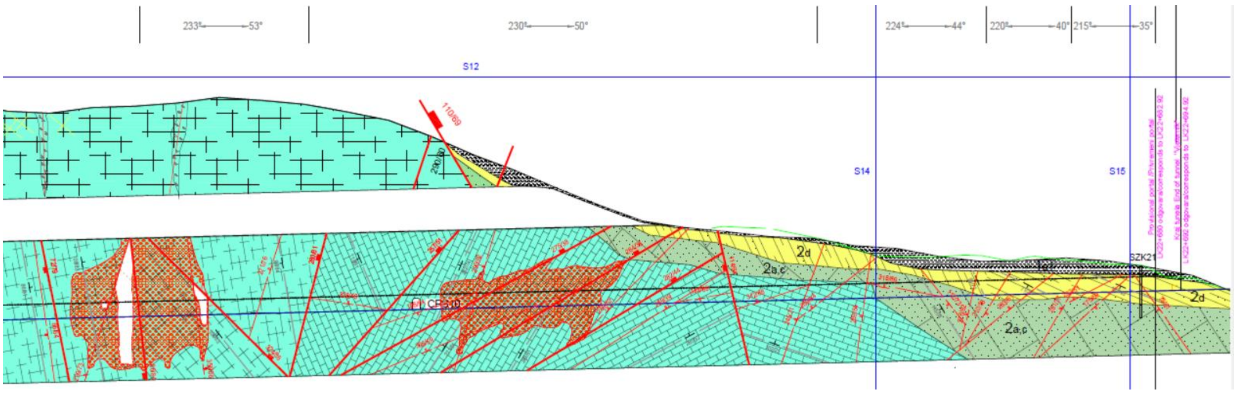
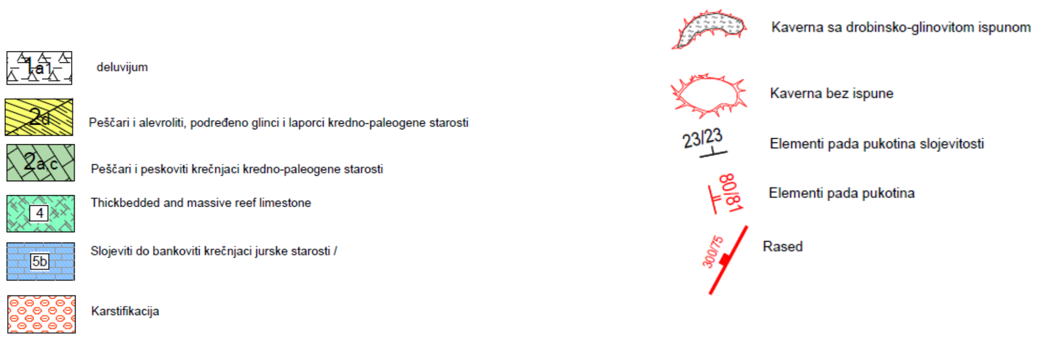


Figure 2. As-built longitudinal engineering-geological profile with a cavern *at km 22+220 (white space outlined red)*
Source: As-built design for tunnel Vjeternik

Legenda/Legend



2.1. Applied remedial solution

2.1.1. Backfilling and installation of adjusted Primary support

In the time of the encounter cavern, only the excavation of the Top heading was in progress. The cavern below was filled with crushed stone aggregate with a certain granulometric size (90% of the material was size 32-65mm). After Bench and Invert were excavated, the backfilled crushed aggregate was removed below the bottom line of Invert to a depth of 1m and replaced with a concrete slab C30/35.

Six perforated drainage pipes, each with a diameter of Ø200, were installed along the cavern walls and embedded within the backfill material. The drainage pipes were routed to discharge below the concrete slab.

In the tunnel sections located before and after the cavern, 5 lattice girders (type 115-30-36) were installed to ensure stability. Within the cavern section itself, HEA 160 steel arches were placed at 80 cm intervals. During installation, the arches were set on a temporary foundation, anchored into the rock mass with 3 m long Ø25 mm anchors, and stabilized in the transverse direction using Ø25 mm rebars with 50cm distance. A double layer of Q188 steel mesh and a 500 g/m² geotextile will be installed above the steel arches.

Concrete C30/35 was pumped through the previously installed pipes, after the completion of the primary support installation, until a minimum thickness of 1 m was reached.

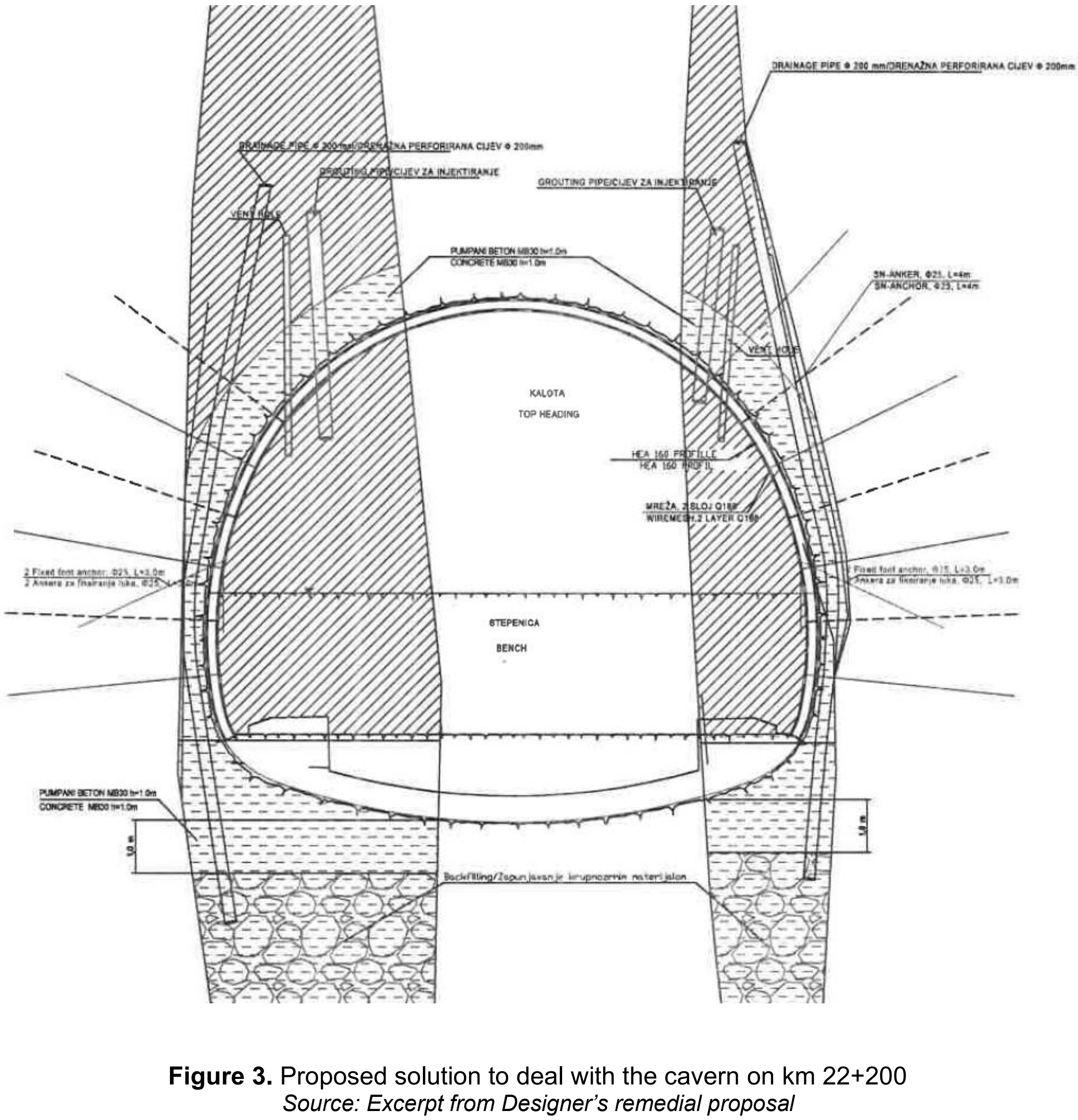


Figure 3. Proposed solution to deal with the cavern on km 22+200
Source: Excerpt from Designer's remedial proposal

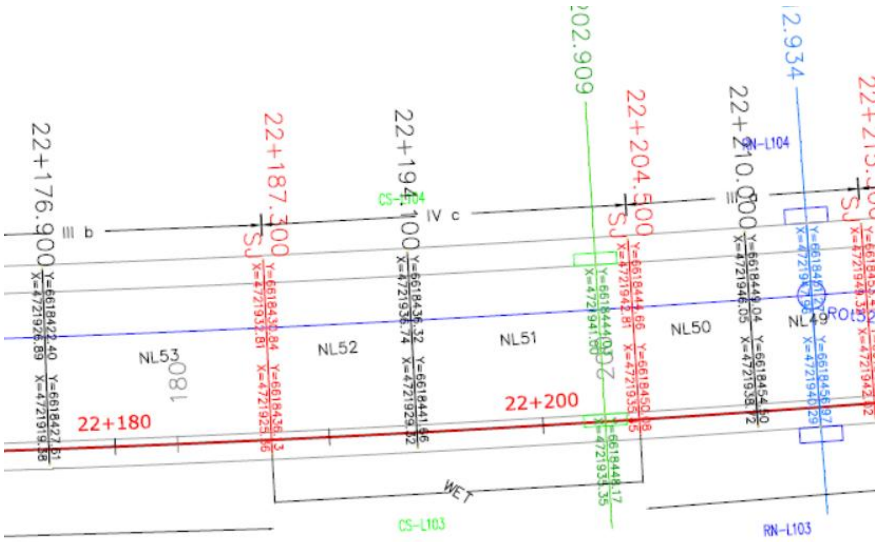
2.1.2. Construction of Inner Lining (Secondary/Upper lining)

In the Main Design, it was foreseen that the section near chainage km 22+200 would be executed as type IIIa, characterized by an unreinforced upper lining.

The inner lining before the cavern (segment NL50 - closer to the tunnel exit) was constructed as support type IIIc (reinforced upper lining). This support type is lightly reinforced, containing 0.614 tons of steel per 1 m of tunnel length.

Inner Lining in the caver section and after (Segments NL51 & NL52) has been constructed as a type IVc (reinforced upper lining, abutments, and invert). This support type is heavily reinforced, containing 1,386 tons of steel per 1 m tunnel length.

Tunnel segment IVc has settlement joints constructed at both ends, connecting it to the adjacent segments.



Segment/ Kampada	Chainage/Stacionaža		Length/ Dužina	Inner lining/ Sekundarna obloga	Wet or dry/ Mokre ili suve
NL 47	22235,50	22225,50	10,00	IV b1	Dry
NL 48	22225,50	22215,50	10,00	IV b1	Dry
NL 49	22215,50	22210,00	5,50	III a	Dry
NL 50	22210,00	22204,50	5,50	III a	Dry
NL 51	22204,50	22194,10	10,40	IV c	Wet
NL 52	22194,10	22187,30	6,80	IV c	Wet
NL 53	22187,30	22176,90	10,40	III b	Dry

Figure 4. *Excerpt from the Coordination drawing*
Source: (As-built design for tunnel Vjeternik)

Note: In the table, NL50 is listed as IIIa. This is correct for the primary support only; the upper lining segment, however, was constructed as IIIc (reinforced).

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3. CONCLUSION

Tunnel construction in karstified formations with cavern occurrences represents a highly challenging engineering task, associated with substantial risks to personnel safety. Such work is time- and resource-consuming. Experienced project supervision and contractor teams are essential for the effective identification of geotechnical and operational risks, the implementation of appropriate remedial measures, and the successful resolution of problems, thereby ensuring the long-term structural stability of the tunnel. However, from a general perspective, this work can also be considered largely craft-based.

Although at first glance this work may seem intended for tunnel engineers, this is not the case. It is primarily aimed at those allocating resources for engineering-geological investigations, as well as my fellow engineering geologists.

Namely, the determined rock mass quality in the Vjeternik tunnel (expressed through Bieniawski's RMR values) during excavation was worse than assumed in both the Preliminary and the Main Design.

Table 1. *Comparison between Designs*

RMR system category	Preliminary	As - Built
II	71%	15%
III	20%	74%
IV	9%	7%
V	-	4%

Source: (D.Panić – Comparison analysis done for Vjeternik tunnel)

Obviously, the engineering-geological mapping along the tunnel alignment, the two boreholes at the two portals, and the scope of seismic investigations were insufficient to provide more reliable information about the quality of the rock mass.

A substantially expanded program of geophysical investigations is required to detect potential cavities, along with the collection of numerous data points on joint and fault orientations to support a reliable structural analysis of the rock mass. In addition, a more extensive and higher-quality exploration drilling campaign with oriented cores is necessary, along with the application of multiple rock mass classification systems.

If anyone considers the insistence on an increased scope of engineering-geological and geophysical investigations excessive, they should be aware that the Contractor for this particular event, in accordance with Subclause 4.12 – Unforeseen Geological Conditions, has requested additional payment of 155,000€ and a 25-day extension of time. For all seven events in the Vjeternik tunnel, the total sum is nearly €1 million. Of course, this is the contractor's estimation and should not be taken for granted. While this paper does not examine the contractual aspects of the problem, it is important to note that this was a Design-and-Build project, meaning that the responsibility may also lie with the Contractor. The allocation of responsibility is currently a matter under consideration by the DAB.

Gratitude

I would like to express my sincere gratitude to my colleagues from the JV Ingerop–Geodata Tunnel team for their excellent cooperation, professional support, and constant willingness to share their knowledge and experience with me. Working with them has been a privilege and a valuable experience that I will carry with me.

Literature

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