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# Problem Solving and Rehabilitation of the Speleological Object of Larger Dimensions Which Appeared During the Excavation of the "Počitelj" Tunnel

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## 1. INTRODUCTION

The "Počitelj" tunnel was built as part of the section of the highway Mostar North - the border with the Republic of Croatia on the corridor Vc, the section Počitelj - Bijača, the subsection Počitelj - Zvirovići with a length of approx. 11.50 km. The Počitelj tunnel is a two-tube, two-lane tunnel with a length of 1163 m on the right tube and 1192 m on the left tube.

During the execution of excavation works on the route of the future roads in weathered carbonate rocks the appearance of speleological objects that were not detected and predicted by investigative works is very common. With regard to the genesis, hydrological character, dimensions and position in relation to the level of the tunnel, unforeseen speleological objects during the excavation can cause a whole series of difficulties and deviations from the planned progress of the work in the form of dynamics, additional investigative work, additional design, and thus increased financial expenses. Therefore, in the design phase, for the purposes of creating a geotechnical design, it is essential to carry out a sufficient number of investigative works, which enables the preparation of a more precise prognostic geological profile of the tunnel route and the detection of speleological objects, i.e. karst phenomena.

However, in the phase of performing investigative works, it is still impossible to detect all speleological objects, which is why the methodology of their rehabilitation after their detection is important. Speleological objects are not subject to classification and require individual treatment during the construction phase, which is why, in the event of their occurrence, the associated rehabilitation project is drawn up.

During preparation projects for the rehabilitation of speleological objects, the cooperation of experts from several fields (speleology, geology, geodesy, geotechnics, mining and construction) is necessary, which is why it is necessary to define the objectives of the research, the structure of the professional team, and the delivery process of professional bases and solutions for all stages of processing.

In the investigation works of the geotechnical design along the route of the "Počitelj" tunnel, the appearance of speleological objects (caverns, caves) is foreseen.

## 2. ENGINEERING-GEOLOGICALINVESTIGA-TION WORKS OF THE ROCK MASSIF THROUGH WHICH THE TUNNEL ROUTE PASSES

For the purpose of determining the geotechnical characteristics of the materials and the geotechnical conditions of passing through the route of the "Počitelj" tunnel, the geotechnical investigation works included: geodetic staking, geological and engineering geological mapping of the corridor of the tunnel route, exploratory drilling with engineering geological determination of the core of boreholes, diffraction seismic and geo-electricity, as well as laboratory tests.

The engineering-geological classification of the area of the rock massif through which the tunnel route passes was carried out from the above-mentioned research works.

### 2.1 Engineering-Geological Characteristics of the Rock Mass at the Location of the Tunnel Passage

The basic rock mass along the route of the "Počitelj" tunnel is made up of sedimentary rocks represented by Upper Cretaceous limestone ($K_2$), where the exit portal is in the zone of limestone with chondrodonts ($K_2^{1,2}$), and the entrance portal is in the zone of limestone with rudists ($K_2^{2,3}$).

In terms of engineering geology, the following are distinguished: eluvial-diluvial cover, degraded geological substrate and geological substrate.

The eluvial-diluvial cover is isolated in the near-surface part of the terrain at a depth of 0.50 - 1.20 m, and it is composed of red-brown humus clays.

The degraded geological substrate is represented as disintegrated and decomposed limestone. The thickness of the drilled formations of the degraded geological substrate is about 3.00 m. From the engineering geological aspect, these zones form conditionally stable to stable terrains.

The geological substrate is limestone with a massive texture, and less often of thick layers. In some places, these rocks have cracked more strongly with the presence of a system of cracks due to the karstification process. Limestones have a layered, bank-like to partially massive texture, and a crystalline to cryptocrystalline structure. The rock mass has fissure-cavernous porosity, and the layering position in relation to the disposition of the tunnel route is generally favorable if the tunnel excavation from the direction of the exit portal is taken into account. They build stable terrains with favorable mechanical properties.

## 3. METHODOLOGY OF SPELEOLOGICAL OBJECTS RESEARCH

### 3.1 Research Methodology in the Phase of Preparation a Geotechnical Design

The investigative works which were carried out for the purposes of preparation of the Main design covered only the area of the entrance and exit portal. However, on the basis of surface engineering geological mapping in the design phase, tectonic disturbances, the appearance of fault zones, contacts of different types of rocks and characteristic collisions were determined, which indicated the possible appearance of an additional number of caves, caverns, pits or coves during the execution of works. A mitigating circumstance lies in the fact that, based on the results of engineering geological mapping, no significant occurrence of water was to be expected in them.

### 3.2 Research Methodology in the Construction Phase

Investigating the rock mass during excavation enables the contractor and designer to solve problems in a timely and adequate manner. It enables the elaboration of the excavation and substructure profile, which leads to safe and continuous work in the tunnel. By drilling or pre- drilling the front of the tunnel, it is possible to establish what kind of geological structure can be expected after blasting. Also, by drilling anchors along the contour of the excavation, speleological objects that were not discovered by excavation can be detected, which alter the profile of the excavation and can cause problems not only during the excavation, but also after the tunnel is put into use when they can be even more dangerous.

During the excavation in the left tunnel tube of the "Počitelj" tunnel at the chainage approx. km 1+190.00, a cavern of larger dimensions was opened that reached all the way to the left side of the right tube. In the right tube, an opening dimensions of approx. 3m x 5m (width x height), that appeared on the left side was repaired, and work on the excavation of the right tube continued as usual. Works in the left tube was stopped because the cavern covered 2/3 of the tunnel's profile and because its position in space was not known.

• In accordance with the above mentioned, interventional speleological investigations and preparation of reports (elaborations) were requested, which must contain:

- the position (coordinates) of the entrance to the cave,
- topographical records of the object's morphology (ground plan, longitudinal profile and cross- sections of the object),
- geomorphological characteristics of the object (type of rock, position of layers and orientation of discontinuities),
- the genesis of the speleological object,
- spatial position of the object in relation to the level of the tunnel,
- assessment of the object's impact on the safety of excavation and tunnel exploitation,
- the hydrogeological character of the speleological object in the dry and rainy periods,
- photo documentation.

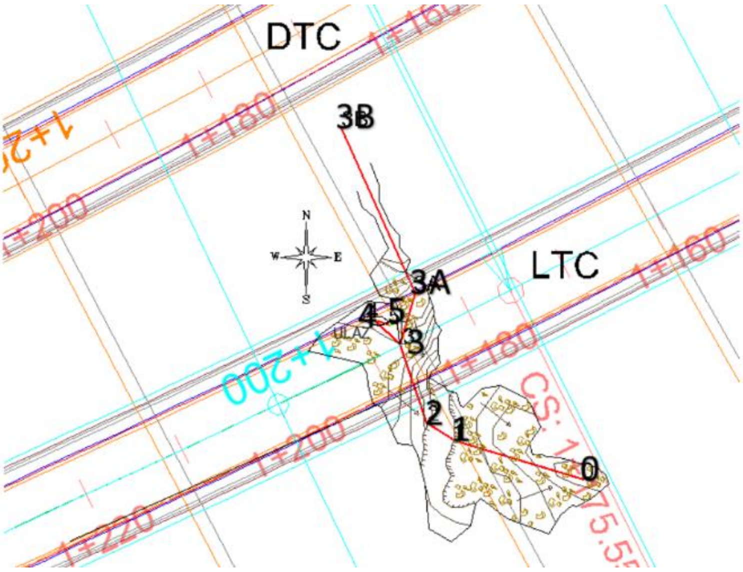
### 3.3 Speleological study of the cavern

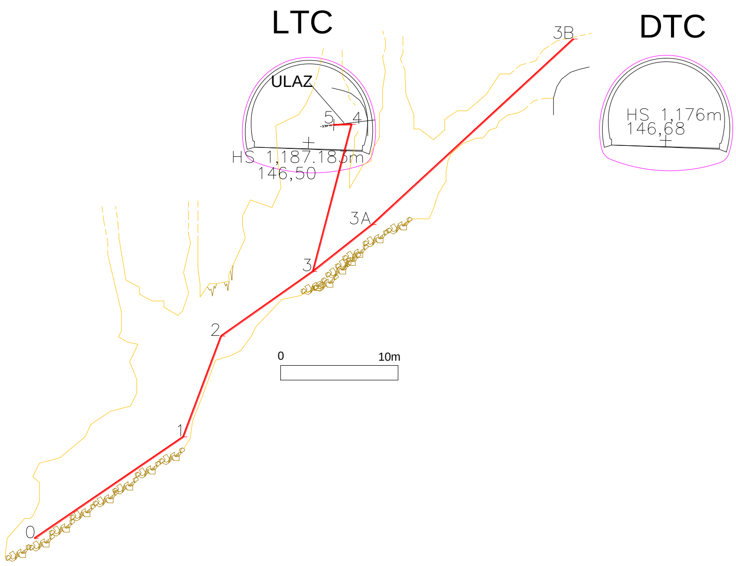
The mapping was done with the help of the Leica DISTOX instrument, which measures lengths, azimuth and slopes.

The DISTOX instrument directly transfers the collected data to a tablet device with the help of a bluetooth connection. The data is then analyzed using the Topodroid application (version 4.2.4g) and saved in DXF format for further processing.

Geodetic point no. 5 on the tunnel wall was used to connect the geodetic network of the cavern with the geodetic network of the tunnel.

Entrance to the cavern. The red sign of geodetic point no. 5 is visible

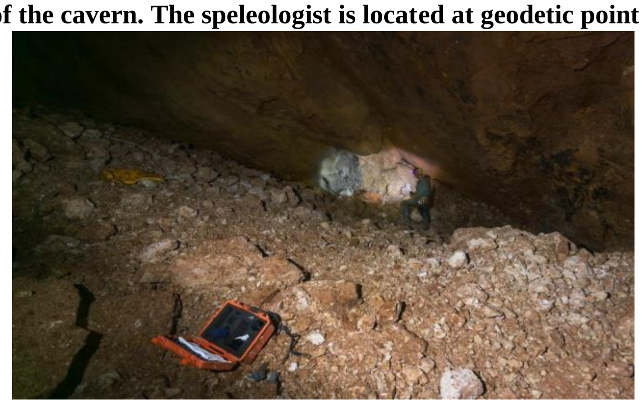



As the tunnel excavation progressed, the cavity of the cavern was cut at several points. The largest entrance was about 2.5 m wide and 2 m high and was the entrance to a vertical shaft that extended above the level of the tunnel. There were two other openings of smaller dimensions through which one could enter the cavern and which led approximately to the same vertical shaft.

From the largest entrance, the cavern descended vertically for aprox. 14 m, reaching a horizontal area with a floor of collapsed stone blocks. From this small plateau, it was possible to advance further by descending diagonally to the southeast a few meters across a thick layer of dry stone material to the border of the new shaft. By descending vertically another 10 m, it was possible to reach the bottom of the cavern. It is a chamber dimensions about 15 m x 10 m with a steep floor built of collapsed stone blocks. The lower part of this chamber is the deepest point in the cavern, which was about -35 m from the level of the tunnel.

**The bottom of the cavern. The speleologist is located at geodetic point no. 0**



The cave wall could be seen below the bottom of the cave between the stone blocks, so it could be assumed that, although blocked at the time, the passages of the cave extend deeper.

Below the entrance vertical shaft (point 3 in the geodetic grid) the cavern extended in the northwest direction, by high channel with a steeply inclined floor built of collapsed blocks. After a few meters, in order to progress further, it was necessary to climb a cliff several meters high. Although the investigation was stopped below this cliff, at the end of the channel, about 15 m further from the reached point, the concrete wall of the second parallel tunnel was visible (ie the repaired opening in the left side of the right tube).

At the time of the investigation (July 1, 2020), there were no active water flows in the cavern, nor were there any indications that this could happen under different hydrological conditions. Water was present only as a thin layer of seepage water on the cave walls and as a thin trickle of water.

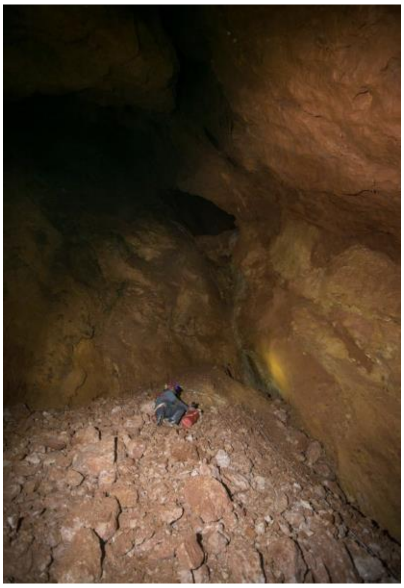
According to its morphology, this cavern represents a vertical shaft in the underground of the karst aquifer, which primarily transports a small amount of water from the surface to the groundwater level, which is at a lower level.

Another vertical shaft was created along a crack that was probably originally a rock discontinuity that triggered the formation of the cavern. It seems that the cavern has currently lost its original hydrological function and surface water has found other different ways to reach the watercourse. Most of the vertical walls are covered with a thin layer of clay/mud, which also suggests that the amount of water is usually very small when present.

There are no speleothems except for a few stalactites above the second vertical shaft (geodetic point 2) and dry stone material found on the cave wall approximately below the stalactites. A short search for the fauna of the cave yielded no results.

**Second vertical pane. The speleologist is located at geodetic point no. 2**

**The bottom of the second shaft. The speleologist is located at geodetic point No. 1**



## 4. REHABILITATION OF THE CAVERN

Due to the unpredictability of the appearance, size and position of speleological objects in relation to the tunnel tube, it is not possible with the project to provide in advance typical solutions of the underground structure in the zone of their appearance. Solutions for stabilization of the excavation in the area of the speleological object are made on the spot with the cooperation of the designer, the supervisory service and the contractor. If it is about more complex speleological objects, the final solutions for stabilizing the excavation are made after a detailed speleological study prepared by a speleologist (geologist).

After the delivery of the speleological study as a basis for the rehabilitation of the cavern in the "Počitelj" tunnel, in the construction office, the contractor, the designer and the supervisor agreed on phased measures for the development of the rehabilitation project for the primary substructure and secondary lining of the "Počitelj" tunnel.

The basic measures that can be taken in order to rehabilitate are basically based on *filling* and *bridging*, and in exceptional cases on *bypassing*.

### 4.1 Rehabilitation of the Cavern at the Level of Tunnel Excavation and Installation of the Primary Support

By passing the tunnel route through the speleological object, the circulation of underground water can be disturbed and unforeseen pressure can be exerted on the lining of the tunnel. Therefore, it is desirable that after the detection of speleological objects, rehabilitation should be started immediately, with the fact that in the case of larger speleological objects, an opening must be left at the site of rehabilitation in order to monitor the condition behind the primary substructure, since it is difficult to predict the inflow of water after intense rainfall.

Technical solutions for filling speleological objects with demined material are very practical due to savings on transport, but they can disable the outflow of groundwater and the raising of the water level and flooding of the tunnel bottom, which of course depends on the hydrological character of the speleological objects.

Considering the geological and hydrological characteristics of the cavern, it was decided that the cavern in question in the Počitelj tunnel will be backfilled. For backfilling, was used material from the excavation of the right tube, but also from the material landfill in order to backfill the cavern as quickly as possible.

During backfilling of the cavern, the granulation of the material was taken into account, as well as the volume of the cavern, which was detected by the speleological study. Material from 8 blasts from the right tunnel tube and the rest from the landfill was poured into the cavern. In total, approx. 2700 $m^3$ of material was used to backfill the cavern.

Complete traffic took place over the filled cavern during the continuation of the tunnel excavation until its breakthrough, with the aim of achieving possible subsidence of the material with which the cavern was filled.

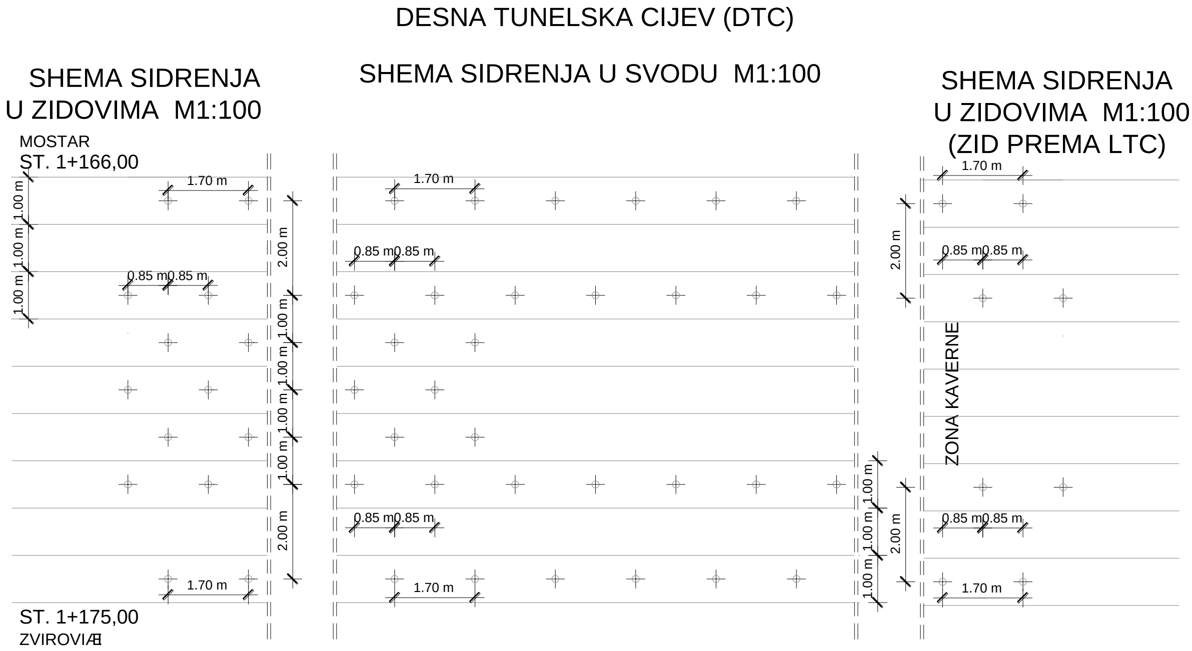
The cavern zone in both tubes of the tunnel is categorized as category V according to the RMR classification, and the following support system adapted to the speleological object was applied:

CRAWN:

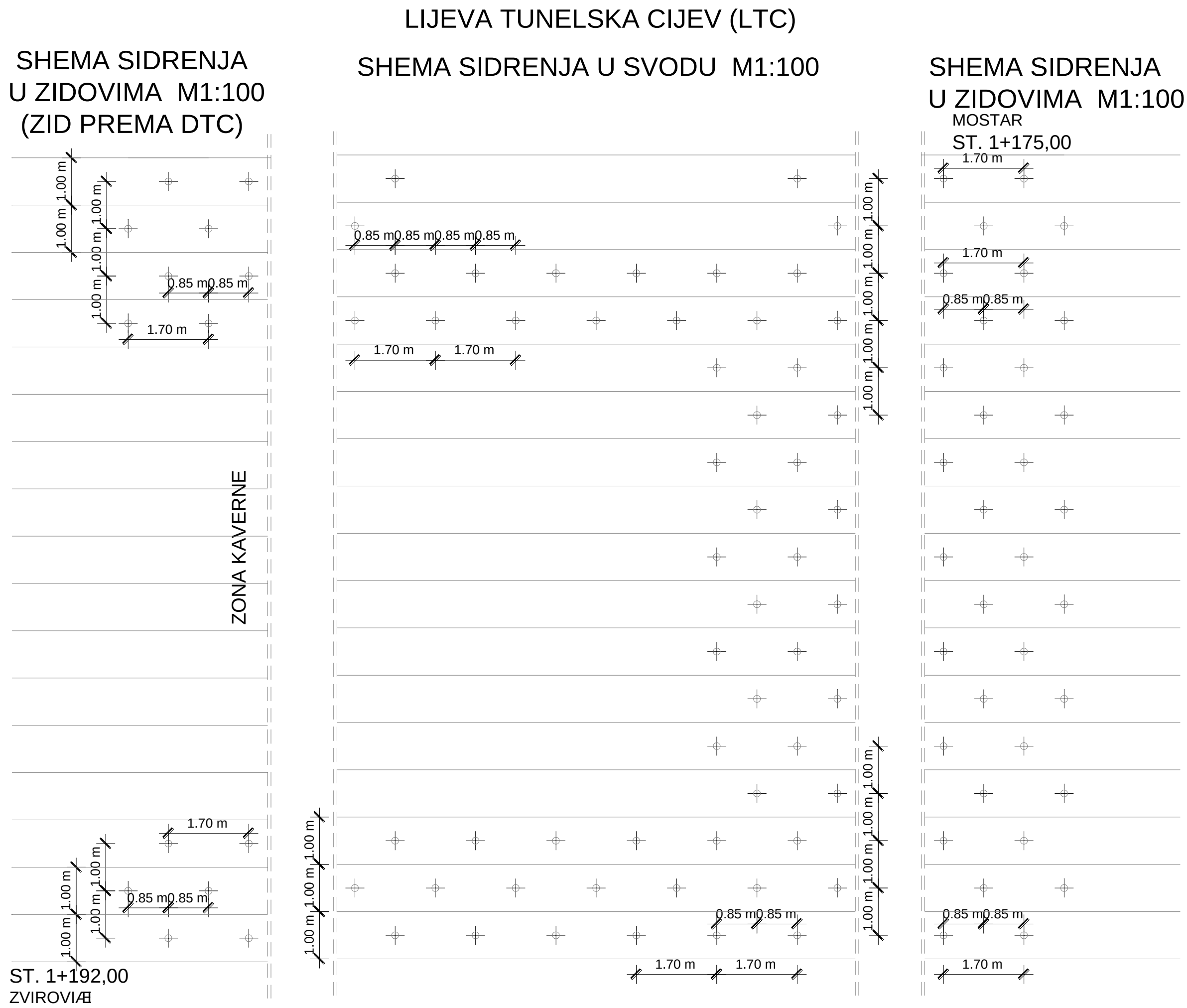
- shotcrete C25/30 20 cm thick,
- two steel welded meshes Q 221,
- steel grid supports PS 95/20/30 at a distance of 1.0 m (total 18 pieces-left tube, total 10 pieces-right tube),
- right tube: adhesive rod anchors, ribbed steel Ø25 mm, L=4 m, at a longitudinal distance of 1.0 m (2.0 m).
- left tube: adhesive rod anchors, ribbed steel Ø25 mm, L=4 m, at a longitudinal distance of 1.0 m (2.0 m) - before and after the speleological object.

WALLS:

- shotcrete C25/30 20 cm thick,
- two steel welded meshes Q 221,
- steel grid supports PS 95/20/30 at a distance of 1.0 m,
- right tube: adhesive rod anchors, ribbed steel Ø25 mm, L=4 m, at a longitudinal distance of 1 m (2.0 m) – without anchors in the left side where the speleological object is.
- left tube: : adhesive rod anchors, ribbed steel Ø25 mm, L=4 m, at a longitudinal distance of 1 m (2.0 m) - before and after the speleological object.




Right tunnel tube / Rock bolt pattern in the walls / Rock bolt pattern in the crown




Left tunnel tube / Rock bolt pattern in the walls / Rock bolt pattern in the crown

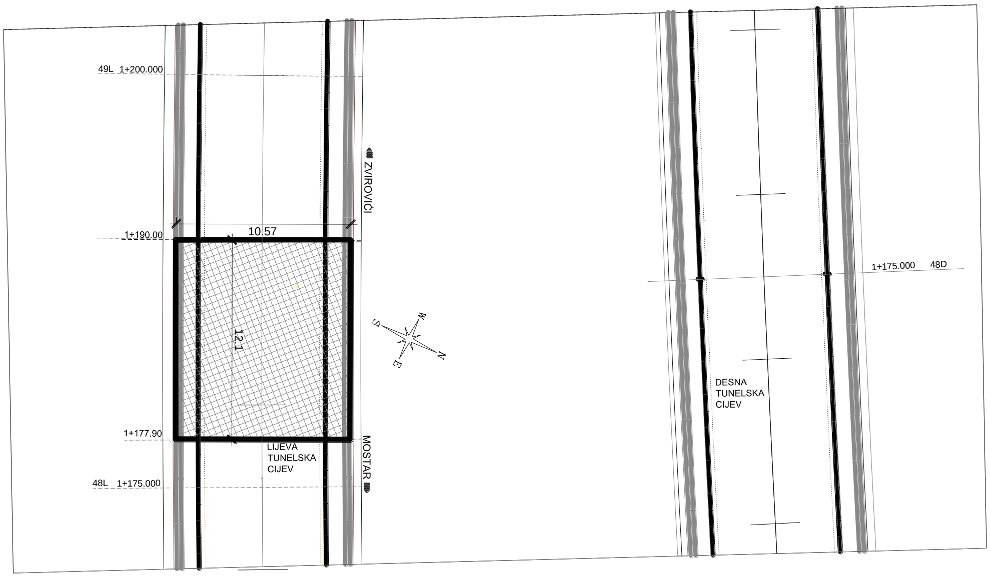
As a support for the steel lattice supports in the right side of the left tube, an AB beam was constructed with dimensions: width 60 cm, height 40 cm and length 5 m. The beam was built on filled material, and its edges are supported on a solid rock in front and behind the opening of the cavern.

Given that the speleological study was made in a dry period (July 1, 2020), an opening was left in the right side of the left tube so that the inflow of water behind the primary support could be monitored during periods of intense rainfall. After the rainy season has passed and confirmation of the absence of adverse influence of leachate on the lining of the tunnel, and before the installation of waterproofing, the opening in the right side of the left observation tube is sealed.

### 4.2. Rehabilitation of the cavern at the level of the secondary lining

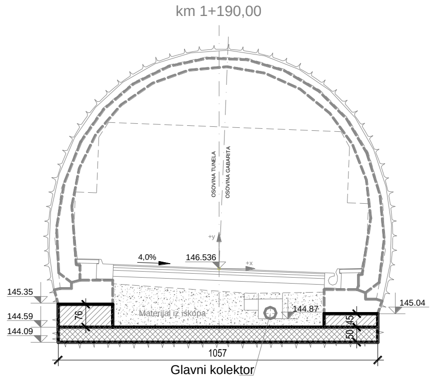
In the continuation of the works, before the construction of the foundation of the secondary lining, an AB slab was performed in the cavern zone to avoid possible settlement under the road structure.

The dimensions of the AB slab were determined on the basis of a geodetic survey carried out after the discovery of the cavern. The slab was built on the filled material of the cavern and its edges rely on sound rock in a length of approx. 1 m. The height position of the AB slab is determined by the height position of the central drainage. The dimensions of the AB slab are 12.10 m x 10.57 m x 0.5 m, and the reinforcement is made with ribbed bars made of high-quality BSt 500-s steel with a diameter of 25 mm and 22 mm at a distance of 15 cm. The slab is filled with material from the excavation.




Left tube Right tube

Plan view of the AB slab constructed over the cavern in the left tube of the tunnel




Cross-section of the left tube in the zone of the derived AB slab above the backfilled cavern

## CONCLUSION

The appearance of speleological objects during the excavation of tunnels in weathered carbonate rocks is a very common occurrence. However, in the design phase, it is not possible to detect all of them with investigative works, because such scope of investigative works would not be profitable for the client. Exploration works for tunnels can be point (exploratory drilling) and linear (geophysical measurements) in nature, however, when it comes to tunnels with large overlayers, even geophysics cannot provide reliable information.

Due to different shapes, dimensions, genesis and position in relation to the tunnel profile, each speleological object requires an individual approach to rehabilitation as well as a multidisciplinary approach, engagement and cooperation of experts in the fields of speleology, geology, geotechnics, mining and construction.

The biggest problem with the occurrence of such geological phenomena is the time required to create the final rehabilitation project. For this reason, it is necessary to transfer the research and design phase to the front of the excavation and start the work as soon as possible in order to avoid delays on the construction site.

If it is about more complex speleological objects, it is often necessary to change or adapt the excavation technology until the end of the rehabilitation, in which the New Austrian Tunnel Method has an advantage over other excavation methods due to its elastic approach and adaptability to frequent changes in geological conditions

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