SURVEYING WORKS DURING THE CONSTRUCTION OF THE ČORTANOVCI TUNNEL

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ABSTRACT:

Underground structures in the form of tubes open at both ends, placed horizontally or vertically on a slight slope, and through which a road passes: railway, road, canal, or waterway, which connect two parts of the road separated by an obstacle, are called tunnels. During the design and construction of tunnels, geodetic works are carried out following legal regulations. Attention should be paid to the geodetic basis, as well as to the tunnel marking network to perform reconnaissance and stabilization of points in a high-quality manner. Further works include the marking of points, as well as their control, then calculations and data transformations to obtain the coordinates in the global coordinate system. This paper presents the mentioned works during the construction of the Čortanovci tunnel.

KEYWORDS:

tunnels, geodetic network, measurements in 1D and 2D network, Čortanovci

1 INTRODUCTION

The construction and subsequent monitoring of tunnels are becoming more and more demanding, as tunnels are being built in previously unimaginable places, and lengths are significantly larger than before. Therefore, many scientists deal with this topic.

For example, the authors [1] propose a new design scheme for a tunnel monitoring and measurement system with laser scanning as the main sensor for tunnel deformation analysis. Field engineering indicated that the repeatability of the convergence diameter detection of the system can reach ±2 mm, dislocation repeatability can reach ±3 mm, the image resolution is about 0,5 mm/pixel in the ballast part, and the resolution of the inner wall of the tunnel is about 1,5 mm/pixel.

Leanne et al. [2] provided a collective review of the current top methods used for tunnel inspection based on the photogrammetric technique. One or more cameras, laser displacement sensors, and structured light devices mounted on a large inspection vehicle, a trolley, an electric car, or a pipeline robot have been used for 3D tunnel clearance inspection [3–5].

The study [6] proposed a risk evaluation model for tunnel collapse based on a quantified grading system and influence factors that significantly affected the tunnel collapse hazard. For this purpose, 24 actual tunnel collapse cases were collected, and a database was established to select significant influence factors as the risk evaluation indices.

The study [7] investigated the causes of collapse during the tunnel construction and proposed a methodology for measuring weathering degree, groundwater level, and surrounding cap rock joint condition. Various studies are available where different probabilistic approaches were used to investigate the potential risk factors in underground excavation projects [8], [9], [10].

The Spatial Plan of the Republic of Serbia from 2010 to 2020 defines a long-term program for the development of railway infrastructure. The plan envisages the construction and modernization of the existing railway for mixed traffic (passenger and freight) and combined transport. The project also foresees the construction of the Čortanovci tunnel, which is the subject of this paper.

2 BACKGROUND AND METHODS

2.1 GEODETIC WORKS IN TUNNEL DESIGN AND CONSTRUCTION

For the conceptual design of the tunnel, the surveyor must provide a suitable geodetic base, which is usually a large-scale map. On such a basis, the project manager draws the route of the tunnel, taking into account the possibility of minor connections to the projected traffic routes. After the adoption of the conceptual solution, the surveyor's work entails going out into the field, locating the entrance and exit portals of the tunnel, as well as additional surveying the terrain to create the main tunnel project [11].

The main starting point when designing the geodetic base for the construction of any tunnel is the permissible deviation during the tunnel breakthrough, which means that the geodetic base must meet the highest requirements regarding accuracy and reliability. When designing, the following parameters should be taken into account:

- the network project is being done on the tunnel project, where all auxiliary facilities that will serve during construction have already been designed,
- the network project must cover the entire tunnel construction site and satisfy all its needs until the end of construction,
- the network must be homogeneous for the entire tunnel construction site and correspond to the accuracy required for marking the points of the tunnel axis during the tunnel breakthrough, and
- for easier calculation of the coordinates of various objects that continue to the tunnel, it is necessary to transform the network into a unique coordinate system [12].

After creating the main or conceptual design of the tunnel, the design of the geodetic network for marking the tunnel is carried out. The geodetic network project, among other things, should contain:

- network sketch,
- a description of how to stabilize network points,
- calculation of the position accuracy of the grid points,
- measurement plan in the network, and
- description of the method of processing measurement results.

For the successful execution of geodetic works, it is necessary, before all works, to create a high-quality geodetic microgrid, which will enable all geodetic works to be carried out with satisfactory accuracy, i.e. within the limits of specified tolerances. By creating a geodetic micro-grid, a 3D spatial rectangular coordinate system is provided for the design, construction and exploitation of the facility [13].

The goal of creating a geodetic marking project is high-quality spatial positioning, i.e. transferring the projected geometry of the object to the field. Considering the characteristics of the objects being marked, it is necessary to approximate the object, i.e. its structural elements, with the following geometric elements:

- the main points of the axis (beginning and end of the circular curve, beginning and end of the transition curve, breakpoints of the horizontal direction),
- axis points in the places where the transverse profile is defined,
- other characteristic points such as the points of the centres of the viaduct piles and the piles of the pre-section structures.

The set of characteristic points selected in this way constitutes the geometry of the object and is the subject of geodetic marking. It is planned that the marking of the object will be carried out by analytical methods. The tunnel geodetic marking project should, among other things, contain:

- a sketch of the geodetic network,
- a list of coordinates and heights of grid points,

- a list of the coordinates and heights of the tunnel axis points and other details in the tunnel profile,
- a sketch of the arrangement of points whose position should be marked,
- calculation of tunnel breakthrough accuracy and,
- description of the way of marking and checking the accuracy of the marked positions of the points [13].

The accuracy of tunnelling will depend on:

- the accuracy of the above-ground and underground geodetic base,
- measurement methods,
- methods of transferring elements into the tunnel (whether it is transferred through entrance portals or vertical shafts),
- the method of extending the tunnel (straight, circular arc) and the method of construction (full profile, undercut), and
- errors during construction.

All the above-mentioned steps must be carried out in order to thoroughly plan and build a tunnel of good quality. This paper presents the Čortanovci tunnel, from the idea to the realization of the project.

2.2 ČORTANOVCI TUNNEL-BASIC INFORMATION

The Čortanovci tunnel is located 56 km from Belgrade. Due to the complex geotechnical conditions of the tunnel section, the tunnel was designed with two separate tunnel tubes, each for one track. The axial distance of the tunnel pipes is 22 m, and in the area of the exit and entrance portals, it decreases to 18 m. The tunnel is located for the most part in the direction. The longitudinal slope in the tunnel is 0.95%. The length of the tunnel pipes is for the left pipe 1156 m, while the right pipe is 1086 m long. The project also provides for two cross passages for evacuation. The entrance and exit from the tunnel are such that there are portal tunnels of different lengths in the open. The geometry of the tunnel is circular, with a variable radius. Commercial speed should be 130 km/h, for passenger trains a minimum of 160 km/h, and on sections where possible up to 200 km/h [14].

3 RESULTS AND DISCUSSION

If the length of the tunnel pipes is longer than 1000 m, the project implies the following safety measures [14]:

- two transverse passages for the evacuation of passengers and staff into the adjacent tube, in case of an accident or fire,
- evacuation routes in tunnel tubes,
- two alarm phones in each tunnel tube, and
- five hydrant niches each at a distance of 200 m.

In the case of the Čortanovci tunnel, the left tunnel tube starts at station 56+400,00 and ends at station 57+556,00, which means that the total length of the left tunnel tube is 1156,00 m. The right tunnel tube starts at station 56+430,00 and ends at station 57+515,00, which means that the total length of the right tube is 1085,50 m. That is why all the above-mentioned measures are met.

The geodetic network in the area of the Čortanovci tunnel represents a geometric framework for geodetic marking and other geodetic-technical works. Within the realization of the geodetic network for the development needs of the main project, it is planned that 3 points of the geodetic network of the Stara Pazova - Novi Sad railway are used as an integral part of the tunnel geodetic network. Based on the known projected length of the Čortanovci tunnel, the necessary positional and height accuracy of the tunnel breakthrough was calculated. The values are shown in Table 1:

Table 1: Positional and height accuracy of the tunnel breakthrough

Left tunnel tube	$\sigma_{PTP} = 6{,}4$ cm
	$\sigma_{PTH} = 2{,}5$ cm
Right tunnel tube	$\sigma_{PTP} = 6{,}2$ cm
	$\sigma_{PTH} = 2{,}4$ cm

Entry portals or false portals are performed to improve the stability of the precut slope (Figure 1). The structure has the same light profile as the secondary structure in the tunnel. The portals were performed by a total station that supports XML data entry because the slope model created in the software is imported into the total station and the tunnel slope is drawn upon completion.

Figure 1: Entry portals of the tunnel

Due to the bad geology in the Čortanovci tunnel, before the actual excavation, it was necessary to make a substructure with tubes, the so-called "Tube shield", which was done for a long time, and the presence of a surveyor was necessary when positioning each tube that is drilled. The tube shield was drilled with tubes 12 m long, and one tube shield consisted of 49 tubes. Before each tube drilling, the surveyor positions the tube at the right drilling angle. The tube shield should look like in Figure 2.

Figure 2: Tube layout foreseen by the project

Any justified over-profile deviation of the excavation must be regularly ascertained and recorded by geodetic measurements with the obligatory consent of the supervising engineer. The contractor is obliged to ensure a minimum profile for the finished construction, which means that the primary construction should be 30 cm wider than the secondary construction.

After the recorded excavation, there is securing of the excavation, which is done with steel arches as primary security, and later it should serve as a reinforcing element of the primary construction of shotcrete. It is made in a certain radius so that it meets the geometrical conditions of excavation in each category of rock material, including the appropriate tolerances. The task of the geodetic team in the tunnel is to place the arches in the appropriate position so that they do not enter the light profile of the tunnel and cause problems during the construction of the secondary structure [14].

When installing the steel arches, at that moment, it is necessary to place measuring marks that will serve in the process of monitoring subsidence and convergence in the tunnel. The measuring marks provided for in the project should be placed at the distance defined in the project. In the case of the Čortanovci tunnel, it is necessary to place stamps every 5 m stationary, 5 stamps in the profile.

After the completion of the primary and secondary construction works, the installation of half-thresholds (finished elements that are made in another place and installed in the tunnel) is started. There are rails on the half-thresholds, which must be arranged in such a way that the deviation in position is no more than 3 mm, and in height no more than 2 mm. The Čortanovci tunnel consists of two tunnel tubes. The half-thresholds are made so that the manufacturer guarantees that the distance between the inner edge of the left rail and the inner edge of the right rail must be 1435 mm (+/-2 mm) (Figure 3) [14].

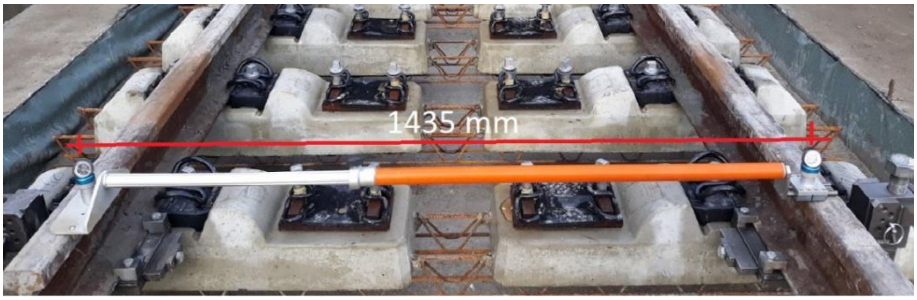

Figure 3: Positioning of rails

Geodetic points, and consoles, with forced centering, are placed every 50 m. The points are attached to the concrete of the secondary lining, the even points are on the left side of the tunnel and the odd ones are on the right, so the network goes in a "zigzag" pattern. It is necessary to observe the network in three gyri, observing three points in the front and three in the back, and measure the angles and lengths with an instrument of 1" accuracy. Figure 4 shows the geodetic network of the tunnel.

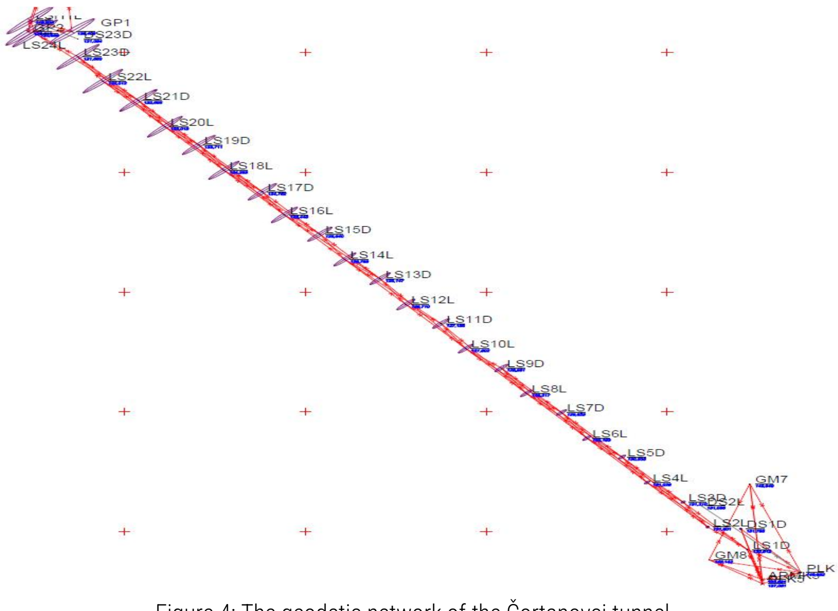

Figure 4: The geodetic network of the Čortanovci tunnel

The setting of the total station must follow the reference system of the tunnel network and the designed track coordinates. All of this is desirable to do to reduce any impact on the error. The positioning of the station itself needs to be done with at least 5 points, preferably on all 6 points. Three prisms in front and three prisms behind, where care must be taken in the arrangement of points because poor arrangement directly affects the quality of positioning and track marking. When moving the station forward or back, the orientation should be taken so that there are at least four points in common with the previous stop and at least one new point, depending on the moving direction. Control by a second total station is considered acceptable if the measurement results of the first and second stations differ by a maximum of 1 mm. Control is essential to eliminate errors of instrument movement, poor aiming, and poor reading of results. Positioning is done with spherical prisms, and it is preferable to carry out the measurements in two positions of the binoculars.

The procedure for positioning the rails is such that it is first necessary to bring the rails to the designed height (Figure 5a), thus the thresholds will also be at a good height. The height is adjusted using screws that are placed under the thresholds. After adjusting the height, the rails are moved to the left and right depending on the need, which is done using a rod that finely moves the rails (Figure 5b) [14].

Figure 5: Positioning of rails by: a) height b) position

After placing the rail in the designed position, the actual condition of the rails is recorded (Figure 6). The recording is repeated in the same places where the rails were positioned before, and the deviation should be less than 1 mm.

Figure 6: Derived state of the rails

4 CONCLUSIONS

Geodetic works in the construction of tunnels represent a complex job, both in terms of the complexity of the project and the execution of the works. The configuration of the terrain, geology, and several other factors that affect the design itself should be taken into account. The geodetic grid must be of high accuracy to ensure the quality of the results.

Based on the opinion of geodetic engineers and supervision, and due to the fact that this has never been done in Serbia, the following conclusion was reached. To place the rails in the tunnel as precisely as possible and to be able to respect the tolerances provided by the project, it is necessary to comply with the following conditions:

- establish a stable geodetic network of the object in which half-threshold rails are installed,
- geodetic equipment that can meet the tolerances required for the installation of half-thresholds,
- element positioning and positioning control, and
- recording of the derived state of the built-in half-thresholds.

Given that the installation of high-speed rails was completed, it can be concluded that this method of work can be applied to the construction of other tunnels in Serbia and that this would significantly improve the quality and progress in this area.

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