IMPACT OF BUILDING A ROAD TUNNEL "KLJUC" ON THE EXISTING RAILWAY BELGRADE – BAR

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ABSTRACT

During the reconstruction of the local road Kolasin - Mateševo, which would be the access road to the future highway, it was noticed that the existing road goes around the ridge in the length of over one kilometer. After the economic analysis it was concluded that the construction of the tunnel through the ridge would reduce the length of the road for about 1km with some savings in relation to the reconstruction and necessary expansion of the existing road, that is, around the ridge (Figure 1).The tunnel is close to the river Tara and goes through an exposed part of the mountain massif (cliff) framed with the river Tara on that side. Above the tunnel "Ključ", at about 34m of difference of levels, there is a railway Belgrade – Bar. The area around and above the tunnel is not inhabited.

This paper presents some aspects of stress-deformation analysis and analysis of possible influence of the tunnel construction works on the railroad. It also presents a comparative measurement of settlement that occurs during the excavation and settlement calculated based on a numerical model.

KEYWORDS: tunnel, land subsidence, overburden, stress-deformation analysis

1 INTRODUCTION

During the reconstruction of the local road Kolasin - Matesevo, which would be the access road to the future highway, it was noticed that the existing road goes around the ridge in the length of over one kilometer. After the economic analysis it was concluded that the construction of the tunnel through the ridge would reduce the length of the road for about 1km with some savings in relation to the reconstruction and necessary expansion of the existing road, that is, around the ridge (Figure 1).

A relatively difficult construction of the entrance portal, a relatively poor rock mass of III category classified based on the RMR classification and the railway Belgrade – Bar, located just above the tunnel, were the aggravating circumstances for the construction of this tunnel. In this section the railway route is in a straight line. It was built on a high retaining wall and observed in its base it cuts the new tunnel at the angle of about 80^{o}.

2 GEOLOGICAL CONDITIONS AND TECHNOLOGY OF CONSTRUCTION

The entry zones of the tunnel (length up to 30m) are in the rock mass which is constituted of thin layered to plate aleurolite and marl (degraded on surface), with thinner limestone interbeds (geotechnical zone "B") in the zone of surface alterations. Roof river drift-alluvial cover 3-5m thick lies on top of them. According to the RMR classification this rock mass is classified as IV category. Central part of the tunnel is in the rock masses consisting of aleurolite and marl, with thinner limestone interbeds (geotechnical zone "A"). Their texture is layered to plate and their structure is finely granular. According to the RMR classification this rock mass is classified as IV category.

As a general method of construction the New Austrian Tunneling Method Construction (NATM), which includes primary shortcrete, wire mesh and rock anchors support was selected. Having in mind the rock mass category, it was suggested to perform escavation and to support calotte in the first sequence and only then to continue with a certain delay with excavations and to support the bench.

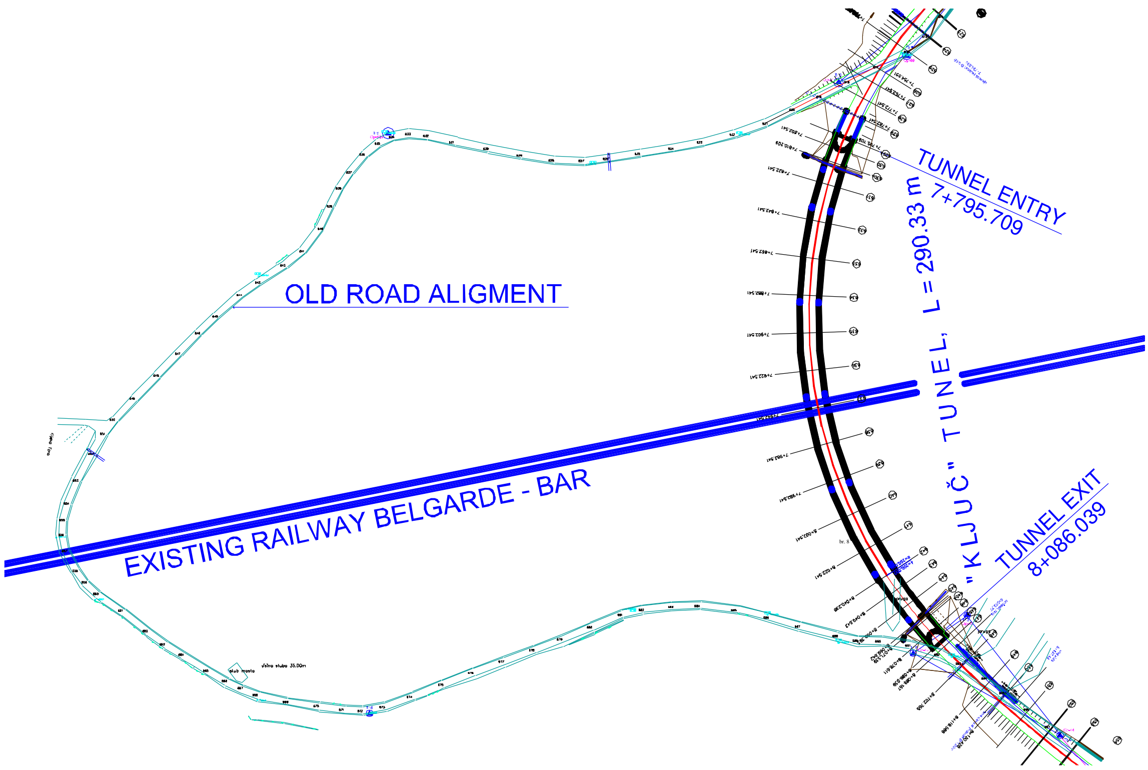

Figure 1. Situation scheme of the road and tunnel

3 STRESS-STRAIN ANALYSIS

Primary stress condition, defined in the Geotechnical Study, was applied to the model in accordance with the assessment of geotechnical zones A and B. In order to provide a ratio of horizontal and vertical primary stress k = 1.2 for the geotechnical zone "A" additional horizontal (tectonic) pressure of 1.6 MPa was applied to the model, while for the geotechnical zone "B" coefficient k = 0.9 was provided by applying the additional horizontal (tectonic) pressure of 0.25MPa;

3.1 Dimensioning of support structure

Calculation of the primary support was implemented by the application of the software package FLAC 4.0. Having in mind the importance of the tunnel (length, type of rock, surcharge etc.) it was estimated that it would be adequate to apply calculation on the 2D model. The projected geometry was incorporated in the model that is the segmental excavation for the construction (calotte and bench) - Figure 2, that is, formation of the support on a partly deformed contour of the excavation. The parameters of shearing resistance of the rock mass presented in Table 1 were used. Parameters relating to materials of the applied structural elements of the support structure (concrete, anchors and wire mesh) were adopted in the real scope when it comes to these materials. Based on bending moments, transverse and normal force calculated when applying this model, structural elements of primary support were dimensioned.

At a total length of the tunnel two types of primary support which were applied in different geotechnical zones "A" and "B" were defined.

Support of the type "A" was used in geotechnical zone "A" from ch. 7 +830 to ch. 8+055; it consists of concrete (MMB30) 10cm thick over the entire contour of excavation and wire mesh Q189 (1.89 cm^2/m) and SN anchors of the capacity N=125kN, 3m long.

Support of the type "B" was used in geotechnical zone "B" on the entrance parts of the tunnel from ch.7+795,709 to ch.7+830 and from ch. 8 +055 to ch. 8+086,039; it consists of concrete (MMB30)

25cm thick over the entire contour of excavation and wire mesh 2xQ377 (3.77 cm^2/m) and SN anchors of the capacity N = 250kN, 4m long in the calotte and anchors 5.0m long in side.

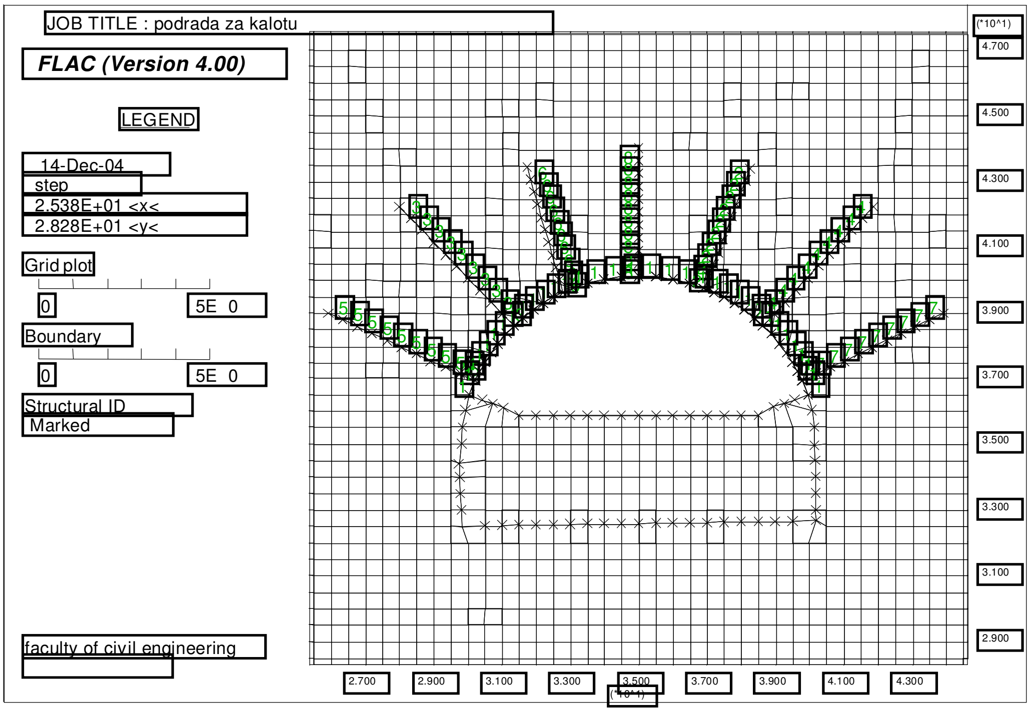

Figure 2. Scheme of mesh for the programme package $FLAC^{2D}$; phase: excavation of arch with support structure (shortcrete, reinforced mesh and anchors)

3.2 Strain (deformation) analysis

In addition to stress analysis and dimensioning of individual structural elements of the support structure for the applied technology of building, we have found deformation analysis also interesting, and particularly the analysis of the potential impact of tunneling on the railway which is placed just above the tunnel presented in this paper.

Excavation of the tunnel was conducted in several phases and therefore the numerical modeling was also applied in appropriate number of phases. In the first phase the primary stress state was calculated. It was followed by calotte excavation without installing support structure, with 50% the initial stress relaxation which is the result of the excavation of the tunnel. This relaxation is a consequence of deformations that occurred after excavation, but before the support elements were installed, as well as of the inclusion of bearing capacity of excavation tunnel face which cannot be encompassed by the 2D analysis. The next step was installing the primary support with the relaxation of all remaining stresses. In the next step the bench excavation was modeled with simultaneous installation of appropriate support elements (anchor, shotcrete and wire mesh).

Table 1. Geomechanical characteristic of rock mass

Geotechnical zone	*Unit weight* γ	*Young's Modulus* ***E***	*Poisson Ratio* ν	*Uniaxial strenght* σ_β	Cohesion ***c***	*Frictional Angle* □
	kN/m³	*MPa*		*Mpa*	*MPa*	*(°)*
A: *Aleurolite with layers of marl and limestone*	*26*	*1800*	*0,30*	*23,0***	*0,38*	*46*
					*0.05**	*32**
B: *Zone of changed aleurolite on surface with layers of marl and limestone*	*25*	*900*	*0,32*	*11,0***	*0.20*	*35*
					*0.03**	*26**

Note: Values marked with * correspond with residual values of strength parameters and ** refer to a monolithic part of the rock mass.

Two-dimensional calculation models of the software package FLAC 2D with mechanical parameters of the rock mass, as defined in Geological Study, suggested that in the most unfavorable case vertical subsidence of ground surface might reach 6cm as presented in Figure 3. Bearing in mind these large calculated displacement during the course of the works extensive observations of the railway are foreseen. A brief overview of the predicted observations of soil and structures is presented below.

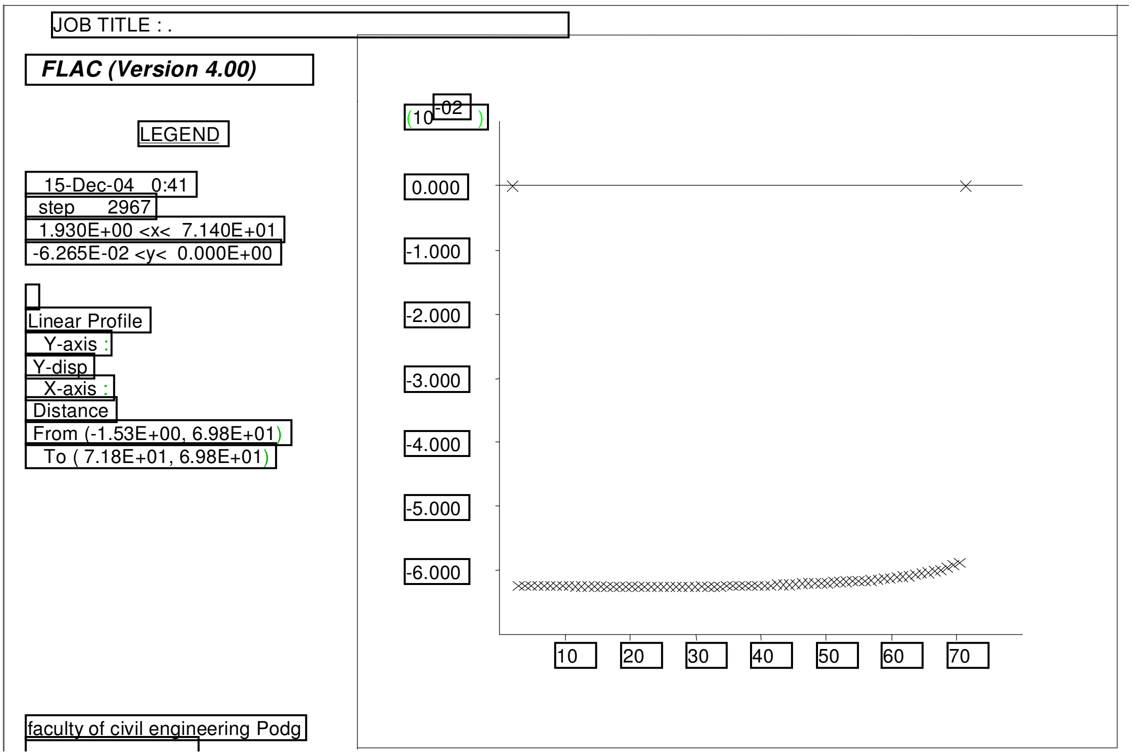

Figure 3. Diagram of vertical displacements of soil surface above the tunnel

4 PROGRAM OF OBSERVATION OF SOIL AND STRUCTURES

4.1 Measurement of land subsidence above the tunnel

The railway Belgrade – Bar is located just above the alignment of the tunnel "Ključ". Altitude at the intersection of the tunnel and the track is about 41.0m (34.0m from the upper edge of the tunnel to the upper edge of the rails). In-plane calculation model indicates that during the construction subsidence of the railway of about 6cm could occur at the intersection. Therefore, it is predicted to conduct control of the subsidence of the railway during the tunnel excavation.

Benchmarks for measuring the land subsidence were projected at 5 measuring profiles consisting of two benchmarks put on two sides of the line. During the course of works the projected measurement points were partly changed. 18 measuring points were posted on the rail ties and 8 measuring points on the ground near the railway (in Figure 4 it is marked from A to F), as shown in Figure 4. Measurements were conducted in time intervals defined in specially designed programs for measurement.

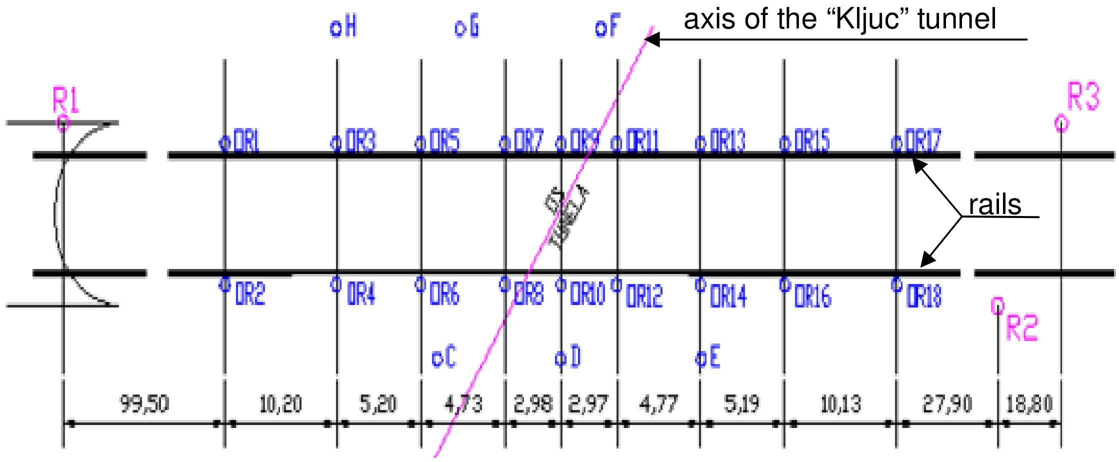

Figure 4. Scheme of measured points for measurement of vertical displacements - railroad settlement and soil around it

4.2 Program of measurement and measurement results of subsidence above the tunnel

It was envisaged to conduct measurement of a zero series of measurement on measurement profiles immediately after the commencement of construction of the tunnel, and then biweekly. When the excavation of the tunnel reached the profile positioned 20m before the intersection of the tunnel and the railway (horizontally perspective) measurements were to be conducted once a day. When the excavation was completed and lining was laid, in the zone ±20m of the center line of the trails, measurements were carried out once a week. Also, the measuring time interval would be increased if the difference between successively measured heights were less than 1.0mm.

The project envisages conducting measurement of subsidence – convergence on the measurement profiles until the increase in the change of benchmarks falls under 0.3mm in one month, after which the measurement would be stopped. If displacement of the surface of terrain reach 90% of the allowed projected subsidence (allowed projected subsidence - 10mm) it is necessary to adjust the technology of tunneling works in order to reduce subsidence and consider the need to strengthen support structure of the railway intersection.

Measurements of the railway subsidence were established two months before the beginning of works in order to assess the stability of geodetic network and benchmarks. To measure vertical movements, grading instrument LEICA NA 2002 was used and encoded strip with measuring millimeter accuracy. The maximum measured movement of rail ties on the track and the surrounding soil was 3mm.

Significant deviations of measured values of the railway subsidence and calculated vertical movements indicated significant deficiencies of a two-dimensional modeling for the overburden considered in this case. Namely, apart from underestimated modules of deformability of rock mass in Geological Study, a decisive influence on deformation of the ground surface lies on a three-dimensional effects that could not be included in a two-dimensional model.

4.3 Movement of the contour of excavation and measured values

The program of measurement of convergence foresees measurement of convergence on five points of the excavation contour. One point is fixed in the calotte and two in the tunnel side. Maximally calculated movement of excavation contour is in calotte and it was about 5.8cm for the rock environment "B". Convergence measurement was conducted with geodetic methods and it was found that maximum movement in calotte was about 2 cm, that is, almost three times lesser compared to calculated values.

Even though deformations caused by the primary stress condition were excluded during the course of modeling and sectional method of construction was included in the model (construction of walls and bench) displacement of excavation contours were measured to be three times lesser as compared to calculated values. The cause of this discrepancy should be found primarily in underestimated modules of deformability of the rock mass on one hand and to a somewhat smaller extent in the application of a two-dimensional model on the other hand.

5 CONCLUSION

According to the length or surface of the cross section, the tunnel “Kljuc” does not represent a significant underground facility. However, excavation of the tunnel under the existing rail tracks, which is rare in Montenegro and the region, is also an interesting experience in designing, calculation and execution of this facility. Comparative experience in regard to the impact of tunneling on facilities on the ground in flysch rock environment did not exist before in the region, which made estimations of the obtained calculated land subsidence more difficult.

Calculated and measured values of excavation contours displacements in this project indicate that up to three times larger modules of deformability should be used for flysch found at this location. Experience in calculation and measurement of deformation of the tunnel contour and surface of terrain are extremely useful in tunnel designing in this landscape which stretches in similar varieties in the length of 20-30 km of the future highway with significant length of tunnels (over 20 km of tunnel tubes or about 10km of two-tube tunnels) along the entire route.

In the tunnel “Kljuc” a support structure was applied for some categories of rock mass and it was defined based on a two-dimensional calculation model (FALC 2D). In the course of tunneling no signs of instability or loosening of support structure were noticed which can indirectly be inferred from relatively small measured values of excavation contour movement.

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