Reconstruction of two road tunnels

Rekonstrukcija dveh cestnih predorov

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Abstract: Reconstruction of road tunnels in so far, as shown in this article, in the Republic of Slovenia has not yet been performed. In the Tunnel Ljubno and the Tunnel below Ljubljana Castle is determined the stable situation. Here we are focusing mainly on the primary lining of tunnel tube, even a fifty or many years to function. For the purpose of the reconstruction have been made more detailed analysis of several important parameters in terms of providing long-term stability of the wider area and the normal function of the tunnel. The project provided technical solutions to the reconstruction which has been successfully performed and to consider a valid technical standards used in the Republic of Slovenia. The final arrangement of the external parts of the reconstructed tunnel tube no changes involved in pre-planned architectural designs. The time course of reconstruction of the Tunnel below Ljubljana Castle corresponded to the time schedule of Municipality of Ljubljana. All participants who collaborated in the reconstruction process were satisfied, because all executed works were done properly with valid technical standards.

Izvleček: Vsebina prispevka se nanaša na opis načrtovanja in rekonstrukcije dveh cestnih predorov v Sloveniji. Prvi je na avtocesti A2 Karavanke–Obrežje, drugi v Ljubljani pod Ljubljanskim gradom. Oba sta bila zgrajena po drugi svetovni vojni. Metoda gradnje predorov je bila tedaj prilagojena vgradnji toge in debele nearmirane primarne obloge brez talnega oboka. Načrtovanje in izvajanje obeh rekonstrukcij je potekalo v skladu z veljavnimi predpisi in smernicami, ki določajo dimenzije in varnostne pogoje pri gradnji sodobnih predorov. V prvi vrsti je bilo ugotovljeno, da profila predorov ne izpolnjujeta osnovnih zahtev. Pri načrtovanju različnih faz rekonstrukcije, vključno z odstranitvijo notranjih oblog, predvsem v predoru Ljubno, so bile upoštevane geološke in geotehnične lastnosti hribin ter geomehanske meritve pri gradnji sosednje predorske cevi. Posebna pozornost je bila namenjena načinu načrtovanja tehnologije gradnje z upoštevanjem meritev nabrekalnih tlakov v sosednji na novo zgrajeni cevi predora Ljubno. Rekonstrukcija predora pod Ljubljanskim gradom, ki je posebej prikazana v tem prispevku, je bila načrtovana in izvedena iz varnostnih razlogov, saj je bila notranja obloga razpokana in dotrajana. Ta je bila v celoti odstranjena, drenažni sistem za hribinsko vodo pa izdelan na novo. Prav tako sta bila na novo vgrajena betonska temelja, hidroizolacija z notranjo oblogo ter vozišče. Temu je sledila vgradnja sodobne elektrostrojne opreme. Obe rekonstrukciji predorov, ki sta prvi tovrstni v Sloveniji, sta potekali hitro in učinkovito. Projekta sta bila tehnično zahtevna tako glede geotehničnih razmer, kar velja za predor Ljubno, kot tudi glede izvajanja zaporednih faz rekonstrukcije glede na izjemno kratek rok izvedbe, saj je zapora prometa v predoru pod Ljubljanskim gradom povzročala velike zastoje na širšem območju centra Ljubljane.

Key words: Road tunnel, Reconstruction old tunnel, Numerical method, Geostatical 3D analysis, Primary shotcrete lining, Inner concrete lining

Ključne besede: cestni predor, rekonstrukcija starega predora, numerične metode, geostatična 3D-analiza, primarna obloga iz brizganega betona, notranja betonska obloga

INTRODUCTION

When assessing the technological progress of the construction of tunnels, it is necessary to ask what technical conditions were present before 60 or more years ago. Although the technical capabilities at the time of construction of underground structures significantly worse than today, most of the tunnels that were built, operated relatively well. Particularly the static stability should be appointed because it was maintained in the different rock environments. It also appeared that the installed concrete inner lining which were exposed to the negative effects of aggressive atmosphere, which is often found in road tunnels, kept accepted working conditions.

In planning phase of reconstruction the tunnels which were built in between 50. and 60. years of a past century required special expert assessment which included the knowledge about techniques and technologies that were used during construction. It was found that global stability of Tunnel Ljubno and Tunnel below Ljubljana Castle is relatively adequate with a few expected uncertainties.

Important requirements of both reconstructions are adaptations to technical and transport requirements which as for new built tunnels as for reconstructions of tunnels include all geometric elements relating to structural and electrical-mechanical conditions. In this case the provided quality drainage has were included waterproofing, stability, requirements for inner lining, pavements and all necessary safety devices.

Taking into account the conditions which were present after the Second World War, the construction of the two tunnels were of high quality without real stability problems until today, according to that time available technological capabilities. More detailed analyses of conditions in the tunnels before reconstruction reveal the stability problems of the invert in Tunnel Ljubno, which was built without it. Another outstanding problem to ensure safety in the Tunnel below Ljubljana Castle was in derogation of cracked and partially deteriorated inner lining and ineffective water drainage (Figure 10). In both cases the technical solutions which proposed tunnel designer Geoportal, d. o. o., were accepted and successfully realized.

Reconstruction of the right tube in tunnel Ljubno

In the northern part of motorway section A2 Karavanke – Obrežje, the old right tube (part of old regional road) close to the new built Tunnel Ljubno left tube, is planned for reconstruction which has included motorway section too. The existing alignment run continue from the west side of the Viaduct Peračica, right tunnel tube and continue to the Viaduct Ljubno in the Jesenice direction – Austrian border.

Reconstruction of the tunnel tube includes extension of the current clearance profile to the standard which allows two lanes 3.75 m width, one intervention lane width 3.20 m and two intervention corridors 0.5 m width. The amount of excavated material in the profile is approximately 86 m^2 per running meter of tunnel. On Figure 1 the location and the old existing cross section of the right tunnel tube is shown.

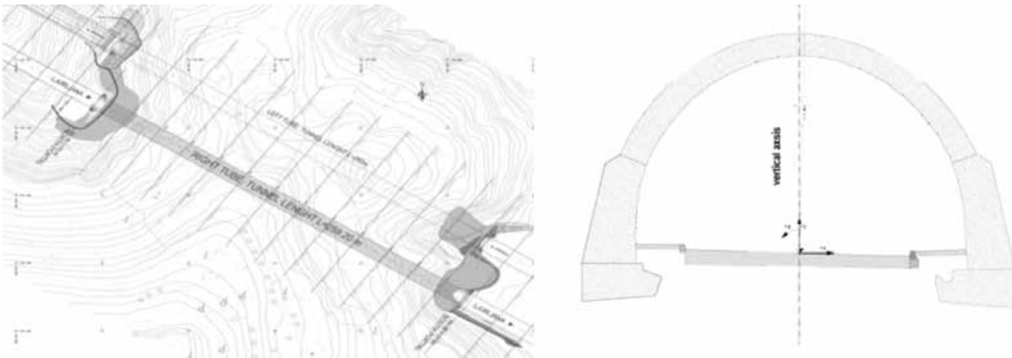


Figure 1. Location of the reconstructed right tunnel tube and cross-section of the right tunnel tube before reconstruction.

Geological and geotechnical conditions

In order to design reconstruction right tunnel tube optimally there were carried out extensive field and laboratory investigations and explorations of characteristic ground materials present in the tunnel area. All mentioned investigations were carried out before the design of new left tunnel tube was done. Special attention was paid relating to investigating the hard clay (Sivica) in which almost full excavation process was expected. Design of excavation and primary support lining was done in an appropriate way because the geological and geotechnical field investigations were carried out in extensive amount. Field's research comprised geological mapping, boreholes drilling, Standard Penetration Tests (SPT) and Pressuremeter Tests. Laboratory tests were included measurements of moisture content, UCS, Triaxial Shear Tests and measurements of swelling potential and deformability of hard clay (Sivica). Changing the rheological conditions shown significant differences in results of performed tests on hard clay (Sivica).

It was found that in a dry environment hard clay (Sivica) has solid strength properties, while contacts with water causes the relatively high presence of swelling potential.

The results revealed the presence of swelling potential, not clear demonstrate the unique possibilities of activation swelling process during reconstruction. This important fact was not measured because the applied ground load on primary lining was smaller against the load calculated from laboratory swelling tests.

The results of monitoring measurements in pressure cells (and extensometers), which were built during the con-

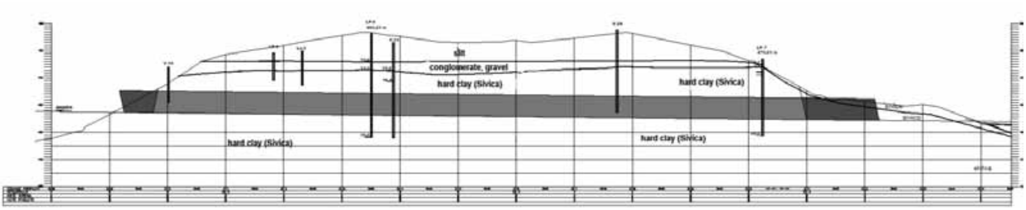


Figure 2. Longitudinal profile of the right tunnel tube.

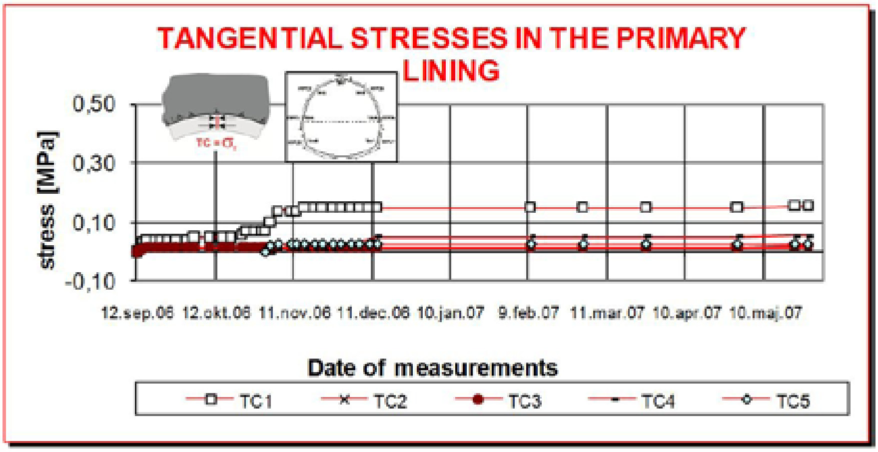


Figure 3. Measurement results of circular (tangential) stress in the primary lining in left tunnel tube

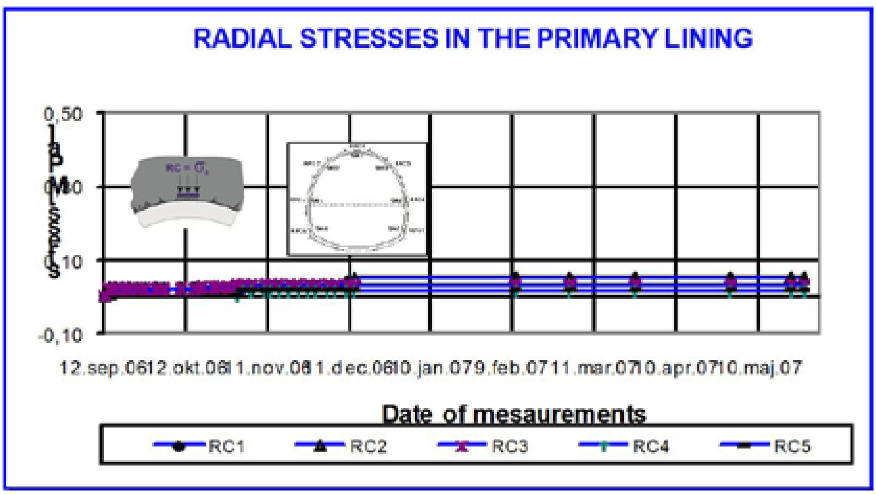


Figure 4. The results of measurements of radial stress on the contact between the primary lining and surrounding rock in the left tunnel tube.

struction of the left tunnel tube in the same geological geotechnical conditions did not show additional increases in circular (tangential) and radial stress (see Figures 3 and 4). In the future the swelling potential will not produce additional stresses on the inner lining, because the primary lining has enough loading capacity. The process which explain swelling pressure increasing in investigating ground shows that the closure of cracks depends of ground water isolation.

This is consistent with the results of extensive research by various swelling rocks (Wittke, 2000, 2002), which have rheological properties similar to hard clay (Sivica). It has been proven that naturally developed swelling pressures are much lower or minimum than those which are obtained from laboratory investigations.

Due to the fact that the rock in contact with ground water expose to effect of self sealing, the potential ability is to reduce swelling by the pores closed. In reality the swelling pressure was reduced with smaller water permeability of rocks. Based on the above observations and interpretations the calculation of bearing capacity of primary lining were taken into account.

Technical characteristics of the existing right tunnel tube

Professional assessment of the situation before reconstruction demonstrated that the existing tunnel lining was in a good condition, exception of portals where a lot of water was flowing since the drainage was not working properly.

Spaced contacts between the tunnel lining and portal structures and some working stitches inside the tunnel allowed flowing water into the tunnel. Road surface was in worse condition, mostly due to excessive traffic loads, and additionally because of the invert was missing.

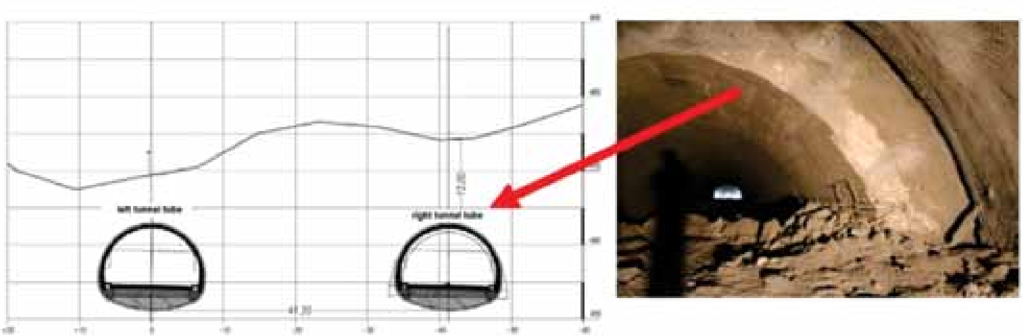


Figure 5. Cross-sections of the left tunnel tube and right tunnel tube which was reconstructed.

The main elements of the existing tunnel layout are:

- total length of tunnel tube: 232.24 m
- longitudinal slope: –1.14 % (in the direction of Ljubljana)
- the transverse slope of pavement: –2.5 %
- maximum overburden: 25 m

Total length of the right tunnel tube after reconstruction with cut and cover sections is 257.20 m. Spacing between tunnel tubes axis is 41.2 m, as shown in Figure 5.

Geostatic analyses and technical solutions of reconstruction

For the purposes of determining the amount of the primary support measures for the excavation profiles several 2D and 3D geostatic finite element analyses were done. To provide sufficient load capacity of support (ULS - ultimate limit states) the primary lining was dimensioned according to the corresponding steps and phases of excavation and primary lining installation.

When planning the excavation steps, special attention was paid to the level of serviceability (SLS – serviceability limit states) where the extension of the influence area was determined.
The steps and stages were designed in a way to prevent additional displacements in the left tunnel tube, caused by reconstruction of old tube.

Figure 6 shows the size of the radial displacements in the direction into the excavation area after re-profiling top heading, bench and invert. Results of analyses showed that the excavation process in right tube has not influence on the area around existing left tunnel tube.

Geotechnical assessments were taken into account the characteristics of hard clay (Sivica) and all necessary measures to reduce the risk of water and air which could affect on the stability of excavation profile.

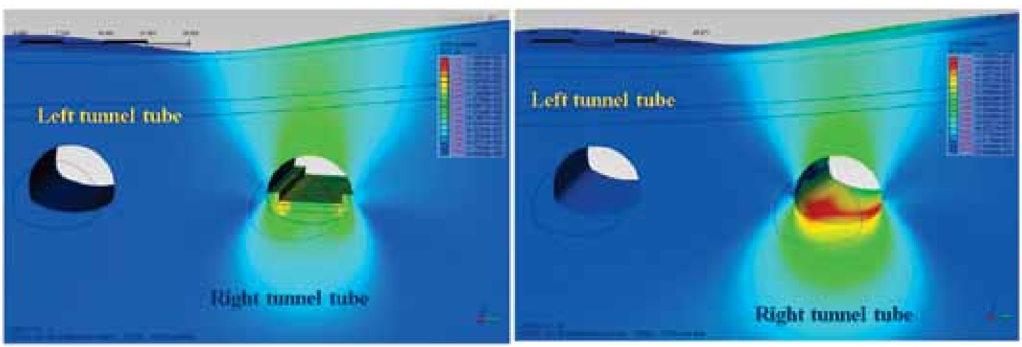
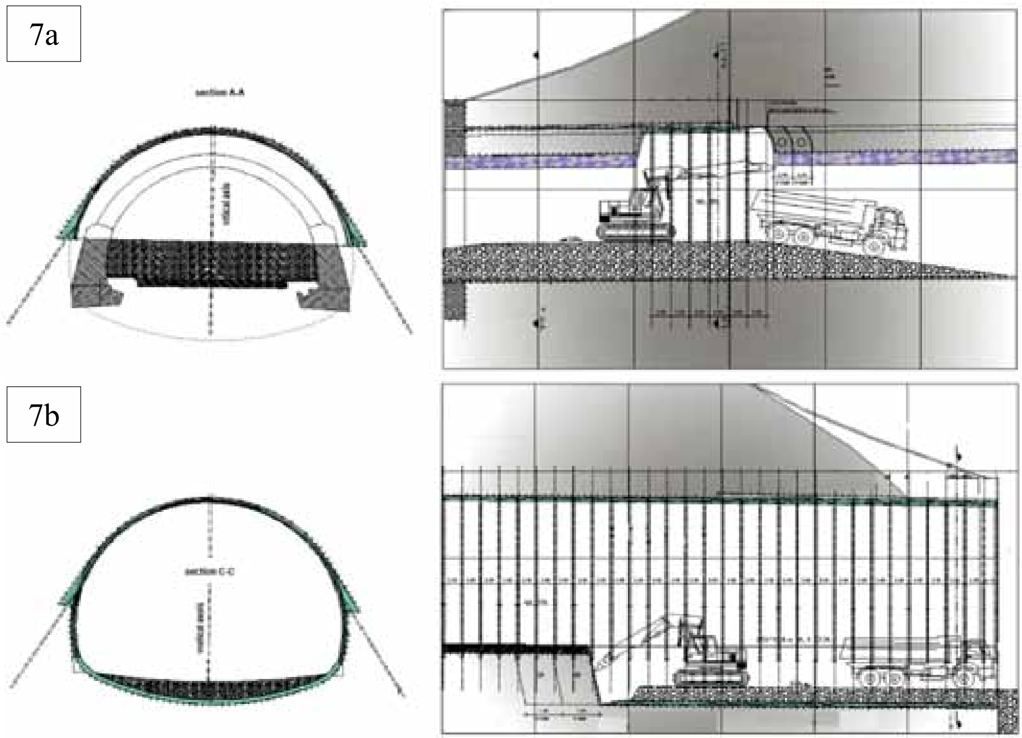


Figure 6. Radial displacements around the excavation and installation of primary support after excavation of top heading bench and invert



Figures 7a and 7b Method of excavation and installation of primary lining after excavation of top heading, bench and invert.

Project covered the operations of drilling and rock bolting if it is necessary, but without use water in terms of swelling limited.

Reconstruction of the right tunnel tube took place in five phases successively one to another:

- excavation of top heading and installation of primary support (Figure 7a.),
- excavation of bench and invert and installation of primary support (Figure 7b.),
- construction of portal structures (Figure 7b.),
- installation of abutments and waterproofing membrane and inner lining (Figure 7b.),
- final civil works (Figure 7b.).

RECONSTRUCTION OF THE TUNNEL BELOW LJUBLJANA CASTLE

Municipality of Ljubljana started the activities for the reconstruction of the Tunnel below Ljubljana Castle in the month of July 2009. The primary purpose of reconstruction is elimination and replacement of ceramic linings,

Figure 8. The final cross-section of right tunnel tube after reconstruction.

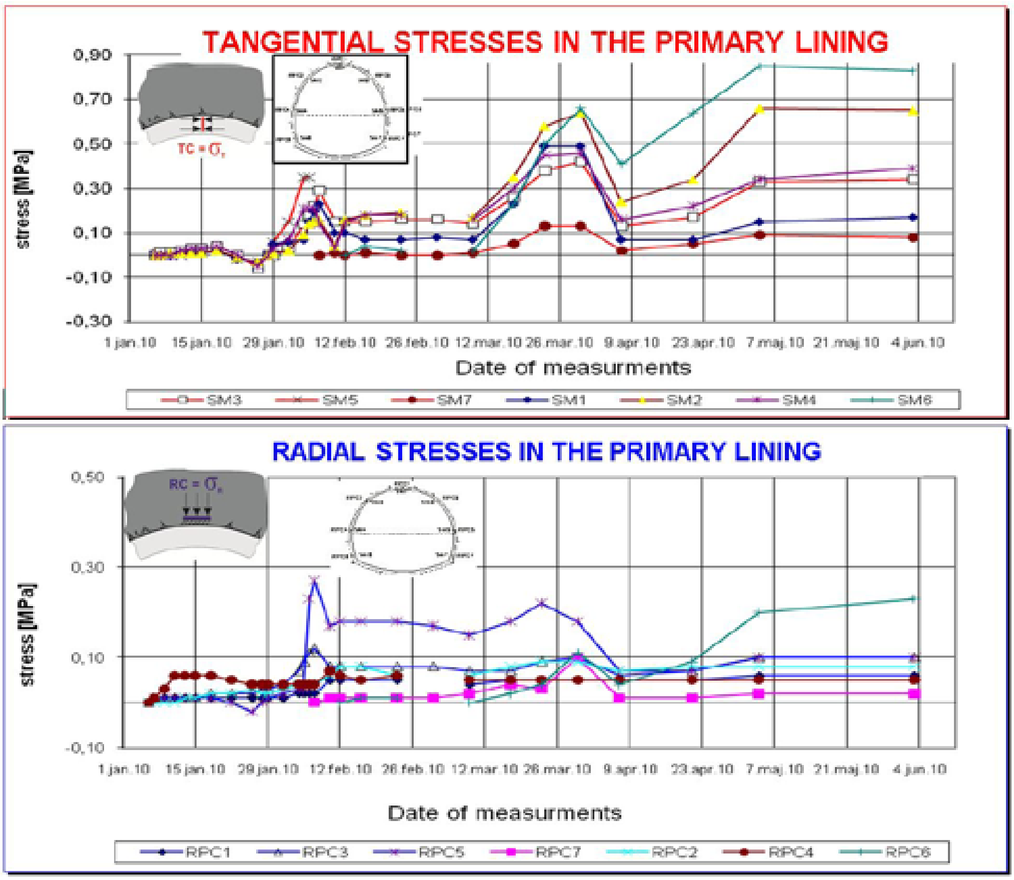


Figure 9. The measurement results of circular (tangential) and radial stress in primary lining of left tunnel tube during reconstruction of right tunnel tube.

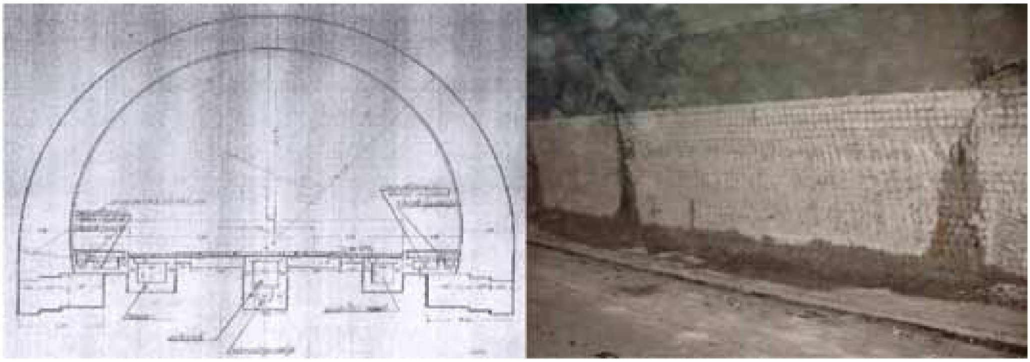


Figure 10. Transverse profile of the tunnel below Ljubljana Castle was dedicated to traffic in 1959. The damages were identified in 2009.

prevention seepage of water into tunnel, reconstruction of cracks in the concrete, painting the tunnel and partial reconstruction of electro-mehanical installations.

Introduction

The Tunnel below Ljubljana Castle was built in the fifties of last century and was constructed by so called old construction method of several smaller audits, which were allowed the gradual concreting of supporting arch, which was 1 m thick or more. To the supporting arch was installed bitumen insulation and at the final stage was installed a thin inner lining due to draining water. The drainage has been resolved by precast lining. The water has drain through channels in the longitudinal system which was blockade over the years.

The tunnel was dedicated to a transport in 1959 as a direct connection between the Poljanska road in Karlovška road. It was built as a two-way tunnel in according with the standards force at that time. It has function without majors interventions or repairs since opening until today. In the last period, the inner tunnel lining began to appear cracks and consequently smaller inflows, which were result of dilapidation of inner lining. ZRMK was conducted research in order to establish the internal structure of the tunnel and concluded that inner lining is 3 cm to 15 cm thick, non-uniformity built in the (axis of the tunnel tube) tunnel and partially cracked. In addition to the reduced static stability of the inner lining was influenced by blocked drainage system. This was a potentional cause of increased hydrostatic water pressure to the inner lining. Well-know example is the Tunnel Ljubelj, there occurred years ago a defect from inner concrete lining due to increasing water pressure, this causing a serious accident. In all this it cannot be excluded neither affect of aggressive tunnel atmosphere and frostiness.

Route of the tunnel and geological conditions of the area

Rout of the road in the tunnel running from the junction with Karlovška road at the south tunnel portal (chainage km. 0+000) to Kopitar road at the south tunnel portal (chainage km. 0+487.73). Surveyable tunnel situation is shown in Figure 11.

Geological structure of the area where the tunnel was built relatively stable with the exception of the last third of the tunnel tube on the south side. This fact is confirmed by research wells that were drilled in the primary lining and the surrounding area before reconstruction was performed. The surrounding soil consisted by mostly sandstones, partially siltstones, extremely minor part of slate. At several places, the present phenomenon of a ground water which infiltrates into the tunnel with the wider area of the Castle hill. All the springs are channelled in a drainage system so the normal stress conditions are provided in the lining around the tunnel tube.

The main elements of tunnel alignments are:

- total lenght of tunnel tube: 487.73 m
- maximum height above sea level: 298.25 m (South Portal)
- longitudinal bend varies from 0.2 % to 1.3 % and decreasing in the direction of chainage increasing (direction Vodnik Market)
- the pavement superlevation: pavement is performed in the roof slope and decrease from the axis of pavement, left – right +2.0 % to –1.3 %
- maximum overburden: 65 m.

Figure 11. A synotropic situation the Tunnel below Ljubljana Castle.

The technical solution to a permanent tunnel rehabilitation mostly includes:

- removal of the inner lining layer and preparation for drainage of water including drilling of drainage wells,
- making of waterproofing with PVC foil
- making longitudinal drainage with cross drainage
- concreting new inner lining with a special tunnel panelling,
- to settle pavements by using installation cable ducts
- colouring the tunnel up to a height 4 m.

Tunnel rehabilitation technology

To ensure prescribed bright pavement profile and having regard to the Regulation on technical standards and conditions for the design of road tunnels in the Republic Slovenia. The reconstruction of the tunnel included removal of existing inner lining to a depth up to 25 cm in the crown, then followed excavation for foundations and concreting foundations in excavation round in the length of 12 m.

At places where caused a major damages in the lining such, the gaps were stabilized local by wired nets Q189 and shotcrete C20/25 to equalization. Reinforcing nets were fixed to the primary liner with anchors RA $\phi = 28$ mm length $L = 30$ cm. The drainage of pit water from behind the primary lining is regulated by the drainage boreholes $\phi = 48$mm layer tunnel tube length of $L = 1.5$ m in span 1 borehole/2.25 m^2.

On sections with higher inflows are on those tunnel points drilled lining drainage wells $\phi = 100$ mm and install perforated drainage pipes $\phi = 75$ mm length $L = 1$m. After installing the drainage system has been performed layer of shotcrete C20/25 to equalization ruggedness in the thickness of approximately 3 cm,

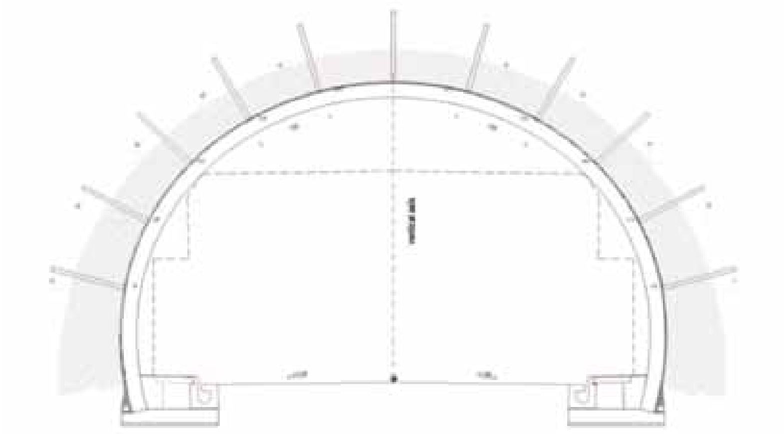


Figure 12. The measure of controlled collection and drainage of background water by drainage bore holes.

Figure 13. View an excavation for the installation of a new foundation and preparation for the installation of inner lining in the substructure roads and laying asphalt pavement and installation of electrical equipment in the reconstruction of the tunnel.

Figure 14. The final appearance of the tunnel when it was re-dedicated to a traffic 11. 11. 2009.

then follows the stage of installing waterproof layer including the installation of three-dimensional nets layer of polyamide fibbers and non-flammable waterproofing layer foil across the tunnel tubes. The last phase include excavation round concreting (L_k = 12 m) reinforced concrete inner lining 30 cm in thickness. Figure 13 shows the reconstruction of certain procedures tunnel.

CONCLUSIONS

- Successful reconstruction and rehabilitation of 50 years and older road tunnels was made on the basis of relevant applied researches and project documentation.
- Surprisingly the primary lining of cast concrete were in good condition even after 50 or more years, although at the time of installation technology was not on such a level as it is today.
- Those considerations are stimulative in the context of verification of long-term stability of the tunnel. In recent years it has been built many such objects in Slovenia and abroad.
- Although some of the technological reconstruction phases are similar to construction of the new tunnels which were performed, but it is necessary to consider the specific conditions of execution.
- Using the results of laboratory studies swelling properties of hard clay (Sivica) is conditionally justified. Intensity of swelling pressures was able to reduce in the Tunnel Ljubno due to consideration of a self-protective effect.
- 3D geostatic analyses were performed in the context of checking a compliance of primary and inner linings and they proved to be useful in terms of rational construction planning.
- Consideration of the spatial effect is essential for high quality design of structural tunnel elements. All works were performed quality in the prescribed time limit at rehabilitating the Tunnel below Ljubljana Castle so that is a legitimate case of a good practise in the rehabilitation of tunnels in the urban environment.

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