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17–19 May 2018, Zadar, Croatia

Road and Rail Infrastructure V

Stjepan Lakušić – EDITOR

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REHABILITATION TECHNIQUES FOR AGED RAILWAY TUNNELS

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Abstract

Due to fact that most of the railway tunnels in Croatia were constructed around hundred years ago, and taking in consideration lack of investments and maintenance strategies, there is an increasing need for their rehabilitation. However, this need is far greater than the available financial framework and therefore it is necessary to properly define the rehabilitation priority list and to apply the state-of-the-art rehabilitation methods to improve the safety and functionality aspects. This will result in overall lifetime increase of these critical infrastructure objects. In order to deal with such challenging task, this paper presents the techniques and methodologies for all stages of tunnel rehabilitation process, starting from investigation works in order to determine current condition of tunnel, through development of rehabilitation design, implementation of rehabilitation measures and quality control programme. The problems of non-satisfactory free tunnel profile, lining instabilities, excessive drainage of groundwater etc. will be presented through the examples of several railway tunnels in Croatia.

Keywords: railway tunnel, investigation works, water ingress, lining weathering, rehabilitation measures

1 Introduction

On more than 2 600 km of railway lines in Croatia, there are 109 tunnels which present the critical infrastructure objects which have a direct influence on structural, operational and logistical aspects of the railway. With total length of 22 km, an average railway tunnel length in Croatia is cca 200 m, where the shortest one has length of 20 m (tunnel Priporac) and the longest one is 2 273 m (tunnel Sinac). Most of these tunnels are located on international lines making their safety and functionality of higher importance. However, like in the rest of Europe where up to 95 % of railway lines were constructed before World War I [1], railway lines in Croatia are aged and this causes their gradual degradation. In average, railway tunnels in Croatia are almost 100 years old and there is an emerging need for their rehabilitation. The ageing process is accompanied by lack of investments, and consequently lack of maintenance efforts, over the past decades, where the transport of passengers and goods is almost completely transferred to the road traffic. The current practice is that the rehabilitation measures for railway tunnels are not considered until visible instabilities appear, making the rehabilitation techniques reactive (not proactive) resulting in higher rehabilitation costs. This paper presents the experience gained through rehabilitation of some railway tunnels in Croatia in last three years, which are marked in Figure 1.
Since these tunnels are located in different geological settings, with different microclimate and are part of different railway lines, most important factors which were taken into account for their rehabilitation are given – from investigation work phase, to the design phase and implementation of rehabilitation techniques.

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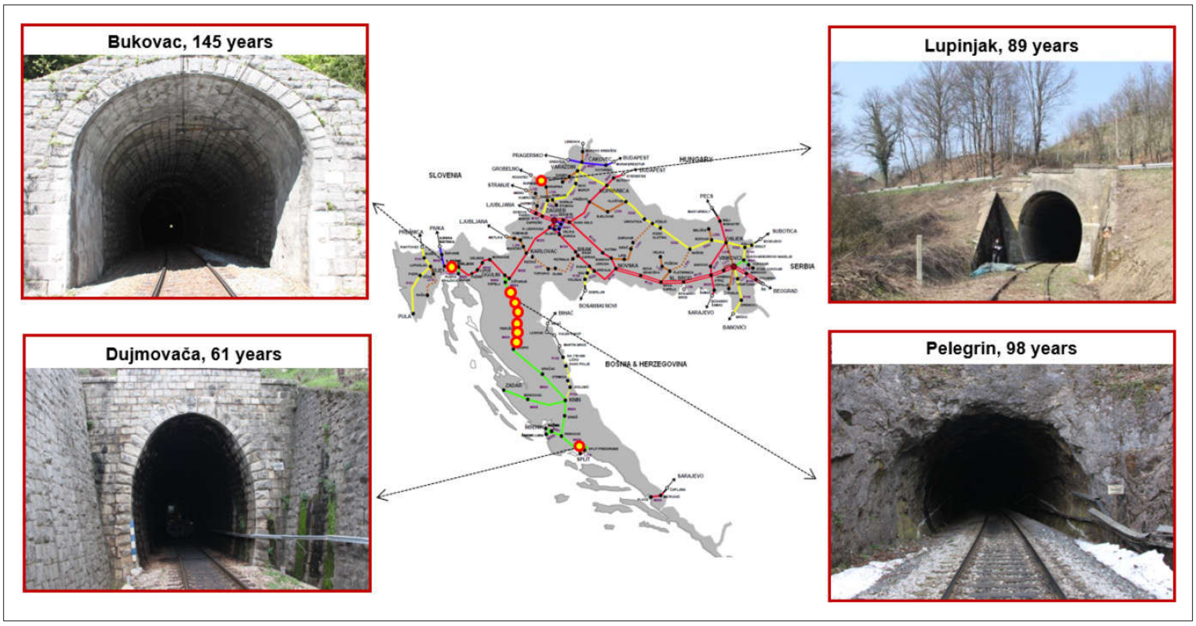

Figure 1 A map with location of railway tunnels considered within the paper

2 Investigation works as a basis for design

Among all structures, issues linked with tunnels can be considered as the most challenging for a geotechnical engineer. This is especially true for investigation work necessary for the assessment of tunnel's current condition, because optimization of the investigation works programme is necessary for linear structures. A good cooperation with railway managers comes to fore in this phase, where cooperation is manifested not just through exchange of experience and knowledge, but also in operational aspects necessary for implementation of investigation.

First step is in collection of the existing tunnel documentation containing information on construction or previously conducted rehabilitation measures. Most of times there is no useful information since prior remediation measures were implemented mostly through the regular maintenance and these implemented short-term measures are dealing with consequences and not with causes.

As a part of the visual inspection of the tunnel, a detailed visual inspection with photo-documentation has to be carried out in order to determine and classify the condition of the tunnel lining, condition of rock mass in locations without lining, the location of the water seepage, the condition of the track etc.

Further, a detailed geodetic scanning of a tunnel must be conducted with the connection to the official geodetic point where the position of all underground and overhead installations, equipment, track position, tunnel axis and the cross sections of tunnel should be given. The later one is of most importance since it is necessary to satisfy tunnel free profile based on current regulations and this is usually an issue for old tunnels.

It is necessary to carry out a detailed geological mapping which involves recognizing and recording the general geological and structural phenomena, but above all engineering-geological and hydrogeological phenomena relevant to the soil or rock mass in which the tunnel was constructed. In the rock mass, the engineering features such as the GSI (geological strength index) and discontinuity orientation and character must be given, while hydrogeological mapping should give an information on groundwater flow, permeability and soil or rock porosity, since water ingress is one of the major concerns linked with old tunnels. Additionally, in some cases it is necessary to define the origin and chemical composition of water.

Assessment of tunnel lining, soil/rock mass, ballast, suballast, etc., can be effectively conducted using rapid non-destructive methods, Figure 2. Destructive investigation methods, such as driling or trial pits, provide good informative, however, they are very expensive and time consuming and usually also require the closure of the track section for a relatively long time period and as a result only very limited information is therefore available along the tunnel, potentially leading to neglection of the main issues [2]. In order to decrease the investigation costs and to increase the efficiency of the investigation works, by investigating a larger volume, the application of non-destructive measurement techniques such as geophysical techniques is recommended.

a) b)

Figure 2 GPR testing, tunnel Lupinjak (a); MASW testing, tunnel P. Glava (b)

A combination of electromagnetic Ground Penetrating Radar method and seismic analysis of surface waves (both SASW and MASW) methods was applied on each tunnel. The aim of the GPR investigation is to determine the locations of anomalies behind the lining in order to optimize the rehabilitation works, while the aim of the seismic investigations is to determine the stiffness ratio before and after the rehabilitation work in order to verify that the repair works did not adversely affect the support system stiffness and thus the potential instability, which is of highest importance in zones where cutting of lining was necessary [3].

3 Design and implementation of remediation measures

The heterogeneity of geological setting as well as diversity of existing support systems are the main factor which determine the type of rehabilitation measures. These factors are especially emphasized for the tunnels located at mountainous regions due to large seasonal temperature variations and the specificity of the karstic terrain. Here, some of the tunnels were constructed without any support system, while all of them are constructed without any waterproofing measures. Considering their current condition, there is a strong need to implement the state-of-the art rehabilitation measures in order to enhance the safety and functionality aspects. A typical railway tunnel cross section with rehabilitation measures is given in Figure 3.

Figure 3 A typical railway tunnel cross section with rehabilitation measures

3.1 Prevention of the water ingress and seepage issues

The absence of waterproof and drainage system is a result of no relevant standards or techniques during their construction. This led, through the years, to several water-related issues from small ones, such appearance of the water drops on lining, to more severe cases with continuous water ingress or the appearance of water film on the rock mass and lining with clearly visible carbonate deposits, Figure 4a. The water ingress is more prominent during the wet seasons with increased precipitations and formation of ice on lining and tracks, where in the absence of drainage systems frozen ballast poses a threat to traffic, Figure 4b. Additionally, water with its eroding and chemical action and the freezing process entails additional stresses in support systems that cause fracture of rock mass blocks or lining elements.

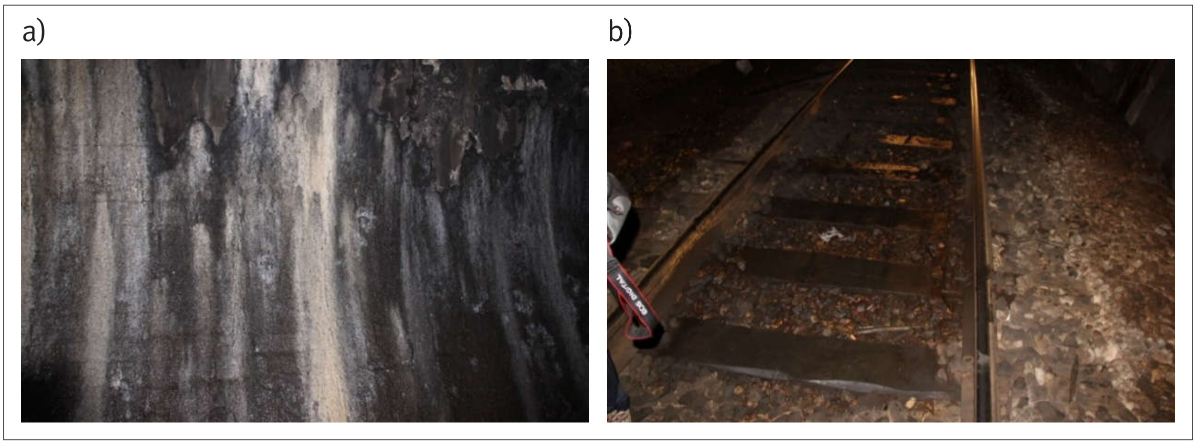

Figure 4 Carbonate deposits on the lining, tunnel Dujmovača (a); frozen tracks and ballast, tunnel Sinac (b)

The rehabilitation measures include implementation of several drainage and water-proof measures where functionality of drainage is directly linked with functionality of water-proof system and vice-versa. After cleaning of complete tunnel interior, small drainage pipes are installed at pre-defined array with larger number in locations of evident water ingress, while in rock mass without lining, these are installed on position of discontinuities with water ingress. Further, a system of half-pipes in installed along tunnel's cross section and these collect the water from small drainage pipes and transport it to a drainage system installed at the bottom, Figure 5a. On the levelling shotcrete layer, a geotextile – geomembrane – geotextile composite is installed and anchored into a levelling shotcrete. The geomembrane serves as a first water-proof barrier, while geotextile helps the drainage and serves as a protection of relatively stiff geomembrane. The next layer is sprayed water-proof material which serves as an additional measure against water ingress, Figure 5b. As a final layer, a micro reinforced concrete is installed which serves both as a protection of installed layers but also has final aesthetic function.

a) b)

Figure 5 A bottom drainage system, tunnel P. Glava (a); installation of sprayed water-proof layer, tunnel Lupinjak (b)

3.2 Deterioration of lining and stability issues

Mostly under the influence of water ingress, but also of other factors, existing lining in railway tunnels is usually significantly deteriorated with the several phenomena such as cracks, weathering of lining stone blocks, washed-out joints which result in falling of stone blocks, Figure 6, etc. Remediation of these issues usually includes so called 'contact' and 'bonded' grouting in order to fill all voids behind the lining and to increase bonding of lining with soil / rock. The locations of grouting points are determined based on investigation works, mainly on the results non-destructive methods. Also, grouting is of highest importance when there is a need for cutting of a lining. Prior to grouting, a reconstruction of washed joints between stone block is conducted. In order to prevent further weathering of lining elements, as well to prevent any loss of strength of rock mass on locations without lining, a shotcrete layer is installed which also serves as a levelling layer for water-proof materials.

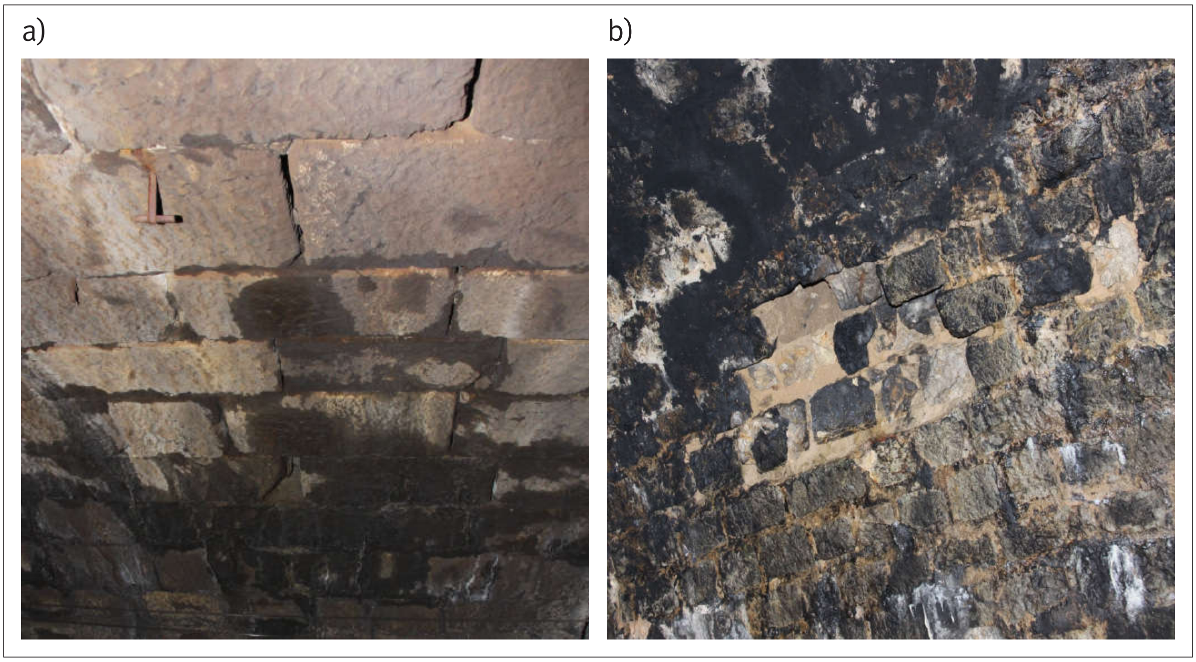

Figure 6 Washed-out joints with deteriorated stone blocks: tunnel Bukovac (a); tunnel P. Glava (b)

Even though the deteriorated issues are more prominent, some tunnels have problems with overall stability where long-term effects from the environment, accompanied with water influence, cause failure of lining system, Figure 7a, or rock mass blocks, Figure 7b. These pose a huge threat to railway traffic safety. The technology which is most often used to deal with stability issues consists of installation of rock bolts or soil nails (passive type anchors). With their interaction with rock mass, along with the application of a shotcrete, safety aspects are significantly enhanced.

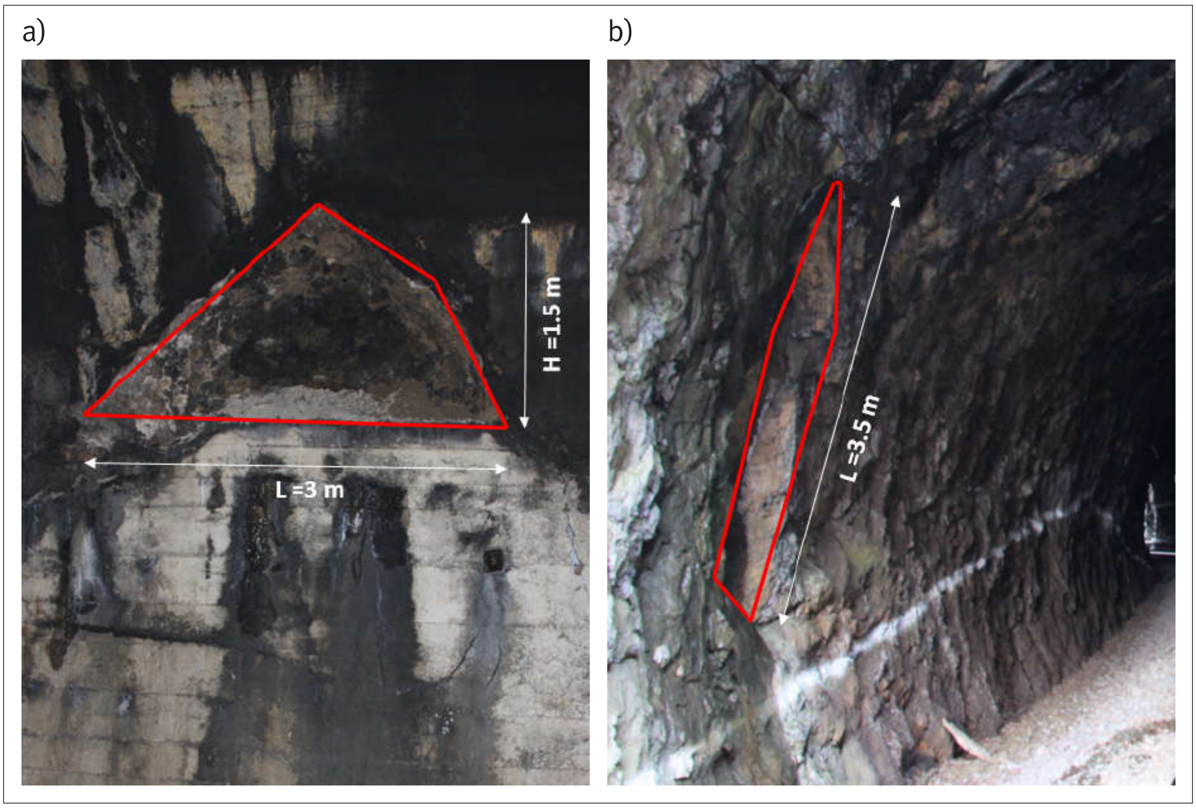

Figure 7 Failure of a part of tunnel lining, tunnel Grabež (a); failure of a rock mass block, tunnel Pelegrin (b)

3.3 A non-satisfactory dimensions of the cross section

In order to fulfil functional aspect, a railway tunnel needs to have satisfactory cross-section. The International Railroad (UIC) has a standardized free profile that allows unobstructed passage of a vehicle, including the cargo. In Croatia, a document called 'Ordinance on technical conditions for the safety of railway traffic to be met by railways' [4] gives the conditions that the railway tunnels have to meet with regard to the free profile. One of the examples of non-satisfactory free profile is given in Figure 8. The free profile is achieved by the standard methods used in tunnel excavation, that enable locally widening of the profile dimensions by cutting and grinding of the rock mass and lining. In electrified tunnels, the tunnel's non-satisfactory height is achieved by lowering of the ballast layer.

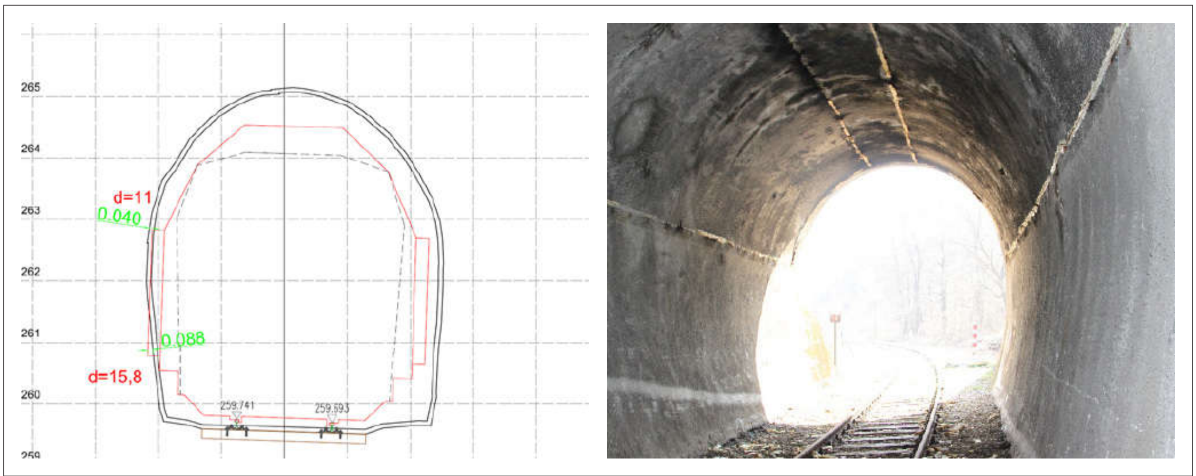

Figure 8 Non-satisfactory free profile, tunnel Lupinjak

3.4 Other aspects

Due to the dynamical loads of the trains and the inadequate drainage from the tunnel, ballast fouling could occur, along with cavities in the ballast body or reduction of ballast integrity. It is often necessary to conduct ballast tamping with levelling and lining maintenance. This can be repaired by various ballast stabilization methods or by installing geogrids or other forms of ballast reinforcement which, however, require a complete replacement of ballast. Wooden sleepers are made of durable material, but due to cyclical changes they become prone to deterioration. However, this issue is not so common.

Usually, a tunnel rehabilitation design and implementation is not just one-discipline effort and civil engineers need to collaborate closely with other experts, most importantly with electrical engineers, traffic experts and safety experts. If electrical installation interfere with rehabilitation works, it is necessary to foresee their temporary or permanent relocation which could be only conducted with engagement of electrical engineer. During the design phase, and according to national law [5], a traffic study which contains information on the type, content and scope of the intervention and the traffic zone impact must be developed. Very important aspect for successful implementation of design measures is the quality control. Both field and laboratory testing of applied materials and monitoring of displacements or other parameters is crucial for a tunnel which should meet all design criteria regarding its safety and functionality.

4 Conclusion

When considering a suitable rehabilitation measures for aged railway tunnels, several factors must be taken into account including geological settings, microclimate and importance of the tunnel in overall railway system. In order to get an insight in the condition of a tunnel, several activities should be conducted including collection of existing documentation, geodetic scanning, geological mapping and non-destructive investigations. Considering the current condition of railway tunnels in Croatia, there is a strong need to implement the state-of-the art rehabilitation measures in order to deal with issues such as water ingress, deterioration of lining, endangered stability or non-satisfactory dimensions. This measures will enhance the safety and functionality aspects of tunnels. However to achieve this, a quality control program must be established and implemented. Multidisciplinary approach, both in design phase and during rehabilitation works, also has an important role.

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