THE APPLIED CONCEPT OF LONG RAILWAY TUNNELS ON HIGH PERFORMANCE RAILWAY LINE „STATE BORDER – ZAGREB – RIJEKA“

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Abstract

The construction of the high performance railway line from State Border (Botovo) – Zagreb – Rijeka also includes construction of two long tunnels, "Kapela 1" 9,273.87 m and "Kapela 2" 14,386 m length. This paper aims to present the parameters relevant for the selection of tunnel concept and tunnel cross section.
Two single-track tunnel tubes were chosen, after the safety, technical and cost analyses were carried out. Although it has its shortcomings, the construction of single tube double track tunnel of such length would require the construction of a parallel service tunnel, which would represent a financially and technologically more demanding option in relation to the construction of two parallel tunnels of bigger cross section.
In terms of safety in case of accidents in one tube, the other serves as a safe area for evacuation.
Furthermore, since safety reasons don't recommend both passenger and freight trains to be in the tunnel at the same time, this would limit the capacity of the railway line if only one tube with double track is constructed.
An aerodynamic study was carried out for the selected cross section, which confirmed the selection. Since it is planned that all interventions in emergency situations, in case of accidents in the tunnel, shall be carried out by road vehicles, the concept of fire protection and construction solutions are based on this requirement. In accordance with these requirements, the system of a permanent way on ballastless track (like RHEDA 2000®) shall be used, which meets the above mentioned requirement with slight modifications (prefabricated concrete slabs).
When compared to ballasted tracks, the need for maintenance of ballastless track is less complicated, which largely contributes to the reduction of costs during its life cycle, and greater durability.

1 Introduction

In the preliminary design, two different tunnel concepts are planned on the subsection Skradnik – Ledenice of the future double track high performance railway line State Border (Botovo) – Zagreb - Rijeka:
- both tracks in one tunnel tube
- a separate tunnel tube for each track

Double track Treskavac Tunnel is 395 m in length, while single track tunnels have the following lengths, [4]:
- Veljun
  - left tube 2 965.85 m
  - right tube 2 954.00 m

· Kapela 1
  · left tube 9 290.37 m
  · right tube 9 290.00 m
· Kapela 2
  · left tube 14 415.58 m
  · right tube 14 428.00 m
· Burnjak
  · left tube 1 495.00 m
  · right tube 1 530.00 m.

Due to the large percentage of carbonate material in rock mass, the New Austrian Tunnelling Method (NATM) was selected as a method of construction, since it is suitable for overcoming karstified structures (caves and joints) as well as possible occurrence of clay pockets which are common in this area.
Horizontal geometry of the track is made in such a way that superelevation of rails is not needed in curves. This fact allows for a constant cross section along the tunnel, and track durability and stability is thus additionally increased.

2 Selection of tunnel concept

Railways throughout Europe are facing a period of development and several tunnel projects are undertaken. The experience with the safety and design of such projects has shown that the most important decision is related to the selection of tunnel configuration for long railway tunnels. The selection of the appropriate tunnel configuration is based on decision criteria such as operability, safety and costs. The basic tunnel configurations are:
· One double track tunnel with a service tunnel;
· Two single track tunnels with a service tunnel;
· Three single track tunnels (in case of huge traffic volume);
· Two single track tunnels without a service tunnel.

The last configuration has been selected in the recent tunnel projects as a compromise between safety and costs, [7].
Two following two concepts were considered in conceptual designs of subsection Skradnik – Ledenica:
· Double track tunnel with two parallel tracks in the same tunnel tube. Service tunnel, which is connected to the main tunnel tube by cross passages (Fig. 1), serves as a safe area for evacuation.
· Two parallel single-track tunnels that consist of two parallel tunnel tubes each with one track, and cross passages separated by fire doors, (Fig. 2).

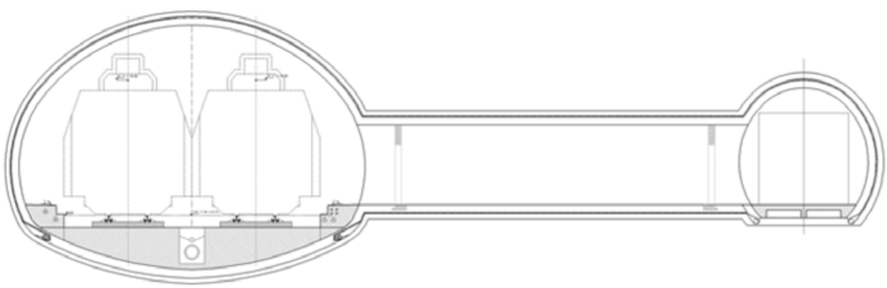

Figure 1 Double-track tunnel tube with the connection to the service tunnel, [3]

Figure 2 Two parallel single-track tunnel tubes connected by a cross passage, [3]

From the safety point of view, it has generally been argued that twin tube tunnels are safer than single tube tunnels, and that new tunnels should therefore be built according to the parallel twin tube concept.
In case of an accident in one tunnel tube, the other serves as a safe area for evacuation. Main tunnel tubes are connected by cross passages spaced at every 500 m. The cross connection allows the evacuation of train passengers from the affected tunnel tube to the safe tube, as well as rescue service access to the accident site.
Although tunnels are statistically safer than the rest of the railway network, the public aversion to fire accidents in tunnels can justify more extensive safety measures than would be required on the basis of the estimated number of fatalities alone, [1].
Double track in single tube tunnels generally have large cross section areas (80-115 m2) with big air volumes under the tunnel roof, which will normally give good
smoke stratification during the first phases near the fire. The natural ventilation direction in the tunnel is relatively unpredictable if there are several trains running in different directions. Normally there will be more than one train in the tunnel and if immediate evacuation from a train in the tunnel is necessary, it is important to regard any possible traffic on the other track, [6].
Double track tunnel is preferable from the economic point of view. However, the construction of a double track tunnel of greater length would also entail the construction of a service tunnel. Since service tunnels have smaller dimensions, their construction becomes technologically demanding. In terms of construction technology by NATM method, it is more acceptable to construct two parallel tunnels with larger cross sections, where communication between initial cut points is achieved by excavating cross passages, which largely simplifies and reduces the cost of works.
After safety, technical and economic analyses were completed, it was established that the concept with two single-track tunnel tubes, regardless of its shortcomings, is the best solution for long tunnels (such as Kapela 1 and Kapela 2). On the other hand, Burnjak and Veljun Tunnels, which can not be categorized as long tunnels, shall also be built as twin tube single-track tunnels, because the required geometric elements of the route within the tunnel itself (minimum radius of 5000 m in order to avoid superelevation of rails inside the tunnel) and immediate vicinity of other structures make it impossible to connect the route axes to the axial distance of 5 m.
This design concept with two tunnel tubes allows uninterrupted maintenance of one tunnel tube, while the other is in operation.

3 Selection of tunnel cross section

Tunnel cross section was selected for design speed of V = 200 km/h (+/- 25%).
Tunnel cross section meets the clearance requirements defined by the Ordinance on Technical Requirements for Railway Traffic Safety (Official Gazette of the Republic of Croatia No 128/08)

as well as the requirements defined by the Austrian guidelines for railway tunnel design RVE 02.00.01 (proposal, 28 November 2006).

The designed cross section allows for the accommodation of necessary equipment within the profile, it meets the criteria for pressure comfort, and ensures the required evacuation possibilities.

Aerodynamic studies were also made with the aim to provide first evaluation of the tunnel aerodynamics. The main objective of the work was to carry out numerical simulations in order to evaluate:

· The pressure forces acting on the tunnel structure and the installed mechanical equipment;
· The comfort of the passengers due to pressure fluctuations;
· The traction power requirements.

The occurrence of the minimum pressure during a single train passage is associated with the train leaving the tunnel and is located near the train exit portal. The maximum positive and negative deviations from normal pressure for the run of a single high speed train are +2.7/-2.7 kPa, whereas for the run of the single freight train they are +4.0/-2.9 kPa. For the encounter between two high speed trains in the double track tunnel Treskavac the maximum positive and negative deviations from normal pressure are +1.8/-3.1 kPa.

For single runs of high speed, fast passenger and regional trains the medical criterion for pressure changes is satisfied (max 10kPa during tunnel passage without accounting for train sealing).

Considering the installed power available on the train it is possible to reach a speed of 200 km/h with the high speed train and 160 km/h for the regional train even with the gradient of 0.8%. The maximum traction power of 14.4 MW is required for the train passages in the tunnel with the constant inclination of 0.8% for the freight train and of 10.4 MW for the high speed train. The required traction power of 14.4 MW exceeds the available power on the freight train. The operational speed of 140 km/h of the freight train can not be achieved.

For the occurring air velocities in the tunnel of approx. 42 m/s the dynamic pressure is in the magnitude of approx. 2.5 kPa, [8].

The selected cross section assumes a ballastless track system (like RHEDA 2000® or similar).

The clear opening of the selected cross section of single-track tunnels amounts to 49.5 m2. Area of excavation for the tunnel with invert is 73.74 m2, and 66.40 m2 for the tunnel without invert (Fig. 3.).

Twin tube tunnel Treskavac shall have a clear opening area of 79.4 m2. The area of excavation of the tunnel with invert is 113.5 m2, and 97.6 m2 for the tunnel without invert, (Fig. 4).

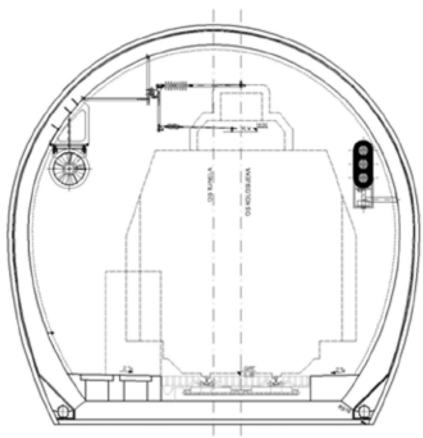

Figure 3 Cross section of a single tube tunnel with necessary equipment, [4]

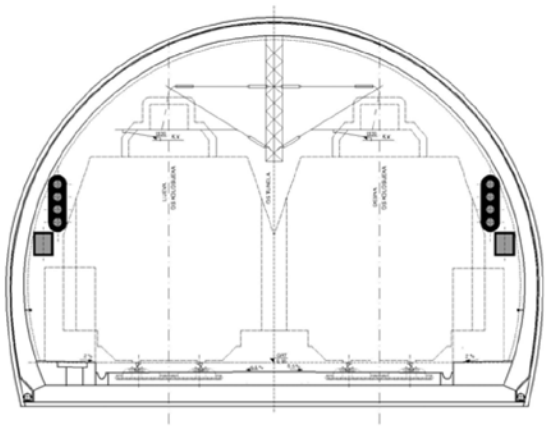

Figure 4 Cross section of a twin tube tunnel with necessary equipment, [4]

4 Selection of track structure in the tunnel

Track structure inside the tunnel shall be a ballastless track like RHEDA 2000® system.
The first application of ballastless tracks was the installation of a slab track in tunnels. The already present solid tunnel bottom slab as well as the requirement of a low construction height of track provides best conditions for using ballastless tracks on newly built railway lines. In general, all construction types of ballastless track used on earthwork structures can be realized in tunnels. Here, hydraulically bound support layers are not necessary. Concrete layers are applied with reduced thickness directly on the tunnel base. Especially the concrete layer with a normal thickness of 30 cm may be reduced to 15 cm for use in tunnels, directly on the tunnel substructure slab.
The climatic conditions in tunnels are advantageous for ballastless track types with concrete slabs. The temperature in the tunnel is quite homogeneous, except the areas of about 100 m next to the tunnel portals. Thus, the crack distributing reinforcement of the concrete slab could be reduced or even omitted, [5].
Ballastless tracks provide a high level of track stability, which allows for the possibility of silent running of trains and high comfort journey. Maintenance needs are decreased significantly, which largely contributes to the reduction of costs during life cycle, and better usability.
The principal function of the permanent way is to ensure vertical and horizontal stability of the track grate, and the dynamic load of rolling stock and stresses caused by temperature changes in the rails act on it. Due to stiff substructure in tunnels, the degradation of the ballast track is accelerated, and the grains become worn and crushed fast at the contact zone with the concrete base, under the impact of traffic load. In this way, the unevenness of track geometry is increased, and at the same time the empty space between larger particles of ballast becomes filled with small particles which causes drainage problems (mudding of the ballast) and this will require frequent maintenance.
Increased ballast degradation on a stiff substructure is explained by the following assumptions in literature, [9]:

- A stiff substructure limits the extent to which the rails distribute the load, so that higher loadings result directly under the sleepers on a quasi-static basis.
- At increased speeds, greater particle velocity in the ballast layer is experienced; velocity of vertical movement at the underside of the sleeper is doubled as the train speed increases from V = 160 km/h to 250 km/h. This effect is reduced with greater elasticity in the track structure.

· Harmonic excitation, for example as a result of secondary bending between the rail supports locations, is reduced with increasing elasticity of the track structure.

For the above mentioned reasons, and due to the fact that ballast maintenance inside the tunnel is much more difficult and complex, it was found that the simplest solution is to use ballastless tracks in tunnels. Asphalt or concrete base course may be placed directly on tunnel base, and its thickness may be reduced, on the condition that corresponding calculations are proven, as compared to the thickness of layers of the track structure outside the tunnel, [9].

Figure 5 RHEDA 2000®

The selected track system such as the suggested RHEDA 2000® system (Fig. 5) employs modified two-part sleepers with countersunk grid reinforcement, which are permanently fixed to the concrete bearing plates. The longitudinal reinforcement of the concrete slab is inserted into the grid reinforcement of the bi-block sleepers. Concrete is poured over all elements, thus constituting a unique monolithic element. Track structure is at sides separated from the tunnel structure

by an expansion gap in its entire length, made of 3 cm thick styrofoam, and sealed with a betonit strip in order to ensure water impermeability.

The track structure is without a gap at the joint with tunnel foundation, so as to achieve better distribution of traffic load forces.

Figure 6 Prefabricated slabs

Figure 7 Fire fighting vehicles [2]

One of Investor's requirements was the implementation of road intervention vehicles in tunnels. In order to satisfy this requirement, the design provides for the placement of prefabricated slabs that will fill the area between rails to the plane of track gauge, and thus enable undisturbed passage of road vehicles inside the tunnel. Prefabricated slabs (Fig. 6.), according to the patented solution of track manufacturer, shall meet the following requirements:
· bearing capacity – relevant intervention vehicle (Fig. 7);
· they shall enable drainage from the top surface into a planned drain channel;
· they shall be fixed in such a way to prevent lifting due to negative pressure.

5 Conclusion

Based on the conducted technological, technical, safety and economic analyses for the selected method of tunnel construction according to NATM principles in the anticipated rock material, the concept of two parallel single-track tunnels was chosen as the best solution. Furthermore, in selection of particular technical concepts of the tunnel, primarily routing through tunnels and the choice of the permanent way, the optimization of operational costs of tunnels was taken into consideration as well. The selected tunnel concept meets all safety criteria related to tunnel users in case of accidents. Moreover, the selected cross section satisfies the aerodynamic requirements for standard rolling stock of high performance railways.

References

[1] Zuber P.: Compared safety features for rail tunnels, Safe & Reliable Tunnels. Innovative European Achievements, First International Symposium, Prague 2004.

[2] Sommerlechner C., Valo R., Neumann C..: Emergency exercises in Austrian railway tunnels, 3rd International Conference „Tunnel Safety and Ventilation“ 2006, Graz

[3] Institut IGH: Idejno rješenje tunela željezničke pruge visoke učinkovitosti Državna granica (Botova) – Zagreb – Rijeka, Zagreb, 2008./ Preliminary concept of high performance railway line State Border (Botovo) –Zagreb-Rijeka, Zagreb, 2008

[4] Institut IGH: Idejni projekt tunela željezničke pruge visoke učinkovitosti Državna granica (Botova) – Zagreb – Rijeka, poddionica Skradnik – Ledenica/ Preliminary design of high performance railway line State Border (Botovo) –Zagreb-Rijeka, subsection Skradnik –Ledenica, Zagreb, 2008.

[5] Fruehauf W., Jungwirth J., Scholz M., Stoiberer H.: „Slab track systems on engineering structures – A holistic design approach“, RTR Special – The German High Speed Rail System, March 2008, str. 78-88

[6] Anderson T., Paaske Borre J.: Safety in railway tunnels and selection of tunnel concept, ESReDA 23rd Seminar, 2002, Delft University

[7] Diamantidis D.: Risk acceptance criteria for long railway tunnels: a need for periodic review, PSAM 6 International Conference San Juan Puerto Rico, 2002.

[8] Nyfeler S., Reinke P.: Aerodynamic studies of the high performance railway line between Zagreb and Rijeka, HBI Haerter Consulting Engineers, 2009.

[9] RTR Special: Slab track, Eurailpress, Hamburg, 2006.

[10] Slab track, the commercial case: A scoping study, Britpave by Ove Arup & Partners Ltd,2003

9 PERMANENT WAY