UPGRADING AND REFURBISHING VENTILATION SYSTEMS IN ROAD TUNNELS - ENGINEERING WITH CONFLICTING INTERESTS

Rudolf, A., Höpperger, B.
ILF Beratende Ingenieure ZT GmbH, Innsbruck

ABSTRACT

A large number of road tunnels have been built in the last decades. In response to serious tunnel accidents recently, the normative requirements for safety in tunnels have increased significantly. This is reflected in the tunnel design guidelines of the EU (2004) and adaptations of national guidelines thereafter.

Due to intense traffic, the structure of many road tunnels show signs of fatigue. Electro-mechanical equipment becomes outdated or needs replacement. Traffic forecasts keep increasing, despite the demographic development and the hikes in oil prices. Due to technological improvements, tunnelling is now quicker, more affordable and more secure than several years ago.

All these factors oblige tunnel operators to review existing tunnels and, while doing that, to consider building new tubes to enhance security, availability as well as traffic capacity.

Hence, there is a highly actual field of activity for tunnel engineers and planners of electro-mechanical equipment: upgrading and refurbishing existing tunnels, eventually coupled with the construction of an additional tube.

As in all projects, there are conflicting interests. However, in this type of project, there is one more group of people involved as compared to the creation of a new tunnel: all those, who are engaged in the operation of the existing tunnel and who have to ensure the security and availability of the road during the entire construction period. This causes that there are less degrees of freedom than for new tunnels built in the past. It is therefore time to prepare for a new type of challenging and awarding engineering task in the decades to come.

The present paper addresses this issue with reference to the actual tunnel projects Bosruck-tunnel (5.5 km) in Austria.

Keywords: tunnel ventilation, refurbishment, 2nd tube, RVS 09.02.31

1. INTRODUCTION

The Bosruck tunnel is a 5.5 km long road tunnel crossing the Pyhrn Pass between the states Styria and Upper Austria. The first tube (east tube) has been opened in 1983 and is since operated with two-way traffic. Due to particular geological conditions with heavy seepage and saline inclusions, the main tunnel is paralleled by a de-watering tube, which is also used to supply fresh air to the fully transverse ventilation system.

Since 2006, the planning for the extension of the Bosruck tunnel to a twin-tube tunnel with directional traffic has begun. It has been awarded to the Planungsgemeinschaft Bosrucktunnel (PGB) consisting of Laabmayr&Partner ZT GmbH / Salzburg and the ILF ZT GmbH / Innsbruck. The new west tube is scheduled to be operational in late 2012. After that moment the existing east tube will be refurbished. Both tubes will operate in directional traffic in the summer of 2014.
The overall project also includes two bridges at both ends of the tunnel and comprises a stretch of 7 km in total.

Even though the tunnels will primarily be used in directional traffic, the ventilation system fully accommodates for two-way traffic. Two-way traffic is necessary during the refurbishment of the east tube (2013-2014) and in case of intentional or accidental closure of one of the tubes.

Availability was one of the major targets in the conception of the ventilation system. This is because the pass is closed for heavy vehicles and alternatives involve significant de-routing.

The starting point was the ventilation concept from the general project for the first tube in 1979. It already contained elements for an extension to a 2nd tube. The ventilation concept basically mirrored the existing system. Cross-vents were built so that they could be extended to the 2nd tube. Portal stations for the 2nd have been built as well.

During the main project, it was found that vehicle emission values have significantly been reduced in the mean time, resulting in much lower fresh air rates than predicted 30 years ago. Also, the requirements of local smoke extraction as well as the consideration of unfavourable weather conditions (pressure, wind) gave rise to a change of priorities. Therefore, the ventilation concept from the initial study needed to be revised.

This revision has led to several discussions involving operational aspects and investment costs. Parallel to the new conception, several draft revisions of the Austrian road tunnel guideline RVS 09.02.31 have been issued. These revisions addressed improvements to safety requirements and contained clarifications to former versions. The following will outline the concepts which have been looked at. Reasons why they have been discarded or followed are discussed. It must be emphasized that this discussion refers to one particular project. The parameters and client preferences in other projects may be different and may lead to other conclusions. Nonetheless, the type of compromises observed here is likely to recur in similar projects, i.e. projects where an existing tunnel is extended during operation.

1.1. Planning Guidelines

The basis for the ventilation concept is the Austrian road tunnel security law from 08/05/2006 and the Austrian guideline for basic principles of tunnel ventilation (RVS 09.02.31). It defines criteria for the required ventilation concept, sets aims for normal and emergency ventilation, specifies flow control parameters and contains the procedure for a simplified risk assessment.

2. Initial Ventilation Concept

The ventilation concept in the general project from 1979 contained provisions for the 2nd tube. The extended concept was the onset for the main project and is therefore shortly described.

2.1. Scheme

The ventilation scheme for the 2 tube system as anticipated in the general project is pictured in Figure 1. It will also be used to describe the current configuration of the tunnel.

The system in the blue rectangle embraces the existing system with fully-transverse ventilation in the east tube. The main components are: the east tube with split false ceiling, the ventilation and de-watering gallery and the fan stations for supply and extract at the tunnel portals. Adjustable exhaust dampers have been added to the east tube in 2002 in order to increase tunnel security.
The scheme shows a fully-transverse ventilation system. The general project anticipated to mirror the existing system keeping the supply fans and adding two new exhaust fans. The portals for the east tube and the ventilation caverns have actually already been built.

Fresh air enters by the tower between the tubes. The supply fans are connected to the central ventilation gallery. The ventilation gallery ist connected to the supply portion of the false ceiling by ventilation cross-vents in the quarter points. In the false ceiling, the flow splits into one branch towards the tunnel center and a second branch toward the portals. Its distribution can be adjusted with dampers in the ventilation cross-vent.

In the Bosruck tunnel, the area of the supply portion of the false ceiling reduces between quarter points and portals continually (the steps in the scheme represent in reality a continuous area change). Between the quarter points, the respective areas of supply and extract portion remains constant. This way, the variation of the flow velocities in the false ceiling is reduced and operational costs optimized. It must be considered that the ventilation system is currently in operation most of the time as there is two-way traffic.

The exhaust fans are directly connected to the end of the false ceiling. The exhaust air leaves the tunnel by additional exhaust chimneys which are connected laterally to the building.

Figure 2 shows 2 vertical cuts with the existing tube and the ventilation gallery as well as the new tube (right hand side, green) as anticipated in the initial project. The upper image corresponds to the zone between the quarter points and the lower image to the portal zones. As the gallery serves also for de-watering, it is below tunnel level over the entire tunnel length.

The current rescue concept foresees that tunnel users seek shelter in the cross-adits, which are designed as waiting areas (seats, telecommunication, and cameras). Rescue personnel enter by the ventilation gallery. The cross-vents between the quarter points and the portals (see Figure 2 below) are accessible by a narrow shaft with a ladder through which tunnel user are evacuated.
Figure 2: Position of the existing cross-vents (grey) and the continuation according to the general project from 1979

2.2. Discussion

The initial concept is a straightforward extension of the general project. However, as many main parameters have changed in the mean time, the requirements for the new system are different now:

1. The general project in 1978 projected a required fresh air rate of 135 m$^3$/s.km on the basis of 1800 PWE/h. Even though the projected vehicle flow fits very well to the actual data, the fresh air requirement is now only 20 m$^3$/s.km. This reduction is due to significantly reduced emission levels of modern vehicles, which exceeded by far the predictions from the 70s. This means that normal operation can be covered with longitudinal ventilation, in most cases even with self-ventilation by the vehicles themselves. A fully-transverse system is not required any more.

2. The relevant tunnel guidelines now impose different standards than 30 years ago. For example: The maximum distance of cross-vents exits is now set to 250 m plus the maximum slope is 10% (existing cross-vents have up to 12%) This leads to a complete re-distribution of all cross-vents.

3. The relevant ventilation guidelines are quite different than in the 70s. The main point is that ventilation systems are now designed with a focus on the emergency ventilation. This lead to re-dimensioning the ventilation system for the existing and the new tube plus additional installations to influence longitudinal flow needed to be added.

4. From the experience with the existing tunnel, the operator has developed ideas which help to increase the availability of the tunnel in case of maintenance works and to reduce operational costs. This lead to new requirements with respect to redundancy, accessibility as well as maintenance costs

For all these reasons, the concept was revised.
3. PGB CONCEPT

In the first phase of the project, the planner of the Bosrucktunnel, the PGB, suggested a ventilation concept which fulfilled the following main targets:

1. Full compliance with RVS
2. Unified ventilation concept for both tubes
3. High security level
4. Powerful extraction capacity considering smoke expansion due to heat
5. Easy to operate
6. Redundancy (not required by RVS, but necessary to achieve high availability)
7. Switching from the current ventilation system to the operation of the west tube in two-way traffic without major traffic disruption possible
8. Providing ventilation for the refurbishment of the east tube
9. Low investment costs
10. Reasonable maintenance costs

![Figure 3: Initial Concept of the PGB](image)

3.1. Scheme

The result can be seen in Figure 3. Its main ideas are:

- rededication of the air supply chimney to an exhaust chimney
- smoke extraction fans placed vertically at the bottom of the chimney
- suction-side connection of both tunnels to the exhaust fans inside the head building (no mined ventilation cross-vent required)
• unmake the north / south separation in the false ceilings
• false ceiling only for smoke extraction, i.e. connection of the two ventilation ducts in the east tube (at this time, it was not clear whether the false ceiling needed replacement)
• jet-fans in the main tunnels, adaptation to required cross-section
• new cross-vents passing above ventilation gallery
• pressurization of cross-vents via supply fans and adjustable dampers connecting from the ventilation gallery

Even though the control system foresaw that smoke is extracted to the nearer fan, it was suggested to dimension the extract fans in a way that they could handle fires over the entire tunnel length. This way, the proposed system would provide full redundancy with only little extra costs (remark: redundancy is not required by the RVS). The jet fans were dimensioned so they could reach 1.5 m/s for the fresh air along the entire tunnel even against the maximum pressure differences, which amounted here to 225 Pa. Expansion of air due to heat was considered.

3.2. Discussion

Even though the concept was first acknowledged by the project team, some scepticism came up about the following points:

• the newest draft of the RVS 09.02.31 required exhaust lengths not exceed 2’500 m
• it was found that the real leakages may exceed the values required by the RVS, hence the full redundancy was questioned
• the jet fans in the driving tunnels were criticised with respect to traffic disruptions for maintenance and their maintenance costs
• it was criticised that the exhaust fans may not provide full exhaust capacity when one exhaust fan is out of order (e.g. due to maintenance)
• as the existing exhaust fans are still in good shape (even though only for temperatures of up to 250°C), it was found that they should not be abolished
• maintenance of a vertical axial fan was found too complex
• it was claimed that consideration of air expansion due to heat for dimensioning of the extract fans (required max. power: ~1 MW) exceed the requirements of the RVS and lead to unnecessary investment costs

In the sequel, a number of alternative ventilation concepts were examined. The main focus was on the aim to avoid jet-fans in the driving tunnels. The most promising suggestion on that path was to use the very powerful supply fans as injectors. This concept was studied in detail by the PGB, even with multiple injector locations. It was discarded due to the unusually high relevant pressure differences, which could not be handled with the injector, and reservations with respect to the control strategy of such a complex system.
4. **FINAL CONCEPT**

The final concept was then found performing a thorough economic analysis including costs for civil engineering, M&E equipment as well as operational, maintenance and opportunity costs for traffic disruptions over 25 years. Even though the main candidates gave very close numbers, the maintenance costs as estimated by the Asfinag were significant and it was found that this item is the least desired one.

4.1. **Scheme**

Thus, the PGB concept, which required small jet-fans, was abolished in favour of an option where fewer, but larger units are used. In turn, additional niches needed to be built. These ventilation niches are build as an extension to the lay-byes. Also, it was the wish of the operator to keep the existing exhaust fans and to add new ones in horizontal portal stations above the new tube. The ventilation RVS does not require a temperature upgrade for the refurbishment of existing tubes. However, in favour of an improved security level, it was decided that the new exhaust fans rated at 400°C over 120 min. should be able to handle fires in the east tube as well. To this end, ventilation cross-vents connecting the false ceilings of both tubes will be built at the quarter points.

The operational points of the extract fans have been determined assuming a volumetric flow rate of 120 m³/s (cold) at the incident location plus the doubled leakages as required by the new draft version of the RVS 09.02.31. The power of the new exhaust fans is about 300 kW.

The jet fans are now able to generate longitudinal flow of 1.2 m/s over the entire tunnel length in a completely filled tunnel in 2-way traffic against a maximum meteorological pressure difference of 235 Pa.

**Figure 4:** Final concept as chosen by the Asfinag
4.2. Discussion
As compared to the system in chapter 0, there are now less jet fans and smaller axial fans. This makes up for savings of investment and maintenance costs. In turn, niches and the ventilation cross-vent have to be built plus the power supply for 4 smaller instead of 2 larger fans needs to be put in place. The reduction in exhaust power does not lead to significant offsets in the original security level as the existing fans will remain in place. These can not handle the today required high temperatures but will be useful in most cases. This is particularly true in the case of maintenance works where operational restrictions can be imposed (e.g. reduced speed limit) in order to mitigate risk. But also when only one of the new exhaust fans is in operation, the 2nd exhaust fan of the west tube and both axial fans in the east tube provide additional extract capacity to compensate unexpected leakages and if larger exhaust capacities are required (e.g. for larger fires or if desired by the fire brigades).

Most importantly, this was a solution where all participants from different departments of the Asfinag could live with.

5. REFERENCES