THE CURRENT STATUS OF THE TUNNEL VENTILATION DESIGN OF THE PLANNED BRENNER BASE TUNNEL BETWEEN AUSTRIA AND ITALY

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ABSTRACT

The key element of the Brenner railway line from Munich to Verona is the currently planned Brenner Base Tunnel (BBT) with a length of about 55 km.

The following paper provides an overview of the current status of the planned tunnel ventilation system for the Brenner Base Tunnel. The tunnel ventilation system ensures that the ventilation goals, based on the requirements of operation, are achieved for the normal, maintenance and emergency mode. In this way, the tunnel ventilation system ensures that the temperature and humidity of the tunnel air during normal operation and the quality of the tunnel air during maintenance work fulfil the requirements during operation of the tunnel. For the eventuality that a burning train stops in the tunnel, the tunnel ventilation system ensures that the passengers are protected from smoke in a safe place up to their evacuation. The design of the tunnel ventilation system for the Brenner Base Tunnel includes the know-how of the Swiss AlpTransit Projects (Gotthard Base Tunnel and Loetschberg Base Tunnel).

1. INTRODUCTION

Various requirements exist for the ventilation concept of the operation phase of the Brenner Base Tunnel. On the one hand it must be guaranteed that the tunnel climate allows a reliable and in this way secure operation of the tunnel system. For this purpose the temperature and the humidity levels must be kept within certain limits. On the other hand an incident case (i.e. train fire) has to be considered in the determination of a suitable emergency ventilation concept. Finally, appropriate ventilation must be provided during maintenance work in the tunnel. The present paper contains an overview about the ventilation system currently planned by the planning group of the Brenner Base Tunnel (PGBBT) within the framework of the UVE planning and the technical project preparation. The following topics are handled:

- the most important requirements for the ventilation,
- a current overview of the state of the ventilation concept and
- calculations of aero- and thermodynamic issues.

Since the project planning is not yet finished, it cannot be excluded that single tunnel elements as well as tunnel ventilation facilities will still change during the further planning.

2. DESCRIPTION OF THE BRENNER BASIS TUNNEL SYSTEM

2.1. Tunnel description and main data

The planned Brenner Base Tunnel between Innsbruck and Franzensfeste is the key element of the railway line from Munich to Verona. The tunnel consists of 2 single track tubes, with a total length of 55'410 m, west tube, and 55'140 m, east tube. The tunnel portals are longitudinally shifted in order to avoid air recirculation. Figure 1 shows schematically the main elements of the tunnel system:
3 multifunctional stations (MFS by-pass Innsbruck, MFS Steinach, MFS Wiesen), containing emergency station, cross-over, and overtaking track (only in the MFS Steinach)

by-pass tunnels and the branching tunnels to the Base Tunnel (number 5, 6) in Innsbruck and the branching tunnels east and west in Franzensfeste (number 7)

3 access tunnels (number 1, 2 and 3) to the MFS

cross-passages with a length of 35 m at a regular distance of 333 m between the 2 main tubes and cross-passages of up to 220 m length between the branching tunnels in Innsbruck,

Escape shafts along the branching in Franzensfeste

The Base Tunnel shows a maximum gradient of 8.3 ‰. However, at the time a reduction of the tunnel gradient to 7.4 ‰ is planned. The portal Innsbruck lies 586 m above the sea level and the portal Franzensfeste lies 742 m above sea level.

2.2. Operation mode

Three main operation modes have been defined for the Brenner Base Tunnel:

**Normal mode:**

The Brenner Base Tunnel is planned for a daily traffic of 264 trains, 140 in the north-south direction (21 passenger trains) and 124 in the south-north direction (21 passenger trains). In the normal mode the north-south traffic takes place in the east tube and the south-north traffic in the west tube.

**Maintenance mode:**

Two different scenarios are possible:

- Maintenance work in tunnel east or tunnel west. The traffic takes place in the opposite tube with alternating running direction of the trains from north to south and from south to north.
- Maintenance work in a single tunnel section. Three maintenance sectors are defined: between Innsbruck and MFS Steinach, between MFS Steinach and MFS Wiesen and between MFS Wiesen and Franzensfeste. In this mode only the maintenance section is closed for train traffic. Trains are redirected through the tunnel section parallel to the maintenance section.

**Emergency mode:**

Depending on the event location three different scenarios are possible:
• Event in emergency station. Self-rescue in the safe waiting area of the station.
• Event outside the emergency station. In case of an event in the main tube the opposite tube serves as a safe place and is reached through open doors in the cross-passages. In case of an event in the by-pass tunnel Innsbruck the security tunnel serves as a safe place (see Figure 1). In case of an event in the branching tunnels Franzensfeste self-rescue takes place over the escape shafts.

3. REQUIREMENTS OF THE TUNNEL VENTILATION

3.1. Requirements of operation

The relevant regulations for ventilation derived from the requirements of operation may be specified as follows:
• Normal mode: sufficient air exchange in order to satisfy the temperature and humidity limits
• Maintenance mode: acceptable air quality during the work
• Emergency mode: The ventilation supports the self-rescue phase by creating safe waiting areas and escape ways.

3.2. Ventilation objectives:

The ventilation objectives depend on the operation mode. For the three defined operation modes the ventilation objectives are as follows:

**Normal mode**
- Maximum temperature in main tubes, cross-passages and branching tunnels: 35°C.
- Maximum air humidity in main tubes, cross-passages and branching tunnels: 70%.

**Maintenance mode**
- A sufficient air flow must be provided by the ventilation, however the air velocity in the maintenance tube or section should not exceed the comfort value of 5 m/s.
- The amount of pollutant gases (CO, NO, NO₂, Methane) and particles in the air should be kept under the limiting values and the concentration of oxygen in the air should be over 19%.
- The pressure variation in short and long time period should not exceed the comfort and the health limits (1.5 kPa in 4s and 10 kPa in a working period).
- The temperature during long and short working periods should not exceed the limit of 30°C and 35°C respectively.

**Emergency mode**
- The ventilation in emergency mode should primarily support the self-rescue and evacuation phases by creating safe waiting areas and ensuring safe evacuation ways.
- Secondarily the propagation of smoke near the safe waiting areas should be kept as low as possible. In case of event in the emergency station, the smoke propagation in the escape tunnels should be avoided and in case of event outside the emergency station, the smoke propagation in the opened cross-passages should be avoided by ensuring a sufficient counter airflow (≥ 2 m/s).
- Thirdly the ventilation should support the rescue team.
Finally the propagation of smoke to sensible locations (closed cross-passages, portals, branching and by-pass tunnels) should be kept as low as possible.

4. CONCEPT OF THE TUNNEL VENTILATION

4.1. Main ventilation equipment

The diagram on l.h.s (left-hand-side) of Figure 2 shows schematically the ventilation equipment of the multifunctional station. The fresh and exhaust air are supplied and extracted through 3 access shafts (one for every multifunctional station) at the portals of which 3 ventilation stations provide the required flow rates. Several dampers are used to direct the fresh and exhausted air, depending on the ventilation mode. Fresh air can be supplied in the west and east tubes through 6 lateral doors, of which each includes a ventilation opening, or the supply points in the area of the cross-overs. In the case of a fire event these doors and the ventilation channels work as escape ways. The exhausted air can be extracted from the middle of the emergency station of both tubes.

![Diagram showing ventilation equipment](image_url)

**Figure 2:** l.h.s: schematic of the ventilation in the emergency station with the transport of fresh air (full line) and the exhausted air (dotted line). r.h.s: schematic of the ventilation equipment in the cross-passages. Arrows show the air flow in the cross-passage ventilation in normal mode.

The cross-passages between the main tubes (short cross-passages) and between the tubes of the branching Innsbruck (long cross-passages) are also provided with ventilation equipment in order to ensure a minimum air exchange between the cross-passages and the railway tube, Figure 2 r.h.s. This air exchange should limit the temperature in the cross-passage to ensure a safe operation of the technical equipment which is installed there. The ventilation system of the short cross-passages consists of two ventilation tubes (with fans) and a ventilation opening, the ventilation system of the long cross-passages consists of a long ventilation tube (with two fans) and 2 ventilation openings.

A 100% fan redundancy is provided for each ventilation stations in the MFS as well as for the fan in the cross passages. Table 1 summarizes the gross specifications of the axial fans used for the tunnel ventilation in the MFS.
Table 1: Specification of the fans in the ventilation stations of the MFS.

<table>
<thead>
<tr>
<th></th>
<th>flow rate [m³/s]</th>
<th>el. power [kW]</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>MFS by pass Innsbruck</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>- supply</td>
<td>215</td>
<td>1'186</td>
</tr>
<tr>
<td>- extraction</td>
<td>250</td>
<td>1'929</td>
</tr>
<tr>
<td><strong>MFS Steinach</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>- supply</td>
<td>215</td>
<td>1'556</td>
</tr>
<tr>
<td>- extraction</td>
<td>250</td>
<td>2'254</td>
</tr>
<tr>
<td><strong>MFS Wiesen</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>- supply</td>
<td>215</td>
<td>1'566</td>
</tr>
<tr>
<td>- extraction</td>
<td>250</td>
<td>2'221</td>
</tr>
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4.2. Ventilation during normal and maintenance operation and in case of an event

4.2.1. Operation of tunnel ventilation in normal mode

The ventilation during normal operation is ensured by the natural air exchange due to the piston effect of the trains running in both railway tubes. In case of an insufficient natural ventilation (i.e. the ventilation objectives specified in Section 3.2 are not satisfied) fresh air can be supplied in the railway tubes and warm and humid air can be extracted from the railway tube using the ventilation equipments located in the multifunctional stations, Figure 3.

![Figure 3: Schematic of ventilation in normal mode with forced air exchange for cooling the railway tunnel.](image)

4.2.2. Operation of tunnel ventilation during maintenance work

Maintenance work in a complete tube

The traffic takes place in the opposite tube in both directions. In the maintenance tube diesel emissions are assumed. The doors of the cross-overs are closed so that the two tubes are aerodynamically connected only via the branching tunnels in Innsbruck and in Franzensfeste. The ventilation is characterized by (see Figure 4 l.h.s):

- Supply or extraction in the emergency station and air supply through the supply points or Saccardo nozzle in the MFS Steinach and Wiesen in order to create a longitudinal airflow in all the tunnel sections
- Separation of the airflow in the tunnel sections by means of the tunnel doors
Maintenance work in one tube section
The trains from the maintenance tube are redirected to the opposite tube through the crossovers. In the maintenance section diesel emissions are assumed. The doors of the cross-over galleries are open where required. The ventilation is characterized by (see Figure 11):

- Air supply through the supply point, saccardo nozzle or open escape doors in the MFS Steinach and Wiesen in order to create a longitudinal airflow in maintenance section.
- Separation of the airflow in the tunnel sections by means of the tunnel doors.

Event inside an emergency station
The burning train stops in one of the 6 emergency stations of the base tunnel. The emergency ventilation is characterized by (see Figure 7):

- In the emergency station with the burning train fresh air is supplied though the open escape doors and smoke is exhausted from the air extraction point.
- The passengers escape from the emergency platform over the open escape doors in the protected area of the MFS. The passengers walk in the safe area to the emergency station in the opposite tube from where they are evacuated by a regular empty passenger train.
- In the 2 other multifunctional stations fresh air is supplied in the non-incident tube to produce there an overpressure.
- The ventilation openings in the cross-passages are open in order to allow an airflow directed from the opposite tube to the incident tube stimulated by the overpressure in the opposite tube (to prevent smoke propagation in the cross-passages with the technical equipment).

Figure 4: Example of ventilation during maintenance work in tube east and train traffic in tube west.

Figure 5: Example of ventilation during maintenance work in the middle section.
Event outside the emergency stations

The burning train stops somewhere outside the emergency stations. The emergency ventilation is characterized by (see Figure 7):

- Over the MFS Steinach and Wiesen fresh air is supplied in the non-incident tube to produce an overpressure.
- The ventilation openings in the cross-passages are open in order to allow an airflow directed from the opposite tube to the incident tube stimulated by the overpressure in the opposite tube (to prevent smoke propagation in the cross-passages with the technical equipment).
- Activation of jet fans at the portals of the opposite tube to assist the emergency ventilation for a fire near the portals.
- The passengers escape through the cross-passages in the opposite tube, which is free from smoke and heat. The evacuation of the passengers takes place in the opposite tube by means of a regular empty passenger train.

Figure 7: Example of ventilation in case of event outside the emergency stations in tunnel east.

5. RESULTS OF THE INVESTIGATION

5.1. Aerodynamic Issues

Several aerodynamic investigations have been performed in order to determine the aerodynamic key parameters for which the different civil construction elements should be designed (tunnel cross section, tunnel gradient, portal area). A selection of these investigations and their results and implications for the tunnel design is presented here.
5.1.1. Investigation of the pressure comfort on a passenger train

Aerodynamic calculations were performed to check whether the medical pressure limit value (TSI criterion: max. 10 kPa during tunnel passage) and the pressure comfort (UIC criteria: max. pressure fluctuations of 0.5 kPa in 1s, 0.8 kPa in 3s, 1 kPa in 10s and 2 kPa in 60s) on a passenger train are satisfied for the planned high speed traffic. The influencing parameters, i.e. tunnel cross-section, decompression measures at the portals and operational measures (adapted train driving speeds near the portal), were examined.

Figure 8 shows the calculated pressure inside an unsealed passenger train during the passage through the tunnel with a train speed of 250 km/h and for different tunnel cross-sections. Figure 9 shows the transient pressure variations for a train speed of 250 km/h in a well sealed passenger train during the passage through the tunnel also for different tunnel cross-sections.

The result of the performed calculations shows that the TSI criterion can be fulfilled for the investigated range of tunnel cross sections and the planned speed of a passenger train of 250 km/h. On the other hand the results of the calculations for the pressure comfort show that the most restrictive criterion is the one for the longest time interval (max. pressure fluctuations of 2 kPa in 60s). This limit is generally not satisfied by any of the investigated tunnel cross sections and the investigated decompression measures at the portal (decompression shaft, enlarged cross section at the portal). The long time criterion can be satisfied with the
following train operational restrictions: early deceleration at tunnel, reduced acceleration at tunnel entrance and tunnel exit deceleration and reduction of the tunnel exit velocity.

5.1.2. Investigation of the traction power of a freight train

The operation concept for the Brenner Base Tunnel incorporates freight trains as well as passenger trains. The necessary traction power of the train for travelling through the tunnel is mainly determined by the tunnel inclination and the aerodynamic resistance of the tunnel. The available traction power of a train is limited by the number of locomotives and the power of the locomotives.

In figure 10 the required traction power for a heavy freight train is represented for a tunnel inclination of 8.3‰ and tunnel cross-section of 43.42 m². The calculations show that the available traction power of the freight train is sufficient in order to run at 120 km/h through the tunnel.

![Figure 10: Required traction power for a heavy freight train travelling at 100 km/h and 120 km/h with a tunnel inclination of 8.3‰ and a tunnel cross-section of 43.42 m².](image)

5.2. Thermodynamical Issues

Thermodynamic simulations were performed in order to find out if the limiting criteria for the tunnel climate are maintained in the tunnel system (see Section 3.2). The thermodynamic conditions were calculated for normal operating conditions with trains running north-south in the eastern tube and trains running south-north in the western tube. The following list summarizes the major influencing parameters:

- time table of train travelling through the tunnel (mix of different types of trains)
- rock temperatures along the tunnel tubes
- water seepage through tunnel lining
- emitted heat by catenary and technical equipment in the tunnel

The results of the simulation are shown in Figure 11.
The temperature profiles exhibit that the temperature increases along the tunnel in the direction of the running trains and then decreases towards the exit portal. The temperature increase is mainly due to the heat transfer to the air from the different heat sources (rock, trains, catenary, cross-passages). The flow in the tunnel tubes generated by the running trains avoids a local accumulation of the heat in the tunnel.

The relative humidity is linked with the temperature profile. At a constant absolute humidity the relative humidity (in %, where 100% mean saturated air) is correlated negatively with temperature. Thus, an increase of the temperature leads to a decrease of the relative humidity and vice versa. Therefore, the relative humidity is lower in the middle of the tunnel, where the temperature is higher and it becomes larger towards the portals. The increase of the relative humidity towards the portals is therefore mainly a result of the lower temperatures and not an indication of a higher level of the absolute humidity.

Overall, the predictions show that the limiting criteria are satisfied for the major parts of the tunnel. The following main conclusions can be derived from the simulations:

- Limiting the seepage through the tunnel lining depends on the degree of sealing of the tunnel lining. The simulations have demonstrated the requirement that seepage is kept at a low level. Finding measures to reduce seepage is a task for civil engineering.

- One parameter with a major influence on the tunnel climate is the rock temperature. The data available so far results from preliminary sample measurements in the geologic surroundings of the future tunnel. In order to reduce the uncertainties of the climate predictions it will be important to monitor the rock temperature and other relevant climatic parameters (such as seepage) while works on the tunnel shell progress. Reducing the uncertainties of these parameters will greatly help to reduce the uncertainties underlying the climate predictions performed so far.

### 5.3. Safety Issues

The essential ventilation objective in case of a train fire in the tunnel is to guarantee a safe place, i.e. an area protected from smoke and heat for the passengers. With the aid of the tunnel ventilation these safe areas are ventilated so that an entry of smoke is avoided. In the event of a train fire in the rescue station the protected area of the MFS will be supplied with air to produce an overpressure against the rescue platform. In the event of a train fire outside the MFS the opposite tube is supplied with air to produce an overpressure against the incident tube. The compliance with ventilation objectives is essentially influenced by the piston effect of the trains leaving the tunnel and the incoming rescue train during the self rescue phase. The ventilation goals were checked using realistic emergency scenarios (train movements, fire load). Based on the simulation the train speed was optimised with regard to the emergency ventilation.
Figure 12 shows the results of a simulation of the air flow in the open doors of two adjacent cross-passages used by the passengers in an event outside the MFS during the phase of the self and external rescue. The figure shows that the longitudinal air flow is influenced by the train movements in the incident tube and the non-incident tube. Investigations of various scenarios showed that with the emergency ventilation system and with optimised train operation procedures the ventilation objectives are satisfied in the event of a train fire independently of the stopping location of the train. In the simulations also the smoke propagation in the incident tube was examined (based on a 20 MW design fire for the burning train).

### Figure 12: Calculated airflow in the open doors of two adjacent cross-passages used to escape in the opposite tube in case of an incident outside a rescue station.

6. CONCLUSION

Within the framework of the UVE project and the technical project preparation a suitable tunnel ventilation concept was developed for the Brenner Base Tunnel by the planning group of the BBT (PGBBT). The ventilation concept guarantees in the normal operation, during maintenance work and in the case of an incident (train fire) that the ventilation objectives can be satisfied in most situations. With the aid of extensive aerodynamic and thermodynamic calculations the effect of the tunnel ventilation could be proved.

The concept represented in this article and the results of the calculations show the current state of the planning. It can not be excluded that within the framework of the finishing of the project in the course of 2006 adaptations of the tunnel ventilation concept will be required due to changes of the boundary conditions in the areas of civil engineering design, equipment, tunnel operation, etc.

7. REFERENCES

[1] INTERNATIONAL UNION OF RAILWAYS (UIC) "Measures to ensure the technical compatibility of high-speed trains" UIC-Codex 660