

AERODYNAMICS, CLIMATE AND VENTILATION OF THE LÖTSCHBERG BASE TUNNEL: FIRST RESULTS OF THE MEASUREMENTS CARRIED OUT DURING THE COMMISSIONING PHASE

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ABSTRACT

The paper includes a short introduction to the Lötschberg base tunnel project and a description of the most important planning criteria for the tunnel climate, the tunnel aerodynamics and the tunnel ventilation in every operation mode. Additionally the concept, the realisation and the substantial results of the elaborate measurement campaign are discussed. Finally preliminary findings of the tests during the commissioning phase are summarized and evaluated regarding future tunnel projects.

Keywords: Measurements, Aerodynamics, Climate, Ventilation, Lötschberg Base Tunnel

1. INTRODUCTION

The 34.7 km long Lötschberg base tunnel is part of the new transalpine tunnels in Switzerland (NEAT). In summer 2007 the base tunnel was taken into reduced train operation. The final opening of the tunnel for the regular train operation took place at the end of 2007. During the commissioning phase of the base tunnel a huge number of tests and measurements were carried out. Amongst others these covered the examination of the tunnel climate, the tunnel aerodynamics and the functionality of the tunnel ventilation. With the help of the tests the most important planning criteria should be verified. In particular the planning hypotheses, the calculation parameters and the simulation codes were to be examined. These comprehensive verifications are not finished up to now.

2. DESCRIPTION OF THE LÖTSCHBERG BASE TUNNEL

Due financial reasons and reduced traffic demands the final configuration of the 34.6 km long Lötschberg base tunnel including two fully equipped and operated single track tubes between Frutigen and Raron is not yet completed. The current set of the 34.6 km long Lötschberg base tunnel consists of one single track railway tube between Frutigen and Ferden and (over 1/3 of the overall length) of two single track railway tubes from Ferden to Raron (cf. Figure 1).

In the northernmost section of the base tunnel between Frutigen and Mitholz a service tunnel accompanies the railway tube for water drainage and safety reasons. The two tubes are connected by cross passages in regular distances of 333 m.

Between Mitholz and Ferden two railway tunnels are provided. However only the eastern tube is technically equipped and under train operation. Since both tunnels hold the same cross sectional areas, it is possible to equip the western tube in a later phase. In the current phase the western tunnel serves as a maintenance and safety tunnel. Again the two tubes are connected by cross passages in regular distances of 333 m.

In the southernmost section between Ferden and Raron the base tunnel is operated as a system of two single track railway tubes. The two tunnels are connected by cross passages in regular distances of 333 m.

The access tunnel Steg is foreseen as a connection tunnel to the loading point for car shuttle operation in a later phase.

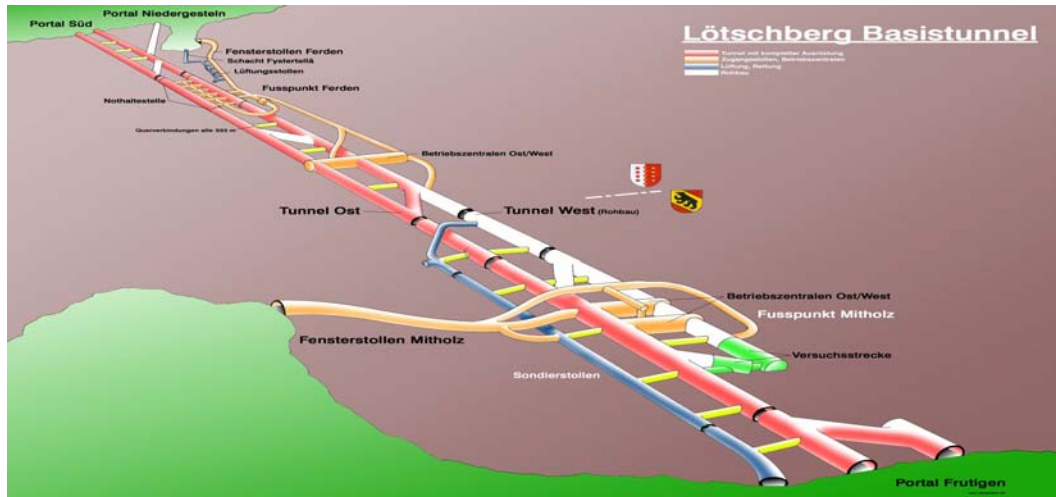


Figure 1: Sketch of the Lötschberg Base Tunnel

A rescue station consisting of two emergency stations is located near the cross over in Ferden. If an incident train is not able to leave the tunnel, it can reach the emergency station either from the eastern or from the western tube.

Starting with the commissioning at end of 2007, 110 trains (passenger trains, piggy back and goods trains) cross the tunnel per day.

3. REQUIREMENTS ON TUNNEL CLIMATE, AERODYNAMICS AND VENTILATION

During normal, maintenance and emergency operation distinct requirements must be fulfilled.

3.1. Normal Operation

In normal operation a safe and fail safe tunnel operation must be ensured. The air temperature in the tunnel must be kept under 35°C independent of the season and of the traffic volume in the tunnel. The surrounding rock contributes to the heating of tunnel air. The initial rock temperature reaches 45°C on particular sections in the tunnel. Additionally the heat loss of moving trains and of technical equipment increases the tunnel air temperature. On the other hand the cooling of tunnel air takes place due to air exchange with the outside based on the piston effect of moving trains.

The arrangement of the tunnel portals, the cross sectional area of the railway tubes as well as the changes of the cross sectional areas along the tunnel were carefully chosen to prevent pressure fluctuations in passenger trains over 1.5 kPa/4s. Apart from these structural measures, the high-speed passenger trains must feature a good sealing against pressure fluctuations to fulfil the specified pressure comfort criteria.

3.2. Maintenance Operation

Maintenance work in the tunnel is carried out at operation off hours. During the maintenance operation climate conditions according to the industrial safety regulations must be guaranteed using the tunnel ventilation. The individual operation of supply air and exhaust air fans will ensure favourable working conditions for the maintenance staff.

3.3. Emergency Operation

The critical scenarios of the emergency ventilation are emergency stops of burning passenger trains or burning freight trains in the tunnel. For these cases the following substantial ventilation goals were defined:

- Guarantee of a smoke free waiting area for the escaping passengers in the emergency station (overpressure within the waiting area by air supply).
- Support of self rescue of passengers escaping along the emergency stop (exhaust of smoke along the emergency stop).
- Guarantee of a safe evacuation way in the not affected opposite tube according to the evacuation concept (prevention of smoke propagation into the opposite tube).

Dependent on, whether the incident train stops inside or outside of the emergency station, the following three cases regarding the emergency ventilation must be considered:

- **Stop in the emergency station:** The conditions for the self rescue and evacuation can be optimized by supply air and exhaust air. By extracting smoked air from the emergency station the smoke propagation along the emergency station can be minimized and the escape conditions for the passengers will be improved. The supply of fresh air into the waiting room of the emergency station prevents a smoke infiltration. The passengers can safely await the evacuation train.
- **Stop outside the emergency station in southern tunnel sections:** Using fresh air supply in the opposite railway tube a smoke propagation from the incident tube via open cross passages can be prevented. Passengers waiting in the opposite tube for the evacuation train are protected against smoke and heat.
- **Stop outside the emergency station in the northern tunnel section (one single track tube):** Using fresh air supply in the service tunnel a smoke propagation from the incident tube via open cross passages can be prevented. Passengers waiting in the safety tube for an evacuation bus are protected against smoke and heat.

4. TEST DESCRIPTION

4.1. Concept

After completion of the tunnel construction and installation of the railway equipment the commissioning phase of the Lötschberg base tunnel was carried out in 5 steps:

1. Testing of each technical installation with the goal to verify the technical contractual specifications (dimensions, quality and functionality).
2. Integration of every technical installation and verification of the integrated system functionality. Examination of the interfaces to other technical and operational disciplines.
3. Technical test operation: Examination of the functionality of the integrated technical installations in the tunnel based on realistic operation procedures.

4. Reduced train operation: The tunnel operator achieves an approval for a reduced commercial operation (first only with freight trains and later with some additional passenger trains). The objective of these tests is to prove that the operator is able to ensure the tunnel safety.
5. Beginning of regular train operation: With the implementation of the definitive train schedule at the end of 2007 the operator accomplishes the approval for a regular train operation in the tunnel.

Within these commissioning steps several tests concerning the aerodynamics, the climate and the ventilation in the tunnel were carried out. The goal of these tests was to verify individual specifications of the tunnel construction and of the functionality of the tunnel ventilation for the individual operation modes.

The following table includes an overview of the accomplished tests and individual measurements.

Table 1: Measurements of aerodynamics, climate and ventilation

Aspects	Measurements	Goal	Test Phase
Tunnel aerodynamics	Determination of the pressure and wind loads in the tunnel due to moving trains	Verification of the pressure and wind loading technical equipment in the railway tunnel (doors, walls) Verification of the specified project assumptions	3 - 5
	Determination of the pressure fluctuations in trains during their journey through the tunnel	Verification of the pressure comfort criteria in passenger trains	3
Tunnel climate	Determination of the tunnel climate (temperature and relative humidity of the air)	Verification of the climatic prognoses Verification of the air exchange and the cooling effect in the tunnel due to the piston effect of moving trains	4, 5
Tunnel ventilation	Determination of the technical specifications and functionality of the tunnel ventilation	Verification the contractual specifications concerning the ventilation plants	1
	Integration of the ventilation system and determination of the ventilation efficiency within the individual ventilation scenarios	Verification of the ventilation functions; Verification of the specified ventilation goals	2
	Determination of the ventilation functions based on realistic scenarios for realistic operation scenarios	Verification of the ventilation goals based on realistic operation scenarios	3

4.2. Measuring Systems

The measurement of the air temperature in the railway tubes was performed with permanent measuring instruments fixed along the tunnel in regular distances of about 300 m. The measured data are continuously transmitted to the tunnel control centre.

The measurement of the tunnel longitudinal air flow and the pressure fluctuations in the tunnel and on the trains were accomplished with temporary measuring instruments installed at representative locations in the tunnel and on the test trains. These measuring instruments were removed after the tests, since a continuation of monitoring of these physical dimensions seemed no longer necessary.

Some measuring instruments and the selected measuring locations in the tunnel and trains may be seen in the illustrations in section 5.

5. TEST RESULTS

5.1. Tunnel Climate

The following main results were achieved:

- The tunnel climate (temperature and relative humidity of the air) has a substantial influence on the availability of the technical equipment. In addition the compliance with the defined climatic limits in the tunnel is important for the maintenance work.
- The tunnel climate will be substantially affected by the heat of the surrounding rock, by the heat loss of the technical equipment, by the traction power of the moving trains, by the ambient climate conditions at the portals and by the air movement in the tunnel.
- In Figure 2 the air speed along the northern single track railway tube during a period of regular train operation and during the off hours are illustrated. The air movement and in the tube as well as the air exchange with the outside has a substantial influence on the tunnel climate.
- In Figure 3 the average air temperature in the eastern railway tube is shown for typical days of the first winter months after the opening of the Lötschberg base tunnel. The simulated air temperature complies quite well with the measured data.

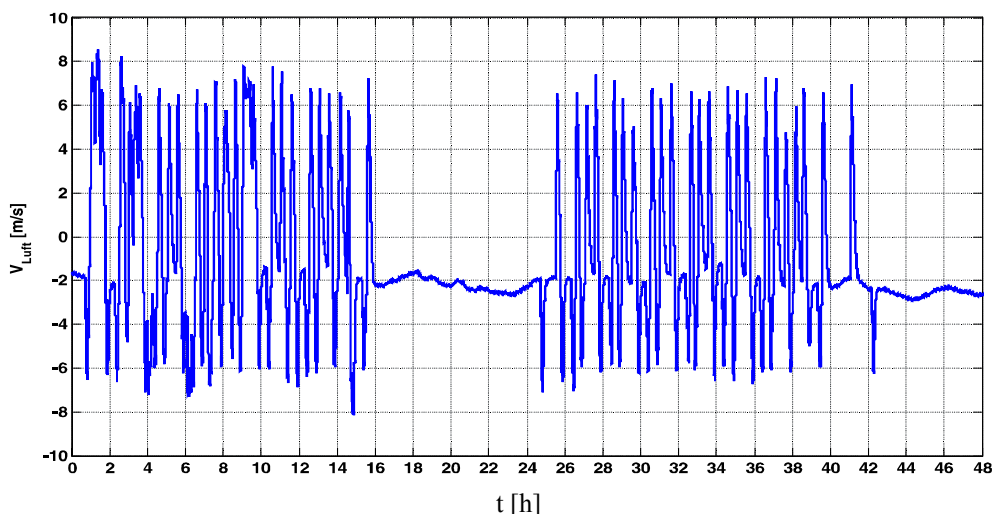


Figure 2: Measured longitudinal air speed during a period of normal train operation in the LBT. During operation off hours (in the night) the residual longitudinal airflow is based on the thermodynamic buoyancy effect of the sloped tunnel and the meteorological boundary condition at the tunnel portals.

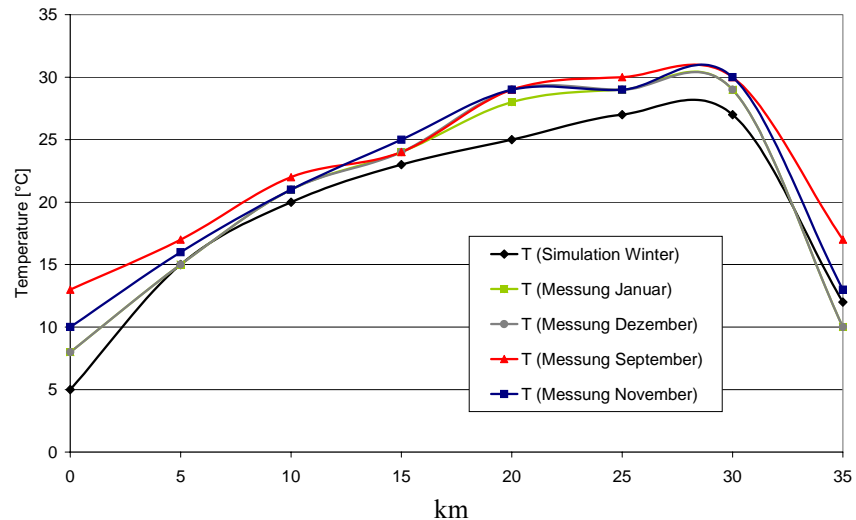


Figure 3: Measured air temperature (daily averages between September 2007 and January 2008) versus predicted air temperature in the eastern railway tunnel.

5.2. Tunnel Aerodynamics

The following main results were achieved:

- The railway equipment in the tunnel has to endure frequently pressure fluctuations and high pressure loads produced by the moving trains. In addition to fast moving passenger trains (up to 250 km/h) especially the aerodynamically unfavourably shaped good trains (high blockage effect) lead to a high pressure load in the tunnel.
- Therefore the examination of the following aspects was of special importance (cf. Figure 4 to 7):
 - The maximum air flow in the different tunnel directions (longitudinal, transversal) for the determination of the wind loads on technical equipment (e.g. jet fans, signage, railway catenaries, etc.)
 - The pressure load on doors, gates, walls, covers, etc. in the railway tubes and on the technical equipment in the cross passages between the railway tubes
 - The pressure fluctuations in a passenger train during its journey through the tunnel. Passengers may experience unfavourable pressure changes induced by the train entry into the tunnel, by the passing of of the cross sectional variations along the tunnel and by the exit from the tunnel. Accordingly smooth cross sectional areas transitions and good sealed passenger trains were specified.
- In the following illustrations some of the measuring systems and collected data are shown.

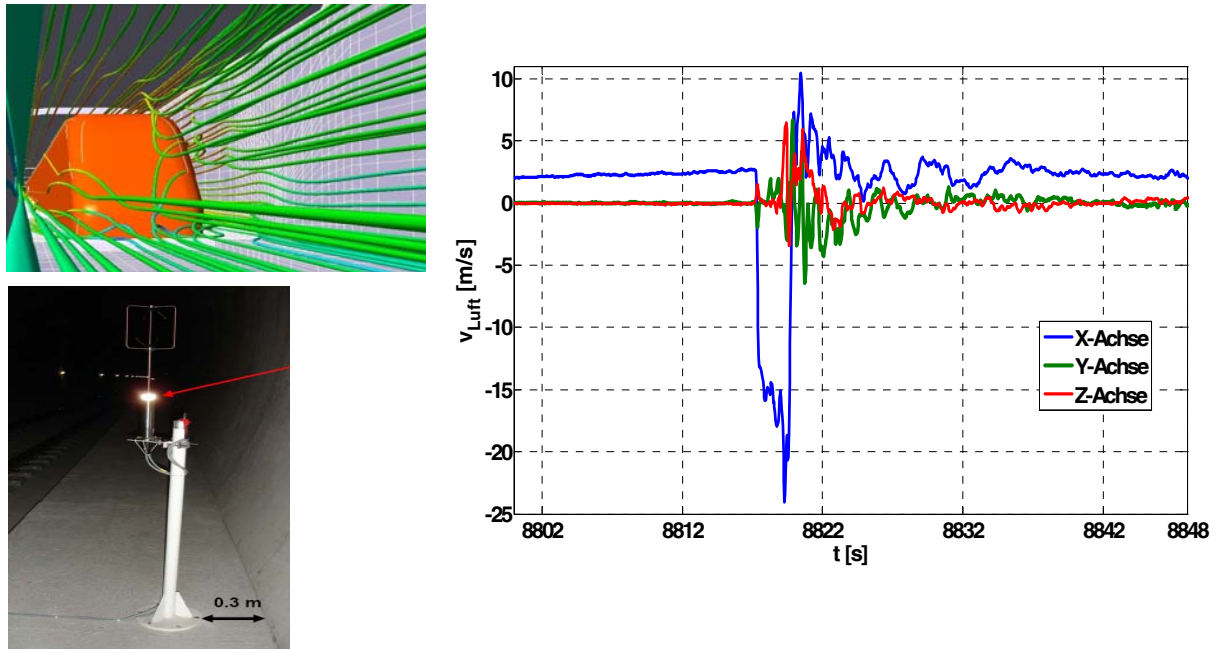


Figure 4: Three dimensional air flow in the railway tunnel. On the upper left side: An illustrative 3D simulation of turbulent air flow along a moving high speed train in the tunnel. On the lower left side: The used ultra sonic air speed sensors to capture the three dimensional air flow in the railway tube. On the right side: Measured 3D air flow on the sideway in the railway tube while a passenger train passes with 200 km/h.

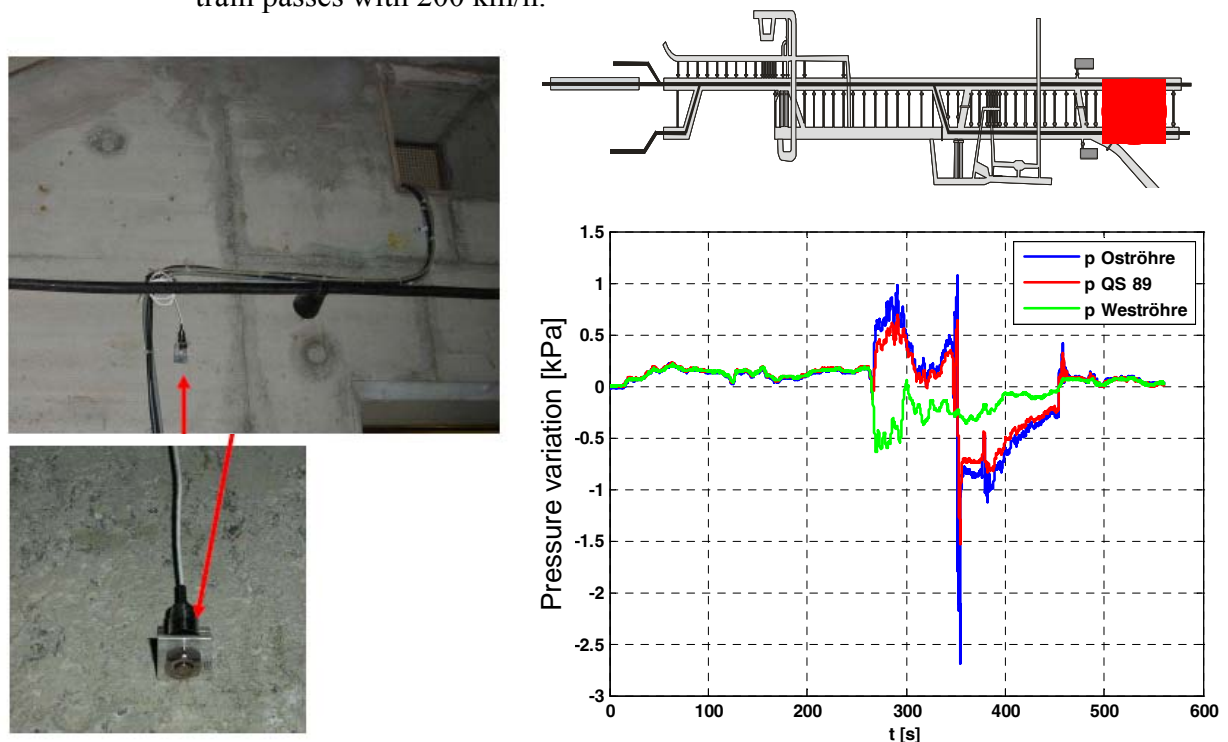


Figure 5: Train induced pressure loads in the south eastern and western railway tubes and in the cross passage between the two single track railway tubes while passing of a passenger train (ICE, $V_{max}=200$ km/h). On the left side: Installed pressure sensors. On the upper right side: Localisation of the measurement. On the lower right side: Measured data

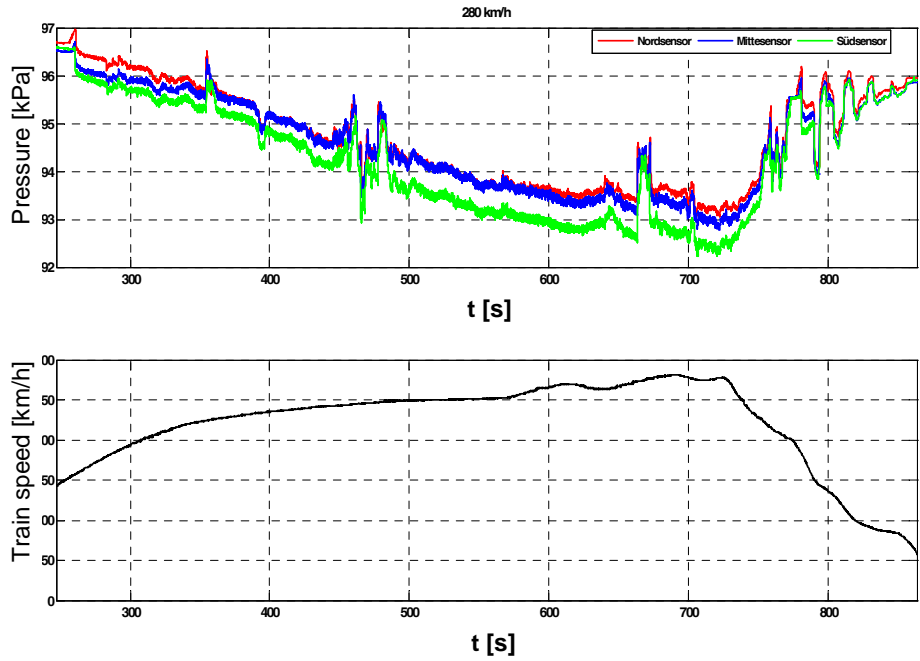


Figure 6: Pressure fluctuation on a passenger train (ICE) at different position on the train while passing the Lötschberg Base Tunnel. On the left side: Pressure sensors installed on the window of the train. On the right side: Measured pressure fluctuation on the train (outside) while passing the tunnel and the correspondent speed profile of the passenger train.

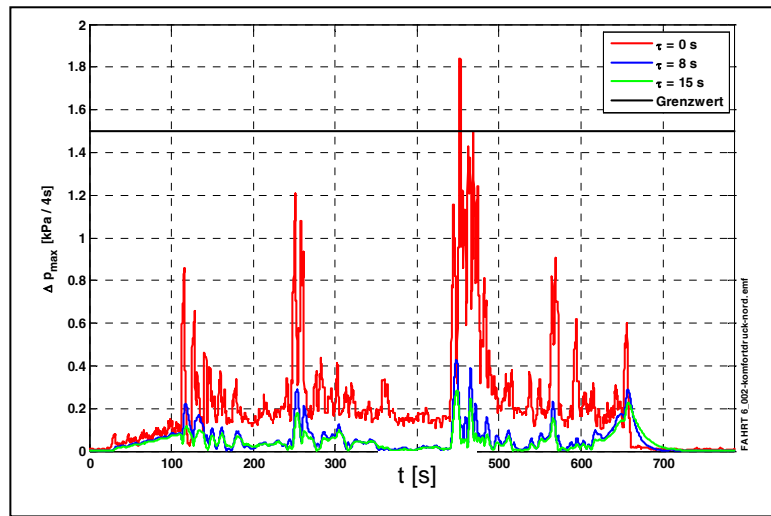


Figure 7: Measured maximum pressure fluctuation within time periods of 4 seconds in the train during its journey through the tunnel (see figure 6). These calculated pressure fluctuations inside the passenger train quote for different sealing factors τ of the train. The dashed horizontal line indicates the comfort criteria of 1.5 kPa/4s. The pressure profiles prove that the comfort criterion is fulfilled only with a sealed passenger train ($\tau > 0$).

5.3. Tunnel Ventilation

The following main results were achieved:

- The objective of the ventilation tests was to verify the efficiency of the ventilation functions for realistic emergency scenarios. Thus the examination of the temporal reaction of the ventilation (in a very long tunnel) and of the influence on the longitudinal air flow in the open escape doors due to the piston effect of the moving trains was of great importance.
- Via cold smoke tests the propagation of smoky air in the tunnel and in the emergency station was examined.
- In the following illustration an example of an emergency scenario applied for the tunnel ventilation tests including leaving trains as well as the entry of rescue and evacuation trains is given. The influences on the longitudinal air flow in the open escape doors due to the piston effect of the moving trains are illustrated.

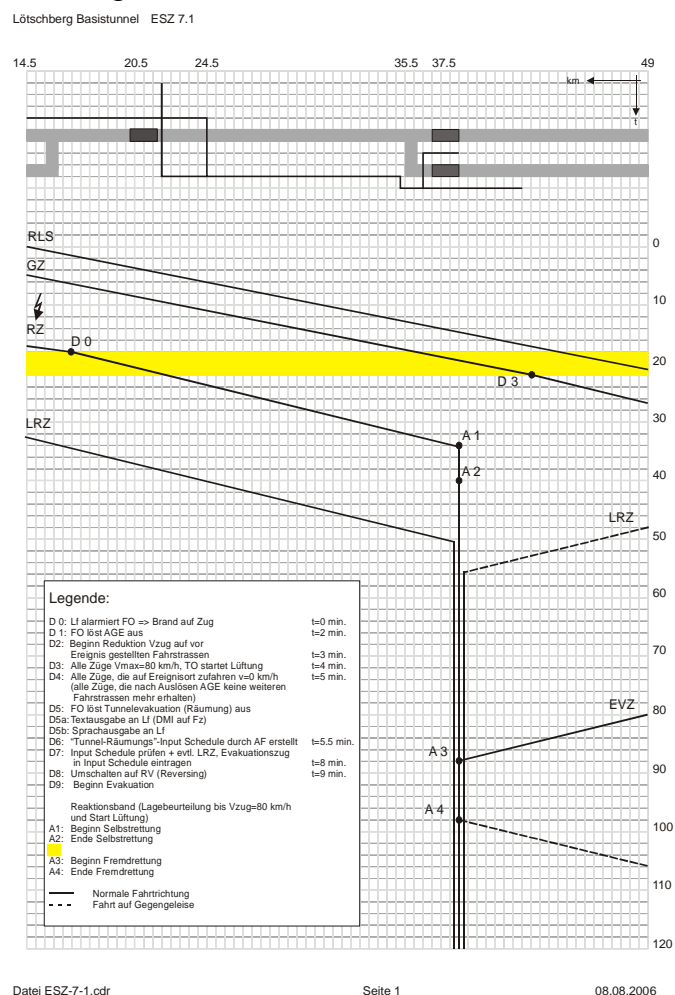


Figure 8: Tests of the emergency ventilation system: Typical emergency operation scenario in the tunnel based on the train control system ETCS II.

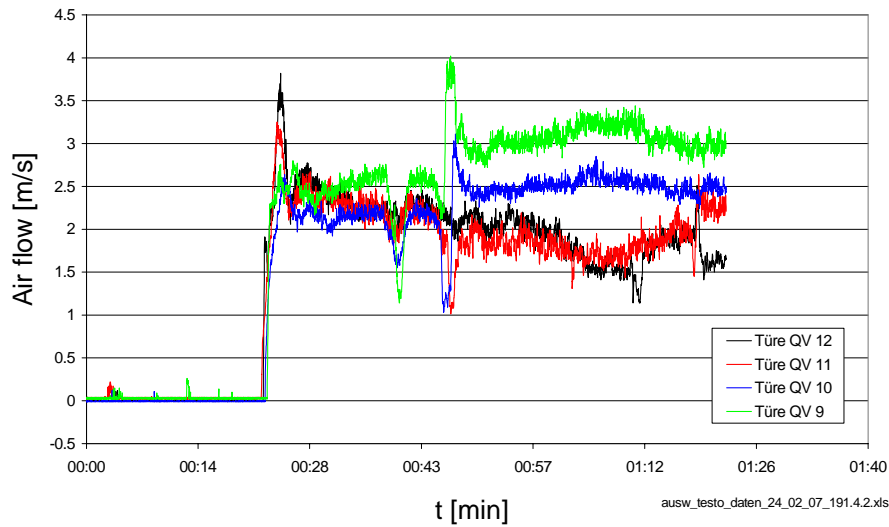


Figure 9: Tests of the emergency ventilation system: Measured longitudinal air speed in the open escape doors of the rescue station as a result of the supplied fresh air of the emergency ventilation system. The temporal fluctuation of the air flow bases on the piston effect of the train movements in the tunnel.

CONCLUSION

The following conclusions can be drawn:

- Detailed measurements of substantial physical parameters such as air temperature, humidity, flow and pressure in each phase of the commissioning of the Lötschberg base tunnel were accomplished.
- These measurements served the verification of the design specifications, of the efficiency of the structural and technical measures as well as of the functionality of the tunnel ventilation.
- Considering the ventilation and tunnel aerodynamics the efficiency of the taken measures could be proven finally. Especially it can be assumed that the tunnel construction and the technical equipment can withstand the high pressure loads during the operation.
- The aerodynamics and thermodynamic specifications for the technical equipment in the Lötschberg base tunnel could be confirmed. Moreover these specifications are transferable to comparable tunnel projects like the Gotthard base tunnel, the base tunnel Lyon – Turin and the Brenner base tunnel.
- The efficiency of the tunnel ventilation for the normal, maintenance and emergency operation could be verified in realistic operation scenarios. It was confirmed that a careful tuning of the operational procedures and ventilation measures are of fundamental importance to assure operational safety.
- Particular comparisons of the of the tunnel climate, aerodynamics and ventilation simulations with the measured data show good agreements. Even though the evaluation of the measuring results is not finished yet.
- In general the measurements help to reduce the planning risks for further tunnel projects with regard to the tunnel ventilation, the tunnel climate and the tunnel aerodynamics.