NATURAL GAS IN THE DRAINAGE SYSTEM OF THE LOETSCHBERG BASE TUNNEL

A. Busslinger, P. Reinke, S. Nyfeler
HBI Haerter Ltd, Switzerland

ABSTRACT

To improve the climatic conditions for people and equipment in a tunnel, it is necessary to keep the relative air humidity at an acceptable level. Additionally, the inflow of aggressive water from the rock requires an efficient protection of the inner lining. Therefore, in most of the new tunnel projects emphasis is put on watertight sealing of the tunnel lining and an efficient drainage system. In particular, this is true for very long tunnels and/or for tunnels in a geology, which is characterised by a significant flow of water from the rock.

Frequently, tunnels pass through geological formations that release natural gas. In well-sealed and drained tunnels, the natural gas will penetrate into the tunnel by passing through the drainage system. Within a certain range of concentrations natural gas is explosive. Thus, a dangerous accumulation of natural gas in the drainage system might occur and poses a potential threat, particularly to the maintenance staff.

In the paper, a practical concept is presented to keep the concentration of natural gas in the drainage system at a safe level. The method was developed for the Loetschberg base tunnel (35 km) in the Swiss Alps.

The concept utilises the ventilation system of the service tunnel. Pipe connections between the service tunnel and the drainage system lead to sufficient dilution of natural gas in the drainage system.

The planned venting of the drainage system has been designed using the simulation tool THERMOTUN. The calculated results could be validated by carrying out measurements in a test section of the Loetschberg base tunnel.

1 INTRODUCTION

Tunnelling experience shows that water ingress in tunnels can become a major problem not only during tunnel construction but also during tunnel operation. An uncontrolled water flow towards the tunnel causes increased humidity in the tunnel air and increased water pressure upon the tunnel lining. Additionally, the presence of water aggressive to concrete requires efficient protection of the inner lining.

To maintain or to improve health protection and comfort of train passengers as well as maintenance staff certain climatic limits should not be exceeded. In addition, humidity and temperature of the tunnel air should not exceed given limits to avoid a reduction of the lifespan of electronic and mechanical equipment. Especially in long tunnels passing through rock with major water ingress the humidity of tunnel air can rise beyond these limits. Therefore, watertight tunnel sealing and efficient drainage techniques to reduce water intrusion into tunnels and water pressure upon linings are common in today's tunnelling.

In addition to water natural gas might be released from the rock as well (methane etc., cf. Seelisberg Highway Tunnel, Switzerland). High concentrations of this gas in the air are explosive posing a potential threat mainly to maintenance staff. Thus, the responsible Swiss authority has defined a maximum acceptable concentration of 1.5 % natural gas (methane, by volume) not to be exceeded in underground workplaces (cf. [1]). In unsealed tunnels, natural gas penetrates the lining and mixes with the tunnel air. Therefore the concentration limit is mostly not reached due to sufficient dilution by ambient air. On the other hand, the sealing and draining of tightly sealed tunnels as mentioned above can lead to increased concentration of natural gas in the drainage system of a tunnel (cf. Figure 1). This problem can arise particularly during periods without train traffic induced air flow in the tunnel, e.g. during maintenance.

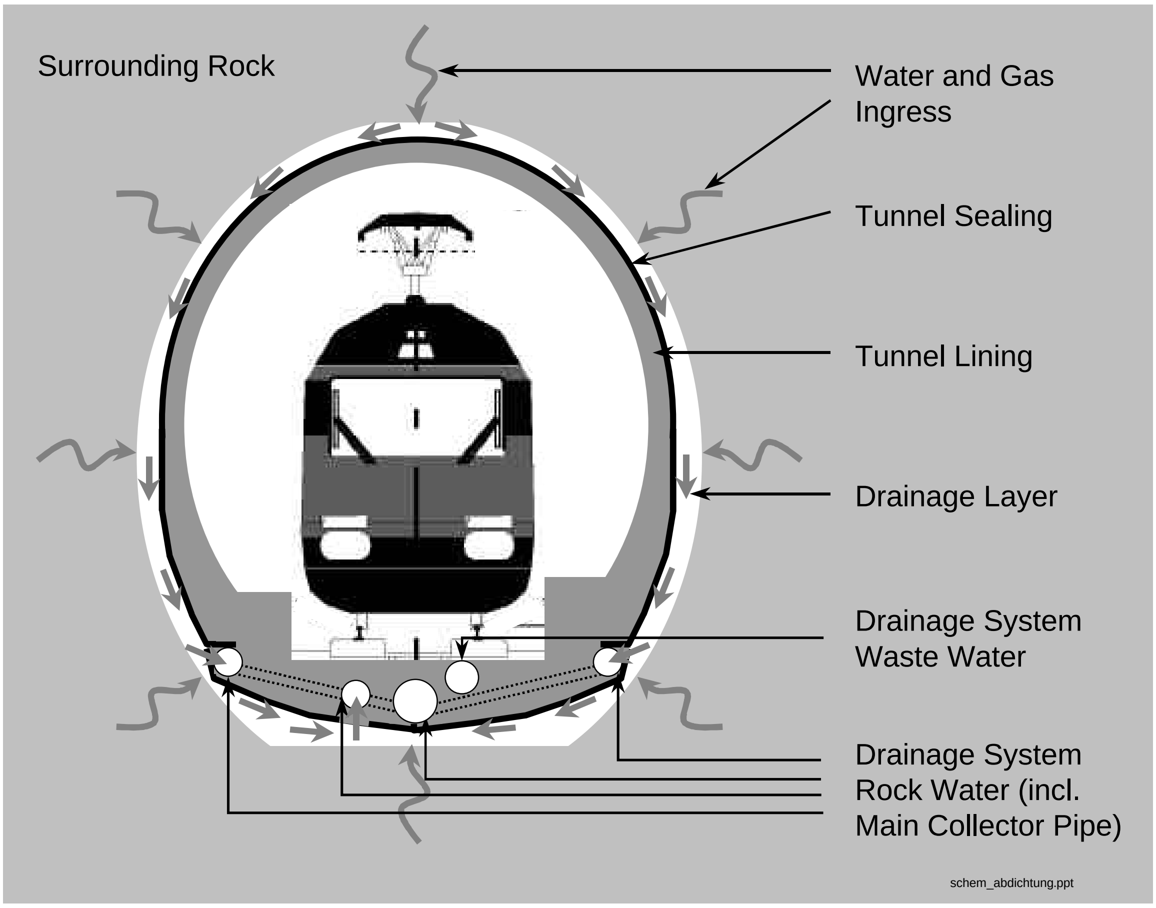

Figure 1. Concentration of natural gas in drainage systems of sealed tunnels

2 NATURAL GAS IN THE LOETSCHBERG BASE TUNNEL

In Switzerland two of the longest railway tunnels in the world, the Gotthard and the Loetschberg base tunnel are currently being built. The Loetschberg base tunnel (opening scheduled for 2007) reaches a length of about 35 km and consists of some tunnels, shafts, adits, cross passages etc. (cf. Figure 2) to accomplish the required functionality.

The main parts of the railway tunnel will be provided with a sealing and drainage system to reduce water pressure on and water ingress through the tunnel lining. This sealing and drainage system consists of combinations of watertight foils, fleece and drainage foils in the roof and/or floor section of the tunnel lining, depending on requirements.

Moreover, according to the geological predictions, natural gas might occur over an extended length of the tunnel (cf. Figure 2). By coincidence the tunnel sections with gas occurrence are parallel to the service tunnel. The maximal predicted (and within the exploratory adit measured) inflow of natural gas reaches $2\,dm^3m^{-2}h^{-1}$. Consequently local explosive concentrations of natural gas in the future drainage system of the base tunnel can not be excluded.

Therefore, an adequate measure had to be found to exclude explosions caused by natural gas accumulated in the drainage system.

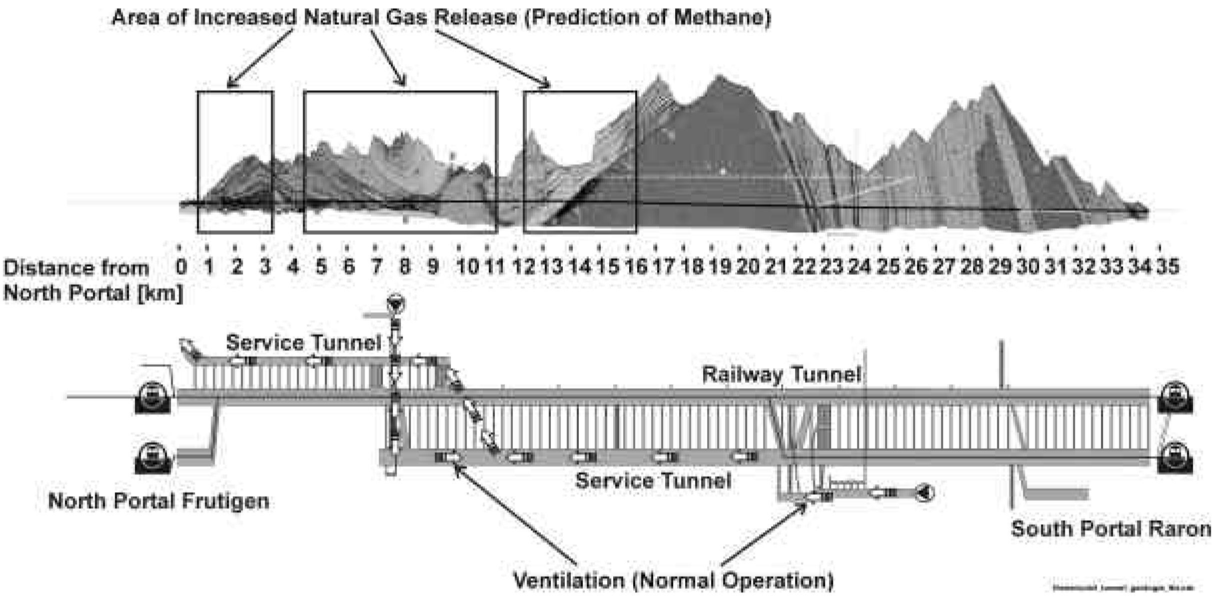

Figure 2. Loetschberg base tunnel: Tunnel system of the first operation phase, geology, prediction of natural gas occurrence, ventilation during normal operation

3 METHOD

Different methods to avoid explosive concentrations of gas in the Loetschberg base tunnel drainage system have been evaluated. Some of the methods are presented in Table 1.

Table 1. Comparison of some Methods to Avoid Explosive Gas Concentrations in the Drainage System

Method	Advantages	Disadvantages
flooding of the drainage pipes with nitrogen	- efficient gas displacement (explosions in drainage pipes excluded) - no water transfer from drainage system to tunnel air	- explosions at outlet not excluded - expensive (installation, operation) - rather inflexible - complex (installation, operation)
complete sealing of drainage system towards rail tunnel	- gas separation from tunnel air - no water transfer from drainage system to tunnel air	- explosions not excluded - expensive (installation, operation) - rather inflexible - complex (installation, operation)
introduction of several openings towards rail tunnel	- gas dilution - simple	- explosions not excluded (e.g. gas accumulation during times without train operation) - high water transfer from drainage system to tunnel air - high increase of scale deposits in the drainage system
separate duct system to remove natural gas	- gas separation from tunnel air - no water transfer from drainage system to tunnel air	- explosions not excluded - very expensive (installation, operation) - rather inflexible
local flaring of natural gas	- gas separation from tunnel - no water transfer from drainage system to tunnel air	- explosions not excluded - expensive (installation, operation) - rather inflexible
drainage system ventilation	- efficient gas dilution (explosions excluded) - redundant - flexible - simple - economical	- water transfer from drainage system to tunnel air - increase of scale deposits in the drainage system

Ventilation of the drainage system was found to be the most promising measure due to its many advantages. This method is based on the following principles:

- Even little air movement in the pipes helps to avoid gas accumulation in the drainage system.

- Venting will only take place in drainage sections with increased gas ingress (namely increased gas flow from surrounding geology); the other venting pipes are closed.

- Fresh air will be supplied from the service (rescue) tunnels, which have to be ventilated anyway. If necessary simple slide valves of the louvres and the venting pipes can be adjusted to direct air into the drainage system or directly through the louvres into the rail tunnel.

- The pressure difference between service (rescue) and railway tunnel forces air into the venting pipes and through the drainage system.

- If higher air flow rate is required due to increased ingress of natural gas additional measures such as small ventilators installed in the air supply pipes next to the cross passages, increase of the ventilation flow rate in the service tunnel, closing neighbouring cross passages etc. will be taken.

The resulting pattern of venting and drainage pipes along the base tunnel is illustrated in Figure 3. Air supplied by the service tunnel is guided by cross passages and venting pipes into the nearby drainage shafts. From there the air spreads over the whole drainage system to be released in the railway tunnel by venting pipes on the opposite site of the track.

Due to the staggered arrangement of the inlet and outlet pipes, zones of stagnant air in the drainage system can be avoided.

The driving pressure difference between service and railway tunnel is strongly dependent on the ventilation of the Loetschberg base tunnel (cf. Figure 2). At the present stage a minimal pressure difference of at least 100 Pa during normal operation is foreseen.

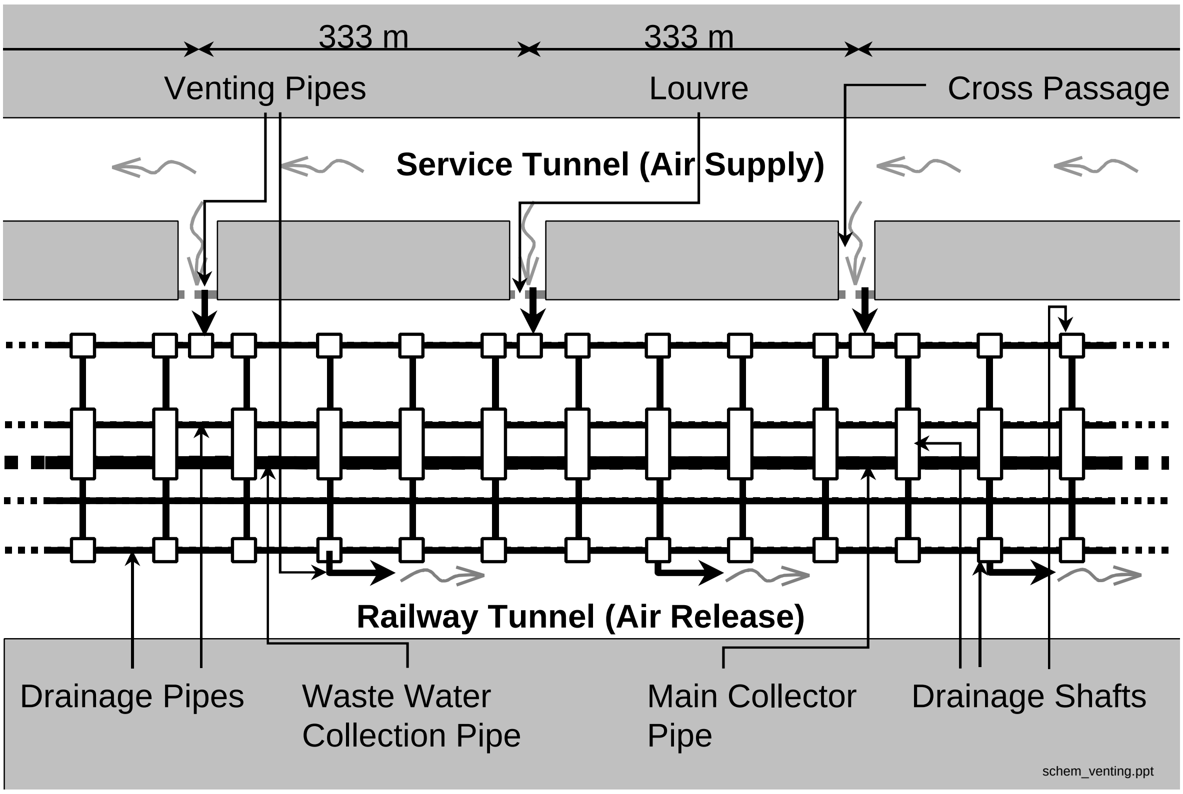

Figure 3. Pattern of the drainage venting in the Loetschberg base tunnel (e.g. tunnel km 6, cf. Figure 2), slightly higher pressure in service tunnel vs. railway tunnel

4 DESIGN

The quantitative evaluation and design of the venting method have been carried out based on a numerical model. The one-dimensional model comprises a representative part of the base tunnel (10 km) including service and railway tunnels as well as drainage system sections. All calculations have been conducted with the program THERMOTUN/5.2 (cf. [2]).

On the basis of the calculations, the best placement and diameters of the venting pipes (cf. Figure 3) to exclude zones of stagnant air in the whole drainage system were found.

As an example of the results figures 4 and 5 show the distribution of the flow rate and the air velocity in the drainage system with a given pressure difference of 40 Pa between service and railway tunnel. Even if the air tends to prefer the flow path with the smallest pressure loss from the air supply to air release pipes, there is air flow in every pipe within the framework of the drainage system. The flow rates reach from about 5 to 105 dm^3s^{-1}, the air flows with a velocity from about 0.1 to 2.3 ms^{-1}.

The needed air flow rate in the drainage system depends on the amount of gas ingress from the surrounding rock. Figure 6 illustrates the distribution of air supply into the drainage system versus the pressure difference between service and railway tunnel. Furthermore, the air flow required to prevent a concentration limit of 1.5 % (by volume) for three flow rates of natural gas is given. As shown low amounts of gas (0.5 $dm^3m^{-2}h^{-1}$) will be removed by pressure differences between service and railway tunnel even smaller than 100 Pa. The highest predicted gas flow rates of 2.0 $dm^3m^{-2}h^{-1}$ require pressure differences higher than 800 Pa.

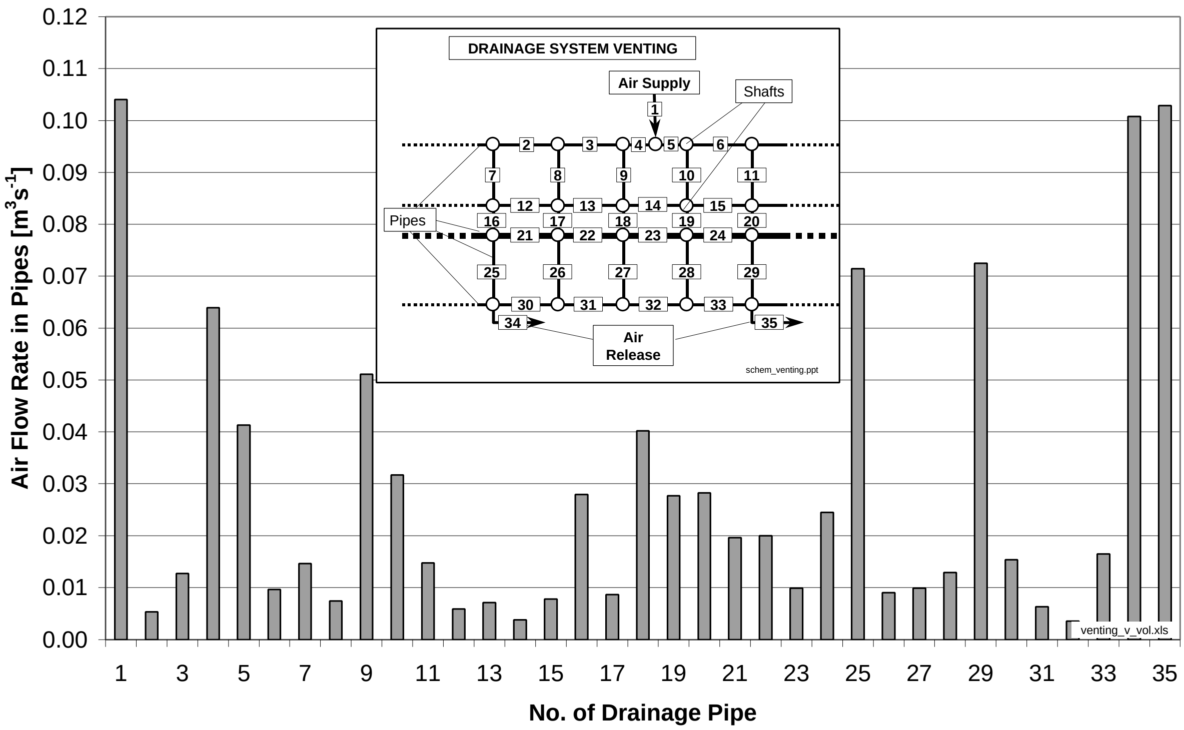

Figure 4. Calculated flow rate in the drainage system of the Loetschberg base tunnel based on a pressure difference of 40 Pa between service and railway tunnel.

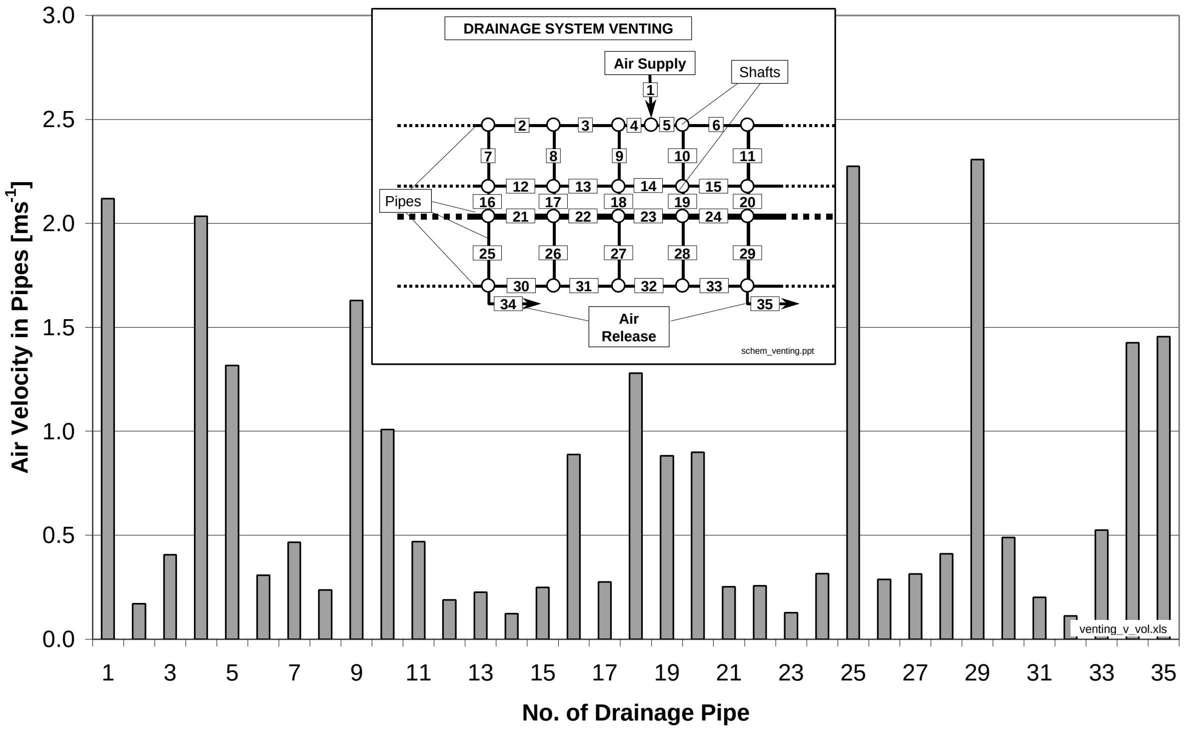

Figure 5. Calculated air velocity in the drainage system of the Loetschberg base tunnel based on a pressure difference of 40 Pa between service and railway tunnel.

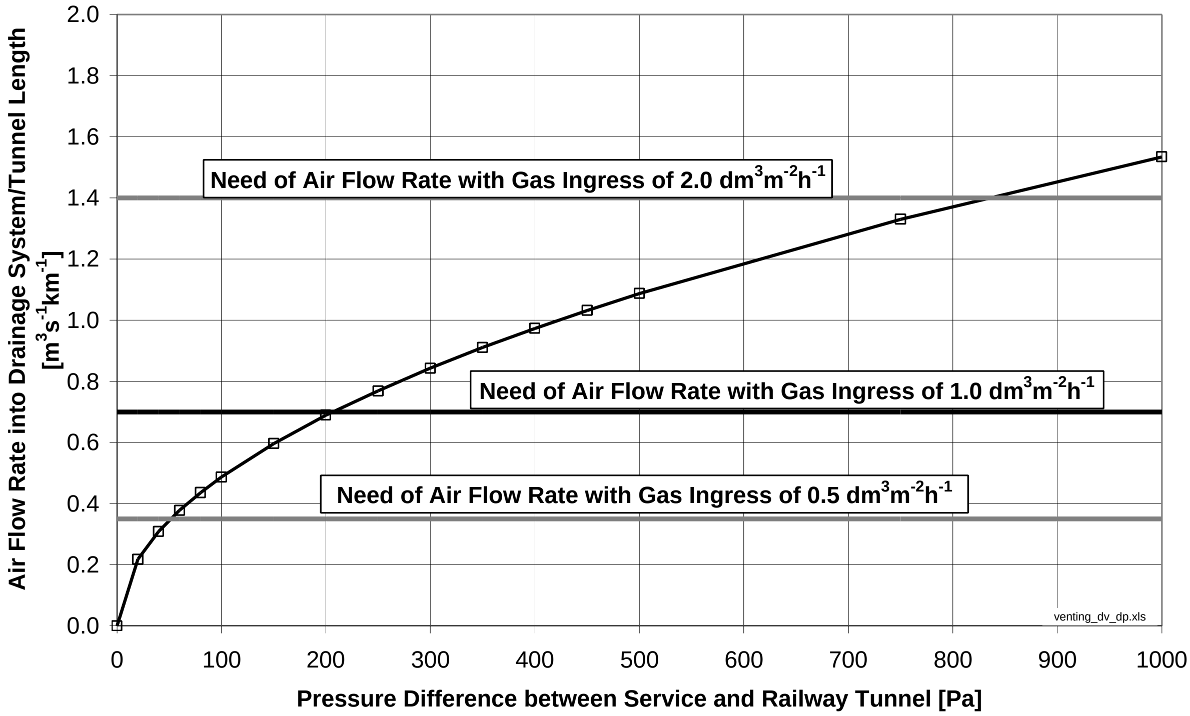

Figure 6. Calculated air flow rate in drainage system vs. pressure difference service/railway tunnel compared with required flow rate at given gas ingress

5 EXPERIMENTAL TESTING

A test site was built within the Loetschberg base tunnel to investigate several tunnel elements and techniques like fixed trackway, emergency lights, cross passage doors, tunnel lining etc.. This railway tunnel section of about 100 m is equipped with a drainage system similar to that of the remaining tunnel and an adjacent cross passage.

The test site allowed to confirm previous numerical simulations. Since a natural gas ingress would be more complex to simulate only the aerodynamic behaviour of the system was investigated. The experimental site was prepared to show defined boundary conditions (cf. Figure 7):

- The pressure difference between service and railway tunnel was created by a ventilator supplying air from the cross passage into the drainage system.

- Except for the air supply and release, all interfaces between the drainage system and the ambient tunnel air were closed and sealed practically airtight.

The air velocity and pressure loss along the pipes could only be measured at distinct points (MP1 to MP14, cf. Figure 7) in the vicinity of the drainage shafts by anemometers and pressure sensors (cf. Figure 8).

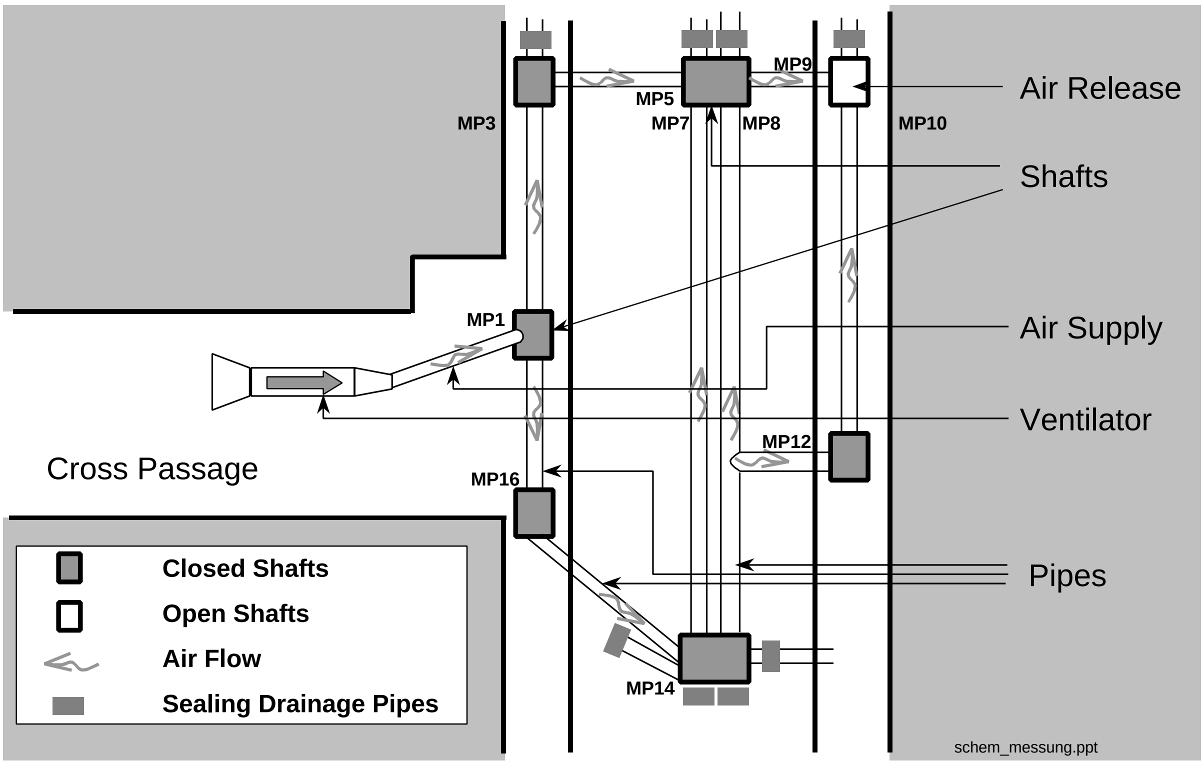

Figure 7. Drainage venting experiment at the test site Mitholz, Loetschberg base tunnel, measurement points, pipe sealings

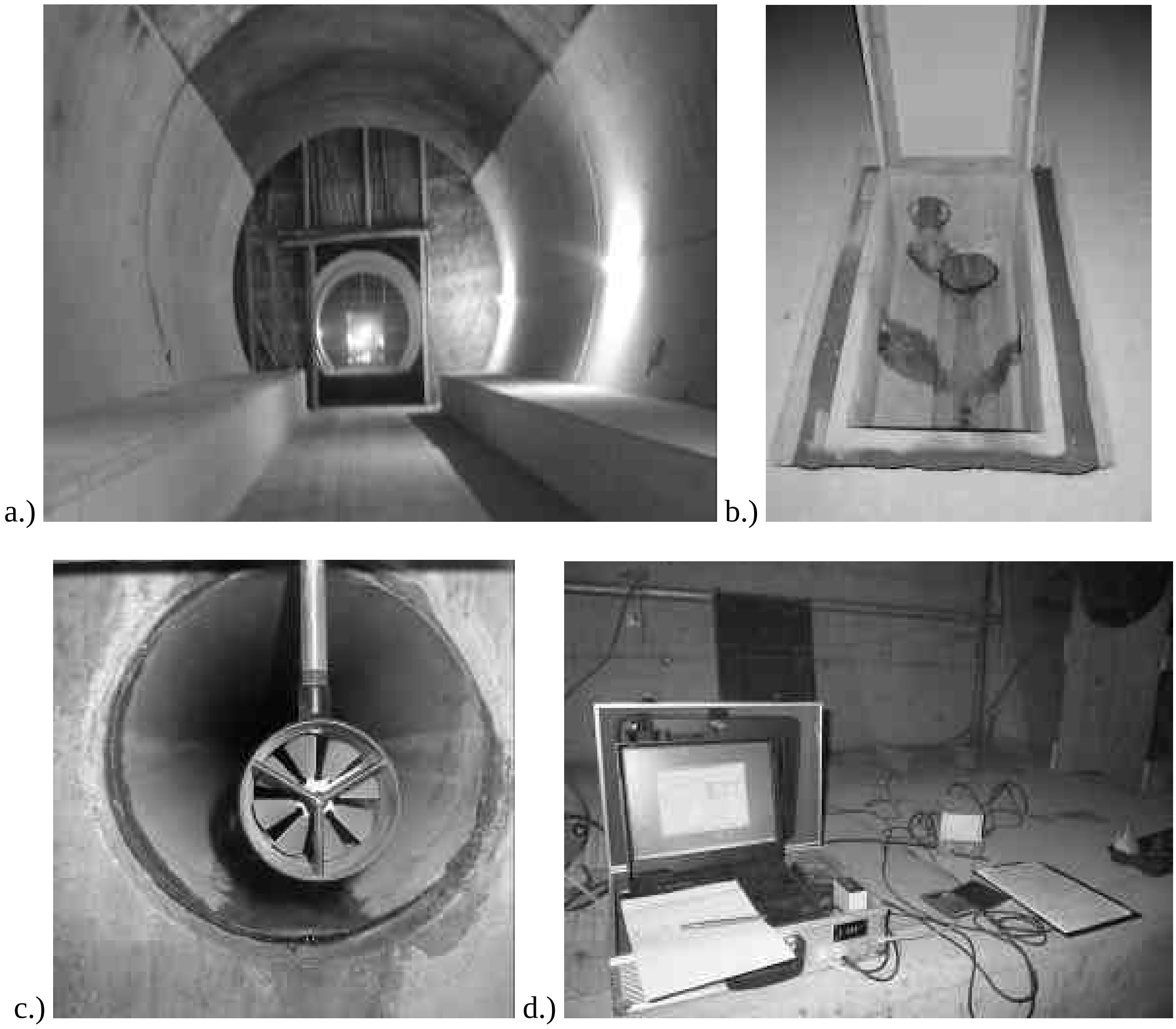

Figure 8. Pictures of the test site without trackway (a), a typical shaft with the main collector pipe (b), an installed anemometer (c) and the data processing unit (d)

Figures 9 and 10 show some of the measuring results. In general, air movement within the whole drainage system was measurable. The air velocities vary from nearly 0 to 10 ms^{-1}. The pressure loss along the pipes between the air supply and the measuring points (cf. Figure 7) are reasonable with low values over short distances (e.g. MP3) and high values over long distances (e.g. MP9).

Moreover, the comparison between these measurements and numerical calculation based on the assumptions for the design is shown in figures 9 and 10. Given an uncertainty of the measurements due to the sensors the measurement and model were in good agreement. This is specially valuable, since the numerical calculations were made before the measurements.

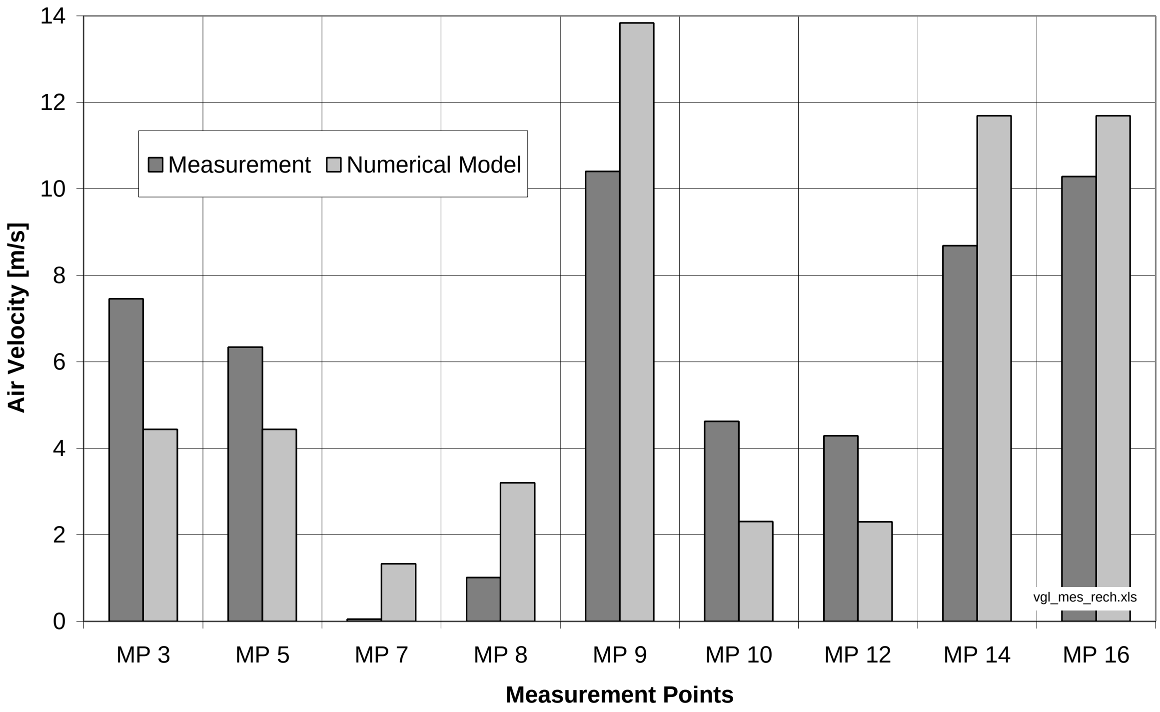

Figure 9. Comparison of measured and calculated air velocity in drainage system of the test site Mitholz, Loetschberg base tunnel

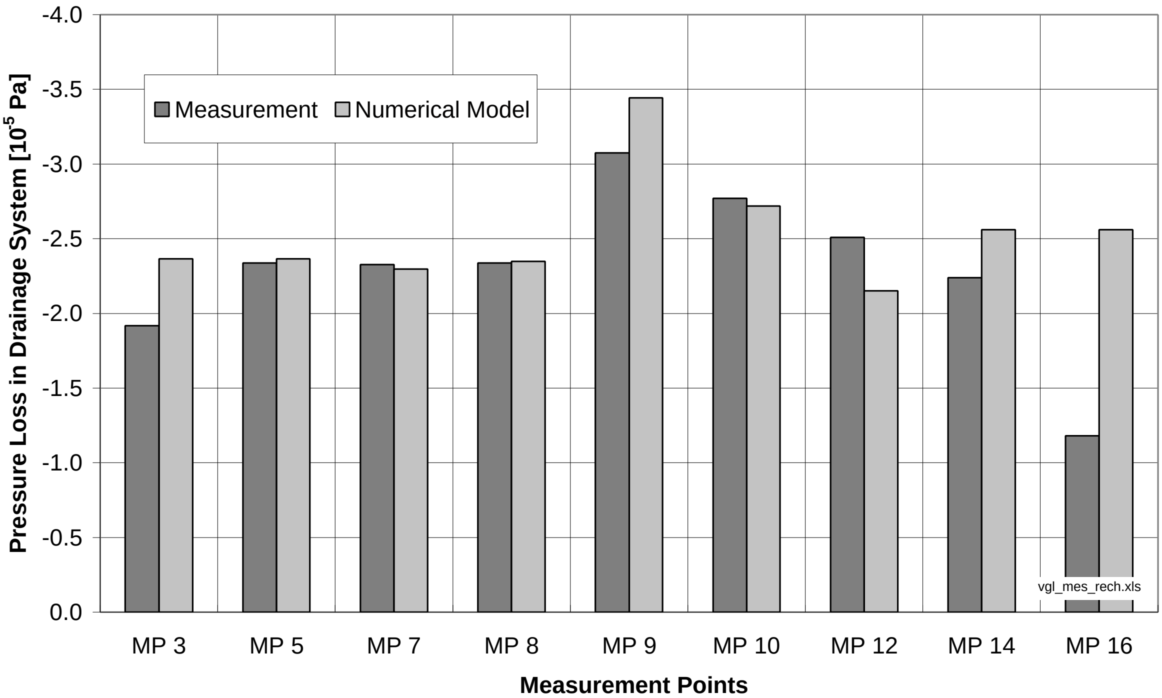

Figure 10. Comparison of measured and calculated pressure loss in drainage system of the test site Mitholz, Loetschberg base tunnel

6 CONCLUSIONS

The results of the numerical simulations and the measurements in the test site of the Loetschberg base tunnel are threefold:

- The numerical results of THERMOTUN, a simulations tool designed for railway tunnel aerodynamics are well in accord with the corresponding measurements.
- The validation of the simulation tool by measurements confirms, that satisfactory predictions for the dilution of natural gas in a similar drainage system in the rail tunnel can be made.
- The proposed method of venting the drainage system will be able to prevent explosive gas concentrations in the drainage system of the Loetschberg base tunnel with a high reliability at a minimum of cost.

Generally speaking, the introduced method proved to be suitable to reduce gas concentration in the drainage system of sealed tunnels to an acceptable level. Therefore, this method can be considered in similar tunnel projects.

7 ACKNOWLEDGEMENT

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8 LITERATURE

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