10th Int. Symp. on Aerodynamics and Ventilation of Vehicle Tunnels, Boston, November 2000

Fires in long railway tunnels – the ventilation concepts adopted in the AlpTransit projects

C RUDIN
HBI Haerter AG, Zürich, Switzerland

SUMMARY

For long railway tunnels such as the Gotthard Base Tunnel (57 km) or the Lötschberg Base Tunnel (34 km) the eventuality of a fire requires special measures to reduce the probability of an incident (preventive measures) and to limit the consequences of an incident (curative measures).

Over the last years the safety department of the AlpTransit working group on Aerodynamics and Climate has developed an emergency ventilation concept for these long railway tunnels. Based on a number of key principles and different studies on smoke propagation, a ventilation concept containing rescue stations and cross-passages has been developed. This concept is currently being refined further.

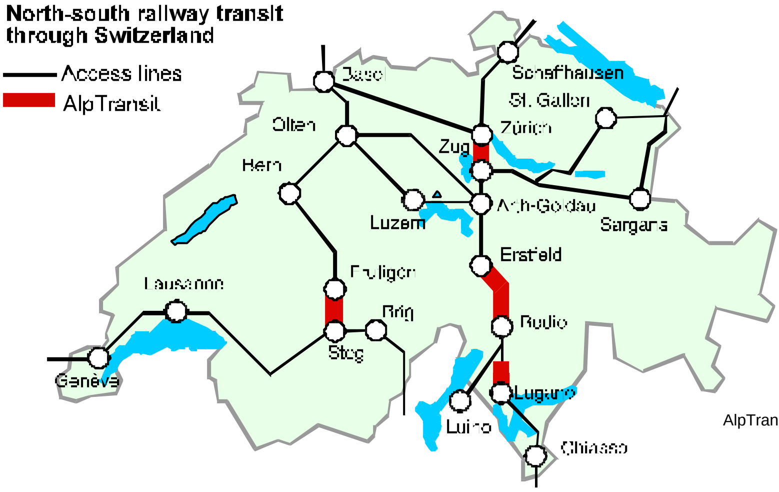
The paper describes the key principles, some of the most important findings from the smoke propagation studies and the adopted solutions for the layout of the rescue stations. In addition, possible ventilation schemes for an incident outside a rescue station are presented.

1 INTRODUCTION

The AlpTransit projects are a central part of the European high-performance rail network for transport of passengers and goods through Switzerland. AlpTransit tunnels link Northern and Southern Europe and passe under the Central Alps in Switzerland (Figure 1).

One of AlpTransit's main elements is the new railway line from Arth-Goldau to Lugano with the Gotthard Base Tunnel (57 km), the Monte Ceneri Base Tunnel (15.6 km) and the Zimmerberg Base Tunnel (20 km). This line provides substantial relief for the congested road system (Basel-Gotthard-Chiasso).

The other main element is the Lötschberg Base Tunnel (34 km) from Frutigen into the Rhone valley. This new line supplements the traffic capacity through the Gotthard and provides a better link between Western Switzerland and the European high-performance rail network. In the final phase of expansion, two national roads will be linked together by the planned motor-rail link.



AlpTransit Gotthard AG

Figure 1: North-south railway lines through Switzerland

2 SAFETY PHILOSOPHY RELATED TO THE ALPTRANSIT PROJECTS

In order to plan the provision of an effective ventilation, it is necessary to know what the tunnel owner wish to achieve. For the safety planning the following key principles were considered:

- In the event of a fire or other life-threatening incident on a passenger train, the train shall not be required to travel more than 20 km before either exiting the tunnel or reaching a dedicated place of safety within the tunnel. Drivers shall attempt to take their train to the first available designated place of safety, where passengers shall be taken to a protected area in a safe and orderly manner. There shall be a high probability that all passengers reach the protected area.
- In the event of a passenger train being unable to reach a designated place of safety, the tunnel ventilation system shall be configured to provide an alternative place of safety to which passengers can be evacuated. The possibility of passengers reaching the place of safety shall be as high as reasonably practicable.
- The designated place of safety and, where necessary, the alternative place of safety shall be maintained free of smoke and supplied with sufficient clean air until all passengers are evacuated from the tunnel.
- In the event of a fire or other life-threatening incident on a freight train, the driver shall attempt to take the train out of the tunnel and, in any case, shall not stop the train alongside a place of safety designated for passenger trains.
- A fire on any one train shall not be allowed to threaten the safety of occupants of any other train. The risk of threat to any other personnel inside the tunnel shall be made as low as reasonably practicable.

- The probability of severe train incidents shall be established through qualitative risk analysis. The design of the tunnel and the operating procedures shall give first priority to the prevention of serious incidents. The provisions for responding to emergencies shall give greatest priority to the most probable life-threatening events. Lower-probability events shall be addressed professionally, but shall have lower priority even if they have potentially more severe consequences.
- The overall tunnel configuration shall be sufficiently simple and sufficiently well signed for passengers to make the most beneficial use of its facilities in an emergency with a minimum of guidance from staff. It shall not be possible for reasonably foreseeable actions by passengers to put other passengers at risk.
- Wherever practicable, operating procedures during an emergency shall be logical extensions of procedures for routine and maintenance operation.
- Unless unavoidable, the safe response to any emergency shall not be critically dependent upon any one action by any one person.

Subsequently, the implementation of the above principles, related to the safety concept for both AlpTransit tunnels will be described:

3 THE GOTTHARD BASE TUNNEL AND ITS SAFETY CONCEPT

The Gotthard Base Tunnel will be the longest tunnel of the new high capacity north-south rail links through Switzerland.

The main elements of the Gotthard Base Tunnel are shown in Figure 2. The tunnel system is based on a physical separation of the two tracks (twin tube system). The two tubes are connected by cross-passages (every 325 m) and two cross-overs located at the basis of the access points Sedrun and Faido.

The safety concept of the Gotthard Base Tunnel foresees two emergency stations which are located at Sedrun and Faido. These stations are situated just before the location of the cross-overs. In the event of an incident in the tunnel, passenger trains reach the next rescue station or portal in less than about 20 km. Passengers can escape into a protected, pressurised area to wait at a safe distance from the fire for an evacuation train to come. The evacuation takes place on the opposite platform of the rescue station. To take account for the risk of train fire, the platforms of the emergency stations are ventilated through the open access doors and smoke is exhausted from the tunnel.

If a burning passenger train has to stop between two stations, the passengers escape through the cross-passages and reach a safe haven in the second tube.

The evacuation of the passengers takes place in the opposite tube with a regular (empty) passenger train. The evacuation train enters the railway tunnel from the north or the south portal. It is not planned to use the access galleries in Amsteg, Sedrun and Faido for evacuation purposes. Special rescue and fire fighting trains are available near the portals for fighting the fire in the incident tube.

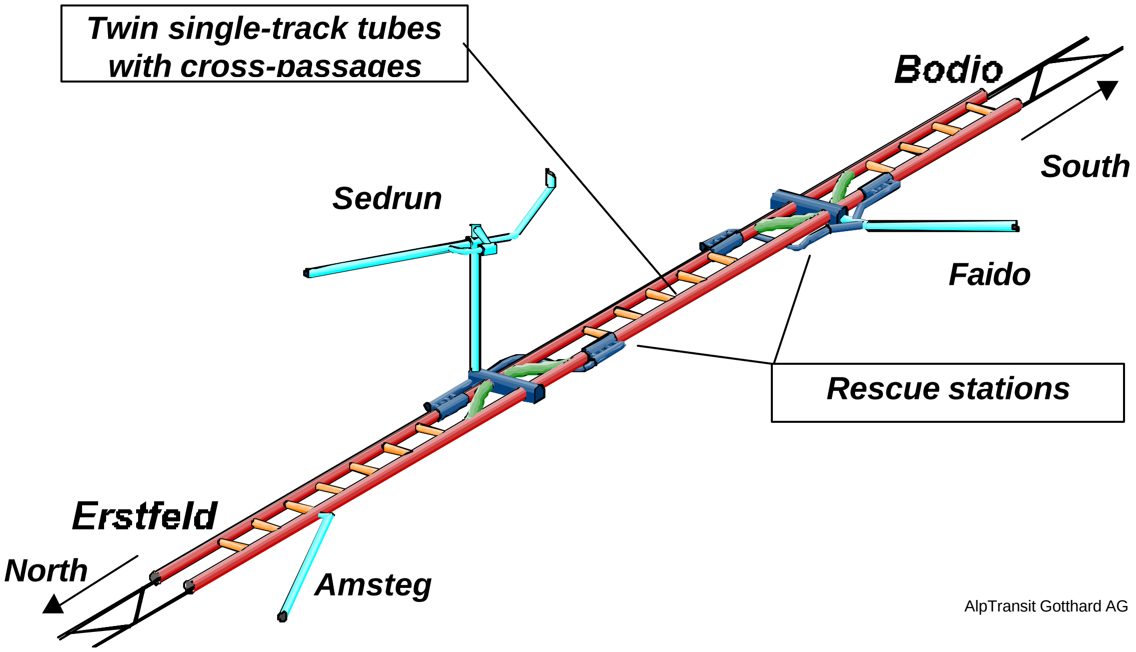


Figure 2: Gotthard Base Tunnel (please note that the picture is not to scale and that there are more cross-passages in reality)

4 THE LÖTSCHBERG BASE TUNNEL AND ITS SAFETY CONCEPT

The main elements of the Lötschberg Base Tunnel are shown ion Figure 3. From the Northern portal up to the cross-over in Ferden there is a 20 km long single-track railway tunnel. From the cross-over in Ferden up to the southern portal two single-track railway tunnels are foreseen. A service tunnel runs parallel to the single-track railway tunnel. The two railway tubes in the south and the railway tube and the service tube in the north are connected by cross-passages (every 325 m).

One rescue station is located near the cross-over at Ferden (about 20 km from the portal in north or south). The safety concept of the emergency station is similar to the Gotthard Base Tunnel. In the event of an incident, passengers can escape into a protected, pressurised area to wait for an evacuation train to come. Smoke is exhausted from the rescue platform through the shaft Fystertellä. The evacuation takes place with a regular empty passenger train from the north or south portal using the opposite platform of the rescue station.

If a burning passenger train has to stop south of the station in the tunnel, the passengers escape through the cross-passages in the second tube and wait there for an evacuation train to come. If a burning passenger train has to stop north of the station in the tunnel, the passengers escape through the cross-passages in the protected, pressurised service tunnel. The evacuation takes place with buses using the service tunnel.

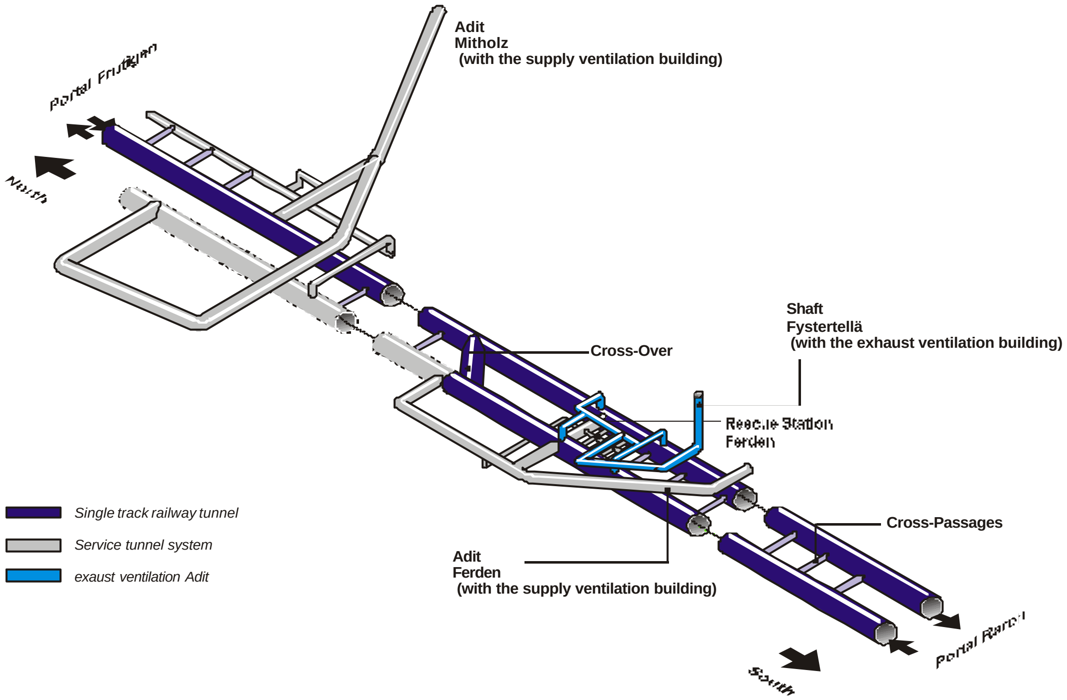


Figure 3: Safety-relevant features of the Lötschberg Base Tunnel

5 THE RESCUE AND THE OPERATION CONCEPT

In the Gotthard- and the Lötschberg Base Tunnel with a regular traffic load of 300 and 110 trains per day, normally, several trains are usually running through the system simultaneously. As the evacuation of the passenger in an emergency situation is based on trains, the access route in the opposite tube must be free. To control the train movements in the normal and incident mode, the Base Tunnels contain a modern signalling system.

For the case, where a burning passenger train is not able to reach the portal and has to stop in or outside a rescue station, operation rules for the trains which are running in the system have therefore to be defined:

- All trains outside the tunnel are stopped before they enter the tunnel.
- Trains in front of the incident train leave the tunnel with normal speed.
- Trains behind the incident train are stopped immediately.
- The speed of the trains in the opposite tube is reduced generally to 80 km/h.
- The evacuation of the passengers is carried out using a regular empty passenger train in the opposite tube.

6 EMERGENCY SCENARIOS

The relevant scenarios have been defined in a qualitative risk analysis using a fault tree approach. By this method, the scenarios to be considered in the emergency planning process are defined in a systematic way. Because of the limited space in a tunnel, the scenarios for a fire in a passenger train or the release of hazardous goods are more of importance than they would be in the open environment.

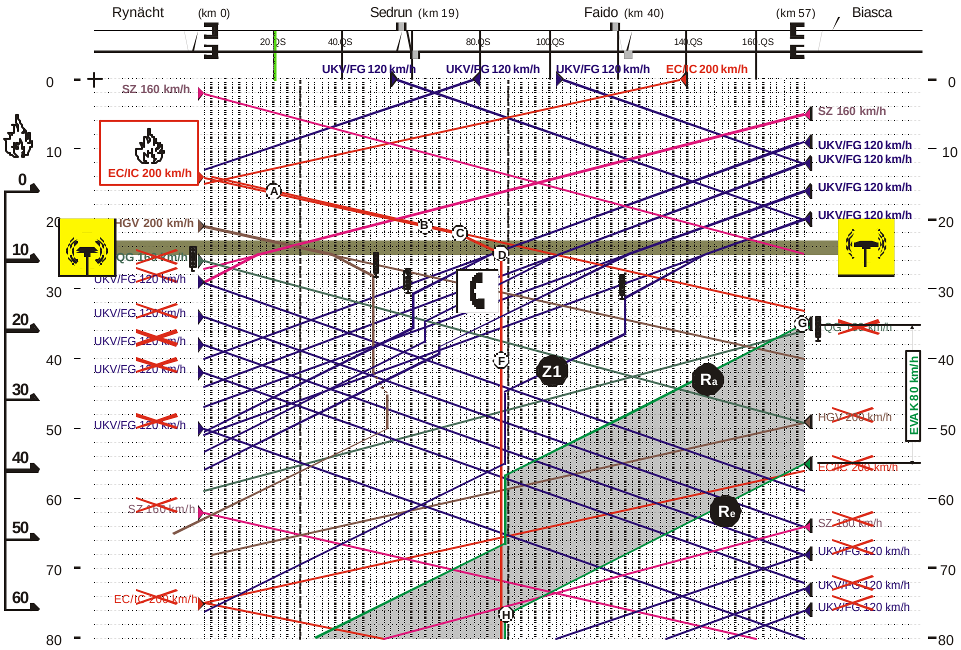
Two main scenarios have to be distinguished:

- the train on fire is able to reach a rescue station
- the train on fire stops outside an emergency station

For both scenarios, a number of sub-scenarios were defined depending on the number and the location of other trains in the same or in the opposite tunnel tube. Finally, for each of these scenarios a detailed time history was developed.

The train movements in a specific scenario based on provisional operation rules are shown in Figure 4. It can be seen that:

- While a passenger train is running through the Gotthard Base Tunnel a fire breaks out in one of its carriages (A).
- Passengers discover the fire (B).
- Passengers pull the emergency brake. The control centre and the locomotive driver are informed immediately (C).
- In spite of the emergency running properties and the settlement of the emergency brakes, a technical failure prevents the train from reaching the portal or the next emergency station, and the train breaks down somewhere in the tunnel (D).
- On instruction of the railway staff, the passengers rescue themselves using the walkways and the closest cross-passages to the adjacent safe tube.



AlpTransit Gotthard AG

Figure 4: Example of an operation scenario in case of an incident for the Gotthard Base Tunnel

The scenario is completed with a reference fire for a passenger train which has been developed using the Eureka measurements of the fire development of a steel IC passenger carriage (1). Using the modelled fire development of a single carriage as a basis, the fire development for a whole train can be estimated using linear superposition. Suitable estimates for the time required for fire spread between the carriages are required. Figures 5 and 6 show the resulting heat release curve for an IC train with ten carriages. This model fire is an important complement to the scenarios for the aerodynamic calculations.

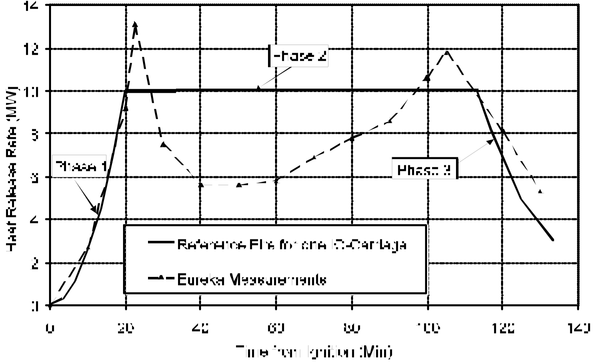


Figure 5: Measured and modelled fire development for one carriage

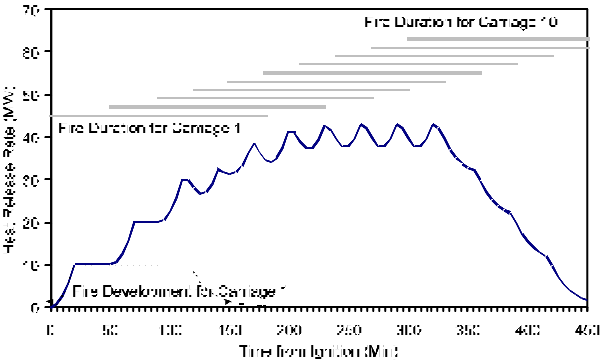


Figure 6: Reference fire for a passenger train

7 RESCUE STATIONS AND EMERGENCY VENTILATION

Figure 7 shows the typical geometrical dimensions of a rescue station in the Gotthard Base Tunnel. Rescue stations are constructed symmetrically. Each station includes two rescue platforms (one for each running tunnel), consisting of an enlarged tunnel cross-section and a widened walkway (2 m) on one side. The rescue station has the same length as a passenger train (450 m). Escape galleries are arranged along the rescue station at regular intervals (90 m), leading into an escape tunnel (protected area). The protected area is large enough to accommodate all the people from one passenger train. The rescue station has direct access to outside. The following particular requirements are placed on rescue stations:

- *Protected area:* a protected area in the rescue station must provide sufficient space for all the people from a full passenger train escaping from the rescue platform, as well as protecting them for a prolonged period of time against the smoke and heat from a train that is on fire. An adequate supply of fresh air must be guaranteed.
- *Protection from smoke and heat:* people leaving a burning train on a rescue platform must be offered adequate protection against smoke and heat, as well as adequate visibility in order to find the escape galleries. A build-up of smoke in the rescue station and penetration of smoke and heat into the protected area must be avoided.
- *Control of smoke propagation in the tunnel:* Non affected trains behind the incident train and trains in the opposite tube must be protected from smoke propagation.

In the following, the essential features of the rescue station are described. These are valid both, for the Gotthard and the Lötschberg Base Tunnel:

- Constant artificial ventilation of the rescue station with a small volumetric flowrate of fresh air (35 m^3/s).
- Fresh air is fed into the rescue station from outside via the adit. Used air is drawn off through ventilation flaps in the escape doors on the rescue platform.
- In the event of an incident, the fresh air supply is increased to 200 m^3/s. The air flows through the open escape doors of the affected rescue platform. This flow rate of air is suf-

ficient to stop heat and smoke penetrating into the escape gallery. To this end, two ventilation fans are mounted on the portal of the adit.

- If there is an emergency, two exhaust air fans working at a total capacity of 250 m^3/s are put into operation and the flap in the channel for the not affected rescue platform is closed. In the event of a fire, in the affected rescue platform the smoke is extracted from the middle of the station through the open flap. Two exhaust air fans are mounted on the portal of the exhaust channel for this purpose.
- The opening of escape doors into the rescue station, the control of the exhaust air flaps and the switching of the fans into the mode of “emergency operation” is carried out automatically from the operation control centre.

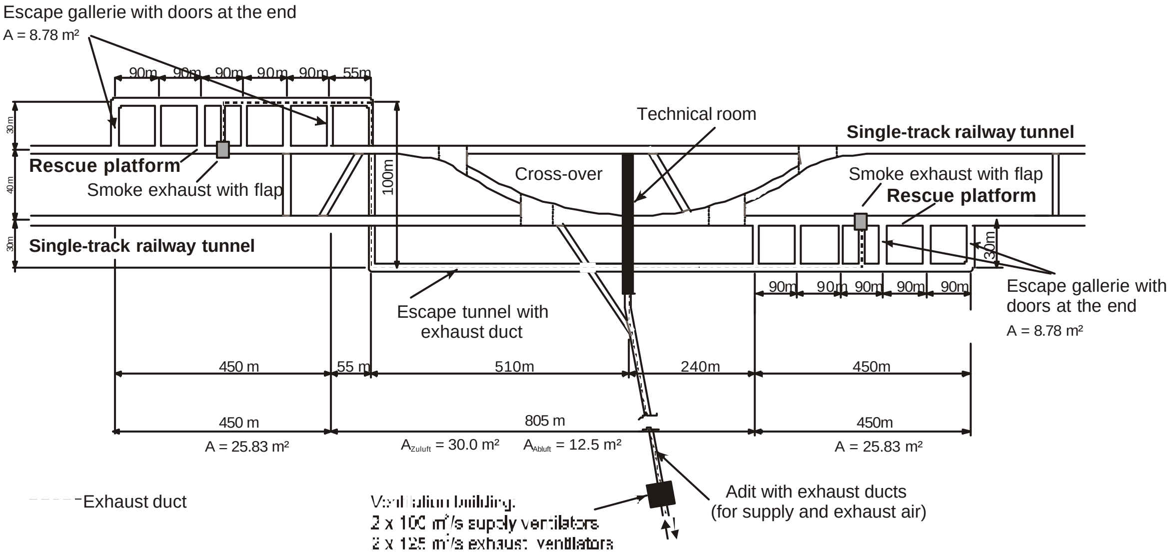


Figure 7: Example of a rescue station in the Gotthard Base Tunnel (similar to the rescue station in the Lötschberg Base Tunnel)

8 CROSS-PASSAGES

If a passenger train stops outside the rescue station because of a fault, the rescue concept provides an evacuation of the passenger via the cross-passages to the opposite tube (Figure 8). The dimension of the cross-passages are too small to be used as a protected waiting room (length=30 m, cross-section=13 m^2). The distance between the cross-passages (325 m) and the length of the passenger train (400 m) ensures that at least one cross-passage is easy to reach directly from the affected train.

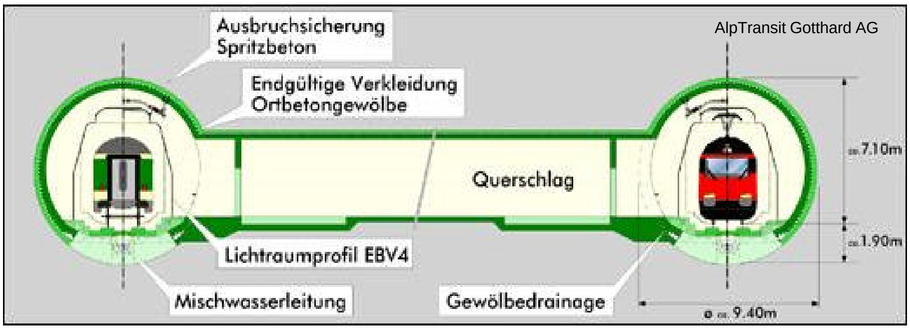


Figure 8: Cross-passages between the single-track tubes in the Base Tunnels

On the basis of the assumption that less than 1% of trains on fire stop in the tunnel outside a rescue station, no emergency ventilation system is currently planned to protect the opposite tube from smoke propagation via the used cross passages. The use of the emergency ventilation system of the rescue station to pressurise the non-incident tube is held as an option for the final design (Figure 9).

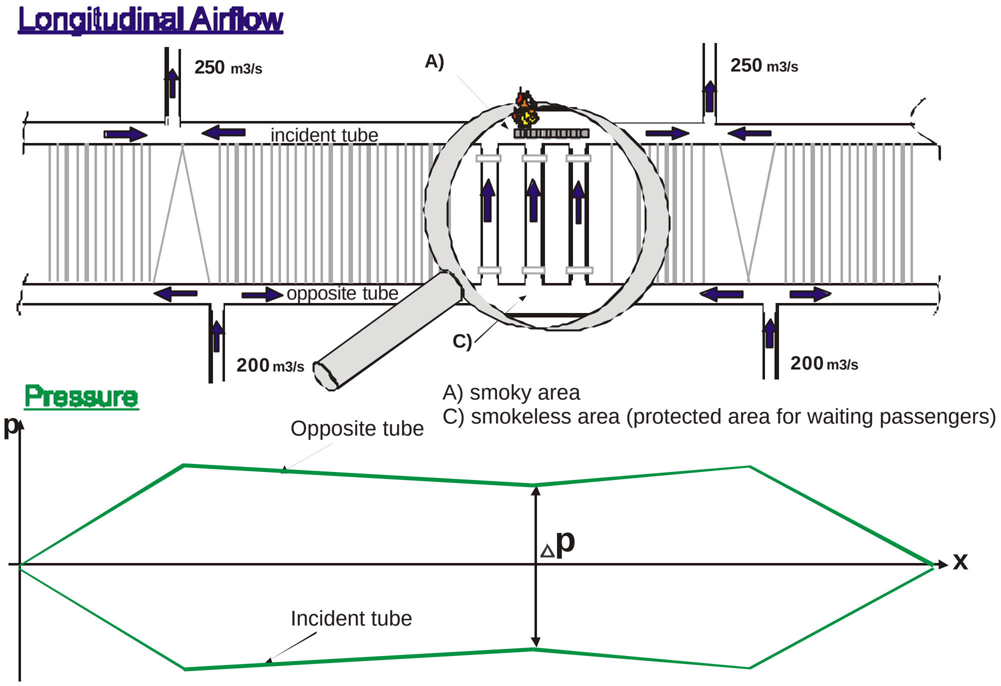


Figure 9: Alternative ventilation scheme for an incident outside a rescue station

9 AERODYNAMIC CALCULATIONS

Based on operation rules and scenarios as shown before, the aerodynamic situation in the tunnel can be explored. The longitudinal airflow due to train movements (according to the scenario, all trains in the tunnel were considered) and the tunnel ventilation were assessed using a computer programme which calculates the one-dimensional transient air flow (THERMO-TUN).

The production of smoke was modelled using a constant smoke generation rate. Simulating the smoke as passive tracer gas emitted from the middle of the burning train, the smoke propagation and the concentration were estimated. For these preliminary results, no thermal smoke layering was assumed, i.e. the smoke was assumed to be cold.

In order to quantify the smoke gas concentration (CO, CO_2, O_2) and the resulting reduction of the visibility in the tunnel, a detailed combustion model for a burning passenger train was used. Furthermore, an appropriate model to determine the visibility had to be chosen. The resulting gas concentrations and the visibility limits were then derived from the calculated smoke concentrations.

The presence of smoke due to train fire in a tunnel limits the visibility for the passengers involved, and hence presents a potential danger to them. Based on the results of these calculations, the risk can be assessed and the measures can be optimised.

An advantage of the one-dimensional aerodynamic computations is the possibility of quickly calculating many scenarios such as the one depicted in Figure 4. This permits estimates of the sensitivity of the tunnel aerodynamics with respect to train operations to obtain.

Figure 10 shows an example of the aerodynamic calculations (air speeds and visibility) for an incident where a burning passenger train stops outside a rescue station. For this particular case, no emergency ventilation is in operation. It can be seen that after the incident train has been stopped, air speeds up to 4 m/s and changes in the flow direction must be expected in the affected tunnel tube. This is mainly due to other trains in the system. As a consequence of these airflows, about 2 km of tunnel are filled with dense smoke after 20 minutes. This plug of smoke is then moved back and forth while the length of the smoke plug remains almost unchanged.

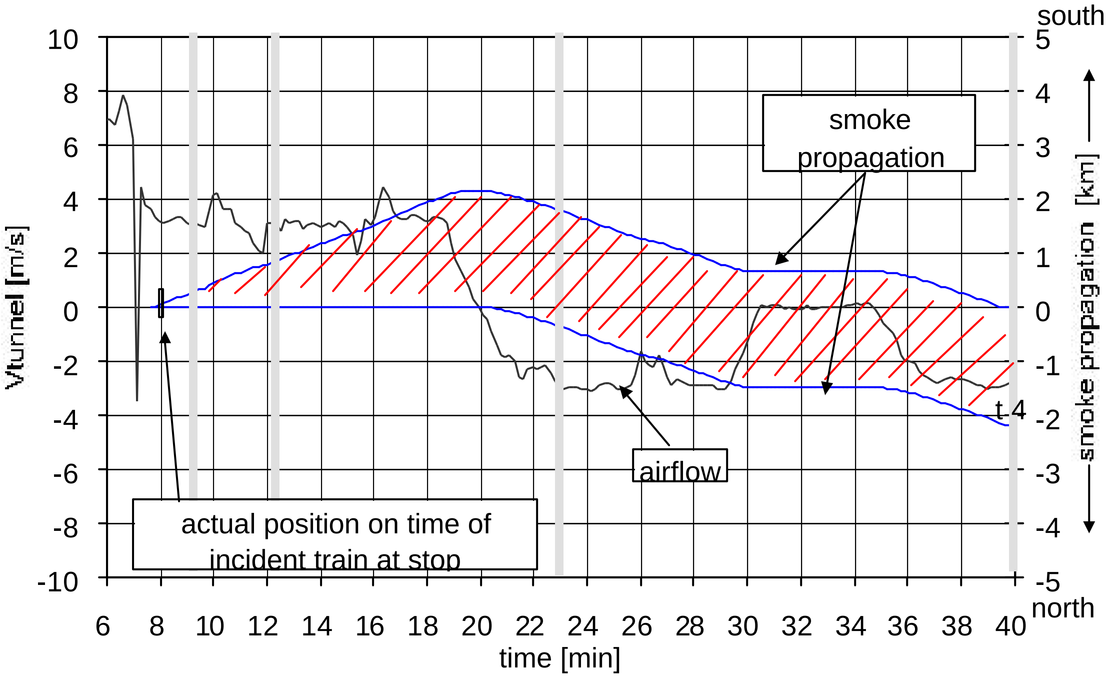


Figure 10: Airflow and smoke movement

10 CONCLUSIONS

With the planned safety concept described in this paper, the key principles of the safety philosophy related to the AlpTransit projects (chapter 2) can be achieved:

- *Protected area in the rescue station:* A smoke entry in the protected area of the rescue station can be prevented by the supply of fresh air. As long as the passengers wait in the protected area for the evacuation by a rescue train over the opposite rescue station, they will not be threatened by smoke and heat. Even if the fire is greater than the reference fire used in the scenarios (Figure 6), smoke entry in the protected area can be prevented by the high air velocity of more than 4 m/s through each of the open escape doors.

- *Assistance of self-rescue on the rescue platform:* By the supply of fresh air and exhaust of smoke from the middle of the rescue platform, the conditions on the rescue platform (visibility, heat) are improved so far, that the affected passengers can orientate themselves on the platform. Independently of the location of a fire on the train, at least half of the rescue platform can be protected from smoke dispersion. The escape direction of the passengers in the train (away from the fire) will also be favoured on the platform (passengers always riches a smokeless area on the platform).
- *Smoke propagation to the opposite rescue station:* By the train induced longitudinal air flow, a smoke propagation to the opposite rescue station is prevented as long as the trains move in the opposite tube. If a smoke propagation should appear later on (after the trains left the tunnel), conditions which allow an efficient evacuation can be obtained quickly by an active air supply over the open doors and/or through an active air exhaust from the incident platform.
- *Trains behind the incident train:* The aerodynamic calculations showed, that the smoke propagation behind the incident train can be limited by the planned measures (smoke exhaust in the rescue station, train operation).
- *Air conditions in the opposite tube:* Because of the doors on both sides of the cross-passages, the air conditions in the opposite tube are much better than in the incident tube for an incident outside a rescue station. In case of a fire on a passenger train, the passengers can survive in the opposite tube as long as the evacuation will be carried out with a rescue train in the opposite tube. In particular up-stream of the open cross-passages, fresh air is available due to the train induced longitudinal air flow.
- *Guarantee for an evacuation route in the opposite tube:* During a fire, the visibility in the opposite tube is possibly limited essentially by the penetrated smoke. In all of the investigated scenarios the air conditions were sufficient to allow a survival for a long time so that an evacuation can be carried out with a rescue train. The ventilation objectives are achieved to a large extent. A final assessment of the risk for the passengers can only occur with a quantitative risk analysis. If the risk is too high, the use of the emergency ventilation system of the rescue station to pressurise the non-incident tube is held as an option (Figure 9).

11 REFERENCES

(1) Eureka Project EU 499: FIRETUN, Nov. 1995. "Fires in Transport Tunnels, Report on Full-Scale Tests", Editor: Studiengesellschaft Stahlanwendung e.V., D-40213 Düsseldorf