Incident management in a very long railway tunnel

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ABSTRACT

A very long railway tunnel requires additional measures to guarantee a sufficient safety level. These measures as emergency stations and ventilation systems however increase also the complexity of the incident management.

For the 32.8 km long Koralm tunnel the tunnel system and the layout of the emergency station with a 800 m long refuge room and a ventilation system using “bypass channels” are illustrated. Due to the piston effect the running of trains in case of an emergency will have an important influence on the airflows in the tunnel. It is therefore crucial to limit the number and the speed of the trains running to met the ventilation targets.

With the analysis of traffic scenarios characteristic operating situations were analysed to realistically reflect the sequence of events in case of an emergency.

Keywords: tunnel safety, railway safety, ventilation, emergency station

THE KORALM TUNNEL PROJECT

The Koralm tunnel is one of the key elements of the new Koralm railway line, which connects the cities of Graz and Klagenfurt in the south of Austria. The Koralm railway line is part of the Baltic-Adriatic Axis, which represents the easternmost crossing of the Alps and links several Eastern European countries and Vienna with southern Austria and northern Italy (see Figure 1). The Koralm line is a 130-km-long high-performance railway line engineered for a design speed of 200 km/h.

In the centre section of the Koralm line lies the Koralm tunnel, which underpasses the Koralpe mountain range at a depth of up to 1,200 m. Its length of 32.8 km makes the Koralm tunnel the longest railway tunnel located entirely within Austrian territory.

Figure 1: Overview map

Following the route selection procedure and the environmental impact assessment, the first construction permit in compliance with Austrian railway law was issued in 2006. At the moment, exploratory measures involving pilot tunnels and deep drillings are being implemented in the tunnel area. The construction works are scheduled to start in 2008.

Starting with the design process for the environmental impact assessment, a system analysis was launched to examine the essential elements of the Koralm tunnel. This analysis considered construction and operating phase criteria. For the operating phase, the effects regarding passenger safety, maintenance, power consumption, aerodynamics and operating safety were taken into consideration.

Based upon this analysis, the following system was chosen (see Figure 2):

- Two single-track tubes
- Cross-passages connecting the tubes at a 500 m distance
- One emergency station in the centre of the tunnel with no direct link to the surface
- No crossover inside the tunnel

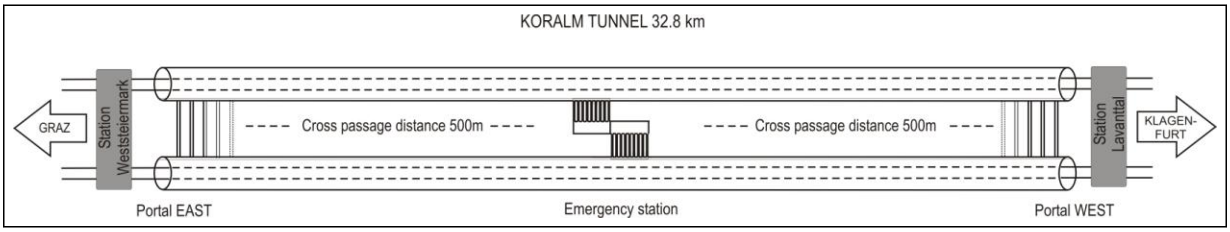

Figure 2: Tunnel system Koralm tunnel

Emergency exits in new Austrian railway tunnels are – in analogy to the Guideline issued by the Austrian Fire Fighters Association [1] – currently constructed with a standard distance of 500 m, regardless whether they lead to a second tube or to the surface. This standard distance has also been adopted for the Koralm tunnel.

In case a fire occurs in a running train inside a tunnel, the train should leave the tunnel as fast as possible, since the chances of people being rescued are considerably lower inside the tunnel than outside the tunnel.
The TSI (Technical Specification for Interoperability) [2] states that, in case of a fire, the running capability of a train is to be ensured for a period of 15 minutes, permitting the train to proceed at a speed of 80 km/h.
These requirements regarding the running capability of trains indicate that, with tunnels featuring a length in excess of 20 km, the probability of leaving the tunnel decreases. It is in response to these findings that the guidelines call for special measures in tunnels exceeding a length of 20 km [2].
For the Koralm tunnel, the construction of an emergency station in the centre of the tunnel was investigated as additional safety measure. This emergency station serves the purpose of creating an area which offers exceptionally favourable self-rescue conditions in case of a fire. A train is brought to a halt in the emergency station before its running capability has reached its limits.

A train operation simulation was performed to decide whether a crossover would be needed in the Koralm tunnel. This crossover would primarily be used during maintenance works, since a section of the tube, which is to be worked on, would then be closed. The simulation also covered an increase in train traffic induced by a possible upgrade of the feeder lines. The studies confirmed that, even if no crossover is provided inside the tunnel and if one tube is completely closed due to maintenance works, a sufficient train operation quality can still be ensured.
Safety considerations (accidents caused by switches are reduced, strict separation of tunnel tubes) as well as the need for additional maintenance work (inspection of switches and connecting tunnel tubes with doors and installations) were facts speaking against a crossover.

RESCUE CONCEPT

When developing the rescue concept for the Koralm tunnel, a special effort was made to assure maximum uniformity with the sequences determined for other tunnels of the Koralm railway line and with the Austrian railway network as a whole.

Railway operation

The first operational steps to be taken when a fire occurs inside the tunnel may be summarised as follows:

- All trains shall leave the tunnel; passenger trains which have not passed the emergency station yet shall stop upon arrival at this point.
- All trains, running ahead of the accident train, shall drive out of the tunnel.
- All trains following the accident train shall – by moving backwards – secure the greatest possible distance to the hazard zone, or they shall be evacuated.
- All trains in the second (safe) tube shall either come to a halt or continue their journey at reduced speed.

Self-rescue, evacuation

A self-rescue becomes necessary, when an emergency occurs, that brings a train to a halt inside the tunnel, that keeps a train from driving on and that puts a person's life at risk. When a train stops at a random location inside the tunnel, the self-rescue is performed via cross-passages leading into the second tube. When a train stops in the emergency station, the self-rescue is accomplished by evacuees proceeding to the rescue room.
People waiting inside the tunnel are predominantly evacuated by passenger trains running on the Koralm line. Problems may occur at night when fewer trains are in operation. In these cases, alternative solutions like "bringing in trains parked at stations along the Koralm line" or "increasing the capacity of the rescue train by adding passenger cars" would be conceivable. An optimized solution will be developed in connection with the operating programme at a later stage, shortly before the tunnel will be opened to traffic.

Assisted rescue, rescue train

An assisted rescue from the Koralm tunnel shall be performed by a rescue team, supported by members of the voluntary fire brigade. For the rescue crew to be transported to the site of the accident, rescue trains shall be positioned at the nearest stations. Rescue operations are planned to be carried out from both sides.

LAYOUT OF THE EMERGENCY STATION

The emergency station in the centre of the tunnel consists of 400-m-long platforms in both tunnel tubes. Inside the emergency station, the walkway, which extends over the entire length of the tunnel, is widened (2,0 m) and raised to the level of the platform (55 cm above rail). The walkway and the emergency exits may thus be kept on the side facing the second tube.

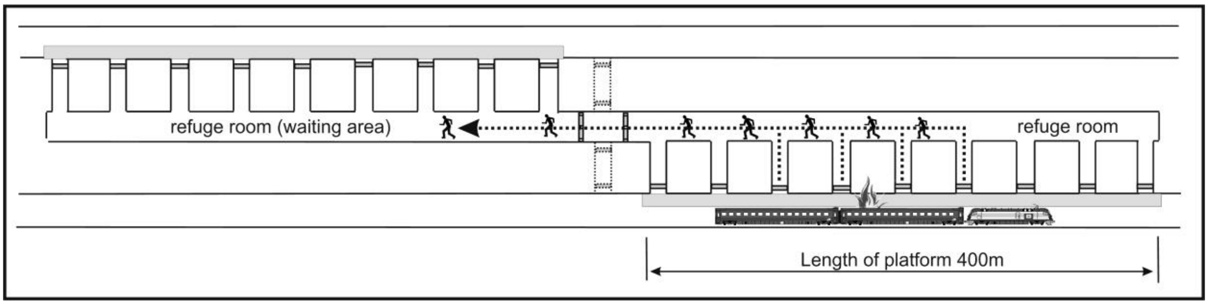

Figure 3: Layout of emergency station

In the emergency station a refuge room is located between the two tunnel tubes. This refuge area is connected to the platforms via escape-passages provided at a distance of 50 m. As Figure 3 shows, a staggered platform arrangement is chosen, which results in an approx. 800-m-long refuge room.
A lock divides the refuge room into two equally large parts. At the emergency exits leading from the platform to the escape-passages, 2-m-wide doors are installed. It is envisaged that in case of an incident, all evacuees will proceed to the more distant part of the refuge room (waiting area), where they will be waiting to be evacuated.

This emergency station arrangement offers the following advantages:

- From a fire protection perspective, the waiting area is clearly separated from the affected platform.
- The distance between two escape passages of only 50 m leads to short escape routes
- People leaving the train cover a distance of approx. 400 m (see Figure 3), in other words they move out of the immediate danger zone. If they were forced to stay in the rescue room directly adjacent to the platform, they would only be shielded by the short escape-passage between the fire scene and the safe area, which would give them the feeling of being very close to the zone of danger. This scenario was considered to be problematic in case of an extended stay in the emergency station – as a period of up to 90 minutes may be required for the evacuation to get underway.
- More space is available for people waiting to be evacuated, a provision which shall help to prevent uncontrolled attempts to leave the waiting room.
- The evacuation and the assisted rescue campaign will be made easier, as unwanted interactions will be prevented (see Figure 4).

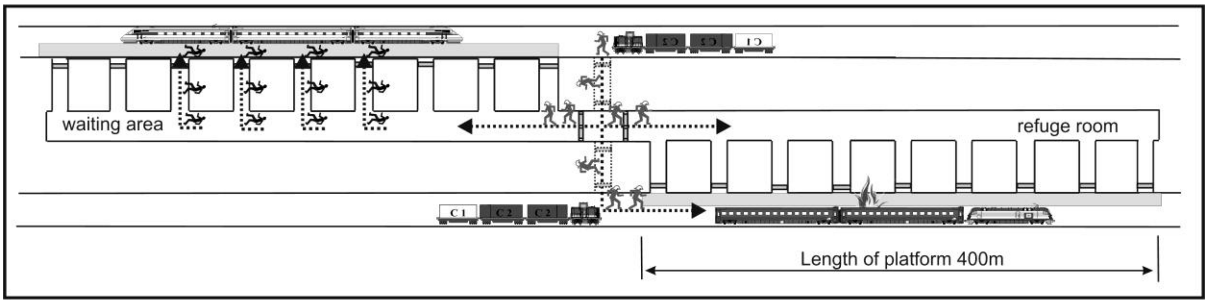

Figure 4: Evacuation train and rescue train in emergency station

Emergency facilities
A team of psychologist was asked for an independent opinion about the emergency facilities including the aspects of human behaviour in an emergency situation.
The emergency station shall be equipped with the following facilities:

- Emergency telephone
- Video surveillance and loudspeaker system for announcements
- Lighting system comparable to that of a station
- Seating accommodations
- The provision of separate areas for the treatment of injured persons and for toilets.

EMERGENCY VENTILATION SYSTEM

Tunnel ventilation concept - overpressure in the non-incident tube

The emergency ventilation concept is based on pressurising the safe areas (emergency refuge room and the non-incident tube). In an emergency situation fresh air is brought into non-incident tube by large axial fans located at the shafts at Paierdorf and Leibenfeld creating an over-pressure which prevents smoke passing from the incident to the non-incident tube (see Figure 5). If the escape doors in cross-passages are opened the overpressure will lead to an airflow through the open doors. The air velocity through open doors varies depending on the door's location and the number of simultaneously open doors.

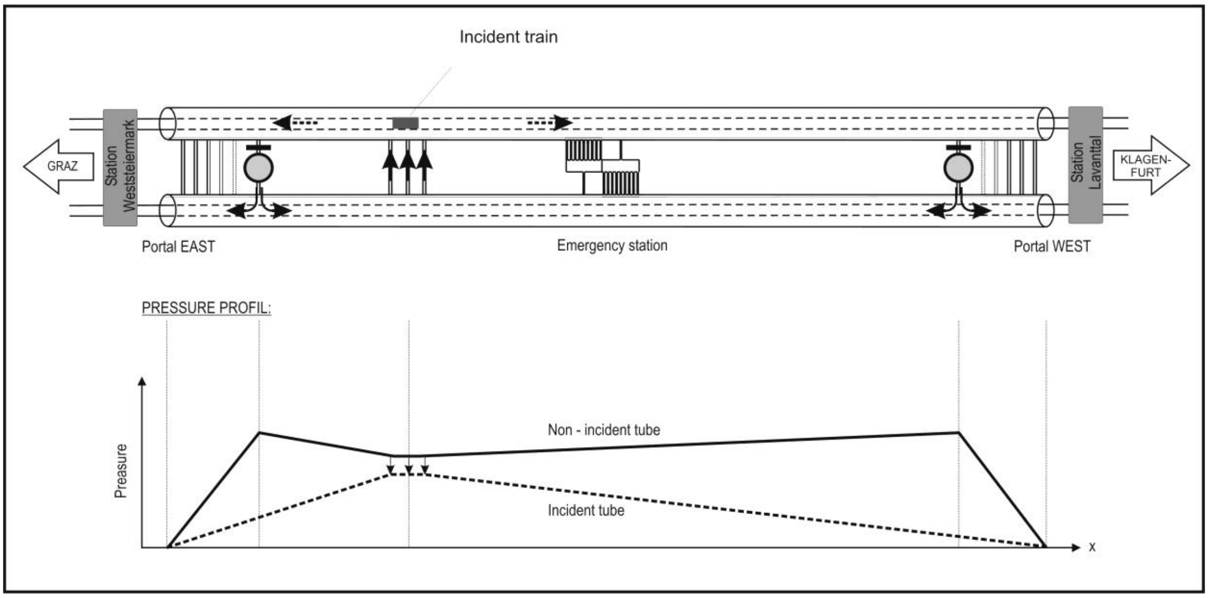

Figure 5: Airflows and pressure profile in an emergency situation with a train coming to a halt outside the emergency station

Ventilation of emergency station

The emergency station is located at great depth in the middle of the tunnel. As there is no airshaft in the vicinity of the emergency station a smoke exhaust system could not be realised. The primary objective is thus to prevent smoke penetration into the refuge room. Additionally a backlayering of smoke in the incident tube should be suppressed to allow the fire fighters to access to the train on a smoke free path and to keep following trains (which may have stopped behind the train on fire) in a smoke free environment.

To reach these targets the over-pressure in the non-incident tube can be used. Additionally the following structural and technical measures are taken in the emergency station (see Figure 6):

- Using special air ducts (bypass channels) - located at both ends of the emergency station - and the overpressure produced by the axial fans at the two airshafts, air can be brought to the incident tube. In the case of a train burning in the emergency station this airflow can prevent backlayering.
- The bypass channels are also used to bring air from the non-incident tube in the refuge area and to guarantee a minimal airflow in the escape-passages when the doors are open thus preventing smoke penetration in the refuge room.
- Fresh air supply for the occupants in the waiting area is provided by special fans which are located in the fire fighter access passages (local ventilation system). The air from the non-incident tube is brought in the waiting area through a ventilation duct. When the doors of the lock, which is separating the waiting area from the rest of the refuge room, are open the air is flowing through the open door thus creating an additional safety barrier.

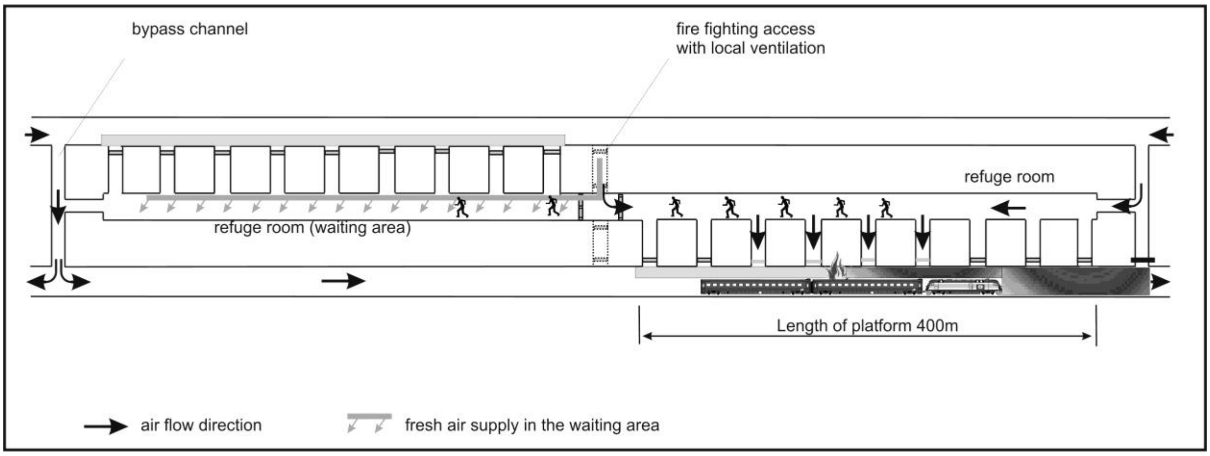

Figure 6: Air flow direction in case of self-rescue (open doors at the escape passages) in the emergency station

Design criteria

The design of the ventilation system is based on a minimum air velocity of 2 m/s through open doors (in the emergency refuge area as well as in the cross-passages outside the emergency station). The effective air flows however can go below this design target velocity of 2 m/s for a certain time due to the effect of other trains still running in the tunnel system.

Influence of train movement

1-D airflow simulations have shown that the overpressure concept is very robust and stable against the influences of the high barometric pressure differences which occur between the two portals. However due to the piston-effect of trains still running within the tunnel during an incident (e.g. trains leaving the incident or non-incident tubes or rescue trains entering the tunnel) the airflow in the bypass and the escape passages leading to the refuge room can be seriously affected however. To guarantee the functionality of the ventilation system the train traffic during an incident must therefore be controlled and the speed of the trains must be limited.

Figure 7 shows the influence of a running train in the non incident tube on the airflows in open cross passages. In front of a train approaching an open connection air is pressed in the incident tube (Figure 7.a). Depending on the speed and the aerodynamic properties of the train (length, area, roughness, etc.) high airflow velocities can occur in the open cross passage. More critical however is the situation when the train has already passed the cross passage (Figure 7.b). In this case the train speed must be reduced to guarantee that no air is sucked from the incident tunnel towards the non-incident tunnel thus transporting smoke in the safe area.

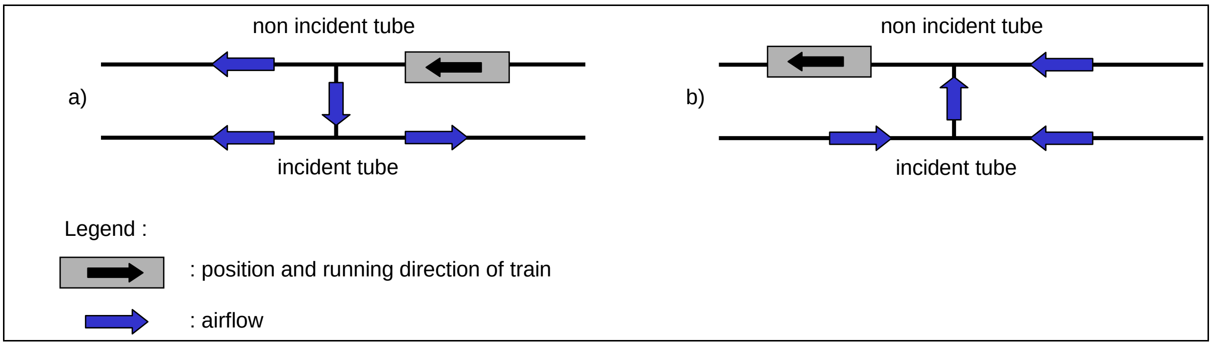

Figure 7: Schematic view of the airflows induced by a running train with open cross-passages

Figure 8 shows as an example the results of 1D instationary airflow calculations for the passage of a train in the non-incident tube. The airflow in the bypass channel as a function of time is shown. It can be seen, that under the action of the ventilation air is flowing from the non-incident tunnel towards the incident tunnel (negative air flow) after the opening of the flap in the bypass channel (at t = 73 min). With the entrance of the train running at 100 km/h (at t = 82 min) the air velocity in the bypass channel is steeply increasing until the train passes the Paierdorf air shaft. The air velocity in the bypass then remains constant at approximately 9 m/s.

In the simulation it is assumed that the speed of the train is reduced from 100 km/h to 40 km/h at t = 91 min. The train comes to a standstill in the emergency station at t = 95 min. This leads to lower airflows in the bypass channel. At t = 110 min the train is starting to leave the tunnel. As it passes the bypass channel the airflow through the bypass is reduced to approximately 1.5 m/s. However due to the limitation of the train speed to 80 km/h the airflow is never directed from the incident tube to the non-incident tube.

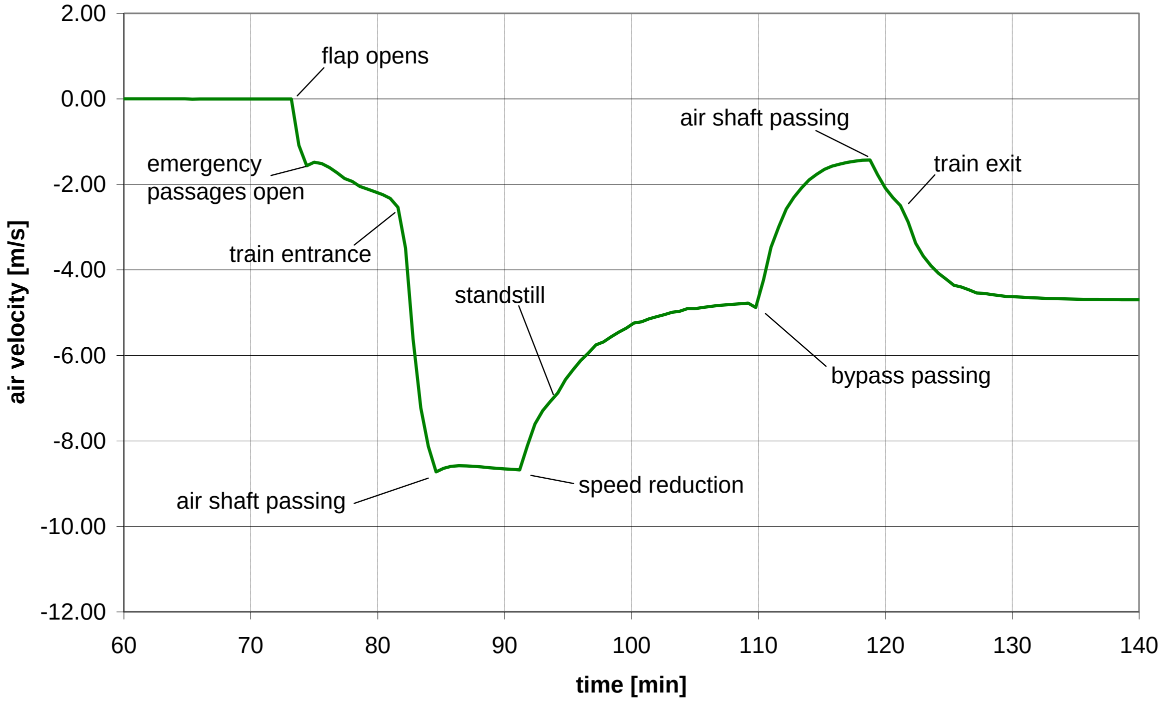

Figure 8: Simulation of the train induced airflows through an open bypass channel

ANALYSIS OF INCIDENT MANAGEMENT BASED ON TRAFFIC SCENARIOS

Due to the extensive length of the Koralm tunnel, there is a non negligible probability of several trains running through the tunnel at the time, at which an emergency occurs. In response to this fact, to the necessity of having to evacuate both passengers and crew, and to the requirement of having to grant rescue vehicles access to the tunnel, special operating sequences have to be elaborated.
In view of the operating programme currently envisaged for the Koralm line, 5 different train schedule scenarios have been developed.

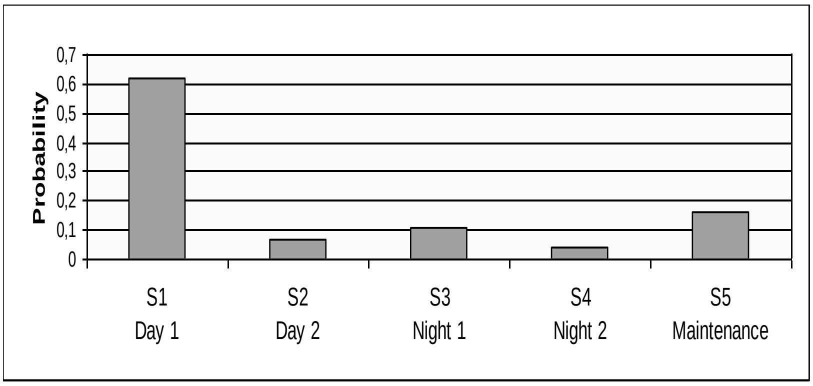

Figure 9: Probability of train schedule scenarios S1-S5

As can be seen from Figure 9, Train Schedule Scenario S1 (Day 1) reflects the most common operating scenario. This is the reason why this train schedule scenario has been used as a basis to analyse operating sequences and to define simple emergency response sequences (example see Figure 10).
Subsequent to this initial step, the analysis has further been extended to other train schedule scenarios to determine whether the selected response sequence would also be suited for these cases too (example see Figure 11).

As, for several hours at night, operation will be limited to freight trains, no self-rescue and no evacuation analysis had to be performed for this period.

Boundary conditions and assumptions
It is assumed that, in case a fire is detected in a passenger train, a message is immediately dispatched to the control centre, allowing operational measures to be taken, before the train is brought to a halt.
All train drivers inside the tunnel are instantly informed of an emergency by the use of GSM-R technology (voice message or SMS). A reduction of the permissible speed or a stoppage of the train will, depending on the options available, automatically be effected by the train control system, but an emergency stopping of the train shall be avoided.

To determine the operating sequences of rescue train and evacuation train, the assumptions shown in Table 1 were taken into consideration. These assumptions are based on a high number of computer simulations of the airflows induced by running trains as shown in figure 8.

Travelling speed – evacuation train (passenger train)	80 km/h
Travelling speed – rescue train	60 km/h
Slowdown of evacuation train and rescue train inside the tunnel	2 km ahead of the incident site, the driving speed is reduced
Reversing of freight trains (adequate operating instructions in case of an emergency are still to be elaborated)	40 km/h
Number of trains, travelling at the same time in the safe tube	One train (or travelling speed must be decreased further)

Table 1: Assumptions made regarding operating sequences

In the endeavour to develop strategies suited to manage emergency incidents, the following topics are to be addressed:

- How will other trains, which are also inside the tunnel together with the incident train, be drived out of the tunnel?
- Which train will be used to evacuate passengers and crew members and from which side shall the tunnel be entered?
- From which side and through which tube will the rescue trains drive into the tunnel (are there several options)?

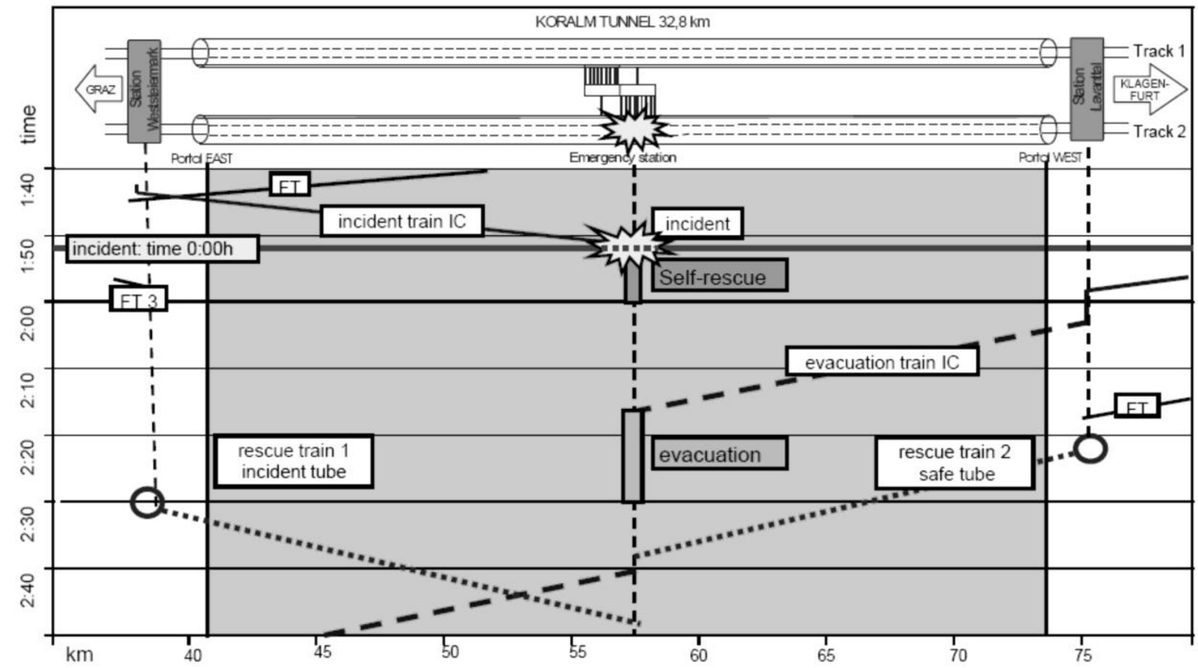

Figure 10: Time-distance diagram illustrating the incident management of Scenario S1 (example)

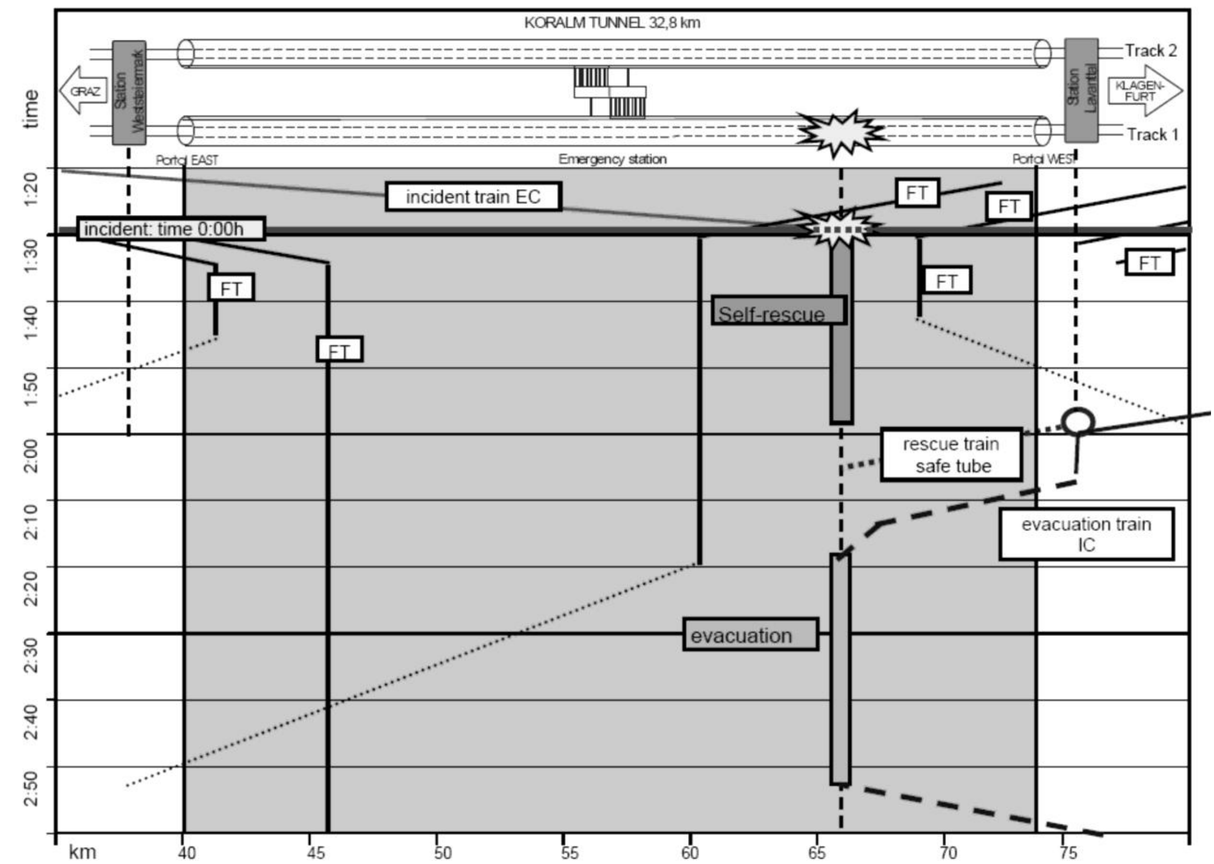

Figure 11: Time-distance diagram illustrating the incident management of Scenario S4 (example)

The decision to analyse possible incident management scenarios with the help of time-distance diagrams allowed sequences to be studied in greater detail and provided answers to such questions as:

- Are there ways of moving the train(s) out of the tunnel in case of an emergency?
- Is it possible to use other passenger trains as evacuation trains within a reasonable period of time? How long will people have to wait inside the emergency station?
- For which sequences will new operating regulations have to be established?
- How long will the second tube have to be separated from the incident tube by the use of fire protection measures?
- How long will electrical installations, such as ventilation, communication and train control systems in the second tube have to remain functional?

CONCLUSIONS

- When designing the emergency station, various aspects have to be considered. By addressing such issues as "prevention of smoke penetration into rescue room", "fresh air supply in waiting area", "location of the fire source in relation to the waiting area", "interaction between evacuation train and rescue train" and "human behaviour in an emergency situation", a lot of requirements have to be met regarding the structural design and the emergency facilities of the emergency station.
- When analysing the train movement in case of an emergency in combination with the incident management strategy and the ventilation concept, the complexity resulting from the excessive length of the tunnel is illustrated. The performance of such a detailed analysis allows rescue concept considerations, operational and organisational measures and structural safety measures to be brought into tune.
- The studies undertaken so far show that for the Koralm tunnel even under adverse assumptions for the operating sequences an evacuation of a train is possible within a reasonable period of time. The restrictions of train speeds, which are necessary to keep the second tube smoke free, do not limit the rescue procedures excessively.
- The aerodynamic effects of trains on the emergency ventilation system and the resulting maximum speeds for trains in an emergency situation should be verified in special test runs during the start up phase prior to the opening of the tunnel.

REFERENCE LIST

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