SELF RESCUE IN THE WIENERWALD TUNNEL

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ABSTRACT

The Wienerwald tunnel is an approx. 13.4-km-long railway tunnel, the eastern end of which does not lead outside but into the Hadersdorf – Weidlingau junction, situated underground in a large hall. From there the line is to be continued into the 8.6-km-long Lainz tunnel towards the Südbahn station and through another 500-m-long underground section towards the Westbahn station.

The Wienerwald tunnel is the first railway tunnel in Austria which is constructed as a tunnel system with two single-track tunnels with cross passages at intervals of 500 m. In front of the Hadersdorf – Weidlingau junction there is a change of tunnel system and the tunnel ends as a conventional, twin-track tunnel in the hall of the junction.

After the completion of the permit application procedure, the emergency ventilation system and the self-rescue concept were developed further in the tender design. By using evacuation simulation models the evacuation sequences for selected scenarios were modelled very realistically. The findings gathered have led to changes in the design of the cross passages and have been important for improving the self-rescue procedure.

1 THE WIENERWALD TUNNEL PROJECT

The Wienerwald tunnel is the crucial element of the 50-km-long new railway line between Vienna and St. Pölten (the capital of Lower Austria), the longest new section of the quadrupling of the Westbahn line between Vienna and Wels.

The Wienerwald tunnel is also part of a tunnel system which consists of the following elements:

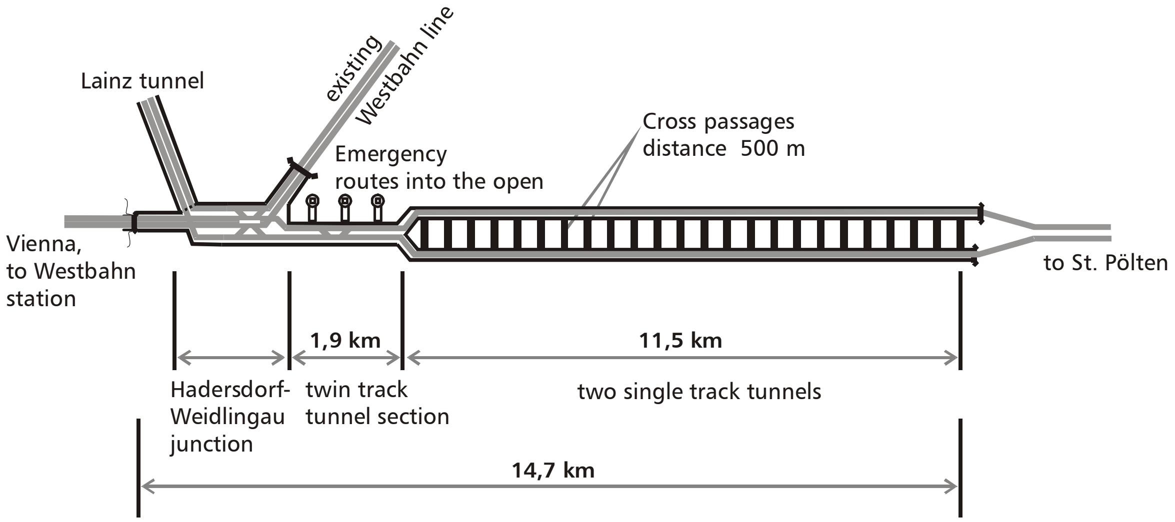
- the approx. 13.4-km-long Wienerwald tunnel
- the Lainz tunnel, an approx. 8.6-km-long twin-track tunnel at the western edge of Vienna, connecting the Westbahn line with the Südbahn line
- an approx. 0.5-km-long, twin-track underground line section, connecting the Wienerwald tunnel with the Westbahn station
- an approx. 0.9-km-long, twin-track underground line section, connecting the Lainz tunnel with the existing Westbahn line running through the Wienerwald
- between the mentioned tunnel sections there is an approx. 800-m-long underground hall, in which the individual track sections are connected with each other by means of several cross-over connections (Hadersdorf – Weidlingau junction)

Thus, the Wienerwald tunnel itself has no tunnel portal on the Viennese side but opens into the underground hall at the Hadersdorf – Weidlingau junction. The main portion of passenger trains coming from the Westbahn station travel through the Wienerwald tunnel. The total length of the underground section is approx. 14.7 km.

The first 1.9-km-long tunnel section adjacent to the Hadersdorf – Weidlingau junction is constructed as a twin-track tunnel. This is due to the crossover, located in the first tunnel section. The remaining 11.5 km of the Wienerwald tunnel are constructed as a twin-bore tunnel system with cross passages every 500 m. The cross passages are closed off from the running tunnels by means of doors at both ends.

Figure 1:

Wienerwald tunnel system with adjacent line sections



The running tunnels will be equipped with the standard safety measures for new Austrian tunnels such as escape routes with handrails, located on the side of the cross passages, emergency escape signs, lighting, emergency telephones and the like. The tunnel has a peculiar feature, since the width of the lateral escape routes which ranges from 1.9 m to 2.2 m is considerably wider than the usual 1.20 m laid down in the guidelines. This does not, however, have safety reasons but is a result of the space requirements of the cross-section of the tunnel.

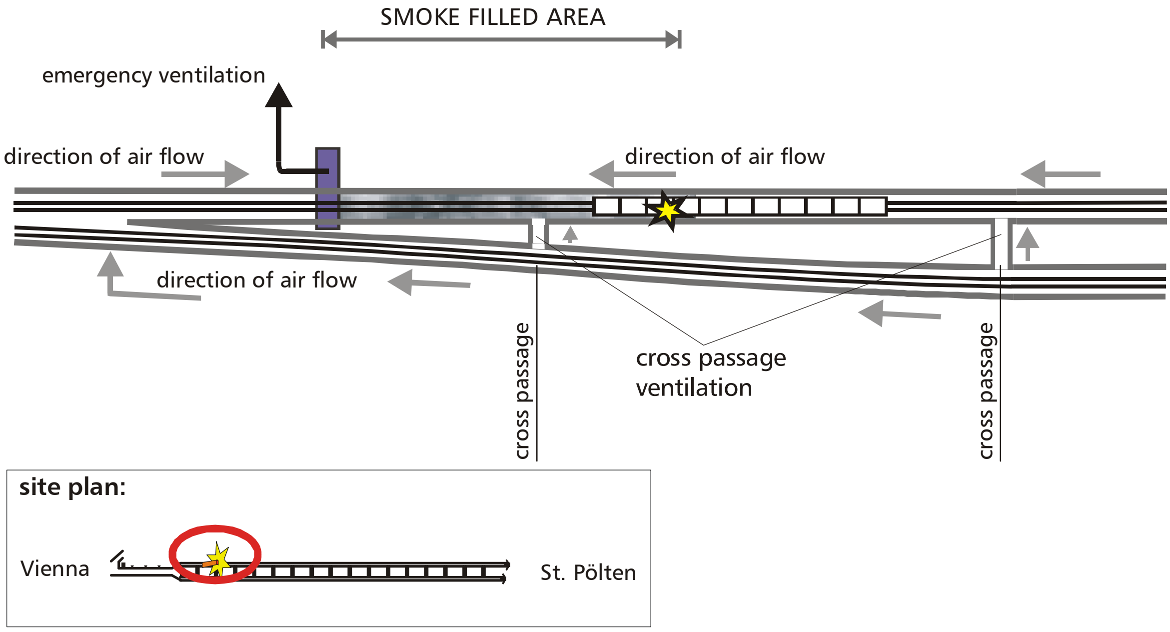
2 VENTILATION SYSTEM OF THE WIENERWALD TUNNEL

First of all it must be mentioned that railway tunnels in Austria in principle have no ventilation facilities as they are not required for standard operation - in contrast to road tunnels. The installation of a ventilation system solely for safety reasons has to date always been rejected because of the unfavourable cost-effectiveness ratio. However, due to the change of system, the safe area in the second bore of the Wienerwald tunnel can only be ensured by means of ventilation measures. This is why the following measures were proposed for the transition area already in the general design phase.

- Installation of an emergency ventilation system in the transition area
  A central emergency ventilation shaft and a fan are placed between the two tunnel bores in the single-track section next to the transition area to the twin-track section. In the event of a fire smoke gas is extracted from the affected tunnel. The ventilation system is designed in such a way that flow conditions can be created which guarantee that no smoke gas enters the second running tunnel which serves as safe area in this case.
- Emergency ventilation in cross passages
  In order to prevent smoke gas from entering the safe area in the second tunnel through the cross passages, ventilation measures are also proposed for the cross passages. Each cross passage is equipped with two ventilation units, which ensure an air flow with a velocity of at least 2.0 m/s from the safe bore towards the affected bore.

Figure 2:

Emergency Ventilation



3 FUNDAMENTALS OF THE RESCUE CONCEPT FOR THE WIENERWALD TUNNEL

3.1 DEVELOPMENT OF THE RESCUE CONCEPT

As early as during the permit application design the principles of the rescue concept were formulated and coordinated with the Austrian Federal Railways and the fire brigade. Based on this initial design the technical safety measures were planned and defined in the course of the permit application design.

The issues raised by the authorities during the permit application procedure had to be further investigated to clarify any impacts on the construction and equipment of the tunnel system before award of construction contract. This in particular concerned the following items:

- Construction of the essential elements of the self-rescue system, especially the cross passages and the doors of the cross passages
- Ventilation control, depending on the decisive scenarios for the evacuation of a train

After completion of construction works, before obtaining the operating permit, all organisational safety measures and their interaction with the technical safety measures have to be further developed in detail and have to be laid down as a tunnel safety plan.

3.2 PROCEDURE TO BE FOLLOWED IN THE EVENT OF A FIRE IN A PASSENGER TRAIN

The rescue concept starts from the following basic assumptions which are identical with the standards developed at the Austrian Federal Railways in recent years for the procedure to be followed for self-rescue in a tunnel. At present, train attendants receive regular training in self-rescue in a tunnel.

- If a fire is detected while the passenger train is travelling through a tunnel, the affected train will first try to leave the tunnel. The passenger carriages will be equipped with an emergency braking system which allows emergency braking override in the tunnel.
- However, if the train comes to a stop in the tunnel, the train attendant has to make a decision after investigating the situation on site and after communicating with the traffic control centre

  - whether the train shall be evacuated
  - and how the evacuation shall take place

  He informs the passengers over the loudspeaker system of the train and the traffic control centre by means of the train radio.
- The traffic control centre informs the fire brigade and issues the necessary instructions for any oncoming or subsequent trains (stopping all train traffic and vacating the tunnel). After clearance has been given for the second tunnel bore, the attendant initiates the evacuation of the passengers. They leave the train and walk towards the nearest accessible cross passage (in the twin-bore section) or towards the nearest emergency exit (in the twin-track section – see figure 2)
- The passengers leave the affected tunnel bore through the cross passage or the emergency exit and reach the safe area.

These steps are independent of whether the train is in the twin-track section or the twin-bore section of the tunnel. In both cases evacuation can only be initiated after all train traffic has been stopped, and in both cases there are emergency exits which lead to a safe area.

It is essential that the crucial decisions in this first evacuation stage are taken by the train attendant. This was decided for the following reasons:

- The attendant is the one who has the most thorough knowledge of the situation on site. He can ascertain where the fire is located in the train, he can also estimate the extent of the fire and in which direction the smoke is spreading.
- He can therefore also react at once to any changes and take the necessary steps.

3.3 INTERACTION BETWEEN RESCUE CONCEPT AND TUNNEL VENTILATION

The emergency ventilation of the Wienerwald tunnel is arranged in such a way as to protect the safe area in the second bore in the event that smoke from the affected bore should spread to the safe bore through the transition area.

At present, the design does not propose, in the first phase of evacuation, to influence the spreading of smoke by means of emergency ventilation. The reason is that using the ventilation to influence the spreading of smoke could either improve or worsen the situation, depending on the location of the fire on the train, the location of the train in the tunnel, the position of any other trains in the tunnel, the behaviour of the evacuated passengers in the tunnel, etc.. The risk seemed too great that the lack of information or incorrect information in the first stage of an incident could lead to serious wrong decisions in a very complex situation. There are several other considerations which make an intervention under the conditions existing at the beginning of the incident rather undesirable (maintaining the direction of air flow prevailing at the beginning of the incident; taking advantage of the more favourable conditions for self rescue at the beginning of a fire accident, due to the vertical layering of the smoke gases).

That is why in the initial phase of a fire accident it is foreseen only to operate the emergency ventilation if the safe area in the second bore could be endangered. In both bores smoke detectors are positioned in the transition area so that the emergency ventilation will be turned on as soon as smoke gas approaches the transition area. In an advanced phase of the incident (e.g. to support the fire brigade) the traffic control centre shall also be able to operate the ventilation system.

However, the cross-passage ventilation will be put into operation as soon as the decision for an evacuation has been made. The only precondition is knowing which bore is affected in order to control the direction of ventilation air flow. The cross-passage ventilation can be started on site or from the traffic control centre.

4 OPTIMISATION OF THE SELF-RESCUE BY MEANS OF AN EVACUATION SIMULATION MODEL

4.1 OBJECTIVES OF THE SIMULATION CALCULATIONS

At present there is relatively little experience as regards the evacuation of a large number of passengers from trains in a twin-bore tunnel system with cross passages. In order to optimise the structures and the evacuation sequence, a simulation calculation was performed for the Wienerwald tunnel using an evacuation simulation model. Such a simulation calculation had also been made a condition during the permit application procedure.

The calculation had the following objectives:

- Realistically estimate the time required for carrying out evacuation as the basis for further considerations regarding the organisation of self-rescue and assisted rescue
- Proof of operativeness of the overall system, also for trains carrying large numbers of passengers
- Identification of problem areas along the escape route, from leaving the passenger carriage to reaching the safe area
- Proposing and reviewing improvement measures.

4.2 EVACUATION SIMULATION MODEL

<u>Software</u>

For the calculation the simulation software Building Exodus 3.0 was used.

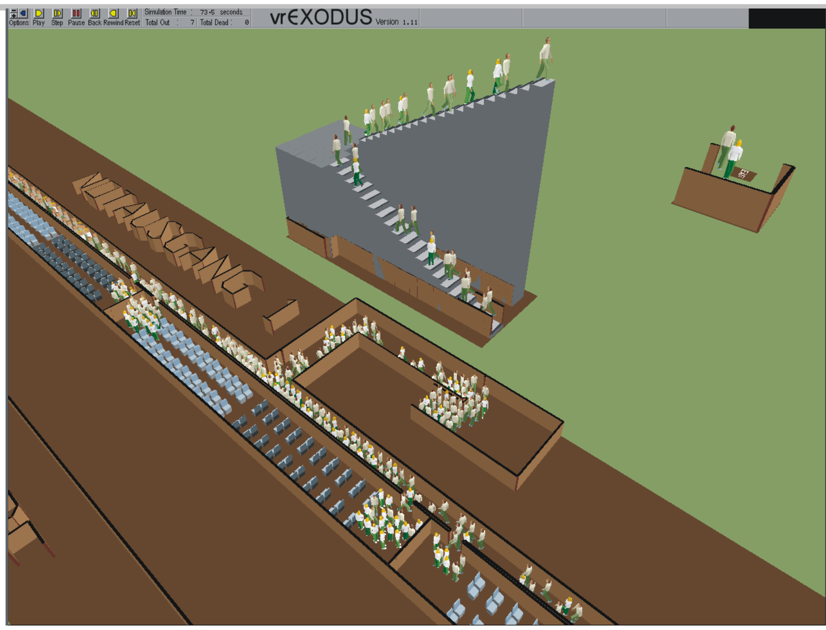
BuildingEXODUS software is an evacuation model for the built environment that can be used for evaluating the emergency and not-emergency movement and behaviour of people. BuildingEXODUS enables the analysis of complex people – people, people – structures and people – environment interactions

The three submodels of the software are:

- Movement:
  Controls the physical movement of individual occupants from their current position to the most suitable neighbouring location, or supervises the waiting period if such a location does not exist. The movement may involve such behaviour as overtaking, side stepping or other evasive actions.
- Behaviour:
  Determines an individual's response to the current prevailing situation on the basis of their personal attributes.
- Occupant:
  Describes an individual as a collection of defining attributes and variables such as gender, age, max running speed, max walking speed, response time, agility, etc.

Figure 3:

Evacuation of passengers in a railway tunnel; simulated with vrEXODUS



<u>Scenarios:</u>

Using a manageable number of scenarios, the decisive influencing parameters were to be identified and the influencing variables analysed. For this purpose an approx. 1000-m-long section of the twin-bore tunnel with 3 cross passages was selected, with the following parameters being used for the crucial elements of the escape route.

Table 1: Parameters for the key elements of the evacuation route

Passenger carriage (without compartments):	26 m long; distance between doors 23 m
Width of lateral escape route:	approx. 2 m
Distance between cross passages:	500 m
Door width of cross passage:	2.0 m
Width of cross passage:	2.25 m
Length of cross passage:	approx. 20 m

The following scenarios were investigated – partly in combination with each other:

Person model:

– Train with 10 carriages and average number of occupants –500 persons in total

– Train with 15 carriages and maximum number of occupants – 1300 persons in total

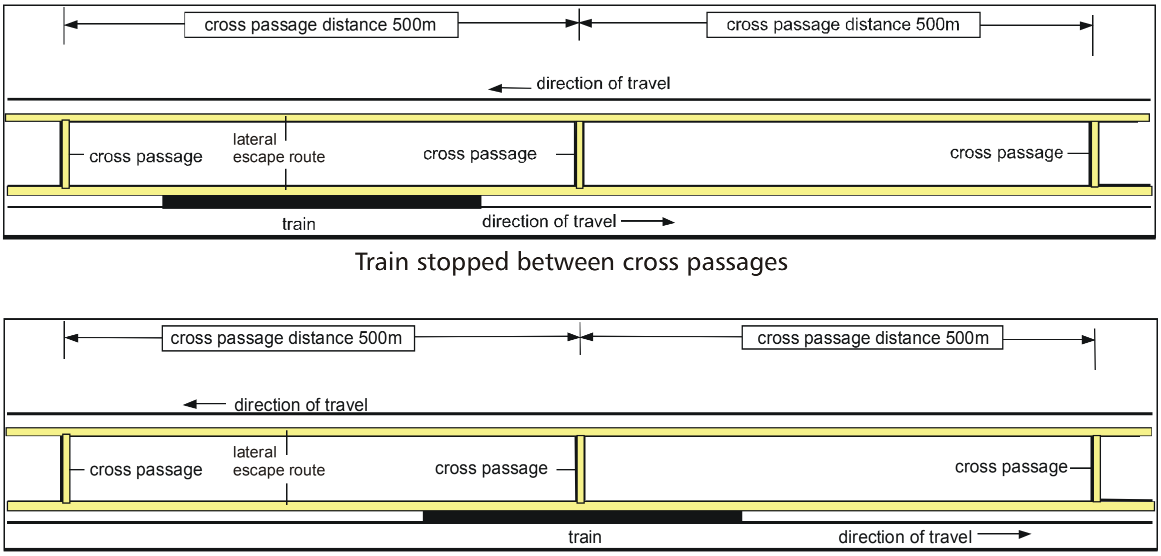
Position of train:

– Train has stopped so that the cross passage is halfway between the front end and the rear end of the train

– Train has stopped between two cross passages

Figure 4:

Different positions of the train in relation to the cross passages



Train stopped between cross passages

Train stopped in front of cross passage

Boundary conditions of the evacuation:

– Evacuation without restrictions

– Evacuation with limited visibility on account of incipient smoke build-up – variation of the position of the assumed fire (front end of train / centre of train / rear end of train)

The limited visibility was simulated by progressively reducing the walking speed to 50 % of the initial speed.

Assumed behaviour of people:

– In case of an evacuation without restrictions it is assumed in the simulation that the people walk to the nearest emergency exit by following the emergency escape signs.

– In case of an evacuation with smoke build-up it is assumed, in accordance with the results of the air flow calculations, that even after the train has stopped an air flow remains for several minutes in the direction of travel so that the smoke at first spreads in the direction of travel. It was furthermore assumed that the fire cannot be passed neither on the train nor outside. People therefore escape on both sides of the fire, away from the fire. Those in front of the source of the fire thus have to escape in the smoke filled tunnel in the direction of flow.

Construction of door area of cross passages:

– First, the variant described in the permit application design was reviewed: the railway authorities criticized that, although the doors open from the affected bore to the cross passage in the escape direction, the second door from the cross passage to the safe bore can only be opened against the escape direction (see Fig. 6a). In this regard it was investigated what the consequences are when only one door leaf can be opened and the second door leaf is blocked by the people thronging forward.

– Alternatively, a cross passage was investigated which has an additional door, on the side, which can be opened in the escape direction and which therefore serves as “exit” from the cross passage to the safe bore.

– This solution only entails relatively little additional expenditure, since all cross passages are constructed in the required width (to accommodate the equipment rooms for the technical railway installations)

Figure 5a:

Types of cross passages - "Einreichvariante"

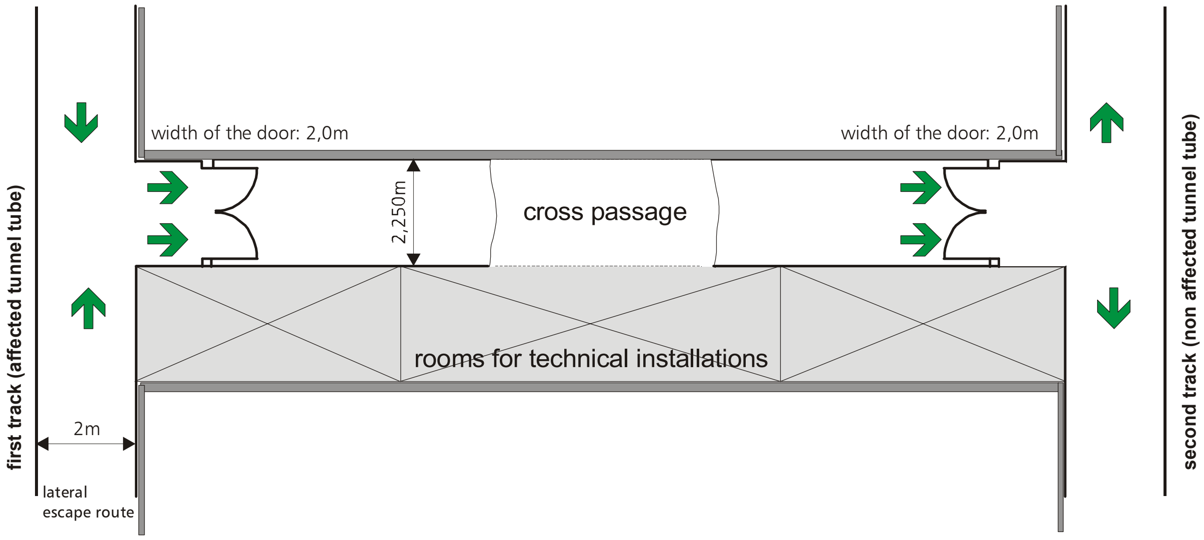
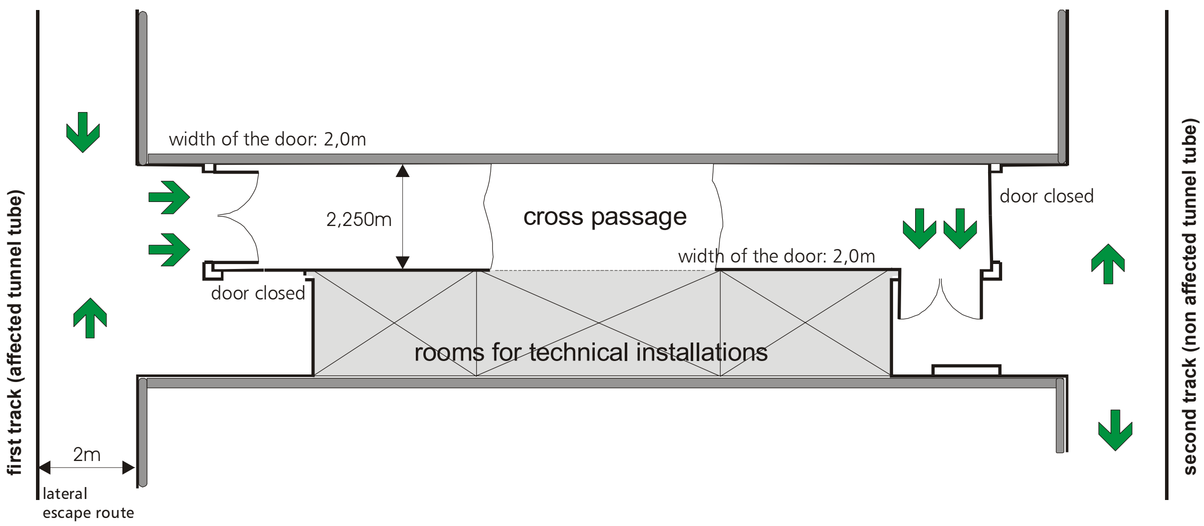


Figure 5b:

Types of cross passages - new type



4.3 RESULTS

Total evacuation time:

The total evacuation time consists of the following:

- Decision time (recognising the danger – coordination with traffic control centre – decision to evacuate the train – instruction to effect self-rescue);
  for all scenarios a constant period of 2 minutes was assumed – this period is realistic if the communication sequences are well organised
- Evacuation time (leaving the carriage – moving away from the danger zone – walking to the safe area, possibly congestion in front of the emergency exit – exit to the safe area in the second bore);
  this value was calculated by means of the simulation programme.

Depending on the position of the train in relation to the cross passages, smoke build-up and location of the fire, the overall evacuation time is

- for a train carrying 500 persons between 6 and 21.5 minutes
- for a train carrying 1300 persons between 10 and 23.5 minutes

The scenario-dependent figures are listed in the table below.

Table 2: Total evacuation time for investigated scenarios

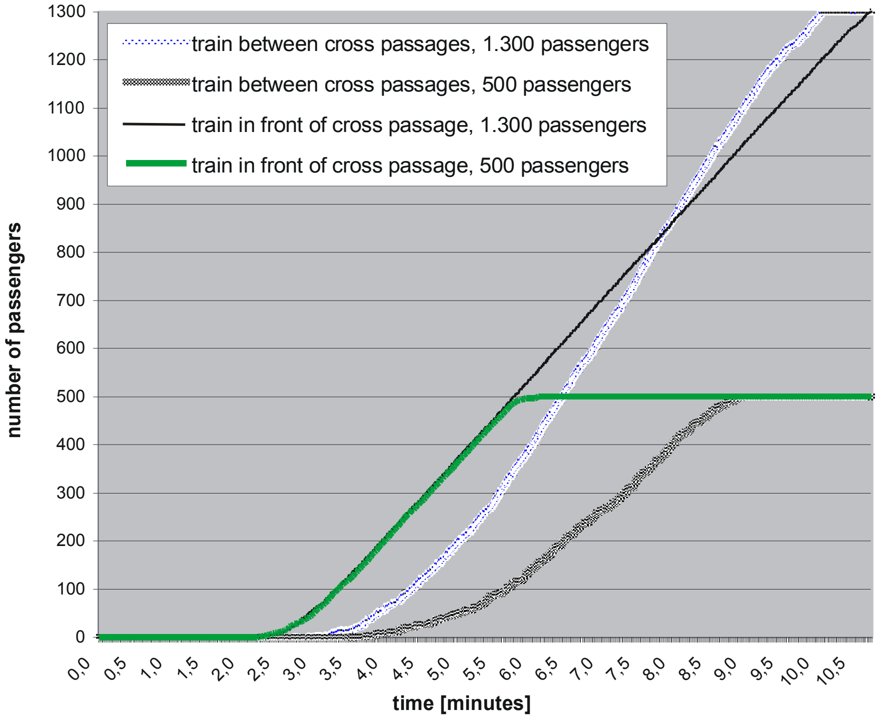
Scenarios	Number of passengers	Train between cross passages	Train in front of cross passages
No smoke build-up	500	8 min 55 sec	6 min 07 sec
	1300	10 min 02 sec	10 min 44 sec
With smoke build-up at rear end of train	500	14 min 57 sec	6 min 43 sec
	1300	20 min 50 sec	11 min 07 sec
With smoke build-up at train centre	500	10 min 31 sec	21 min 27 sec
	1300	12 min 17 sec	23 min 31 sec
With smoke build-up at front end of train	500	12 min 37 sec	6 min 23 sec
	1300	18 min 28 sec	10 min 40 sec

In particular, the following conclusions can be drawn from the results:

- If the evacuation takes place under favourable boundary conditions (no smoke build-up) the number of persons (500 to 1300 persons) and the position of the train in relation to the cross passages has amazingly little influence and the overall evacuation times are relatively short. The period ranges from 6 to just under 11 minutes.
- In the case without any smoke build-up and stop of train so that the cross passage is halfway between the front and rear end of the train, the limiting factor is the capacity of the doors of the cross passage (people thronging forward from two sides to one exit – see linear increasing graph lines in figure 7).

Figure 6:

Number of passengers reaching the safe area in relation to time



- The width of the lateral escape route (generously dimensioned in the case of the Wienerwald tunnel) is not a limiting factor in either case.
- Smoke build-up in the tunnel bore and especially the forced selection of a different escape route due to the unfavourable position of the fire has a much greater influence (people will escape away from the fire and will not try to get past the fire). The most unfavourable situation occurs when the source of the fire is located in the immediate vicinity of a cross passage so that it cannot be used and people have to escape to the next cross passage (evacuation time 21.5 – 23.5 minutes). This situation can be avoided by stopping the train immediately before a cross passage. Another unfavourable scenario is when the fire is located at the rear end of the train and all passengers have to escape through the smoke filled area (15 – 21 minutes).
- Opening the doors at the cross passage exit in the opposite direction to the escape direction is not a serious problem when the train has stopped between the cross passages people arrive at the cross passage with a time delay and at first singly or in small groups; failing to open one door leaf only causes a delay of 10 % when the train has 1300 passengers.
- This changes significantly when the train stops directly in front of a cross passage, people very quickly arrive in great numbers at the door; with a train carrying 500 persons there is a delay of up to 20 %, in case of 1300 persons there is a delay of over 60 %.
- The redirection of the stream of people in the alternative cross passage construction in the most unfavourable scenario in comparison only causes a delay of 10 %; that is why this variant was adopted for the project.

5 CONCLUSIONS

In summary, the analysis of the self-rescue sequence in the twin-bore section of the Wienerwald tunnels yielded the following results.

1. The evacuation simulation model provides a detailed analysis both of the building structures and the organisational sequence of the evacuation of a passenger train in the Wienerwald tunnel. the model has proved to be very flexible and made a differentiated depiction of all decisive influencing factors possible.
2. In detail this tools can be used to
   - identify the weak points of the escape route
   - depict the effect of changes quantitatively (impact on evacuation times) and qualitatively (analysis of the evacuation sequence)
   - gather important findings for a scenario-related, more precise emergency planning
3. The building structures in the Wienerwald tunnel have proven to be very functional and allow rapid evacuation even of a large number of people (1300 person in just 11 minutes)
4. The results of the analysis contributed significantly to the decision on the design of the cross passages
5. The analysis also showed that for some scenarios the evacuation time could be much longer (more than 23 minutes); above all when an unfavourable location of the fire coincides with an unfavourable position of the train in the tunnel.
6. The analyses have shown that the position of the train in the tunnel in relation to the emergency exits greatly influences the evacuation time. Since it is possible to influence where the train stops in the actual event, this constitutes a starting point for further investigations to improve the self-rescue concept.

REFERENCES

[1] F. Bauer; B. Kohl; Ch. Neumann
Safety Design for the Wienerwald Tunnel – from the decision on the tunnel system to the permit application design
Safety in Road and Rail Tunnels, Fourth International Conference
Madrid, April 2001

[2] Building Exodus 3.0 Manual
University of Greenwich, 2000

[3] Transporttechnik der Fußgänger, transporttechnische Eigenschaften des Fußgängerverkehrs
Schriftenreihe des IVT Nr. 90, ETH-Zürich
Zürich, March 1993

[4] Grundlagen zur Berechnung der Fahrgastwechselzeit
Schriftenreihe des IVT, Nr. 106
Zürich, June 1995

[5] Lüftungstechnische Untersuchungen zum Wienerwaldtunnel
EB-Operat Notfallentlüftung
ILF Consulting Engineers commissioned by HL-AG
Innsbruck, December 2002