ABSTRACT

As escape ways are an integral part of rail tunnel safety, the escape doors themselves require particular attention. The doors must be solid enough to withstand the high pressure fluctuations caused by high-speed rail traffic, and must also be capable of withstanding high temperatures.

This paper focuses on the defined temperature requirement for escape doors in the Koralmtunnel. Various regulations define the temperature requirements, e.g. for concrete surfaces. These requirements define temperature levels and exposure times in the form of time-temperature curves. As there is no uniform international standard, the requirements imposed depend more or less on national policy. Well-known temperature curves are the HC curve, the HC-increased curve, and the ‘standard fire time-temperature curve’, in accordance with EN 13501-2. All of these differ in terms of maximum temperature value, time dependent increase in temperature, and duration of temperature exposure.

In order to define a credible temperature requirement for tunnel doors, numerical investigations were performed taking an incident with a maximum heat release rate of 100 MW as a thermal boundary condition. These investigations resulted in a time-temperature curve which could be used in testing the fire resistance of escape doors. The results from an analysis of temperature and heat release data from full-scale fire tests up to 200 MW peak heat release confirmed the validity of the newly-defined test conditions. It turns out that the ‘standard fire time-temperature curve’, as defined in EN 13501-2, represents reliable test conditions.

Keywords: Emergency doors, thermal resistance, tunnel safety, CFD calculations

1. INTRODUCTION

The so called ‘southern corridor’, with the Koralm railroad and the Koralmtunnel, is part of the some 1,800 km long Baltic – Adriatic rail corridor of the Trans European Network – Transport (TEN-T) [2], [3].

The Koralm railroad connects the Austrian federal regions Styria and Carinthia, and their capital cities, Graz and Klagenfurt. This new, high-performance track is characterized by very low track gradients. It reduces the travel distance between the two capital cities by 100 km and the travel time by more than 2 hours.

The core part of this new route is the Koralmtunnel with a length of 32.9 km, and is currently the 6th longest railway tunnel in the world. The maximum rock overburden is some 1200 m.

An emergency stop station with a length of 900 m is situated between the two tubes roughly in the middle of the tunnel. Cross passages are located every 500 m. These serve as escape routes and also house the necessary equipment required for tunnel operation and maintenance.
2. REQUIREMENTS FOR ESCAPE DOORS

2.1. General

Upon operation, the Koraln railroad will constitute an important part of the TEN-T. A high level of safety and reliability/availability are thus of the utmost importance. In the event of a fire, it is essential that passengers can be evacuated to so-called safe areas. The use of appropriate escape doors in the safe areas is thus a key element of any safety plan. These doors must comply with multiple (sometimes conflicting) requirements. For example, while the need for doors to withstand high pressure fluctuations and high temperatures implies the use of heavy doors, this may also make it more difficult for passengers to open the doors. An overview of the various requirements for escape doors can be found in [4].

2.2. Pressure fluctuations

All equipment within the tunnel is exposed to high pressure fluctuations resulting from rail traffic. Pressure waves caused by trains entering the tunnel, and reflected at the exit portal, can amount to some thousands of Pa, depending on type of the train, train speed, drag coefficients, and tunnel cross-section. These shock waves result in additional loads on doors, and exceed those resulting from static forces. Door durability and maintenance requirements are also important considerations ([5], [6]).

2.3. Fire resistance and time-temperature curves

In the case of a tunnel fire, train users must be evacuated into a safe area via escape doors. These doors must withstand the fire and provide sufficient shelter from the fire over a predefined time period (TSI-SRT survivable conditions). Standards such as DIN EN 13501 define the necessary level of fire resistance of escape doors.

Combustion is a process where heat and smoke are released. In practice, the release rate depends on many parameters and is largely unpredictable. After ignition the development of the fire depends on parameters relating to fuel, temperature, oxygen content, humidity etc. In order to have clear and replicable testing conditions, time-temperature curves are used to define subject exposure. All of these have a certain initial phase, where the temperature rises from ambient to maximum values. These curves are intended to idealize the characteristics of a design-fire. The maximum temperature to be achieved varies according to the different application ranges. For road and rail tunnels various time-temperature curves are in use, but no one has yet defined an internationally valid standard.

Viewed historically, the ‘standard fire time-temperature curve’ in accordance with EN 1363-1:2012/ISO 834 was the first attempt at standardization in Europe (around 1920). Other curves such as the HC-curve (1970’s), the RABT-curve (1985), the ZTV-ING curve (1995), the RWS-curve, and the HC_inc (for fuel fires in road tunnels) were then subsequently established. Research projects such as EUREKA 499 (FIRETUN), tests at the Runehamar test site, and others, aimed to verify the validity of these curves with respect to different fire sources, such as road and rail vehicles. In Austria, the so-called EBM/HC1200 curve was established for application in rail tunnels.

However, as seen in Figure 1, the majority of these curves has more or less the same shape and differs largely only in terms of maximum temperature level. Most of the curves are mainly applied to structural fire protection, while the ETK curve (standard temperature curve according to ISO 834) is often used for installations such as escape doors.
Which time-temperature curve best meets tunnel requirements is often the subject of debate and curve definitions normally represent a practical compromise between basic necessity and feasibility. However, due to the differences concerning the objectives of structural fire safety and escape way safety for tunnel users, the temperature requirements for the structure need not be identical to that for escape:

- Tunnel users require escape possibilities for a certain timespan related to the self-evacuation period
- Structural fire protection must guarantee the self-support of the tunnel and the escape ways

3. NUMERICAL SIMULATIONS

The objective of the investigations was to determine the temperature loads in the case of a fire acting on mechanical equipment (dampers, escape doors etc.) mounted in the area of the cross passages. For this study a cross passage with an escape door (sliding door including frame and guidance elements) mounted outside of the cross passage (this means towards the rails), was examined. While such door installations are required where there is a lack of space inside the cross passage they also result in the smallest distance to a potential fire source (worst case). Such a situation was analysed for a fire with a peak heat release rate of 100 MW and 75 MW. An additional case with a heat release rate of 75 MW and an escape door mounted inside the cross passage (affects approx. 90% of all cross passages of the Koralmtunnel) was also examined.

In order to minimize the requisite computational effort, only a tunnel segment of 290 m in the proximity of the fire location, and the cross passage under analysis, were considered. The fire source (a low floor carriage with a lorry) is located 180 m downstream of the inlet in order to provide enough space to avoid any adverse influences on the inlet boundary conditions, e.g. by a possible back layering of the hot smoke gases. Standard quality assurance procedures were applied in the CFD calculation (e.g. grid independency).

The highest gas temperatures normally appear some meters downstream of the fire source (see [8]). Based on this experience, the fire source with the dimension of 4.5 m x 3 m x 20 m (height x width x length) was situated approximately 3 m upstream of the centreline of the emergency door. Figure 2 shows the computational domain of the Koralmtunnel.

The tunnel segment considered has a cross section of 45.6 m² and a slope of 0.3%, and a concrete lining with a depth of 0.4 m. The concrete lining was taken into consideration when calculating the convective heat transfer. The physical properties used were: specific heat capacity of 1000 J/kgK, a density of 2400 kg/m³, heat conductivity of 2.0 W/mK and an initial rock temperature of 15°C.
3.1. Numerical Model

ANSYS Fluent software was used for the numerical study. Turbulence was modelled using the realizable k-ε model [7] and the enhanced wall function. A hybrid mesh comprising a few million elements was applied for the discretization of the 3D geometry analysed and a method with second order accuracy was selected for the numerical computation of the conservation equation.

In the case of fire, the ventilation system provides a volume flow rate upstream of the fire location of approx. 70 m³/s. This results in an air velocity of approx. 1.5 m/s (inlet boundary condition). An air temperature of 15°C at the inlet was assumed. For the outlet, an outlet pressure boundary condition with an average gauge pressure of 0 Pa was chosen.

The surface of the escape door was defined to be adiabatic. This means that the temperature at the surface of the escape door is equal to the gas temperature adjacent to the escape door and that the escape door does not influence the surface temperature due to the heat transfer (depending on heat conductivity and specific heat capacity of the escape door). This makes it possible to compare the calculated gas temperature at the escape door with the fire time-temperature curves (see Figure 1).
The fire is represented by a volumetric heat and mass source as suggested in [10]. Thus the numerical model does not simulate the combustion process and requires information on the heat release rate (HRR), the mass source, the time course and so on. For this, it was assumed that the fire exhibits a linear increase in heat to the maximum HRR within 5 minutes (which represents a strongly conservative approach), followed by a constant HRR for the remaining simulation time. Both, the increase of the HRR and the retention of the peak value represent an extreme fire scenario and are therefore a strongly conservative approach. Real fire tests e.g. the Runehamar fire tests, showed that the time to peak for such heat release rates (100 MW and 75 MW) was consistently >10 minutes and the peak value was retained only for some minutes [9]. Nevertheless, these characteristics of the heat source were chosen in order to consider a worst case scenario. As heat source, fossil fuel with a calorific value of 42.6 MJ/kg was used. This results in a fuel mass flow of 2.35 kg/s for the 100 MW case, and 1.76 kg/s for the 75 MW case.

Owing to the expected high soot proportion of the combustion gases and their insulating properties, the effects of thermal radiation were neglected. Hence, it is assumed that all heat release is captured in convection.

Simulations were carried out until steady state flow conditions were obtained. Longer simulation times would only result in an increase of the wall temperatures, which can be assumed would only have an insignificant effect on the temperature load on the escape door.

3.2. Results

In all simulation cases, steady state flow conditions were recorded after 10 minutes simulation time. Figure 4 depicts the temperature distribution after 10 minutes at the surface of the escape door (right) and in the tunnel cross sections at the heat source (left) as well as in a plane parallel to the floor (at half the height of the escape door). It can be observed, that in addition to the longitudinal air flow, a secondary flow with two counter-rotating vortices is formed. Due to these vortices hot smoke gases move from the tunnel ceiling to the bottom along the tunnel profile, resulting in a relatively high temperature gradient between the traffic room and the cross passage (see Figure 4). Because of this flow pattern the gas temperature in the cross passage region, as well as at the escape door, is noticeably lower than in the traffic room.

Figure 5 (100 MW case) and Figure 6 (75 MW case) depict the temperatures at the surface of the escape door (maximum local temperature and the area-averaged temperature) and compare them with commonly used time-temperature curves. After reaching steady state flow conditions the temperature values were extrapolated for the considered time period of 90 minutes.

For the 100 MW fire case maximum local temperature amounted to 1095°C and the area-averaged temperature to 860°C for the installation case “outside”. For the same installation, but a fire size of 75 MW, the temperature values are lower by about 20%. Considering the installation case “inside”, the maximum local temperatures are lower by about 10%. However, although the escape door is in this case less exposed to hot smoke gases, the area-averaged temperatures are almost the same. Owing to the strong increase of the heat release rate (time to peak of 5 minutes), a strong increase of the temperature values at the escape door can be observed. This leads to the situation that for this period (the first 30 minutes) the area-averaged temperatures overshoot the values of the standard fire time-temperature curve (ETK/ISO834). For the remaining time they remain below the ETK/ISO834 values.
100 MW after 10 minutes (escape door outside)

75 MW after 10 minutes (escape door outside)

75 MW after 10 minutes (escape door inside)

**Figure 4:** Temperature distribution and velocity vectors in the traffic room and on the escape door for all simulation cases after a simulation time of 10 minutes
An evaluation of the total energy input (area under the curve and calculated according to eq. 1) results in the fact that for all simulated cases the energy input is below the energy input resulting according to the standard fire time-temperature curve (ETK/ISO834). When defining the specific energy input (which can also be considered as time-average temperature) it was assumed that the heat transfer coefficient \( h \), and the area of the escape door \( A \), are constant for all calculated cases.

\[
\frac{\dot{Q}_{90}}{A \cdot h} = \int_0^{90 \text{min}} \Delta T(t) \cdot dt / 90 \text{min} \quad \text{eq. 1}
\]

Figure 7 depicts the specific energy input, the maximum area-averaged and maximum local temperature at the escape door for all simulated cases compared to the values related to the standard fire time-temperature curve (ETK/ISO834). In all cases the ETK/ISO834 scenario reflects the worst case, except for the maximum local temperature in the 100 MW fire.
However, a HRR of 100 MW at a volume flow rate of 70 m$^3$/s is a theoretically attainable value. Real fire tests in tunnels have shown that the heat release rate is restricted by the effective calorific value and the required amount of air/oxygen (see chapter 3.3). Hence, in the case of real combustion, the HRR at an air-volume flow rate of 70 m$^3$/s is lower (by about 90 MW, see Figure 9). A 90 MW fire case would result in a maximum temperature of some 1000°C and would be in the range of the ETK/ISO834 values.

![Figure 7: Temperature load on the escape door in all simulation cases compared with the values of the standard fire time-temperature curve (ETK/ISO834)](image)

3.3. Discussion of the results

The simulations were performed for a specific tunnel geometry. In order to test the validity of the results with respect to other combinations of heat source, tunnel geometry and air volume flows, comparisons with results from full-scale tests were performed.

In order to do this the fire characteristics (calorific value $H_W$, minimum air requirement $L_{\text{min}}$ etc.) for two of the Runehamar fire tests (with a peak heat release rate of about 200 MW and 120 MW, see Figure 8) were analyzed and the minimum air requirement derived. The data used for this process are summarized in Table 1 and were obtained from [9] and [11].

At a given air mass flow rate $\bar{m}_L$ the peak HRR $\tilde{Q}$ mainly depends on the fire load (type of fuel), the efficiency of the combustion and the interaction between the fuel and the passing air (how much air/oxygen reaches the surface of the fuel). When comparing the two selected tests (T1 and T3), it can be seen that the mass flow rate of the air was the same for both cases (same amount of oxygen). However, T1 resulted in a HRR maximum that was twice as high, due to a higher calorific value of the fuel and the fact that oxygen (air) could penetrate the combustibles (wooden pallets) in a uniform way.
Based on the calorific value and the minimum air demand of both tests, the maximum HHR - as a function of the volume flow rate upstream of the fire - was determined, and is shown in Figure 9 (left). The diagram also includes the results from the simulation cases 100 MW and 75 MW at an air volume flow rate of 70 m³/s. As can be seen, in the simulation for 100 MW, HRR exceeds the values found in the real fire tests. For a volume flow rate of 70 m³/s, it is supposed (based on T1 data) that the achievable maximum HRR is lower (~90 MW), due to oxygen limitations.

As shown in Figure 9 (left), the HRR increases linearly with volume flow rate. On the other hand, when keeping the HRR constant the mean temperature at the location of the fire \( T_B \) decreases linearly with the increasing volume flow rate. The right side of Figure 9 depicts temperature vs. volume flow rate. It can be seen, that the mean temperature remains constant with increasing volume flow rate even as the HRR increases and only depends on the calorific value and the minimum air demand.

Figure 9 (right) depicts the mean temperature at the location of the fire depending on the volume flow rate. Data was derived from the Runehamar fire test (T1 and T3) and the numerical simulations. The maximum value of the air temperature recorded during the fire test T1 was 1365°C (202 MW). This also indicates that the temperature level of the simulated 100 MW fire
(at a volume flow rate of 70 m³/s) is too high. Hence, it can be concluded that the simulation reflects more of a theoretical case than reality.

![Figure 9: Heat release rate and mean temperature at location of fire, depending on the volume flow rate derived from the Runehamar fire tests acc. to [9] and [11] and obtained from the simulations](image)

4. SUMMARY AND CONCLUSIONS

The aim of this study was to determine the temperature load on the escape doors for the tunnels of the Koralmtunnel in order to derive a representative fire time-temperature curve when testing the fire resistance of the escape doors. For this a CFD-model based on the Koralmtunnel geometry was created and the temperature load of the escape door for a fire with a heat release rate (HRR) of 100 MW and 75 MW was evaluated. The results of this CFD study were then compared to data from full-scale fire tests.

An evaluation of the full-scale fire test showed that the HRR increases almost linearly with the mass/volume flow rate in the tunnel (owing to an increase of oxygen) but the mean temperature at the location of the fire remains constant as the mass/volume flow rate increases (assuming the same fuel/calorific value and minimum air requirement).

Based on data from the CFD study, together with data from the full-scale tunnel tests, a maximum temperature of 1000°C and an area-averaged temperature of about 860°C at the escape door was derived. These results are valid for tunnels with a similar shape and flow characteristics (secondary flow with two vorticities as presented in Figure 4) and are then independent of the mass/volume flow rate in the tunnel.

This study leads to the conclusion that escape door fire resistance may be adequately tested using the standard fire-temperature curve, as defined in DIN EN 1363 or ISO 834.

5. REFERENCES

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