VENTILATION OF PROTECTED AREAS IN ROAD TUNNELS

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ABSTRACT
During the past few years big efforts have been undertaken to improve the safety of the tunnel users. Even though signalisation, ventilation, detection, alarming as well as the education of the users have been examined and enhanced certain risks remain. Normal truck loads can initiate tunnel fires that are overwhelming for all technical equipment designed for a limited size of incident. Under this aspect the ventilation of the protected areas, which can be summarised as being the path between the escape doors and the environment, gets an important role for the safety of the tunnel users as well as for the rescue personnel.

Key words: tunnel, ventilation, design, protected areas, escape way, emergency exit, lock, safety

1. INTRODUCTION
The fatal fire disasters in the years 1999 and 2000 have influenced the public discussions in a way that new and more stringent requirements for tunnel ventilations had to be established. In Switzerland the general design rules of 1983 are replaced by the requirements of the guideline Ventilation of Road Tunnels. The guideline includes indications for the maximal distance between the emergency exits. The Federal Road Administration (FEDRO) plans to set up a separate guideline for the ventilation of the escape ways this year. The aim is to set a standard for sufficient protection and for rigid systems with low energy consumption during the permanent operation. The paper here presented is based on the provisional version GR 2003 which was mandated by the Civil Engineering Department Canton Grisons. Presently in the canton Grisons several long safety galleries are planned or are under construction.

2. EMERGENCY EXITS
2.1. General remarks
Emergency exits as part of the safety concept have to be adjusted to the ventilation system in the tunnel itself. Therefore the concept of emergency exits and escape ways is integrated in the Swiss guideline for Tunnel Ventilation. A second reason for the integration of escape ways in the mentioned document is a possible interaction of its ventilation systems with the one of the tunnel itself.

2.2. Maximal distance of emergency exits
The requirements in the former guideline of 1983 allowed the construction of single bore tunnels with smoke extraction over the full tunnel length without emergency exit. One of the lessons that had to be learned from the recent fatal tunnel fires were that

- the detection systems are too slow to give an acceptable chance for the tunnel users to escape
- the smoke layering in a real case is less ideal than assumed
- the extraction density in m³/s·m of the conventional ventilation systems is far too small to prevent a large tunnel length to be filled with smoke
Even though the FEDRO-guideline 2003 prescribes for long tunnels the installation of a locally forced extraction capacity by means of controllable dampers, maximal distances between emergency exits for all road tunnels types have be defined as well.

For dual bore tunnels the distance of the cross connections remains 300 m. Every third cross connection has to be sized for the passage of large equipment of the fire brigade. In accordance with the European directive on Minimum Safety Requirements for Tunnels in the Trans-European Road Network the maximal distance between emergency exits in single bore tunnels is generally set to 500 m. In the Swiss guideline FEDRO 2003 the distances are specified according to the fact whether there is natural or mechanical ventilation of the tunnel and according to the tunnel slope. The basic assumptions for the determination are

- a reaction time of the tunnel users of 3 minutes
- a reasonable time to reach the next emergency exit of 3 to 5 minutes depending on the ventilation system
- a walking speed of 2.4 m/s in slopes up to 2 % and of 1.2 m/s at a slope of 8 % with a linear interpolation at slopes in between.

The resulting maximal distances are shown in Figure 1.

Figure 1: Maximal distance of emergency exits in single bore road tunnels

The values in Figure 1 apply as well for unidirectional tunnels without a parallel tube. The construction of new tunnels with slopes higher than 5 % should be avoided. Nevertheless tunnels with higher slopes already exist especially in the alpine region and it is questionable if steep tunnels can always be avoided in future.

3. DEFINITIONS
For a proper understanding of the following chapters it is necessary to define some special terms:

Area with primary risk Area with the incident. In this zone all emergency exits are opened presumably. For the design of the ventilation of the protected area in this paper it is assumed that the length of the zone with primary risk is 600 m for tunnels with smoke extraction, for tunnels with other ventilation systems it is the tunnel length but not more than 1'200 m.

Protected area Area between the escape door at the tube with the incident and the open. In a dual bore tunnel the non-incident bore is part of the protected area.

Escape door Door marked as emergency exit between the area with primary risk and the protected area. It must be possible to open escape doors easily at any time. The escape door can be integrated in a larger gate for vehicle passage.
Intermediate door: Door which can be opened at any time within the protected area. An intermediate door is not a part of a lock.

Safety gallery: A tunnel leading from the road tunnel to the open. A parallel safety gallery is connected with the road tunnel by connecting tunnels and leads at its two ends to the open. A safety gallery leading directly to the open has only one exit to the open.

Connecting tunnel: Connection between the road tunnel and the safety gallery.

Cross connection: Connection between two parallel tubes.

Lock: Passage space with two interlocked doors. A lock allows a continuously controlled overpressure.

Normal operation: State of the ventilation without special incident.

Emergency operation: State of the ventilation during an incident during which the emergency exits might be used.

4. ARRANGEMENTS OF ESCAPE WAYS

For the design of the ventilation of the escape ways four different arrangements have to be regarded. Figures 2 and 3 related to one bore tubes - mainly tunnels with bidirectional traffic - figures 4 and 5 show double bore tunnels with unidirectional traffic.

Figure 2: Arrangement with a parallel safety gallery

Two exits to the open equipped with locks characterises the arrangement of the escape ways in figure 2. Depending on the design of the aerodynamic system intermediate doors can reduce the necessary installed power.

Figure 3: Arrangement with safety galleries leading directly to the open

The necessity of a controlled overpressure with a lock in safety galleries leading directly to the open depends on its length and its slope. A length over 30 m or a difference of height over +3 m were chosen as criteria.
Figure 4: Arrangement with cross connections between two tubes

In drilled two bore tunnels the non-incident tube represents the escape way. The distance between the bores is big enough to allow two escape doors on either side of each cross connection. Instead of shifting the exit portal by 30 m a dividing wall of at least 30 m length can be built (see figure 5) in order to prevent a recirculation of smoke.

Figure 5: Arrangement with cross connections between two tubes of a cut and cover tunnel

Usually a simple wall divides the two tubes of a cut and cover tunnel. As a consequence only one escape door per cross connection is possible. The portals of such tunnels are closely adjacent. Additionally to active means with the tunnel ventilation separating walls or shifted portals (see figure 4) have to guarantee a sufficient protection against recirculation of smoke or other harmful gases from one tube to the other. (Further indications are given in FEDRO 2003, ch. 7.2.6)

5. VENTILATION

5.1. Goals

The design goals for the ventilation of the protected areas are

- In normal operation: Reduce the intrusion of pollution (A small transmission of pollutants is acceptable.) The slight overpressure gives at the same time a certain protection against smoke transmission even before the emergency operation is functional. Minimise the energy consumption of the permanently running system.

- In emergency operation: Keep the protected area sufficiently clear of smoke and other harmful gases.

5.2. Basic requirements

For arrangements with safety galleries the basic requirements for pressure, air speed, volume flow and fan redundancies are tabulated in figure 6.
Type of operation and fan failure | Type of requirement Setting | Arrangements with parallel safety gallery (fig. 2) | Arrangements with safety gallery directly to the open (fig. 3)
--- | --- | --- | ---
Normal operation | Δp at closed escape doors  
Air flow per closed escape door | 50 Pa  
0.2 m³/s | 50 Pa  
0.5 m³/s
Emergency operation, all fans available | - 1 single escape door open  
- 3 adjacent escape doors open  
- 2 escape doors in unfavourable position open | 3.0 m/s  
1.5 m/s  
1.5 m/s | 3.0 m/s
Emergency operation, failure of a single fan | - 1 single escape door open  
- 3 adjacent escape doors open  
- 2 escape doors in unfavourable position open | 2.0 m/s  
1.0 m/s  
1.0 m/s | 2.0 m/s
Emergency operation, total failure of a fan station | - 1 single escape door open  
- 3 adjacent escape doors open  
- 2 escape doors in unfavourable position open | 1.6 m/s  
0.8 m/s  
0.8 m/s | No requirement  
Only 1 fan station

Figure 6: Basic requirements for the ventilation of safety galleries of single tube tunnels

The installed system has to meet the requirements in figure 6 including adverse effect from the tunnel ventilation in an emergency case as well as unfavourable thermostatic and barometric conditions.

For arrangements without a safety gallery the tunnel users have to escape through a tunnel tube and a portal. In tunnels with two tubes the cross connections and the non-incident tube have to be kept sufficiently clear of smoke and harmful gases by one of the following concepts:

a) Normal case for two bore tunnels with two escape doors per cross connections (figure 4): The design of the escape doors minimises the cross flow: The second hinged door must close by the air flow or supported by a closing mechanism. Sliding doors must be equipped with closing mechanism.

b) Normal case for cut and cover tunnels: Cross connections are equipped with sliding doors with closing mechanism.

c) Special case: In rare cases - depending on length and slope of the cross connection - a mechanical ventilation can be necessary. As a rule to define a special case a height difference of more than 3 m between the two escape doors of the cross connection can be used.

The cross connections in the concepts a) and b) are not mechanically ventilated. In normal operation the ventilation of concept c) must be chosen individually in order that a comparable safety standard as with the arrangement for concepts a) and b) is reached. In emergency operation with concept c) the corresponding requirements in columns 3 or 4 of figure 6 must be fulfilled. The force of sliding doors that are self-closing must not endanger fleeing tunnel users.

5.3. Special requirements and standard values

Doors and gates:

Typical Dimensions

Door for person passage only: W x H = 1.25 m x 2.10 m
Gate for small personnel cars and service cars: W x H = 2.60 m x 2.30 m with integrated door: W = 1.25 m
Gate for large rescue vehicles: W x H = 4.50 m x 4.50 m with integrated door: W = 1.25 m

Gates for large rescue vehicles are required in two bore tunnels at intervals of 900 m.
• Fire resistance
  The fire resistance of the escape doors is 30 minutes (T30). A higher fire resistance of escape doors leading to an escape tunnel under overpressure is presently discussed (T90). For intermediate doors no special requirement concerning fire resistance is set.

• Force to open
  The maximum allowable force to open the doors must not exceed 80 N. For the design of doors with “crash-bars” the force to open the doors has to be assumed in the middle of the bar.

• Opening concept
  The opening concept can be hinged doors or sliding doors. All escape doors in a tunnel must be of the same type. Mechanical opening aids should be avoided. In any case such aids must not block the door.

Detection in the protected area:
• The intake for fresh air of the protected area must be equipped with smoke detection.
• Detection of fire and smoke is not required neither in safety galleries nor in cross connections. A fire in technical equipment is reported by a technical alarm.

Periodical tests:
• Periodical tests must guarantee the functionality of the system. The results have to be documented.

Initialisation of emergency operation:
• Fire alarm in the tunnel
• Pre-alarm in the tunnel (e.g. alarm from fire extinguisher)
• Opening of escape door
• In a safety gallery: Drop of overpressure of more than 50 % during 30 seconds
• Manual initialisation

5.4. **Resulting systems**

The above described requirements lead to ventilation systems for safety galleries with the following characteristic values:

<table>
<thead>
<tr>
<th>Installed power</th>
<th>10 kW/km</th>
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<tbody>
<tr>
<td>Used power</td>
<td>200 W/km in normal operation with energy costs of €400/km, year</td>
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</tbody>
</table>

6. **OUTLOOK AND ONGOING WORK**

The publication of the guideline for the ventilation of road tunnels and a guideline for the ventilation of protected areas is planed this year. Presently a guideline for doors in road tunnels is established. The Swiss Road Administration coordinates the work for the different guidelines.

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**REFERENCES**

- Swiss Federal Road Administration, FEDRO 2003: Guideline for the Ventilation of Road Tunnels – Choice of System, Design and Equipment, Draft of December 19, 2003 (in German and in French)