SLOVAK ROAD TUNNEL GUIDELINE

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ABSTRACT
The Slovak Republic has 4 existing road tunnels and will build 17 new road tunnels with lengths of 280 m to 7460 m in the next years. In order to harmonize the planning process and to establish uniform requirements for all road tunnels, the Slovak Tunneling Association together with the Slovak Highway Company and external planners has established a new road tunnel guideline.

This guideline follows in particular the requirements of the EU guideline on minimum safety requirements for tunnels in the Trans-European Road Network from 29 April 2004. Further, it pursues consequently the approach to specify functional requirements, i.e. it sets primarily the ventilation aims. These aims represent in turn the safety level required by the Slovak Republic, which exceed the EU requirements.

The specifications of functional requirements accounts for the fact that optimal technical solutions are different for all tunnels, even tunnels which appear similar. Hence, the guideline gives the planner at the time clear guidance about minimal requirements for road tunnels in the Slovak Republic and relies on his expert knowledge with respect to the methods and the ideal technical solution for the specific project.

Keywords: guideline, road tunnel, ventilation design

1. INTRODUCTION
The EU guideline on minimum safety requirements for tunnels in the Trans-European Road Network from 29 April 2004 sets the minimum standard for safety installations in Europe. Ventilation is a small but integral part of this guideline. To meet or exceed the European standard is within the ruling of each EU country and is triggered by the country specific safety level. This has led to different road tunnel standards in most EU countries, the most well-known being the German RABT, the Austrian RVS 09.02.31, the Swiss ASTRA guideline, the French « ANNEXE N° 2 à la circulaire interministérielle n° 2000- 63 du 25 août 2000 relative à la sécurité dans les tunnels du réseau routier national » and the Italian “Linee Guida per la progettazione della sicurezza nelle Gallerie Stradali”.

While it is not unusual that guidelines set not only the ventilation aims but specify also constructional details or methods, the Slovak guideline concentrates on functional requirements and passes on the responsibility to choose state-of-the-art engineering methods and to come up with an ideal project specific solution to the ventilation engineer. Where engineering solutions should be prescribed and for standardized calculation or test procedures or technical standards, technical bulletins are attached to the guideline.

This structure appears most appropriate in order to ensure at the time that the guideline

- remains a stable prescription expressing the fundamental safety requirements of the Slovak Republic and
- provides an opportunity to adapt standardized calculation or test procedures or to add technical standards.
2. **GENERAL ASPECTS**

2.1. **General ventilation aims**

The guideline lists the following general ventilation aims for the system choice, the dimensioning, the implementation and the operation of ventilation systems in road tunnels:

- control of heat and smoke in case of an incident with smoke production
- control of exhaust gases and particulate matter during normal operation
- limit the concentration of noxious gases and opacity during maintenance and incident without smoke

The choice and size of the ventilation system shall be governed by the requirements for emergency operation (incident with or without smoke) or normal operation. The ventilation system shall be energy efficient during normal operation. If necessary, temporary operational measures shall be considered for maintenance.

2.2. **Deviations from the guideline**

The guideline allows deviations if a particular technical solution results in an unbalanced cost / benefit relation. In these cases the regulating authority must authorizes these deviations and the planner must provide:

- a thorough documentation of the motivation, the technical and the financial consequences for the suggested deviation
- a risk analysis if requested by the regulating authority.

2.3. **Tunnel categories**

The tunnel categories referred to in the Slovak road tunnel guideline in Table 1 are based on the categories in the EU directive 54-2004 and account for the increased risk of longer and more frequented tunnels.

**Table 1:** Tunnel categories

<table>
<thead>
<tr>
<th></th>
<th>A</th>
<th>B</th>
<th>C</th>
</tr>
</thead>
<tbody>
<tr>
<td>traffic volume</td>
<td>&lt; 2000 veh / (d.lane)</td>
<td>&gt; 2000 veh / (d.lane)</td>
<td>&gt; 2000 veh / (d.lane)</td>
</tr>
<tr>
<td>or</td>
<td></td>
<td>and</td>
<td>and</td>
</tr>
<tr>
<td>tunnel length</td>
<td>&lt; 1000 m</td>
<td>&gt; 1000 m</td>
<td>&gt; 3000 m</td>
</tr>
<tr>
<td></td>
<td>or &lt; 3000 m</td>
<td>or &gt; 3000 m</td>
<td></td>
</tr>
</tbody>
</table>

The length of the tunnel is defined as the maximum length from any entrance to any exit portal. Galleries with a roof covering more than half of the road or tunnels less than 200 m away from the tunnel portal are added to the total length.

2.4. **Traffic**

The guideline requires that traffic data for the year the tunnel opens and 10 years thereafter, whatever triggers the more demanding ventilations requirements, must be considered for the ventilation design.
2.5. Meteorology
The ventilation system must reach the ventilation aims in the presence of the following meteorological conditions:

a) pressure
   • the 95-percentile of the barometric pressure difference between tunnel portals $\Delta p$
   • the 95-percentile of the maximum wind speed $u_W$ in direction of the tunnel portals, measured 10 m above ground and in approximately 300 m distance from the corresponding tunnel portal,

whatever is higher.

b) temperature (for buoyancy)
   • the 5- and the 95-percentile of the ambient temperatures $T_{a,5}$ and $T_{a,95}$
   • the (predicted) tunnel temperatures inside the tunnel during winter $T_{i,W}$ and summer $T_{i,S}$

at the same time.

3. VENTILATION SYSTEM
The guideline requires that the ventilation system covers all possible incident locations. It leaves it up to the planner to define the scenarios required to prove the feasibility of the ventilation concept.

The ventilation installations shall be determined by the requirements of emergency or normal ventilation. If possible, installations for emergency operation shall also be used for normal operation.

In order to account for the impact of seasonal density variations on the power requirement of the ventilation system, the fans have to cover at least the reference density of 1.2 kg/m³ or the density at $p_0$ and $T_{a,5}$, whichever is bigger.

The guideline also requires that temperature and density variations due to a fire must be considered when the operational points are determined. This obliges the planner to consider the density reduction in the pressure drop calculations as well for the operational points of the fans. The guideline does not refer to a simplified model but requests to perform these calculations in a conservative manner, if needed also unsteady.

The required smoke extraction capacity at the incident location results from the required longitudinal flow velocities in the traffic area and the relevant heat release rate.

3.1. Emergency Ventilation
The emergency ventilation covers incidents with smoke and incidents without smoke.

The guideline distinguishes the following tunnel categories which define the emergency ventilation concept as shown in Table 2. If a risk analysis is performed, it may lead to stricter requirements.
A1: <500 m or >500 m with directional traffic: no mechanical ventilation required  
A2: >500 m with bi-directional traffic: longitudinal ventilation

B1: directional traffic with no traffic jam: longitudinal ventilation  
B2: bi-directional traffic or directional traffic with sporadic or regular traffic jam: longitudinal ventilation only if risk analysis results in acceptable risk, otherwise smoke extraction near incident location

C1: directional traffic with no traffic jam: longitudinal ventilation or longitudinal ventilation with punctual smoke extraction  
C2: bi-directional traffic or directional traffic with sporadic or regular traffic jam: smoke extraction near incident location

**Table 2:** Schematic drawings of possible ventilation systems for the different tunnel categories

<table>
<thead>
<tr>
<th>A1</th>
<th><img src="image1" alt="Schematic Drawing" /></th>
</tr>
</thead>
<tbody>
<tr>
<td>A2</td>
<td><img src="image2" alt="Schematic Drawing" /></td>
</tr>
<tr>
<td>B1</td>
<td><img src="image3" alt="Schematic Drawing" /></td>
</tr>
<tr>
<td>B2</td>
<td><img src="image4" alt="Schematic Drawing" /> or, if a risk analysis results in acceptable risk:</td>
</tr>
<tr>
<td>C1</td>
<td><img src="image5" alt="Schematic Drawing" /> or</td>
</tr>
<tr>
<td>C2</td>
<td><img src="image6" alt="Schematic Drawing" /></td>
</tr>
</tbody>
</table>
3.2. Ventilation aims for emergency ventilation

The determination of the ventilation aims is the central part of the guideline as it contains the main functional requirements which have to be met by the ventilation system.

Under all relevant boundary conditions, the ventilation system must at least be able to achieve the ventilation aims as given in Table 3:

| A1 | n/a  | n/a |
| A2 | 1.5 m/s | n/a* |
| B1 | \(v_{\text{crit}}\) | n/a* |
| B2 | 1.5 m/s | -1.5 m/s |
| C1 | \(v_{\text{crit}}\) | n/a* |
| C2 | 1.5 m/s | -1.5 m/s |

* In these cases, the velocity downstream of the fire is no ventilation aim. It results in particular from the required velocity upstream of the fire and the heat release rate.

with

\[
v_{\text{left}}: \text{longitudinal flow velocity left of incident location towards incident location}
\]

\[
v_{\text{right}}: \text{longitudinal flow velocity right of incident location away from incident location}
\]

In a tunnel with directional traffic the tunnel entrance portal is left and the tunnel exit portal is right. In a tunnel with bi-directional traffic, left and right are chosen for each incident so that

b) the least amount of people are exposed to smoke

c) the initial flow direction is not reversed by the mechanical ventilation

The critical velocity \(v_{\text{crit}}\) must be calculated as:

\[
v_{\text{crit}} = \frac{C_0 C_3 \sqrt{C_1 C_4} \sqrt{1 + \left(1 - \frac{C_2}{C_1}\right) C_4 \frac{A^2}{\rho H}}}{1 + C_4 \frac{A^2}{\rho H}} B
\]

with
\[ C_0 = 0.9 \cdot (1 + 0.0374 \cdot \max(0; -s)^{0.8}) \]  \hspace{1cm} (2) \\
\[ C_1 = \frac{1 - 0.1 \frac{\mu}{\mu}}{1 + 0.1 \frac{\mu}{\mu}} \left[ 1 + 0.1 \frac{\mu}{\mu} - 0.015(\frac{\mu}{\mu})^2 \right] \equiv 1 - 0.1 \frac{\mu}{\mu} \]  \hspace{1cm} (3) \\
\[ C_2 = \frac{1 - 0.1 \frac{\mu}{\mu}}{1 + 0.1 \frac{\mu}{\mu}} 0.574 \left[ 1 - 0.2 \frac{\mu}{\mu} \right] \]  \hspace{1cm} (4) \\
\[ C_3 = 0.613 \]  \hspace{1cm} (5) \\
\[ C_4 = 6.13 \left( \frac{\mu}{\mu} \right)^2 \]  \hspace{1cm} (6) \\
\[ B = \left( \frac{QgH}{c_p T_a \rho_a A} \right)^{1/4} \]  \hspace{1cm} (7) \\

where

- \( Q \) :: heat release rate [W]
- \( g \) :: gravity [m/s²]
- \( c_p \) :: heat capacity of fresh air current [J/(kg.K)]
- \( H \) :: height of the driving tunnel [m]
- \( W \) :: width of the driving tunnel [m]
- \( A \) :: cross-sectional area of the driving tunnel [m²]
- \( s \) :: slope of the driving tunnel (negative when tunnel is falling) [%]
- \( T_a \) :: temperature of fresh air current [K]
- \( \rho_a \) :: density of fresh air current [kg/m³]

**Remark:** Eq. (1) corresponds to the formula for the horizontal tunnel in Kunsch (2002) except for the factor \( C_0 \). The coefficient \( C_0 \) has been introduced by the author of this guideline. It contains the “Kennedy” slope factor according to Fig. 9.3 in SES (1997) and an additional factor of 0.9. This factor gives a good fit to the critical velocity in the horizontal tunnel as measured in small scale models. It is therefore less conservative than the original formula by Kunsch (2002) but a bit higher than the formula in SES (1997).

For all tunnel categories the risk for tunnel users to be exposed to smoke before the start of the automated emergency response shall be minimized.

### 3.3. Ventilation aims for normal operation

The ventilation system as defined by the requirements for the emergency ventilation (see ch. 3.2) shall be used also for normal operation. If necessary, it has to be enhanced, which ideally creates additional capacities for the emergency case.

The following threshold values for the opacity and the CO-concentration must be met inside the tunnel:

- \( OP_{\text{max}} = 5/\text{km} \)
- \( c_{\text{CO, max}} = 70 \text{ ppm} \)

Until the emission values of the Slovak car fleet has been empirically assessed, base emissions and the calculation procedure for the required flow rate of fresh air have to be calculated according to the Austrian RVS 09.02.32.
3.4. Ventilation aims for emergency exits

The flow velocity through open passenger escape doors as averaged over the open cross-section must be larger than 2 m/s, should be evenly distributed and must be directed towards the traffic area in all points. The flow velocity should not exceed 6 m/s. The opening force of the escape door must not exceed 100 N. For times larger than 120 s after the emergency response has been triggered, this ventilation aim must be reached at most 3 s after the escape door is opened.

3.5. Redundancy

In general, the availability of the tunnel has a very high priority. Depending of the consequences of the failure or maintenance of one piece of the ventilation system during normal operation, an additional redundancy for normal operation may be required.

4. EMERGENCY CONTROL STRATEGY

The Slovak guideline applies a similar control logic to the one outlined in ASTRA (2009), where a moving incident and a localized stationary incident are distinguished. A localized stationary incident triggers the alarm, which sets off the emergency operation. The release of fire extinguishers and the opening of escape doors trigger the pre-alarm.

4.1. Moving or stationary incident

An incident is considered moving if
- at least 3 smoke detectors measure an opacity larger than 12/km

An incident is considered stationary if
- at least 1 sensor measures an opacity larger than 30/km
- the smoke propagation speed is similar to the flow velocity in the tunnel

The smoke propagation speed is given by the distance of activated smoke sensors divided by the time lag between their activation.

4.2. Pre-alarm

A pre-alarm is triggered by
- a moving incident or
- the fire detection system.

The ventilation system shows the following reactions:
- the escape path ventilation is turned on (if applicable)
- all smoke exhaust dampers are closed and attached exhaust fans are turned off (if applicable)
- the air supply system is turned off (if applicable)
- the longitudinal flow velocity is reduced to a value below 1.5 m/s

Additionally, the traffic lights at the entrance portal turn red.

4.3. Alarm

An alarm is triggered by
- a stationary incident or
- the fire detection system.
The ventilation system shows the following reaction:

**step 1 (automatic)**

<table>
<thead>
<tr>
<th>bi-directional traffic</th>
<th>system with smoke extraction</th>
<th>systems without smoke extraction</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>smoke exhaust fan is turned on with extraction points open</td>
<td>the longitudinal flow velocity is maintained at a value close to 0</td>
</tr>
<tr>
<td></td>
<td>the longitudinal flow velocity is maintained at a value of 1.5 m/s towards the smoke zone on both sides of the smoke zone</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>directional traffic</th>
<th>smoke exhaust fan is turned on with extraction points open</th>
<th>the longitudinal flow velocity is maintained at a value of no more than 1.5 m/s</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>the longitudinal flow velocity is maintained at a value of 1.5 m/s upstream and 1 m/s downstream of the smoke zone towards the smoke zone</td>
<td></td>
</tr>
</tbody>
</table>

**step 2 (manual)**
The operator or trained rescue personnel decide when to switch from step 1 to step 2. In step 2, the ventilation system is controlled to reach the ventilation aims according to ch. 3.2.

### 4.4. Ventilation of parallel tunnel

In tunnel systems with 2 parallel tunnels, the non-incident tunnel must be ventilated
- to support the ventilation of the emergency exits
- to avoid recirculation by the portals

Typically, the jet-fans at both ends of the non-incident tunnel are turned on with their thrust to the inside of the tunnel. If smoke escapes from the incident tunnel, the flow at the neighboring portal of the non-incident tunnel must exit with at least 0.5 m/s.

### 5. CONCLUSION

The new Slovak guideline sets mainly functional requirements to the ventilation systems in all Slovak road tunnels. It describes in particular the ventilation aims and the control strategy. It relies on the planner to apply state-of-the-art methods for his ventilation calculations and to come up with an optimum technical solution for the particular project.

Technical bulletins contain more specific details which may be adapted to reflect actual developments.

### 6. REFERENCES

1. EU directive 2004-54-EG on minimum safety requirements for tunnels in the Trans-European Road Network. 29/04/2004.