THE NECESSITY OF FIRE TESTS
USING THE PASSÜR TUNNEL AS AN EXAMPLE

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ABSTRACT
The Austrian design guideline RVS 9.261 “Tunnel Ventilation” requires the performance of fire tests prior to the opening of a new tunnel. These tests shall serve to verify the proper functioning and efficient interaction of the individual equipment components, especially the fire detection and the ventilation system.

Using the 1,855-m-long Passür tunnel as an example, the necessity of such fire tests shall be demonstrated, since malfunctions or defects in the ventilation control system may not always be detected by tests and simulations during start-up.

In a function test performed as part of the fire test, the design requirements for the ventilation control system were checked in accordance with the design guidelines for ventilation operation in case of a fire (fire program) drawn up during software development.

When starting the tunnel’s fire program through the existing linear fire detection system, a number of problems inherent in the program sequence emerged.

In this paper, the project shall be presented from the ventilation engineer’s perspective, listing the design requirements and comparing them to the fire test evaluation, a process which ultimately led to an adjustment of the ventilation control system.

Key words: Ventilation, ventilation control, fire test, fire response program

1. LOCATION
The Passür tunnel, which is located in the Province of Vorarlberg at an elevation of 1,300 m above sea level, forms part of the B197 federal road over the Arlberg pass, which passes by the Austrian ski resorts of Zürs and Lech. It is a 1,855-m-long road tunnel, which is operated in a two-way traffic or bi-directional mode. 1,152 m of this tunnel were constructed adopting mining methods, while the remaining 703 m were built in cut-and-cover. At a distance of 500 m to the west portal, the tunnel features an emergency exit.

The tunnel gradient ranges between 3 and 8 %. The tunnel ventilation is accomplished by a longitudinal ventilation system with 8 reversible jet fans, which have been arranged in pairs. Each fan has a thrust of 1,170 N and a power consumption of 37 kW.
2. GENERAL

On 24.10.2000, a fire test was performed, which was to meet the following objectives:
- Verification of proper functioning of ventilation system and fire management program
- Monitoring of smoke and temperature development
- Collection of information regarding site accessibility for rescue teams.

3. TEST ARRANGEMENT

The fire tests were conducted in line with the RVS 9.261, Item 8, using 2 steel trays, each measuring 1 x 1 m. These trays were filled with 20 l of diesel, 5 l of petrol, and 10 l of water.
Underneath the fire trays and at the tunnel roof, thermal insulation was provided to protect the electrical installations against damage.

4. TEST PROGRAM

For the tests, two test sites were selected (Fig. 3), one in the area of the emergency exit, the other in the transition zone tunnel – gallery.

**Test site no 1:** at km 18.9+20.0 (approx. 50 m west of the emergency exit)
The fire alarm was automatically triggered by the sensor cable. Depending on the location of the fire, either the fire response program FRP No. 2 or the fire response program FRP No. 3 was to be activated.

**Test site no 2:** at km 18.3+60.0 (transition zone tunnel - gallery)
During the second fire test, the automatic ventilation system was deactivated, only using the natural ventilation resulting from the actually prevailing meteorological conditions.

Upon receipt of the alarm, the fire management program (FMP) shall automatically launch the adequate fire response program (FRP).
A change to a different program, subsequently initiated by the alarm of another sensor line, is not intended.

![Fig. 3: Location of fire test sites in the longitudinal section](image-url)

The tunnel is subdivided into 7 fire sections, each with an approximate length of 260 m.
5. **MEASUREMENTS AND RECORDING**

The following data were recorded:

a) Air velocity and direction inside the tunnel before and during the test
b) Temperature development close to the fire seat
c) Logging of all messages and alarms for the duration of the test in the tunnel control centre
d) Control of ventilation system
e) Video recording of fire development and smoke spread by means of existing cameras.

6. **TEST SEQUENCE**

Before the test was started, the local meteorological conditions produced an airflow of 0.7 m/s from west to east.
The smoke would – based upon the given parameters and depending on the prevailing flow direction as well as the actual fire seat – either have been conveyed to the east portal or to the west portal.

The following table, for example, lists the ventilation scenarios for FRP No. 2. The recommended ventilation configuration for an airflow of 0.7 m/s has been highlighted by a light grey background.

<table>
<thead>
<tr>
<th>pair of jet fan</th>
<th>1 + 2</th>
<th>3 + 4</th>
<th>5 + 6</th>
<th>7 + 8</th>
</tr>
</thead>
<tbody>
<tr>
<td>air velocity m/s</td>
<td>direction of operation</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>&gt; +2.5</td>
<td>west</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2.5 - 2.0</td>
<td>off</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2.0 - 1.5</td>
<td>off</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1.5 - 1.0</td>
<td>off</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1.0 - 0.5</td>
<td>off</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0.5 - 0.0</td>
<td>off</td>
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<tr>
<td>0.0 - 0.5</td>
<td>off</td>
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<tr>
<td>0.5 - 1.0</td>
<td>off</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1.0 - 1.5</td>
<td>off</td>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>2.0 - 2.5</td>
<td>off</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>&gt; -2.5</td>
<td>off</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

7. **SEQUENCE OF EVENTS**

At 21:07, the fire brigade set both steel trays on fire, which at 21:08:46 induced sensor line No. 2 (SL No. 2) of the sensor cable to produce an alarm.
Fig. 4: Ignition of fire at test site No. 1 (21:07)

FRP No. 2 was launched precisely 30 seconds after an alarm from sensor line No. 2 (SL No. 2) was received. This period shall offer the operating personnel a chance to eliminate any possible false alarms. 28 seconds later, an alarm of sensor line No. 3 (SL No. 3) was triggered.

Contrary to expectations, the ventilation control system subsequently activated FRP No. 3, yet without deactivating FRP No. 2.

This sequence of events was not only completely unscheduled but was actually to be prevented, since it led to a combination of both fire response programs and thus to an undefined situation.

Once the trays had been set on fire, the smoke slowly spread to the east portal. A short backlayering of smoke extending over approximately 10-15 m could be observed. The ventilation control – in line with FRP No. 2 – next activated jet fans Nos. 3+4 (JF Nos. 3+4) and jet fans Nos. 5+6 (JF Nos. 5+6) which were blowing in westerly direction.

Table 2: Log excerpt

<table>
<thead>
<tr>
<th>Datenpunktbezeichnung</th>
<th>Quellzeit</th>
<th>Wert</th>
<th>INVGA SPO</th>
</tr>
</thead>
<tbody>
<tr>
<td>PA_BS_Sensorlinie.LA2............ ALARM</td>
<td>2000.10.24 21:08:46</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>PA_BS_BMZ-Brandsummenalarm....... EIN..</td>
<td>2000.10.24 21:08:46</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>PA_BS_Brandsummenalarm.MÜTECL20. EIN..</td>
<td>2000.10.24 21:08:46</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>PA_BS_TR-Meßstelle.1.............. EXT..</td>
<td>2000.10.24 21:08:51</td>
<td>2,28</td>
<td>0</td>
</tr>
<tr>
<td>PA_BS_Ampel.Portal.Ost........... ROT..</td>
<td>2000.10.24 21:08:55</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>PA_BS_Ampel.Portal.West   ROT</td>
<td>2000.10.24 21:08:55</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>PA_BS_Sensorlinie.LA3... ALARM</td>
<td>2000.10.24 21:09:14</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>PA_BS_Löschwasseranforderung.. EIN</td>
<td>2000.10.24 21:09:16</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>PA_BS_Lüftungsautomatik... EIN</td>
<td>2000.10.24 21:09:16</td>
<td>1</td>
<td>0</td>
</tr>
</tbody>
</table>
FRP No. 3 put JF Nos. 1+2 into operation directing the airflow towards the east portal, while JF Nos. 3+4 and JF Nos. 5+6 directed the airflow towards the west portal – as intended by FRP No. 2. As a result of this setting, the jet fans now worked against each other, creating a swirling airflow and filling the entire tunnel cross-section with smoke.

The jet fans reversed the airflow from east to west and FRP No. 3 further enhanced this westerly flow. With both jet fans now blowing in westerly direction, an excessive number of jet fans was now activated and/or deactivated which led to a sinusoidal airflow curve illustrating the respective airflow acceleration and deceleration.

The recordings of video camera no. 5 clearly reveal that, after the ignition of the fire trays, the smoke spread approx. 150 m in easterly direction, to then – after JF Nos. 3+4, and JF Nos. 5+6 were in operation – be forced back in westerly direction to the emergency exit.

Once JF Nos. 5+6 were deactivated, the smoke was again blowing in easterly direction to emergency lay-by No. 2 (EL No. 2) – some 130 m east of the fire site. JF Nos. 3-6 were then reversed in direction, blowing the smoke westwards to the emergency exit.

It was at this point in time that all jet fans were deactivated again. Yet shortly later JF Nos. 5+6 were activated again in easterly direction.

This chain of events induced the smoke to flow to EL No. 2 area and from there, after JF Nos. 3-6 were re-activated, to flow back in westerly direction.

The sharp increase in air velocity and the steep amplitude response curve reflecting the sinusoidal airflow curve (see Fig. 5), would – if the control system had been working properly – only have been half as steep and/or would have stabilized after a few minutes.
Fig. 5: Test evaluation in graphical form

8. TEMPERATURE EVALUATION

Fig. 6 illustrates the temperature development in the course of time. As the sensor above the seat of fire was covered up, the maximum value reached was 100 °C. The covering up of the sensor led to a delayed fire detection. The “bottleneck” in the diagram represents the covered sensor.
9. DISCUSSION OF RESULTS

All fire management sequences were in full compliance with the design requirements except for the fact that more than one fire response program was activated at a time. For a proper ventilation system operation, it is to be ensured that only one fire response program is active. In automatic mode, a later change to another fire response program is inadmissible, i.e. the fire response program which was initially launched, is to remain active. If this requirement can not be met, the conditions for persons trying to escape from the tunnel will be anything but defined and the situation inside the tunnel is in fact likely to deteriorate.

An improvement would be a shortening of the measuring cycle time and – against this background – an adjustment of the jet fan response time.

It furthermore seems to be preferable if the individual jet fans were activated individually instead of being activated in pairs.

The test revealed that, at an airflow velocity of approx. 1-2 m/s, a laminar smoke layer extending over a length of 150-200 m may be maintained. This is also evident from the videos, in which an area of approx. 1.5 m above the road surface was found to be smoke-free.

10. CONCLUSION

The fire test confirmed that a perfectly functioning ventilation control is imperative for a safe escape from the tunnel and that any false operation may easily worsen the conditions inside the tunnel. If the fire test had not been conducted, one would not have discovered this malfunction in the control system, since the automatic response reaction induced by the rise in temperature could not have been simulated under normal operating conditions. The performance of fire tests is thus a valuable tool in analysing the tunnel control system and especially the ventilation control system.