SAFETY MEASURES FOR ROAD TUNNELS – NEWEST DEVELOPMENTS FOR THE PLABUTSCHTUNNEL, AUSTRIA

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Abstract.
Compared to other federal regions in Austria, Styria has the densest tunnel network. By the end of 2005 more than 100 km will be in operation. The Plabutsch tunnel – with a length of 10 km – has just recently been equipped with the most up to date safety installations. This paper deals with the safety features and fire tests designed to test the effectiveness of the risk management system.

Road tunnels in Styria

The federal region of Styria has currently some 100 tunnel-km in operation. In the 10 km long Plabutsch-tunnel the second bore was been opened in January 2004. The first one is currently closed for maintenance and will be reopened at the end of 2004. It will then be the longest unidirectional road tunnel in Europe. The Plabutsch-tunnel is a very good example for the state of the art in tunnel safety in Austria.

The Plabutsch tunnel was opened in 1987 as a single bore tunnel with bi-directional traffic. The permanent increase in traffic forced the construction of a second bore. When opened in 1987, an average 10,000 vehicles per day passed through the tunnel. By 2003 the average daily traffic volume already amounted to some 23,000 vehicles, reaching a maximum of 32,000 per day and 3,000 per hour. Figure 1 shows the development of traffic volume since the tunnel was opened.

The increased safety for the tunnel users was one of the main objectives in the creation of the new bore. The costs of the safety installations in both bores amounted to some 33 M€, while the upgrading of the ventilation system called for an additional 20 M€.

Figure 1: Development of the traffic volume in the Plabutsch tunnel

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Developments in tunnel Safety

The safety of tunnel users was always a focal point for the department of road infrastructure and tunneling. Hence, Styria was very often a pioneer in introducing safety features. The following table shows the main topics implemented for the first time in Austrian road tunnels.

<table>
<thead>
<tr>
<th>Year</th>
<th>Feature</th>
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<tbody>
<tr>
<td>1979</td>
<td>Usage of the traffic channel with decoder signals transmitted from the tunnel control room.</td>
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<td>1980</td>
<td>Fire resistant cabling (E90) for fans and emergency lights as well as usage of stainless steel for constructions inside the traffic room.</td>
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<tr>
<td>1983</td>
<td>Fully redundant data transmission systems</td>
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<tr>
<td>1984</td>
<td>Start of the first fiber-optic cable installation</td>
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<tr>
<td>1985</td>
<td>Control of ventilation and lighting dependent on actual traffic volume</td>
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<tr>
<td>1987</td>
<td>Tunnel lamps in stainless steel (VA4) and introduction of special effects to reduce the monotony in long tunnels. Frequency control for ventilation</td>
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<tr>
<td>2000</td>
<td>First NOx controlled ventilation system for city tunnel</td>
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<tr>
<td>2000</td>
<td>Fully redundant data transmission network</td>
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<tr>
<td>2002</td>
<td>450 KW fan engines tested for operation at a temperature of 400°C over two hours</td>
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<tr>
<td>2003</td>
<td>First emergency call system base on “basic voice over IP”, introduction of a fully redundant control room</td>
</tr>
<tr>
<td>2003</td>
<td>Fire detection based on smoke analyses</td>
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On going improvements are being made in supply sections (max. distance 250 m), traffic control with CCTV, direction dependent switch able guidance lamps, etc.

Tunnel lighting

An increase in the efficiency of the lighting has been reached due to improved glass shields (8%) and a change in the distance of the reflector (3%). With newly developed mirrors it was possible to reach an efficiency of 80% and an increase of illumination density from 200 cd/m to 260 cd/m, keeping the energy consumption constant. A side effect of these improvements was the lower operating temperature, and hence a longer lamplife.

A further effect concerned the control of the lighting, where convenient simplifications were replaced by empirically gained parameters.

Temperature requirements for cabling and lighting

Great emphasis has been place on increased fire resistance for all equipment within the traffic room of a tunnel. The cabling has to be E 90 resistant. For the lighting the following test protocol was required.

1) The lamp has to be placed in an oven at a heat of 250°C. It has to be in operation and the orientation has to be the same as in the tunnel.
2) A temperature sensor has to be mounted on each individual part.
3) The lamp has to operate over a period of one hour.
4) The values of temperature, voltage and electrical current have to be monitored and recorded.
Ventilation system and fire detection

Risk management in the case of a fire is based on proper ventilation strategy, as smoke free escape routes are a pre-requisite for self-rescue and rescue-operations.

In such cases a quick and accurate detection and location of the fire is very important. Fire detection is based on a fibrolaser®-system. In addition to this a unique smoke detection system based on gas analyses has been developed and installed. It is thus possible to locate the fire source within 30 m.

The exhaust air fans have been upgraded with improved heat resistant motors (400°C over 2 hours). For accurate smoke extraction, adjustable dampers with a cross-section of 12 m² were installed. As an extra safety feature, it is possible to connect the ends of two adjacent exhaust air ducts via a moveable vertical damper, in case one of the exhaust fans fails.

The Plabutsch tunnel has a transverse ventilation system, consisting of 5 ventilation sections. The ventilation of the south end is provided by jet fans. The reason for this is that due to environmental protection issues no polluted air may be exchanged via the portal. Figure 2 shows a sketch of the ventilation system.

Figure 2: Ventilation scheme of the Plabutsch tunnel

Section 1 is ventilated via the portal fans at Raach. The remaining sections are ventilated via vertical stacks, sections 2 and 3 use the north shaft and sections 4 and 5 the south shaft. In this unique situation one stack supplies 4 ventilation sections, two in each bore. The operation and control of the fans can thus result in fairly complex procedures.

Control of the longitudinal air flow inside the Plabutsch tunnel

Even in a tunnel with a fully transverse ventilation a longitudinal flow of the air inside the tunnel occurs. During bi-directional traffic the wind speed will be low (dependent on the share of traffic in one direction and on meteorological conditions). During uni-directional traffic wind speeds up to 6 to 8 m/s can be expected.

However, in the case of fire, the wind speed must be controlled and should not exceed a certain threshold value. The ventilation of the tunnel is designed to suck off at least 120 m³/s at the location of the open damper. In order to gain an air (smoke) movement from both sides to the open damper, the velocity inside the tunnel must not exceed 1.5 – 2 m/s. The automatic
ventilation control software steers the system towards this goal. This is done by operating the individual fans (exhaust and fresh air) in such a way that pressure is built up or reduced in the individual sections, and hence a longitudinal flow within the proposed velocity limits is imposed. At the same time an overpressure has to be built up in the second bore, in order to prevent an overflow of smoke through open doors in the cross-passages.

This unique software for ventilation control in the case of fire, was developed at the Graz University of Technology, and was adapted and improved during the fire tests (see next section) in co-operation with the company SAT.

Fire tests

In order to check the risk management procedure and the effectiveness of the ventilation system in cases of fire, the Austrian standard RVS 9.261 makes fire tests compulsory. Multiple tests were performed to check the procedure. The first set of the tests concerned aerodynamics. These tests were made without smoke. The fire alarm was triggered manually and the air flow inside the tunnel monitored with flow meters (sonic instruments) and reached visible by means of cold smoke. Some 10 different locations were tested and a couple of malfunctions were found. It became clear during the testing that the whole ventilation procedure is very sensitive to establishing correct readings of the air velocity in the ventilation section under consideration.

In accordance with standard RVS 9.261, these tests were followed by hot smoke tests. Two pool fires (1m² each) each consisting of 20 l of diesel and 5 l of gasoline were ignited. That fire tests were performed without any problem in the middle of section 3. A second set of tests was made exactly at the boundary between ventilation section 3 and 4. In this case the exhaust fans are almost 2 km away, and hence the pressure drop reaches a maximum and the exhaust air volume a minimum for this section. This location is one of the most critical locations inside the tunnel.

The fire was ignited in section 3 but due to a wind velocity of some 2 m/s inside the tunnel, detection occurred in section 4. Hence, the nearest damper in section 4 was opened.

Figure 3 shows a sketch of the fire location.

Figure 3: Location of the fire test
Having the detection of the fire in section 4 results in the following actions:

- full power exhaust ventilation in section 4 (100%)
- no fresh air supply in section 4 (0%)
- the remaining fans (section 1,2,3,5) are used for steering the longitudinal velocity inside the tunnel
- opening of the damper closest to the fire
- using the air velocity information from a velocity sensor in section 4

Figure 4 shows the velocity of the air flow south and north of the fire source. One line depicts the fixed velocity sensor (A210), while the other shows the mobile sensor (mobile 2). The fixed sensor is used for ventilation control. The mobile one is a high quality sensor with a very high accuracy and was used to check the results. The other two lines represent the velocity measurements north of the fire source. A224 represents the fixed sensor and mobile 1 the movable sensor for quality control.

In the case of fire at this location, the software tries to steer the ventilation towards a velocity between 1.0 and 2.0 m. As can be seen from Figure 4, the fixed sensor (A210) showed totally incorrect values. While the software tried to reach the proposed velocity, the real velocity was already much too high. This resulted in smoke being driven back. For a certain period the smoke was even pushed behind the open damper. During this period only fresh air was sucked in and a large section north of the fire (in section 3) was totally filled with smoke (some 600 m).

![Figure 4: Wind speed inside the tunnel during fire test (uncorrected sensor).](image-url)
Due to the malfunction of the velocity sensor a velocity of -5 m/s was produced with the ventilation system instead of (-1) to (-2) m/s. The malfunction was mainly due to an incorrect calibration of the sensor and the sensor location, which was influenced by traffic signs, traffic signals and a niche.

The result of this malfunction can be seen in Figure 5, where the “upstream” location is depicted. The test started with a flow in southerly direction. Shortly after the ignition a back layering was built up (upper two pictures), followed by a change in wind direction, due to an “overshooting” of the control software. Hence, the smoke was driven in direction of the people, who where initially at the “save” side of the tunnel.

Re-siting and proper calibration of the sensor solved the problem. A repetition of the fire test was performed and no problems were found. As can be seen from Figure 6, the readings from the fixed and mobile sensors matched well.

During the aerodynamic and fire tests the parameters of the implemented PID-controller were optimized, and as a fall back position, software for ventilation control, with fixed values for the fans – dependent on the fire location – was implemented.
The normal operation of the ventilation system is based on the measurements concerning the in-tunnel air quality and the traffic-density. In addition, the control software is able to cope with a breakdown of one fan. In such cases the neighboring fans impose a longitudinal flow in the ventilation section affected. This method has already been used successfully, e.g. during the refurbishment of the first bore when some fans are not in operation for certain periods.

![Figure 6: Wind speed inside the tunnel during fire test (corrected sensor)](image)

**Control system and data transmission**

A main safety feature is the centrally managed data transmission and control. A flat structure and decentralized automatic steering devices are essential for tunnel safety techniques. A serial data transmission to stand-by PCs is not sufficient to have control of single malfunctions of equipment or sensors. Hence, one of the most important conditions for redundancy is parallel data transmission and processing in order to have a smooth changeover in case of a malfunction. Soft SPS-solutions have to be rejected, even for minor steering tasks, due to their rapid obsolescence and their vulnerability to virus attacks. Thus, no PC-solutions were adopted in the Plabutsch tunnel.

Instead of the former point to point data transmission the Ethernet is now the tool for data transfer and remote control of equipment. It is important to have enough capacity for data transmission and – again – to have a back-up net in order to ensure the necessary data transfer in case of an incident. The rough tunnel atmosphere is an additional parameter which has to be considered. For data transfer multiple local 100 Mbit LAN’s are connected to a back-up GBIT LAN. Even emergency calls are transmitted via these LAN’s. The only exception is the video system. For quality reasons and owing to uncertainties in transmission and the need for centralized image processing, analog transmission is still used for the video system.
Emergency exits

A main feature of safety in a road tunnel is the clear marking of the emergency exits. The signaling has to be simple and full of contrast. Decision making aids should be present to help individuals to find the right emergency exit, especially if unexpected situations block the nearest one. The marking of only one exit – which in an actual emergency can not be used – may result in panic.

A big help for people fleeing would be an indication of the direction they should take. As in most cases direction of the smoke movement is determined by the ventilation, direction signaling could be done automatically as a function of fire location and smoke movement.

Conclusion

The second bore of the Plabutsch tunnel was opened in January 2004. More than 50 M€ were spent on safety installations and upgrading of the ventilation systems. Currently the first bore is closed for refurbishment. When it is opened again at the end of 2004, the Plabutsch will be the longest road tunnel in Europe with two bores operating with uni-directional traffic. For the sake of the users, the tunnel has been equipped with the most up to date safety equipment.

In the case of fire smoke is extracted via large (120 m²) adjustable dampers. In order to force the smoke to the open damper ventilation control software has been installed which utilizes all available fans in order to build up or reduce pressure in the tunnel and hence impose a longitudinal flow from both sides to the open damper. The Plabutsch is the first transverse ventilated tunnel with such a ventilation control system.

Further improvements in tunnel safety were carried out in incident detection with video and gas analyses, data transmission, use of electronic equipment, control room installations, lighting, etc. Most of the systems are fully redundant.