After the disasters which in 1999 occurred in several European tunnels it has been realized that the behaviour of drivers has a great influence on tunnel safety. Therefore an appropriate method to analyse the behaviour of drivers in tunnels has been searched for.

In spring 2001 the ÖSAG has charged the KfV (Austrian Board of Trustees for road safety) with a study on the behaviour of drivers in motorway tunnels. The research has been finished in autumn 2001 and its results were presented on the 1st symposium in April 2002.

The results of this research have been considered in the planning of the ÖSAG-projects “Semmering pass” consisting of a tunnel chain with a total tunnel length of 16 km and “Tunnel chain Klaus” on the A9 Pyhrn Motorway which consists of 6 tunnels constructed by mining method and 4 short tunnels constructed by cut-and-cover method. Most part of the long tunnels constructed by mining method are divided only by valley crossings.

Additionally, these results have been considered in the guidelines for the design of portal areas and in the revised guidelines for operating and safety equipment in tunnels.

1. GUIDELINE FOR THE DESIGN OF PORTAL AREAS:

In summer 2002 within the ASFINAG group there has been established a working group charged with the working out of guidelines which in autumn 2003 have been finished. In collaboration with a traffic psychologist (author of the above mentioned study) the members of this working group have tried to find strategic principles for designing the portal area and to draw up model plans for the portal area.

In detail the following regulations have been worked out:

A) Main principles of these guidelines

- The design of the portal area has to keep the drivers free of optic impressions, so that he can concentrate on the driving into the tunnel. The driver shall have as few disturbing impressions and information as possible approaching and entering the tunnel. The definition of the portal area is a distance, which you can pass in 5 seconds using the allowed speed. Driving with 80 or 100 km/h this is a distance of about 110 to 140 m before the portal.

- If a driver error occurs in the portal area and there is a collision, the consequences of the collision have to be minimized; primarily the design has to protect other road users but also the driver himself.

- An architectural design of the portal also has to fulfil these principles.

- If topographical situations do not allow to obey the specific regulation, as a minimum the mentioned principles have to be fulfilled.
B) Special regulations

- Definition of the placement of traffic lights (directly at the portal and 250 m before the portal), it is preferred that they are overhead and they shall be in LED-technique.

- The markings before the portal in a length of about 250 m shall be made with a short distance of the lines.

- Rumble strips have to be made at the edge line and at the continuous traffic line at bi-directional tunnels for about 100 m before the tunnel portal to give an acoustic sign when a car looses its way (s.pic 1).

- Dampers have to be installed on the right side of tunnel portals of bi-directional tunnels (s.pic.2).

- The situation of the signalization of the speed limits and the speed limits themselves before the tunnel portal are defined in the draft of the new regulation as follows (s.tab.1):

<table>
<thead>
<tr>
<th>Kind of traffic</th>
<th>Speed on open road [km/h]</th>
<th>State of operation</th>
<th>Speed limit [km/h]</th>
<th>Distance [m]</th>
<th>Speed limit [km/h]</th>
<th>Distance [m]</th>
<th>Speed limit [km/h]</th>
<th>Distance [m]</th>
<th>Speed limit [km/h]</th>
</tr>
</thead>
<tbody>
<tr>
<td>bi-directional</td>
<td>130</td>
<td>Normal</td>
<td>100</td>
<td>300 - 500</td>
<td>80</td>
<td>300 - 500</td>
<td>--</td>
<td>100</td>
<td>80</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Works in the tunnel</td>
<td>100</td>
<td>300 - 500</td>
<td>80</td>
<td>300 - 500</td>
<td>50</td>
<td>100</td>
<td>30</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Jam - closure</td>
<td>100</td>
<td>300 - 500</td>
<td>80</td>
<td>300 - 500</td>
<td>Stau</td>
<td>100</td>
<td>General prohibition of driving</td>
</tr>
<tr>
<td></td>
<td>≤ 100</td>
<td></td>
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<td></td>
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<td>Works in the tunnel</td>
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<td>80</td>
</tr>
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<td></td>
<td></td>
<td>Jam - closure</td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>General prohibition of driving</td>
</tr>
<tr>
<td>uni-directional</td>
<td>130</td>
<td>Normal</td>
<td>100</td>
<td>500 - 800</td>
<td>100</td>
<td>500 - 800</td>
<td>100</td>
<td>100</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Works in the tunnel</td>
<td>100</td>
<td>500 - 800</td>
<td>80</td>
<td>500 - 800</td>
<td>30</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Jam - closure</td>
<td>100</td>
<td>500 - 800</td>
<td>Stau</td>
<td>500 - 800</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

General prohibition of driving
The signalisation of the name and the length of the tunnel together with the tunnel symbol will be situated not in the mentioned portal area, but some hundred meters before the tunnel. The board with radio frequencies will also be situated not in the portal area. (s.pic.3)

There will be installed information boards about 1.5 km before the tunnel entrance and directly at the entrance of the tunnel, to make it possible to inform drivers in case of emergency or road works inside the tunnel (s.pic.4).

2. TUNNEL CHAIN AT KLAUS:

The fact that the motorway section between Schön and Lainberg Nord runs through a deep valley required the building of many tunnels.

As a result about 10 km or 70 per cent of this 16 km long motorway section run underground in tunnels.

The planning of this project was very challenging especially because of the direct succession of so many tunnels which partly are divided only by valley crossings.
2.1. **Operating and safety equipment**

The arrangement of construction elements such as lay-by niches, cross passages for pedestrians and cross passages for vehicles as well as the installation of operating and safety equipment have been carried out according to the RVS 9.281 and RVS 9.282 and according to the latest technical standards.

On the motorway section between Schön and Lainberg Nord among others the following safety facilities have been installed:

- Emergency phones
- Fire alarm devices
- Video monitoring system with digital recording of video images
- Surveillance of air quality in the tunnel
- Ventilation during operation and in case of fire
- Fire extinguishing facilities
- Tunnel radio system
- Height control facility
- Tunnel lighting
- Information boards for additional traffic information

All facilities are controlled by the control centre situated in Ardning (s.pic.6).

Considerable emphasis has been laid on the quality of the lighting system in the tunnel.

In the interior zone of the tunnel 150W Sodium high pressure lamps have been installed in distances of 17,85 m which leads to an average luminance of 5 cd/m² during operation. At the lay-by niches in the interior zone there are installed 250W HMI-lamps in order to reach halation-effects. Additionally, the emergency phone niches are lighted up by 250W HMI-lamps installed in the lighting axis and rotated through an angle of 90°.
LED-arrows indicating escape routes in case of emergency and stroboscopic flashes represent important safety criteria (s.pic.7).

The working out of a traffic control plan was a very challenging task.

The main problem consists in the fact that before the tunnels traffic cannot be diverted and there is not enough space in case of jams because the open road sections between the tunnels forming the tunnel chain are very short (often with bridge constructions).

Considering these facts traffic control plans for two cases have been defined:
- Short term obstructions
- Long term obstructions

Normally, short term obstructions have no impact on neighbouring tunnels so that traffic control measures have to be taken only for the tunnel concerned. For example: emergency information in unidirectional tunnels.

Long term obstructions inevitably impact on neighbouring tunnels (on tunnels lying before the tunnel concerned). Depending on the kind of obstruction general danger alarms (eg. yellow flashing traffic lights) or traffic diversion at the junction lying before the tunnel chain are put into effect.

For example: fire alarm

3. PSYCHOLOGICAL INVESTIGATIONS

On 26 September 2003 the tunnel chain has been opened to traffic. In order to check over the efficiency of the measures which have been taken the KfV (Austrian Board of Trustees for road safety) has been charged with a new psychological research.

Like the research carried out in 2001 in this new research varied data have been collected from 67 test subjects. In both researches the test subjects had to drive with cars provided with
instruments through several tunnels of the Pyhrn Motorway. Then they were interviewed in a detailed way about their impressions and about other aspects. In the latest research the test subjects had additionally to undergo high-frequency ECGs which allow to collect objective data about the stress the test subject is under.

The test section of the recent research was about 90 km long and ran on the A9 between Ardinging and Schön. On this section older tunnels such as the Bosrucktunnel and the Lainbergtunnel had to be passed as well as the tunnels of the tunnel chain at Klaus which - as mentioned above - have been constructed according to the latest standards. But also the older tunnels meet the latest standards under many aspects because they have been renovated in the last years. Comparisons with former standards could be made on the basis of the data collected in 2001 partly on the same motorway sections.

The latest analysis has been carried out under the aspect of traffic signs, tunnel entrances, tunnel lighting, design of the tunnel walls, road markings, safety equipment and design of transition areas (transition from one or more lanes to one lane, rapid succession of tunnels and open road sections). The results of the study carried out in 2001 have already shown that differences in the above mentioned designs have impact on the behaviour and the subjective feeling of the driver.

The results of the recent research show that the new tunnel designs have been accepted positively by the drivers. In the area before the tunnel information have been structured in a new way and have been reduced to the essential. As a result drivers now record more easily the important traffic signs which call for actual action. The new designs of tunnel portals show also elements of art. The comparison between portals of different designs shows that every design is accepted. In 2001 as well as in 2003 the test subjects were asked about suggestions for improvement under all aspects. The study of 2003 virtually brought no actual new idea which has not been realised in the meantime. The test subjects are very satisfied with tunnel lighting, the design of tunnel walls, marking signs and reflectors. The drivers also know more about safety equipment and the right behaviour in case of emergency.

Nevertheless the latest research show that there are also some points - specific of this section - which potentially could be improved. Several test subjects felt uncomfortable about the rapid succession of tunnels and open road sections. Some drivers felt also irritated by traffic signs and guidance systems lit by LED-technique which generally have been accepted positively but at night-time make a sharp contrast with the background. To solve this problem it has been suggested to dim the lights.

Like the former research also the recent study compares the statements of the test subjects with their behaviour in order to compare the subjective feeling about safety with objective safety indicators. As higher levels of planning standards should lead to a reduction of driving errors and this indicator sometimes may be not exact enough, variability of heart beat frequency has been analysed, too. On the basis of this physiological indicator the stress of the test subject can be measured objectively and details which did not come out during the interview can be found out. Using this method above all the stress of anxious people can be measured more exactly. The latest research is now being analysed and evaluated, the results will be available in time when the symposium takes place.