SINGLE TUNNEL AND STILL SAFE
THE FELBERTAUERN TUNNEL

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INTRODUCTION
Do you know the children’s story “The Ugly Duckling”? You ask: What do children’s stories have to do with tunnel safety? You are right. There is no relationship!

However, let us retain the “ugly duckling” and keeping this picture in mind turn to the subject of incident monitoring in existing road tunnel systems. Let us replace “ugly” with “40-year old technology”, with “non-reversible supply air semi-transversal ventilation” and “meteorologically caused longitudinal air flow speeds up to 8.0 m/s”, with “escape route lengths up to 5,300 metres”, with “detection possibilities missing”, with “only limited video monitoring system present”, with “central controller not available” and let us replace “duckling” with “Felbertauerntunnel with mid-1990s safety status”.

BACKGROUND
At that time, the primary concern of all operators of underground traffic systems was the optimisation of the operation. Therefore, infrastructure maintenance and reduction of operating costs were also in the foreground for Felbertauernstraße AG for all the adaptation plans for the Felbertauerntunnel realised until 1995. If safety was also increased, this was seen as a welcome added bonus. However “more safety” was never the direct initiator for the investments.

Analyses of an accident and fire incident in the Pfändertunnel, Vorarlberg were the starting point for changes in the approach to safety. These changes were not suddenly completed, but gradually as everywhere. Considerations of the possible liability aspects for “route liability” and “contractual liability” between tunnel users and the operating company followed the shock of the tragic personal injuries. New light was also cast on the possible material and operation interruption damage.

Therefore, the accumulation of the personal, material and liability damages had to eventually lead the decision makers for the toll tunnel to the question: Are actions for improving the risk standard required by adapting to the current “state-of-the-art” as regards safety? The inventory analysis subsequently performed by comparison with the current new construction guidelines (assumed state-of-the-art at that time) was rather sobering. The above negative points listed under “ugly” could still then be enhanced in any way although the system inventory and mainly the construction conditions provided options for future improvements. But the time for this was not yet ripe in 1996. A risk analysis was applied to the sobering actual-new construction target comparison and the result was finally a need to take action.

The determined need for action was reflected in the development of a comprehensive adaptation concept for the Felbertauerntunnel whereby the current new construction guidelines were indeed included from the start as standards however not binding in the sense of restricting. In establishing “what is the current technical state?”, “what are the possibilities?”, it was necessary to collaborate closely with the Austrian Road Safety Board.
and the emergency services – mainly the fire brigades -, and last but not least also to check commonly used standards abroad and to incorporate all of this into the design considerations. There was an initial result at the end of 1996 which still largely reflected the current new construction guidelines. The first phase of the concept implementation started one year later. A time frame of 10 years until final completion was envisaged.

The catastrophic damage experienced in the year 1999 ignited the proverbial “implementation turbo” for Felbertauernstraße AG as well as for all other operators of road tunnel systems. Suddenly “tunnel testers” were on the move and certified the Felbertauern tunnel bad safety standard. However, the market was also suddenly in action. Many technical safety solutions on a scale hitherto unknown were suddenly available.

In the year 2000, the operating company, with a concept revised in many details, together with the ambitious plan, started to approach the status “safety swan” by 2007 from the status “ugly duckling” for the single Felbertauern tunnel and doing this without building a new tunnel. It became quickly clear in the concept revision that a satisfactory safety result would only be achievable with significant modification of the requirements of the new construction guidelines. Alternative solutions, practically a made to measure safety solution for the Felbertauern tunnel, had to be found. To everyone’s surprise, there were many promising and above all, realisable, ways to the safety objective after removing the rigid adherence to the guidelines by using unconventional solution approaches.

However, at that time, the objective was opposed to the general “tenor” of the tunnel experts: “As a single road tunnel, the Felbertauern tunnel can never achieve the “very good” safety level”.

Experts who know the Felbertauern tunnel make a different judgement today. Why?

1. **FELBERTAUERN TUNNEL VENTILATION SYSTEM**

The ventilation system of the tunnel – we remember: a non-reversible supply air semi-transversal ventilation, divided into four ventilation sections – has been converted to a multifunctional ventilation system. It was specified in the dimensioning of the new system to maximise use of the infrastructure (*tunnel geometry, sewer cross sections, connected loads, ...*) and to produce an accompanying realisation concept that allowed implementation with moving traffic. The system was completely adapted to the requirements in several phases. Full transverse, partial transverse, exhaust air semi-transverse and longitudinal ventilation operation are now possible.

![Figure 1: Exhaust air flap in the verification test](image)
The features of the ventilation system in the Felbertauern tunnel include

a) the system performance – a total of 220 m$^3$ per second exhaust air capacity for unfavourable position in the tunnel using three exhaust air flaps for a length of 144 metres is achieved by concentration of the total available exhaust air capacity (exhaust air blowers in both portal stations) by flexible connection (mechanical cover flaps) of the respective assigned exhaust air sections (moving vertical closures in the exhaust air duct);

b) the exhaust air flaps (a total of 72 exhaust air flaps spaced at approx. 72 metres designed as baffles with a maximum open cross section in each case of 8.95 m$^2$ at 90° angle and with an actuator motor in the secure supply air duct) with the possibility of turning the baffle fins depending on the main exhaust flow direction (flap setting angle from 0° to 125°);

The adapted ventilation system has been available since Spring 2004.

2. FELBERTAUERNTUNNEL ESCAPE SYSTEM

The escape route lengths in the tunnel were previously max. 5,300 metres – we remind ourselves: the traffic space was the only escape route and thus the tunnel length was the maximum escape route length – shortened to max. 230 metres. Strictly following the principle of self-rescue, the integration of the emergency call recesses in the system, a functioning interaction with the adapted ventilation system, the optimum use of infrastructure and the “implementation while traffic is moving” condition, were the direction of the requirements for the design. In other words: Whoever has to raise the alarm and/or escape must be given the possibility of making the emergency call in safety – in the protected emergency call recess –, together with the same local escape option without having to make a detour again across the “unsafe” traffic space. Among other things, the local grouping of emergency call and escape route access was reflected in the positive assessments of the escape psychologists consulted and also of the Tirol association for the disabled.

Possible alternatives were checked in the course of the preliminary work. A parallel escape route tunnel and a connection to an existing pipeline tunnel of TAL were ruled out for technical and economic reasons. The task was solved using the existing supply air duct divided into two sections.

Figure 2: Felbertauerntunnel escape route system diagram  
Traffic space-Emergency call recess-Escape route staircase-Supply air duct
In the operating case, two supply air fans deliver fresh air as required into the portal stations above the duct into the tunnel. In the case of an incident, this supply air duct which can be walked on (cross section height up to 2.60 metres) will be connected and integrated for the safe escape route. In both portal stations, so-called “escape route bypasses” are conducted out of and past the supply air duct to the supply air fans and the flaps of the flow brake into the open air. The escape system can be accessed from the traffic space via 23 emergency call recesses and directly at the escape staircases connected to the recesses spaced at 230 metres apart. Thus for the most unfavourable incident position (incident directly in front of an emergency call recess), the maximum escape route lengths in the tunnel are 230 metres. The escape system also provides possible access in the opposite direction for the emergency services. These reach very close to the incident location safely and very quickly (engine powered small emergency vehicles). The necessary emergency equipment is located in the fire extinguisher recesses directly opposite the emergency call recesses.

The features of the escape system in the Felbertauerntunnel include:

a) 416 motor-operated supply air flaps for secure closure of the supply air duct against the traffic space for the incident operation (standard position “closed”);

b) Pressurised ventilation of the complete escape system by using the “free” – not in use for the flow brake – idling capacity supply air fan;

c) Access to the escape system via “safe” emergency call recesses (F 90 and T 90 or REI 90 and EI2 90 c closure to the traffic space) and gates (2 x T30 closures or 2 x EI2 30 c closures);

d) Pressure relief of the emergency call recess doors in the case of overpressure in the escape system in order to maintain the maximum counter pressure requirements for the escape doors;

e) Automatically effective escape guidance system coupled with the system for incident detection based on the core idea of “displayed escape direction always leads away from the incident”;

The new escape system has been available since the beginning of 2005.

3. FELBERTAUERNTUNNEL PROTECTION SYSTEM

Suitable possibilities for extended protection for persons, structural elements and systems for the Felbertauerntunnel have been researched and available variants compared in parallel with the 5 years of intensive work on the ventilation and the escape system. The comparison of achievable risk reduction to economic cost produced clear benefits for an active protection system. The passive high temperature protection of the structure by means of cladding with fire protection plates and by high temperature insulation of the partition wall in the exhaust air duct proved to be inferior. The requirements for the protection system were defined in the next step. In doing so, it was first necessary to optimally integrate the infrastructure and infrastructure relationships in the concept development and to ensure the unimpaired interaction with the ventilation and the escape system. The length of the groups (36 metres) and thus the lengths of the protection zones (3 x 36 metres) of 108 metres emerged from the infrastructure. The infrastructure relationships also resulted in the requirement for reliable system functioning for temperatures down to -30 °C. A further essential requirement for this system was the protection of the suspended roof, mainly the suspended roof support and thus last but not least the protection of the escape system. This resulted in the requirement to protect the system assuming 1,200 °C within 180 seconds after ignition against a maximum temperature of 250 °C at a distance of 5 metres from the source of the fire. Furthermore, the
maximum temperature at 20 metres distance was established at 50 °C with the emergency services and the requirement was developed also to be effective for large area liquid fires using wetting agent additions.

Available systems on the market were assessed on the basis of the requirements and sorted according to the state of development and suitability for practical use. The functional and documentation claims of many providers proved to be unsustainable for the tunnel already in this phase. The preselection followed joint efforts for further development and for further harmonisation of the systems with the requirements set.

The result, a stationary water spray system usable over the complete tunnel length for reducing the effects of fire incidents in the tunnel traffic space, was installed in one extreme tunnel section with respect to temperature differences, entrained water entry and contamination and continually stressed for one and a half years, jointly tested with the emergency services and thus tested for Felbertauern tunnel suitability.

Another tunnel test was also carried out Europe-wide in the Spring of 2005. With the rating of “good”, the Felbertauern tunnel is in the safest category for single tunnel systems. This is not a reason for the operating company to lose sight of the objective.

The final component in the safety concept for the Felbertauern tunnel, “the protection system” was finally ready for installation at the beginning of 2006. The selection was made for a stationary “extinguishing system” designed as a high pressure water spray system with a wet and insulated main line and with group valves in the supply air duct and with dry distribution and nozzle lines in the traffic space. The difference to conventional sprinkler or water spray systems: the finest water droplets (water mist) emitted by high pressure using special high pressure nozzles act with direct destructive energy in the truest sense of the word due to the enormous surface area.

Fires at any location in the traffic space of the tunnel can be tackled with the protection system using water mist – the water output is approx. 3,800 litres per minute, distributed over a section length of 108 metres.

The fire output can be reduced or restricted to a “tolerable” level with the system. In this way, the smoke output is reduced and the temperatures in the incident surroundings are reduced so that fire expansion – the fire spreading to other vehicles in the tunnel – and destruction of the surrounding parts is inhibited. This results directly in the protection of persons involved. Safe escape conditions are maintained in the traffic space for a long time and the essential system functions such as video system, lighting, radio signal transmission, traffic lights and
emergency call equipment remain intact at least until clearance of the affected area. This makes it possible for the fire services to reach the incident location. They can intervene quicker and finally extinguish the fire.

The features of the protection system in the Felbertauerntunnel include:

a) the position of all essential installation components in the safe supply air duct;
b) the “feed-in protection” realised by the so-called “in-pipe nozzles”;
c) the proven effect, both for solid as well as for liquid fires, up to fire outputs of 180 MW and the proven function also after long exposure by the system to temperatures of more than 1000 °C;
d) the proof that the operation of the exhaust air system in fires is not adversely affected irrespective of whether the opened exhaust air flaps are inside or outside the triggered section. In the course of the associated proofs, even positive effect on the distribution uniformity of the water mist in the traffic space cross section could be documented.
e) multiple system redundancy based on, e.g. pump stations in both portal stations, spare pumps in both portal stations, …;
f) the available running time of the system which with more than 3 hours safely covers the required lead times of the emergency services;
g) the possibility of adding wetting agents to the extinguishing medium;

The system, which could also generally be called a high pressure extinguishing system, has been ready and in operation since late autumn 2007.

SUMMARY

Incident safety in the Felbertauerntunnel is a customised interaction of many components. “Prevention” using information of the tunnel users is certainly in first place. The Felbertauernstraße can also build on the available potential in the interrelationship. The high proportion of the so-called frequent drivers also opens the way for information using multiple direct contacts. However “prevention” and preparatory “emergency management” due to the contact with the responsible fire services must also be seen in the interrelationship. There is close collaboration which was and is extremely important for Felbertauernstraße AG. The portal fire brigades were intensively incorporated in the development and continuing adaptation of the safety concept and in preparatory actions for emergency management. Many of the preliminary tests for the ventilation conversion and the protection system have been performed and assessed jointly. Therefore, the status of the system knowledge must be designated as at least “high”. The safety brigade – a small tunnel fire brigade equipped with a special vehicle – which is reserved for the operating company for rapid first deployment around the clock directly at the south portal station of the Felbertauerntunnel, also has a preventive effect.

The many components today also include self-evident technical requirements which are essential for the function of the systems described above. The fact that suitable programmable logic controllers for them, a corresponding process control system, measuring and detection systems with current technical standards and many other things were required goes without saying.

To summarise, we see the Felbertauerntunnel today at the current state-of-the-art after completion of the essential points in the safety concept. We have certainly come nearer to providing the desired “swan” end result or rather the “maximum possible safety for the users in the Felbertauerntunnel.