Tema 1 / Topic 1:

Varnost, upravljanje in nadzor pri uporabi podzemnega prostora

Safety, Management and Control in the Underground Space Used

Upgrading of Existing Road Tunnels

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ABSTRACT

Many of the existing Austrian long road tunnels are now for more than 25 years in operation. All of them were built as single tube tunnels serving bidirectional traffic. Some of these tunnels can not carry the increased traffic load anymore, and second tubes have to be built.

When existing structures have to be upgraded problems arise in meeting the standards required for new tunnels. In some cases extraordinary financial and constructive efforts would be necessary in order to fulfil all requirements (design parameters, safety, economy, etc.) of new tunnels.

This paper takes the Tauern and Katschberg tunnel as examples in order to demonstrate the efforts which have to be undertaken when applying current safety standards and technology to existing structures.

KEYWORDS

Upgrading ventilation system, Katschberg tunnel, Tauern tunnel, design parameters, safety standard

1 INTRODUCTION

Many of the big Austrian road tunnels have now been in operation for more than 25 years. All of them were built as single tube tunnels serving bidirectional traffic. Although safety equipment has been upgraded regularly in the past, major systems such as ventilation and electrical equipment have reached the end of their useful life. In addition, some tunnels can no longer carry the increased traffic load. Hence second tubes have to be built.

However, when existing structures have to be upgraded problems arise in meeting the standards required for new tunnels. In some cases meeting new requirements would impose inacceptable costs in terms of time and effort. A compromise between safety standards, economic usage and overall costs thus has to be found.

A similar problem arises concerning construction of second tubes. Many ventilation structures for the second bore were already designed and erected together with the first bore, e.g. ventilation buildings, air shafts, air exchange stations, etc. As the requirements at the time of design and construction were quite different to the situation nowadays, these structures do not match current needs. E.g. while in former years normal operation called for extensive fresh air supply, nowadays and smoke extraction volume in case of fire is the key factor in the design of the exhaust fans. Hence, the dimensions (cross-section area, mechanical load of the construction) of existing exhaust air and fresh air ducts do not match current needs at all. This makes updating with respect to ventilation and safety issues more arduous than it would normally be.

This paper focuses on the ventilation design of the second bores of the Katschberg (5.4 km), as well as the subsequent upgrading of the existing (old) bores. As all the work has to be performed under full operation of traffic of the parallel bore special measures had to be foreseen to keep ventilation and safety standards at an acceptable level. While in some cases "standard" technology was applied, in some other cases quite innovative technologies had to be used to reach an acceptable safety standard.

2 KATSCHBERG AND TAUERN TUNNEL

The A10 highway (Tauernautobahn) is a main transit route through the Alps, connecting the federal regions Salzburg and Carinthia, and traversing the main ridge of the Eastern Alps. Opened in 1975 the Katschberg tunnel are one of the core elements of this route. The length of the two bores of the Tauern tunnel is 6.8 km for the old, and 6.5 km for the new bore. The Katschberg tunnel has a length of 5.6 km in the old tube and 5.9 km in the new tube.

Ventilation of road tunnels is one of the key issues in safe operation. However, as the needs and objectives for ventilation systems in road tunnels have constantly changed over the years, any upgrading of existing systems and/or adding of new components is problematic where existing structures have to be taken into account [2], [5].

Due to the length of the tunnels and its operation in bidirectional traffic a full transverse ventilation system was the only option. During the original construction of both tunnels ventilation buildings had been designed with the equipment for a second tube already in mind. In addition all the ducts between ventilation hall and tunnels, and ventilation hall and outside had been designed and constructed together with the installations of the first bores. Hence these existing structures act as boundary conditions in the design of any new system. Deviations from the existing set-up would either be impossible or would result in very high costs combined with severe constraints on ventilation of the existing bores.
According to the currently valid Austrian guideline for tunnel ventilation RVS 09.02.31 0 tunnels with a length of more than 3,000 m must be equipped with exhaust gas/ smoke extraction systems. This would require at least a semi-transverse ventilation system with smoke extraction. However, as both existing tunnel tubes are to undergo refurbishment as soon as the new ones are opened, during this period bidirectional traffic operation is also required for the new tubes also. Hence, it was decided to equip the new bores with a full transverse ventilation system.

Changes in the RVS 09.02.31 which needed to be taken into account related to:

- minimum extraction capacity in case of a fire
- consideration of leakages for dampers and ducts
- temperature requirements for fans and equipment in the exhaust air duct
- the consideration of high meteorological pressure differences at both portals

2.1 Katschberg Tunnel

The general layout of the existing bore of the Katschberg tunnel consists currently of 4 ventilation sections with a length of 1.5 km each. Figure 1 shows the general layout of the ventilation design. Two ventilation zones are provided with air exchange from each of the portals. A separate ventilation duct is responsible for the inner ventilation zone.

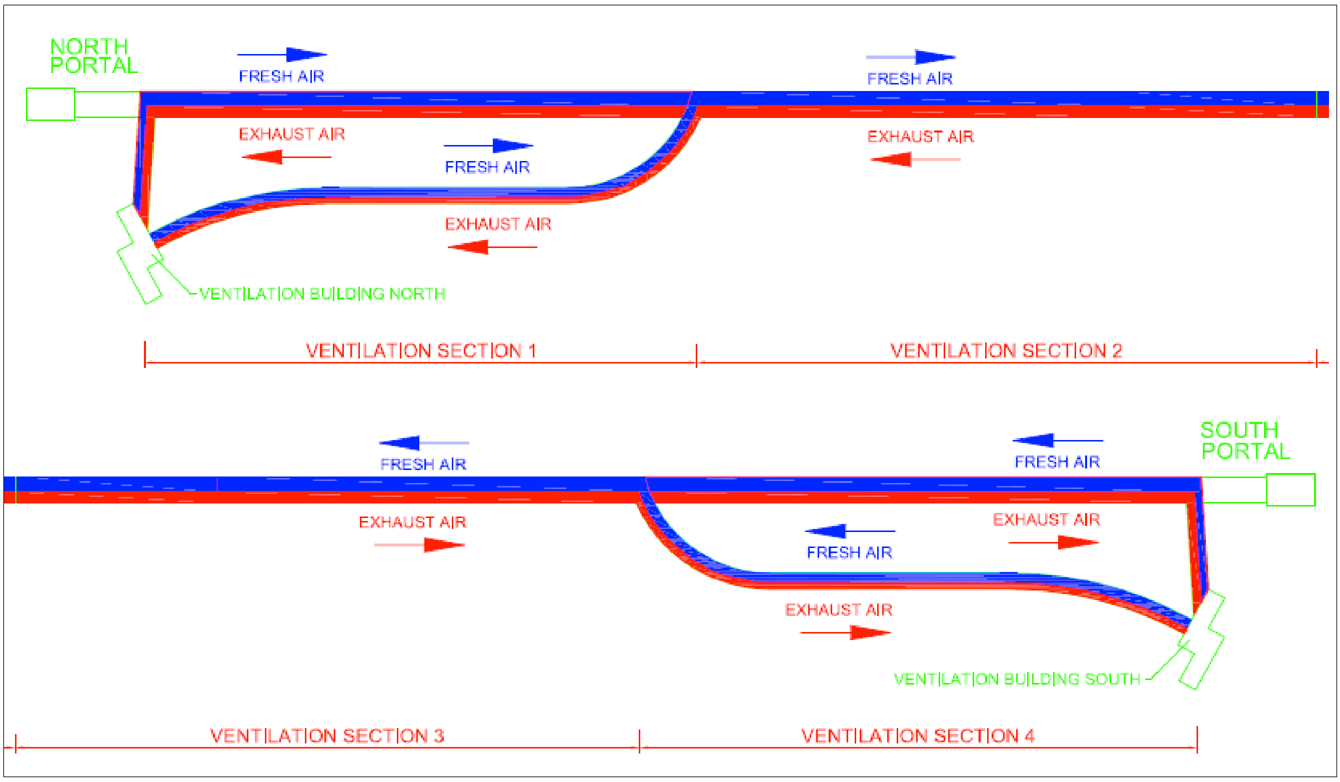

Figure 1: Sketch of the ventilation scheme before refurbishment

2.1.1 Problems during Upgrading

The key issue of upgrading ventilation systems is the retention of existing fans. The upgrading of the system requires smoke extraction at the two dampers closest to the fire location with a volume flow of at least 120 m^3/s (density = 1,2 kg/m^3) and the control of the longitudinal air velocity inside the tunnel in case of fire. The existing ventilation system could not meet this requirement due to following reasons:

- too small exhaust air ducts according to oversized fresh air ducts
- too high head losses resulting in to high dynamic forces on the intermediate ceiling
- too much electricity power of the existing exhaust air fans
- too high leakages of the exhaust air ducts
- too long exhaust air ducts

2.1.2 Refurbishment of the ventilation system

The main goal of the refurbishment was to reduce the pressure loss in the exhaust air ducts in order to improve smoke extraction and reduce leakages in the exhaust air ducts. This resulted in some basic changes in the airways of the exhaust and fresh air.

Instead of having four separate sections for the fresh air supply, section 1 and 2, as well as 3 and 4 will be connected and supplied from the portal vent buildings. Sufficient fresh air can be supplied through the two portal zones (see Figure 2).

The ventilation tunnel between the inner zones and the fans will be used for exhaust air only, and the separation wall between section 1 and 2 (as well as that between section 3 and 4) in the exhaust air duct removed (see Figure 3). The pressure loss in the exhaust air duct can thus be reduced significantly and the required extraction volume provided without changing the fans. The new (2nd) tube is to be operated with two ventilation sections instead of four, as in the existing one.

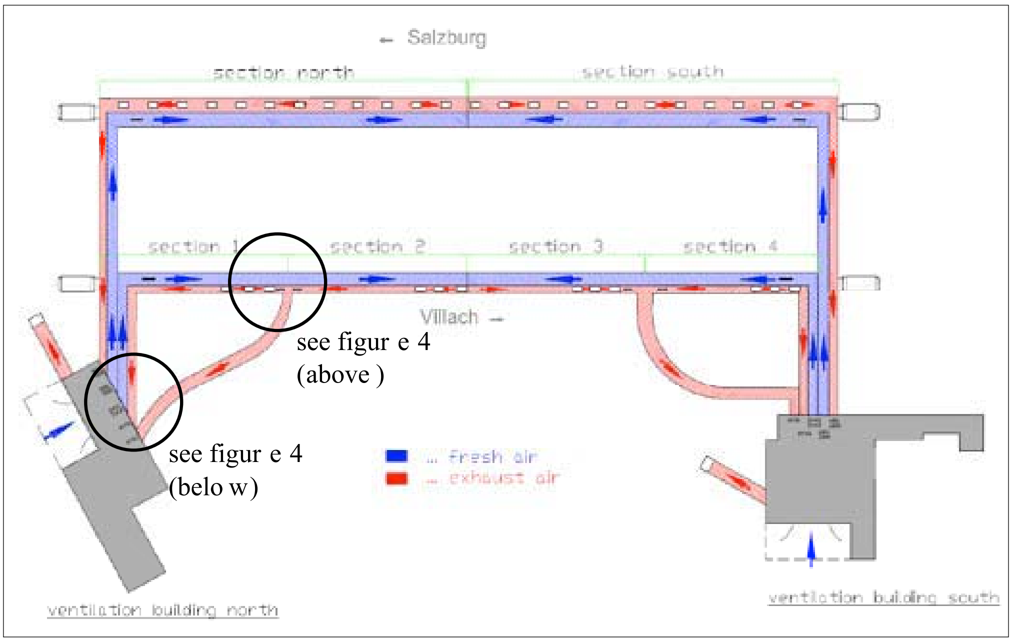

Figure 2: Sketch of the ventilation scheme after refurbishment and construction of the 2nd tube.

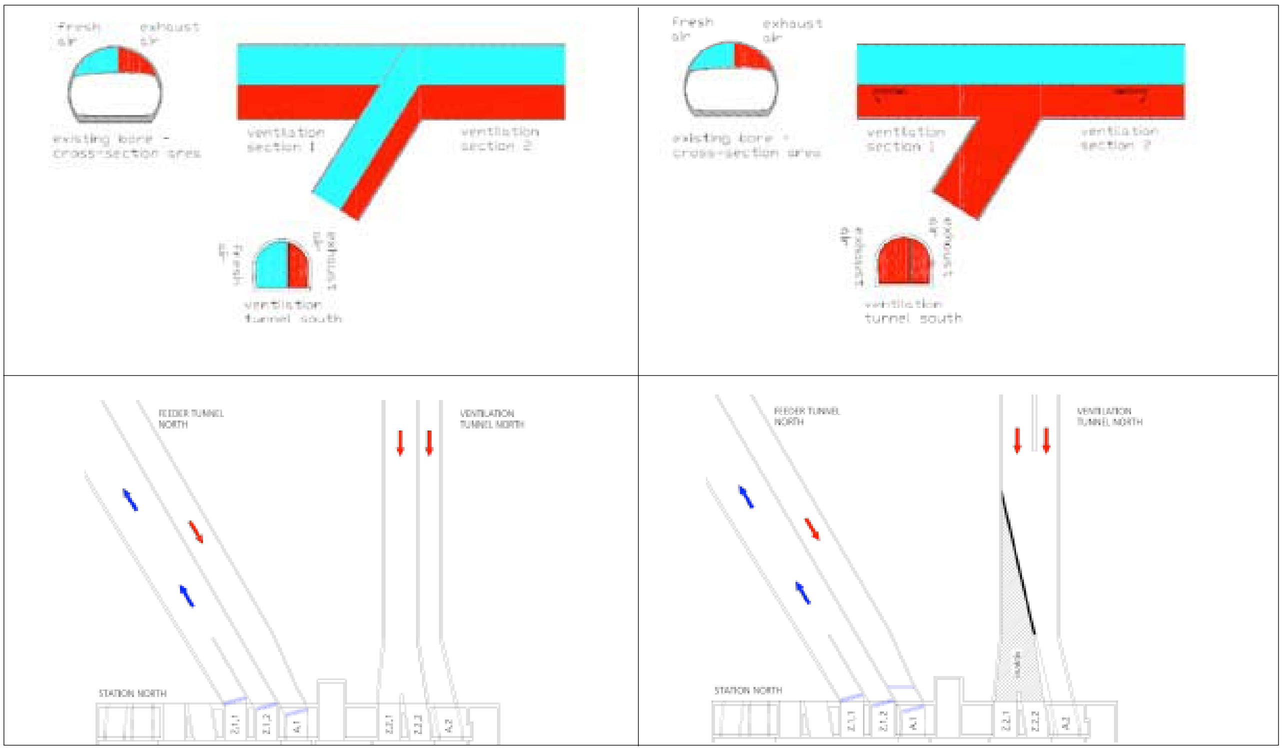

Figure 3: Sketch of the structural alteration works in ventilation section 1 and 2

Due to the new design of the airways of the new ventilation system the head losses were reduced significantly (see Figure 4). Some adaptations in the analog control of the pitch angle had to be done in order to guarantee the required operation mode of the exhaust air fans.

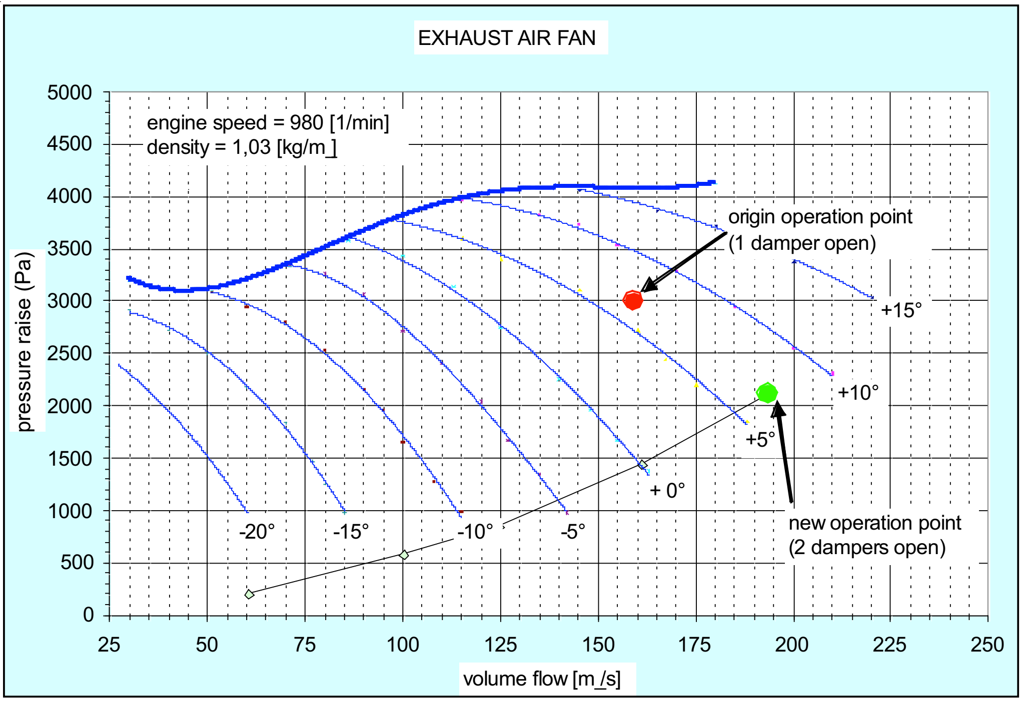

Figure 4: Characteristic diagram of the exhaust air fan ventilation section 2

2.1.3 Ventilation opertion in case of fire

Figure 5 sketch the situation in the case of fire. If the fire is located in the portal zone (section 1 or 4) the exhaust air fans for the fire section and the neighbouring section will be operated in parallel. In case of fire in one of the central sections (2 or 3) the extraction will be performed by one fan alone. An injection of fresh air at both portals will support smoke confinement between fire location and open dampers (see section 2.3). The ventilation of the unaffected 2nd bore will be operated at low load to provide overpressure in that bore in order to prevent smoke movement through open doors in cross passages during the evacuation phase.

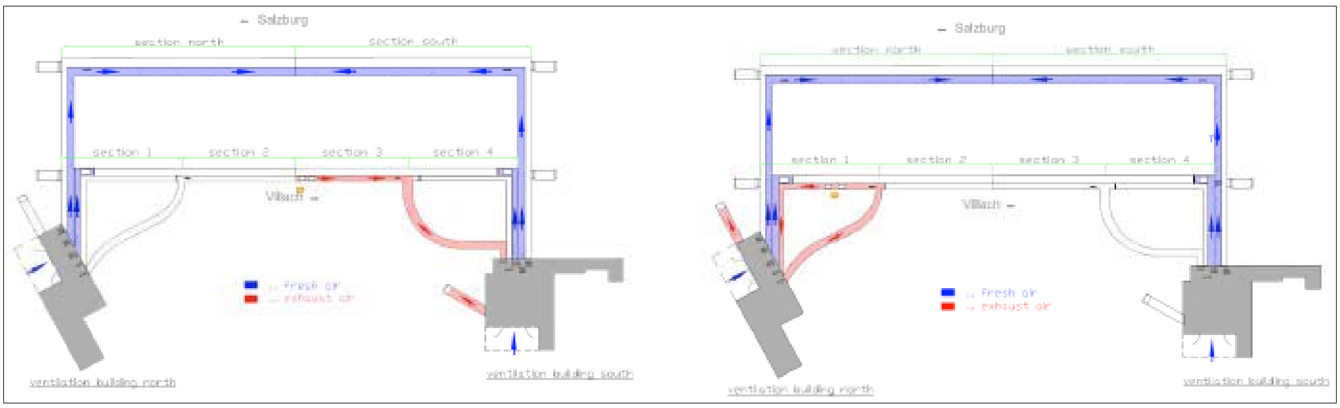

Figure 5: Operation of ventilation in case of fire in section 1 and 3

2.2 Tauern Tunnel

The general layout of the Tauern tunnel consists of 4 ventilation sections with a length of 1.5 km to 1.9 km each, two portal ventilation buildings furnishing the portal zones, and a ventilation cavern with a 650 m high vertical shaft, supporting the air exchange for both central ventilation sections. In contrast to the Katschberg tunnel, replacement of all axial fans is planned.

The main restriction in the design of the ventilation system lies in the fact that existing structures have to be used. While in former years the dilution of exhaust gases was decisive in ventilation design, nowadays extraction capacity in case of fire is the key factor. The original planning for the Tauern and Katschberg tunnel was based on a fresh air demand and extraction capacity of roughly 100 m³/s/km. The cross sections of the ducts were designed in order not to exceed air velocities of some 10 m/s. The ducts for the 2nd bores were designed under the assumption, that future vehicles will emit less pollution, hence less fresh and exhaust air are required. This led to significantly smaller duct cross sections. However, the shift in ventilation requirements from pollution control to smoke extraction, means that much higher exhaust air volumes are now required compared to those originally predicted. High air volumes and small cross sections result in high air velocities in the ducts and hence very high head losses and power requirements for the fans. The fresh air requirement has fallen from some 100 m³/s/km to roughly 45 m³/s/km, although traffic volume increased strongly. The extraction volume for pollution control behaves in the same way. The extraction volume for smoke control has risen from 80 m³/s to 165 m³/s.

2.2.1 Problems with the new design

Figure 7 shows the ventilation system of the Tauern tunnel. While the fresh air for the existing bore is currently supplied by two fans, the new bore – as well as the existing one after upgrading - requires only one. Following design problems occurred due to the existing construction elements:

- too small exhaust air ducts according to oversized fresh air ducts
- much higher exhaust air demands
- too big dynamic loading of the intermediate ceiling according to small exhaust air ducts and higher pressure loss (resulting in too much electricity power of the existing exhaust air fans)
- too much leakage of the exhaust air ducts
- the natural frequency of the fan platform and of the new fans are very similar during start up time

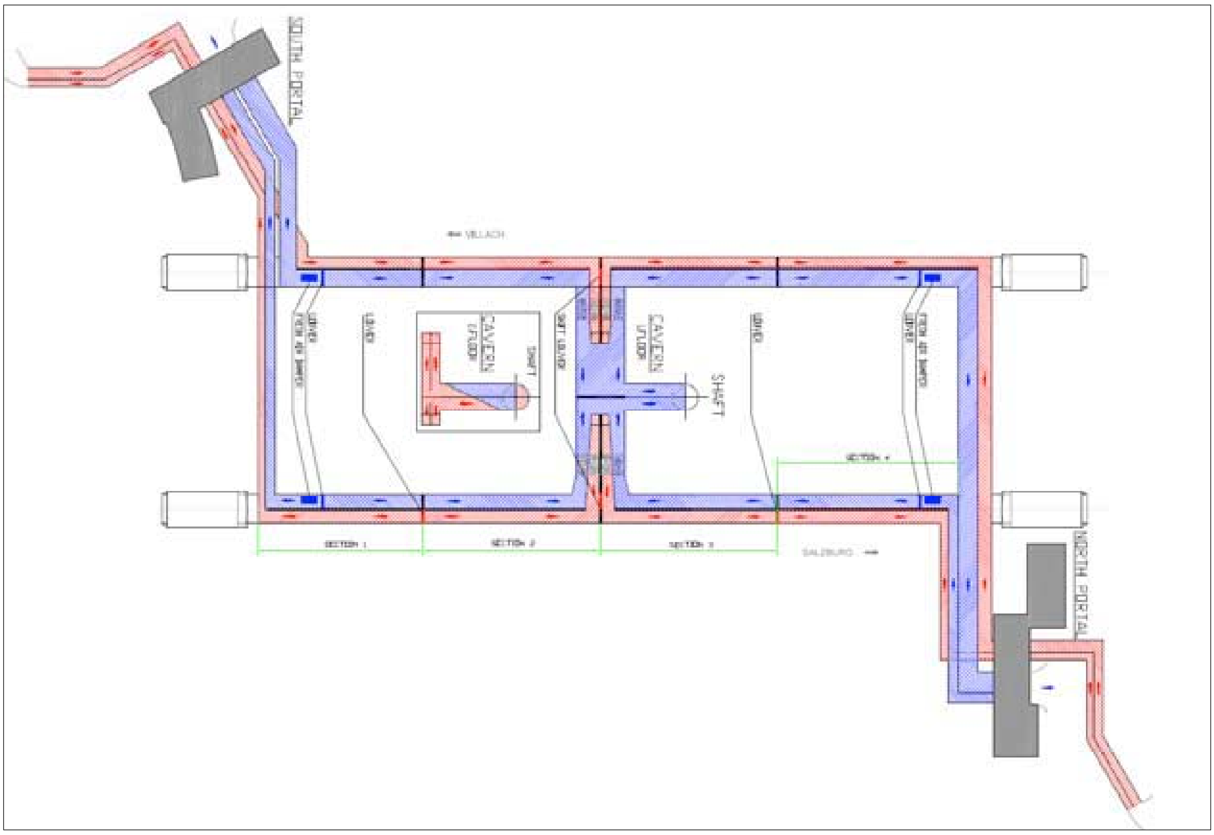

Figure 6: Sketch of the ventilation system

2.2.2 Extraction capacaty

Due to higher extraction capacities and sharp changes in flow directions the power requirement for the fans changed (see Table 1). The volume of the fresh air supply was reduced by a factor of two. The exhaust air fans have now to deliver a higher pressure increase which results in a higher power demand. The effect of smaller exhaust air ducts can be seen in the required pressure increase for the new bore. Although the extraction capacity is the same for both tubes (165 m³/s) the reduced cross sections in the connection ducts between the new tube and the axial fans cause a roughly 20% higher pressure loss for the whole system.

		Volume Flow [m³/s]	Pressure increase [Pa]	Max. Power [kW]
Original	Fresh air	2 x 180	1,650	2 x 390
Upgraded	Fresh air	150	1,625	350
New bore	Fresh air	150	1,625	350
Original	Exhaust air	192	1,980	550
Upgraded	Exhaust air	165	2,550	600
New tube	Exhaust air	165	3,100	700

Table 1: Fan parameters for ventilation section 4 of the Tauern tunnel

2.2.3 Geometrical problems for the flow calculations

Figure 8 (left) shows a part of the geometry of the connection tube for the exhaust air duct between the existing tube and the ventilation building Tauern north. As the distance between the 90 degree bend and the fan entrance is very short, it was doubted whether the required uniform entrance flow profile to the fan could be assured. CFD calculations verified that although at full extraction capacity (165 m³/s) velocities of up to 20 m/s upfront of the blades are to be expected, a uniform flow towards the fan is to be expected (see Figure 7 and Figure 8).

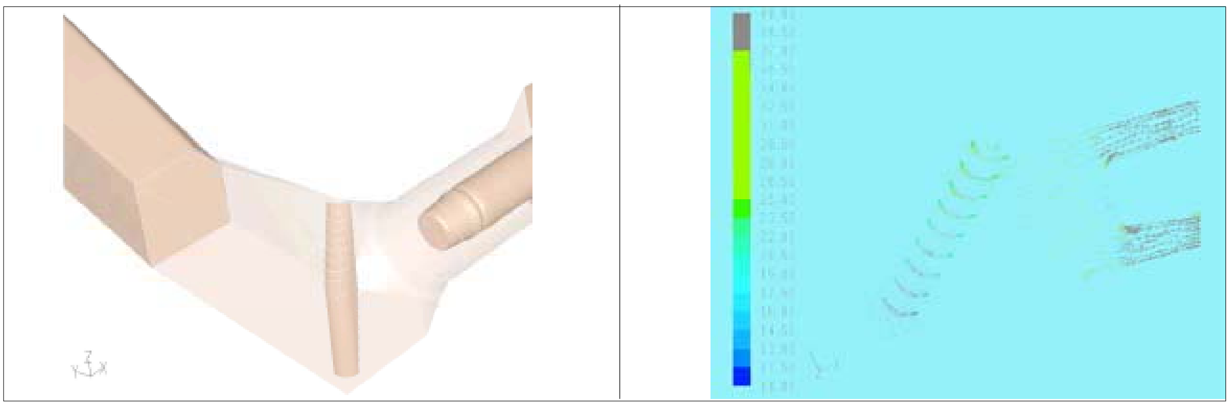

Figure 7: Detail of the guiding blades and horizontal plane of the velocity field, ventilation building Tauern north

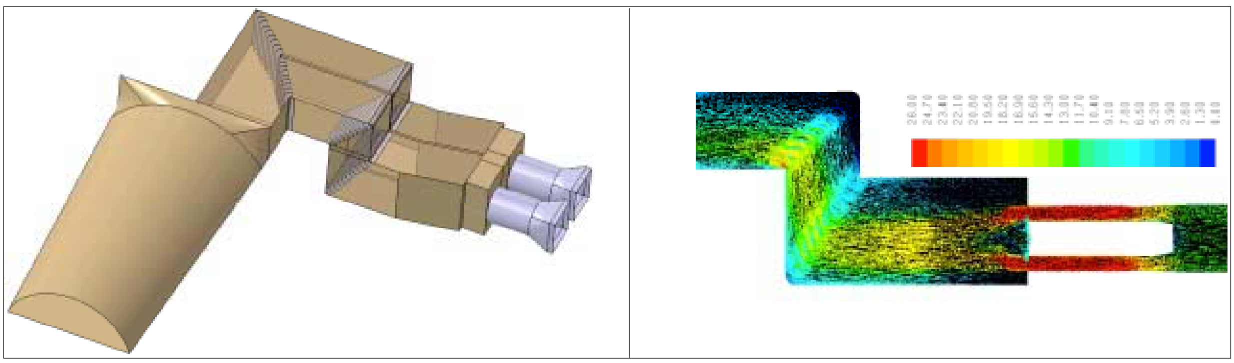

Figure 8: Detail of the exhaust air duct (tube Villach) – fan platform (velocity field)

A further topic which had to be considered was the positioning of the exhaust air fans in the central cavern. Figure 9 shows the position of the fan for the exhaust and fresh air in the cavern. The current location of the exhaust air fans is in level 3 of the cavern. The supply air duct and fans are located in the second level of the cavern. Currently two supply fans are needed per ventilation section. For the future situation with two tubes, only one supply fan per section will be needed. This allows for the removal of the exhaust fan from the third level and repositioning of the new one on the second level at the former supply fans location. All the expensive stainless steel work for connections to the tunnel and the shaft can thus be avoided. shows the new design, now having all fans at level two. However, as room is very limited two 90° deflections have to be realised within a very short distance. This results in additional high head losses. shows the design for the new bore. Much more space can be provided between exhaust fan and the first 90° deflection, hence pressure losses are smaller.
It has to be remarked that due to the existing structures within the cavern, and the maximum allowable load on the false ceilings between the individual layers, the possibilities for designing and/or redesigning the ducts and positioning the fans are severly restricted. Very often solutions have to be accepted which result in quite high pressure losses and hence in a high power requirement for fan operation.

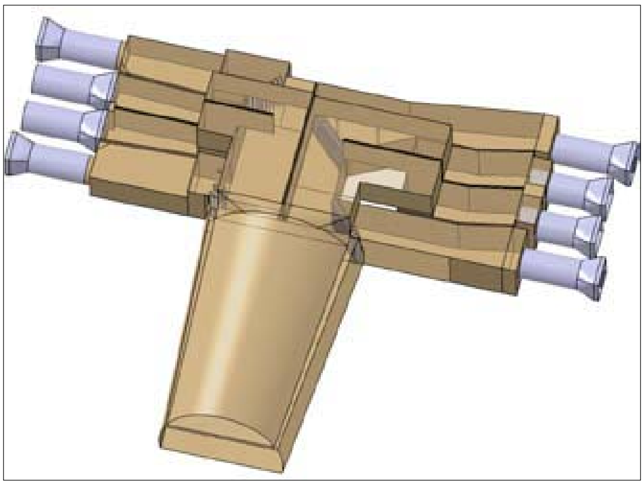

Figure 9: fan platform (cavern)

2.2.4 Ventilation shaft

A further challenge is the ventilation of both middle sections of the tunnel. Air exchange is provided via a 650 m high vertical shaft. This shaft has a separation wall for fresh and exhaust air. In the current situation one exhaust air fan and two fresh air fans are employed for each of the sections. Currently, the operation of two exhaust and four supply air fans is performed via the same shaft. In future, the second bore also has to be supplied from the same source, i.e. additional air has to be transported via the same shaft. A parallel operation of all four sections at almost full load during peak hours can increase the volume flow by a factor of two. This results in an increase of the head losses for this section by a factor of four and an increase of power demand by a factor of eight. The operation of multiple fans into/from one single shaft is challenging in that it demands a clear definition of possible fan operation ranges. Meteorological pressure differences between the tunnel and the shaft head, as well as buoyancy effects in the shaft create additional difficulties. Measurements at the closed cut-off damper at the inactive fresh air fan, showed pressure differences of up to 700 Pa. Fans with variable pitch control are employed in order to overcome operation problems.

2.2.5 Fan platform

A lot of calculations were done by the civil engineers in order to check the strength of the fan platform. To reduce the maintenance time in case of a problem with one of the fans, the origin entering orifice had to be modified because of changed positions of the exhaust air and fresh air fans in the 1st floor of the fan platform in the cavern.
During the start up time of the fans they reach the natural frequency of fan platform. To avoid damages of the platform contingency measures had to be done (see Figure 10).

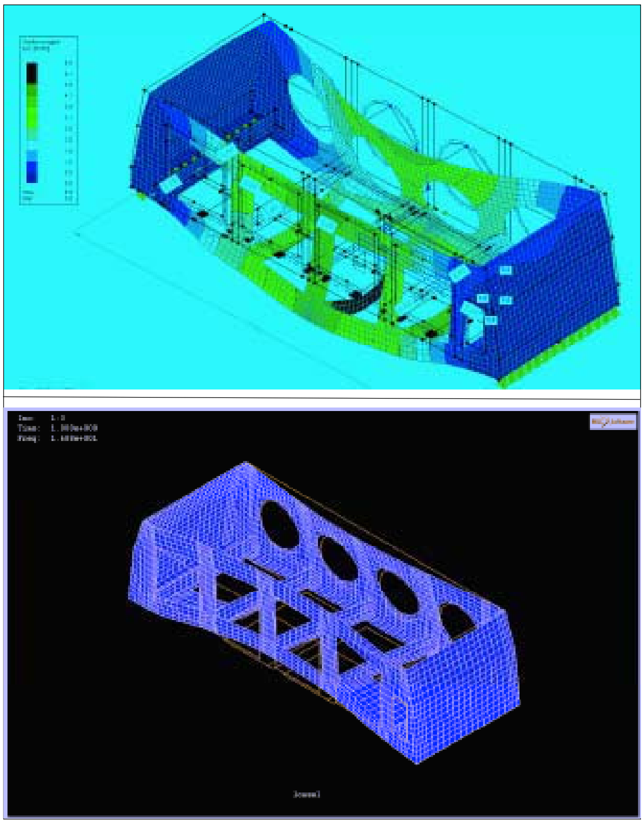

Figure 10: Calculation of the bending vibration (done by the designer)

2.3 Smoke extraction

A massive smoke extraction is only effective when the smoke is confined between the fire source and the open damper(s), control of air/smoke movement within the traffic room is required. In longitudinal ventilated tunnels the air/smoke movement is performed by jet fans. In transverse ventilated tunnels with multiple ventilation sections, smoke movement can be supported by applying different pressure levels using the exhaust air and supply fans. This is the current method applied in both these tunnels. However, with this method the possibilities for influencing longitudinal flow are limited.

Both tunnels cross a main ridge in the Alps. Hence, quite high meteorological pressure differences between portals may occur. According to the local met office the 95 percentile value for the pressure difference at the Tauern tunnel in N-S direction is some 240 Pa, and 180 Pa for the S-N direction.

As only limited space is available for mounting jet fans, some 25 to 30 units per tube would be necessary in order to overcome the meteorological pressure differences. This was not acceptable for the tunnel operator, as during fan maintenance the required level of service of the traffic can not be provided. In order to utilize the possibilities of the available supply air fans, a Saccardo type air injection nozzle was installed. Here the available fresh air can be injected utilising its own momentum and hence is much more efficient than injecting the air via the regular supply air inlets [6]. Figure 11 shows such an air injection device mounted in the supply air duct. In case of fire the damper is be opened and the duct downstream of the injection nozzle is closed by a remote controlled vertical flap. Of course, the efficiency of such a device is not very high. As soon as very high pressure differences have to be dealt with it quickly reaches its limits. The restrictions are imposed by (a) the velocity in the damper and in the driving room underneath the damper, (b) the admissible stress in the false ceiling and (c) last but not least, the possibility to control the airflow inside the tunnel. As soon as the momentum brought in into the tunnel by such a nozzle becomes too high the whole system becomes unstable and it is not possible to stabilize air flow behaviour inside the tunnel.

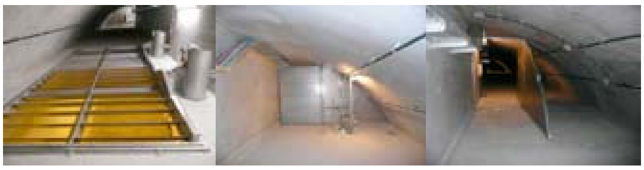

Figure 11: Fresh-air injection device: damper (left), blocking element closed (centre), blocking element open (right) [2]

The effects of the injection nozzle were simulated using a 3D CFD code. The results from these simulations were taken as boundary conditions for the 1D calculations of the whole tunnel structure.

3 CONCLUSIONS

The above mentioned changes in ventilation arrangements in the existing tube (direction Salzburg) meant that it was possible to fulfil the requirements concerning the minimum smoke extraction capacity in case of fire, even with the existing fans.

The refurbishment of ventilation systems in transverse ventilated tunnels is always influenced by the original design and layout of the existing structures such as ventilation ducts, buildings, shafts etc. As such structures were originally designed to meet the requirements and regulations at those times these structures are no longer adequate. However, in most cases old structures cannot simply be removed or redesigned to comply with modern standards. Hence a compromise has to be made between meeting standards, achieving efficiency and keeping costs at an acceptable level. In many cases, for example, satisfaction of requirements given in the currently valid guidelines means that there is a greater demand for powered during operation and/or that stronger axial fans become necessary.

As the needs for tunnel ventilation have changed over the last few years in many cases fresh air supply is not as important as it used to be. This often allows for a reduction in fresh air and an increase in exhaust air capacity. Full transverse ventilation systems can sometimes be converted to semi – transverse systems with smoke extraction. The requirements for smoke extraction can thus be met without the need for big changes in the overall design. However, fresh air supply may have to be achieved either by other means (e.g. jet fans) or by reducing the number of ventilation sections with fresh air supply.

Restrictions given by the tunnel operators mostly concern the situation inside the tunnel. The less equipment has to be placed inside the tunnel the easier it is to avoid maintenance inside the traffic room. This has lead to a renaissance in methods employing Saccardo nozzles or other type of fresh air injection, since these can be installed outside the traffic room and hence are much easier to maintain. The resulting loss in efficiency – compared to that of jet fans inside the traffic room – is accepted by the operator for the sake of maintaining a high level of service for tunnel users.

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2

Tema 2 / Topic 2:

Materiali in oprema

Materials and Equipment

Tema 2 / Topic 2:

Materiali in oprema/Materials and Equipment

The Emperor's New Clothes for Tunnels

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1. ABSTRACT

I would like to expose three tunnels of different lengths (L, XXL and XXXL) and their current fire safety "imperfections". EU Dir. 2004/54/EC: all road tunnels must meet minimal safety requirements before 2019.
Definition of "safe tunnel" is not always interpreted equally. To my understanding, tunnels must be safe for all people in and around the tunnel and must also be protected from major structural damage caused by fire. Extensive fire may never be able to develop and traffic should restart in mater of hours or days, without extended repairs and higher cost.
Detection systems, ventilation, extinguishing systems, human response, and concept design are crucial for all future events in a particular tunnel. Financial resources for safety in tunnels are limited. On the other hand, our ignorance and desire for gambling with safety is not limited at all. I would like to open discussion, and prove, that safety in some tunnels may not be as expensive as it is usually presented.

2. INTRUDUCTION

Tunnels are sensitive stitches of Europe.
We may not be aware of importance of our daily benefits from road and rail tunnels, because we take them for granted. There are several tunnels that were designed more than 25 years ago, at the time when fire safety was not an important issue. Traffic density and fire load did increase since then. New materials and new safety technologies were developed after first large fire disasters in the 90`s.

The biggest problem is, that most of tunnels are public owned, so in case of large fire event all costs are paid by the state (taxpayers). There are only a few exceptions, such as Felbertauerntunnel, Eurotunnel. Astonishingly, insurance and major shareholders, as Deutsche Bank, don't show much interest in protecting its investment against fire damage.

Why do new technologies reach tunnels slowly?
It appears that final decisions are not based on expert opinion but are made by politicians and their gambling with disaster statistic. Perhaps new generation of experts will be more sensitive for safety issues as designers of old tunnels are.
Repairs or safety upgrades cost significantly less than lack of income while tunnel is closed. Example: Taueren tunnel (Austria) repair cost 10mil.€, income loss (3 months) about 25mil.€.

I don't accept separation between "not dangerous" and "dangerous" loads. Even an empty vehicle contains flammable materials that can cause suffocation of people and tunnel damage.

I would like to introduce three tunnels of different length, their current fire **"imperfections"** and potential impact on economy, in case of major fire event in those tunnels.

- Šentvid tunnel 1.490m, two tubes, (SLO)
- Karavanke tunnel 7.864m one tube, (SLO-A)
- Eurotunnel 50.450m two railway tubes +service tube, (F-GB)

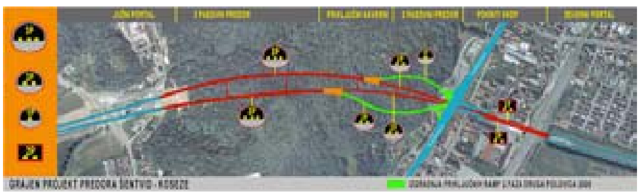
I will also present operator's future plans and, as an alternative, show some possible much cheaper solutions that could be implemented in near future, so those tunnels can become safer for passengers as well as for investors.
I feel that there is lack of knowledge; some projects are idle for many years without evident reason. Especially in tunnels that connect two countries discussions take forever.

3. ŠENTVID TUNNEL (1490m, SLO)

Two tube highway tunnel consist of:

- Old gallery, 100 m, under railway, prefabricated construction (built 1984)
- Old gallery, 150 m, under gym hall and tennis court, prefabricated construction (built 1984)
- New gallery, 150 m, under Celovška Street (built 2004)
- Tunnel, 1090 m, under a hill
-

Future connection tubes to Celovška street



Scheme of Šentvid tunnel

North portal of Šentvid tunnel: first 400m are old and new galleries; the rest is tunnel trough a hill.

Šentvid tunnel attracted first attention of Slovenian media when initial price estimate of 41 million € exploded due to project change (from 2 lanes to 3 lanes) to almost 139 million € for 1.490 m of 2 tube tunnel.

Only 6 hours after grandiose inauguration of the Šentvid tunnel on July 1st, 2008, the sprayed fire protection cast fell of the ceiling of the old gallery.
Some loose areas of cast were removed and ex-transport minister of Slovenia forced the second opening immediately.

In the morning of July 2nd, 2008, I wrote an E-mail to the acting traffic minister (by profession chemical engineer), suggesting him to stop the traffic until "full tunnel repair and cast removal" is performed.
As my concern was not taken seriously I did write him an "open letter" in which I informed him that new cast fall-off will happen, if not in next months of tourist season, then certainly at Queen Elisabeth's visit to Slovenia, or at beginning of winter.
August 7th, 2008, at 2 AM, 100kg chunk of fire protection cast fell on a German tourist's car travelling at 100km/h. Car was totally damaged, luckily no casualties.

After that accident, the fire protection cast was removed completely, and tunnel was reopened with collective signature of all inspectors. Speed limit was lowered from 100km/h to 80km/h. Operator DARS did not publish reconstruction plan and ministry for transportation stated that there is plenty of time, (until 2019) to adjust tunnel according to EU directive.

4. REAL FACTS BEHIND ŠENTVID TUNNEL

Construction facts